Karlsruher Institut für Technologie

# Module Handbook
# Techno-Mathematics Master 2016 (Master of Science (M.Sc.))

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KIT DEPARTMENT OF MATHEMATICS

# Table Of Contents

**1. Study Program Structure ..... 10**
1.1. Master's Thesis ..... 10
1.2. Internship ..... 10
1.3. Applied Mathematics ..... 11
1.4. Electrical Engineering / Information Technology ..... 15
1.5. Experimental Physics ..... 16
1.6. Chemical and Process Engineering ..... 16
1.7. Wildcard Technical Field ..... 16
1.8. Computer Science ..... 17
1.9. Mathematical Specialization ..... 18
1.10. Interdisciplinary Qualifications ..... 22
1.11. Additional Examinations ..... 23
**2. Modules ..... 28**
2.1. Adaptive Finite Elemente Methods - M-MATH-102900 ..... 28
2.2. Advanced Inverse Problems: Nonlinearity and Banach Spaces - M-MATH-102955 ..... 29
2.3. Advanced Methods in Nonlinear Partial Differential Equations - M-MATH-106822 ..... 30
2.4. Algebra - M-MATH-101315 ..... 32
2.5. Algebraic Geometry - M-MATH-101724 ..... 33
2.6. Algebraic Number Theory - M-MATH-101725 ..... 34
2.7. Algebraic Topology - M-MATH-102948 ..... 35
2.8. Algebraic Topology II - M-MATH-102953 ..... 36
2.9. Analytical and Numerical Homogenization - M-MATH-105636 ..... 37
2.10. Aspects of Geometric Analysis - M-MATH-103251 ..... 38
2.11. Astroparticle Physics I - M-PHYS-102075 ..... 39
2.12. Banach Algebras - M-MATH-102913 ..... 40
2.13. Basics of Nanotechnology I - M-PHYS-102097 ..... 41
2.14. Basics of Nanotechnology II - M-PHYS-102100 ..... 42
2.15. Batteries, Fuel Cells, and Electrolysis - M-ETIT-107005 ..... 43
2.16. Bayesian Inverse Problems with Connections to Machine Learning - M-MATH-106328 ..... 44
2.17. Bifurcation Theory - M-MATH-103259 ..... 45
2.18. Biopharmaceutical Purification Processes - M-CIWVT-103065 ..... 46
2.19. Boundary and Eigenvalue Problems - M-MATH-102871 ..... 47
2.20. Boundary Element Methods - M-MATH-103540 ..... 48
2.21. Boundary value problems for nonlinear differential equations - M-MATH-102876 ..... 49
2.22. Brownian Motion - M-MATH-102904 ..... 50
2.23. Class Field Theory - M-MATH-107387 ..... 51
2.24. Classical Methods for Partial Differential Equations - M-MATH-102870 ..... 52
2.25. Cognitive Systems - M-INFO-100819 ..... 53
2.26. Combinatorics - M-MATH-102950 ..... 54
2.27. Combustion Technology - M-CIWVT-103069 ..... 55
2.28. Complex Analysis - M-MATH-102878 ..... 56
2.29. Complex Geometry - M-MATH-106776 ..... 58
2.30. Compressive Sensing - M-MATH-102935 ..... 59
2.31. Computational Fluid Dynamics - M-CIWVT-103072 ..... 60
2.32. Computational Fluid Dynamics and Simulation Lab - M-MATH-106634 ..... 61
2.33. Computer Architecture - M-INFO-100818 ..... 62
2.34. Computer Graphics - M-INFO-100856 ..... 63
2.35. Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems - M-MATH-102883 ..... 64
2.36. Condensed Matter Theory I, Fundamentals - M-PHYS-102054 ..... 65
2.37. Condensed Matter Theory I, Fundamentals and Advanced Topics - M-PHYS-102053 ..... 66
2.38. Condensed Matter Theory II: Many-Body Theory, Fundamentals - M-PHYS-102313 ..... 68
2.39. Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics - M-PHYS-102308 ..... 70
2.40. Continuous Time Finance - M-MATH-102860 ..... 72
2.41. Control Theory - M-MATH-102941 ..... 74
2.42. Convex Geometry - M-MATH-102864 ..... 75
2.43. Curves on Surfaces - M-MATH-106632 ..... 77
2.44. Deep Learning and Neural Networks - M-INFO-107197 ..... 78

2.45. Differential Geometry - M-MATH-101317 ... 79
2.46. Discrete Dynamical Systems - M-MATH-105432 ... 81
2.47. Discrete Time Finance - M-MATH-102919 ... 82
2.48. Dispersive Equations - M-MATH-104425 ... 83
2.49. Dynamical Systems - M-MATH-103080 ... 84
2.50. Electromagnetics and Numerical Calculation of Fields - M-ETIT-100386 ... 85
2.51. Electronic Properties of Solids I, with Exercises - M-PHYS-102089 ... 87
2.52. Electronic Properties of Solids I, without Exercises - M-PHYS-102090 ... 88
2.53. Electronic Properties of Solids II, with Exercises - M-PHYS-102108 ... 89
2.54. Electronic Properties of Solids II, without Exercises - M-PHYS-102109 ... 90
2.55. Ergodic Theory - M-MATH-106473 ... 91
2.56. Evolution Equations - M-MATH-102872 ... 92
2.57. Exponential Integrators - M-MATH-103700 ... 94
2.58. Extremal Graph Theory - M-MATH-102957 ... 95
2.59. Extreme Value Theory - M-MATH-102939 ... 96
2.60. Finite Element Methods - M-MATH-102891 ... 97
2.61. Forecasting: Theory and Practice - M-MATH-102956 ... 98
2.62. Formal Systems - M-INFO-100799 ... 100
2.63. Foundations of Continuum Mechanics - M-MATH-103527 ... 101
2.64. Fractal Geometry - M-MATH-105649 ... 102
2.65. Functional Analysis - M-MATH-101320 ... 104
2.66. Functional Data Analysis - M-MATH-106485 ... 105
2.67. Functions of Matrices - M-MATH-102937 ... 106
2.68. Functions of Operators - M-MATH-102936 ... 107
2.69. Galerkin Methods for Time-dependent PDEs - M-MATH-107647 ... 108
2.70. Generalized Regression Models - M-MATH-102906 ... 109
2.71. Geometric Analysis - M-MATH-102923 ... 111
2.72. Geometric Group Theory - M-MATH-102867 ... 112
2.73. Geometric Group Theory II - M-MATH-102869 ... 114
2.74. Geometric Numerical Integration - M-MATH-102921 ... 115
2.75. Geometric Variational Problems - M-MATH-106667 ... 116
2.76. Geometry of Schemes - M-MATH-102866 ... 117
2.77. Global Differential Geometry - M-MATH-102912 ... 118
2.78. Graph Theory - M-MATH-101336 ... 119
2.79. Harmonic Analysis - M-MATH-105324 ... 120
2.80. Harmonic Analysis 2 - M-MATH-106486 ... 122
2.81. Heat Transfer II - M-CIWVT-103051 ... 123
2.82. High Temperature Process Engineering - M-CIWVT-103075 ... 124
2.83. Infinite dimensional dynamical systems - M-MATH-103544 ... 125
2.84. Information Security - M-INFO-106015 ... 126
2.85. Integral Equations - M-MATH-102874 ... 127
2.86. Integrated Photonics - M-ETIT-107344 ... 128
2.87. Internet Seminar for Evolution Equations - M-MATH-102918 ... 130
2.88. Internship - M-MATH-102861 ... 131
2.89. Interpolation Spaces - M-MATH-107456 ... 132
2.90. Introduction into Particulate Flows - M-MATH-102943 ... 133
2.91. Introduction to Artificial Intelligence - M-INFO-106014 ... 134
2.92. Introduction to Convex Integration - M-MATH-105964 ... 135
2.93. Introduction to Cosmology - M-PHYS-102175 ... 136
2.94. Introduction to Dynamical Systems - M-MATH-106591 ... 137
2.95. Introduction to Fluid Dynamics - M-MATH-105650 ... 139
2.96. Introduction to Fluid Mechanics - M-MATH-106401 ... 140
2.97. Introduction to Geometric Measure Theory - M-MATH-102949 ... 141
2.98. Introduction to Homogeneous Dynamics - M-MATH-105101 ... 142
2.99. Introduction to Kinetic Equations - M-MATH-105837 ... 143
2.100. Introduction to Kinetic Theory - M-MATH-103919 ... 144
2.101. Introduction to Microlocal Analysis - M-MATH-105838 ... 145
2.102. Introduction to Scientific Computing - M-MATH-102889 ... 146
2.103. Introduction to Stochastic Differential Equations - M-MATH-106045 ... 148
2.104. Inverse Problems - M-MATH-102890 ... 149

2.105. IT Security - M-INFO-106998 ..... 150
2.106. Key Competences - M-MATH-102994 ..... 151
2.107. Lie Groups and Lie Algebras - M-MATH-104261 ..... 152
2.108. Lie-Algebras - M-MATH-106950 ..... 153
2.109. Localization of Mobile Agents - M-INFO-107663 ..... 155
2.110. Logical Foundations of Cyber-Physical Systems - M-INFO-106102 ..... 156
2.111. Markov Decision Processes - M-MATH-102907 ..... 158
2.112. Master's Thesis - M-MATH-102917 ..... 159
2.113. Mathematical Methods in Signal and Image Processing - M-MATH-102897 ..... 160
2.114. Mathematical Methods of Imaging - M-MATH-103260 ..... 161
2.115. Mathematical Modelling and Simulation in Practise - M-MATH-102929 ..... 162
2.116. Mathematical Statistics - M-MATH-102909 ..... 164
2.117. Mathematical Topics in Kinetic Theory - M-MATH-104059 ..... 166
2.118. Maxwell's Equations - M-MATH-102885 ..... 167
2.119. Medical Imaging Technology - M-ETIT-106778 ..... 168
2.120. Metric Geometry - M-MATH-105931 ..... 169
2.121. Minimal Surfaces - M-MATH-106666 ..... 170
2.122. Modelling and Simulation of Lithium-Ion Batteries - M-MATH-106640 ..... 171
2.123. Models of Mathematical Physics - M-MATH-102875 ..... 172
2.124. Modern Experimental Physics I, Atoms, Nuclei and Molecules - M-PHYS-106331 ..... 173
2.125. Modern Experimental Physics II, Structure of Matter - M-PHYS-106332 ..... 174
2.126. Modern Methods in Combinatorics - M-MATH-106957 ..... 175
2.127. Modular Forms - M-MATH-102868 ..... 176
2.128. Monotonicity Methods in Analysis - M-MATH-102887 ..... 177
2.129. Neural Networks - M-INFO-100846 ..... 178
2.130. Nonlinear Analysis - M-MATH-103539 ..... 179
2.131. Nonlinear Control Systems - M-ETIT-107644 ..... 180
2.132. Nonlinear Evolution Equations - M-MATH-102877 ..... 181
2.133. Nonlinear Functional Analysis - M-MATH-102886 ..... 182
2.134. Nonlinear Maxwell Equations - M-MATH-105066 ..... 183
2.135. Nonlinear Wave Equations - M-MATH-105326 ..... 184
2.136. Nonparametric Statistics - M-MATH-102910 ..... 185
2.137. Numerical Analysis of Neural Networks - M-MATH-106695 ..... 186
2.138. Numerical Analysis on Quantum Computers - M-MATH-107646 ..... 187
2.139. Numerical Complex Analysis - M-MATH-106063 ..... 188
2.140. Numerical Linear Algebra in Image Processing - M-MATH-104058 ..... 189
2.141. Numerical Methods for Differential Equations - M-MATH-102888 ..... 190
2.142. Numerical Methods for Hyperbolic Equations - M-MATH-102915 ..... 192
2.143. Numerical Methods for Integral Equations - M-MATH-102930 ..... 193
2.144. Numerical Methods for Maxwell's Equations - M-MATH-102931 ..... 194
2.145. Numerical Methods for Oscillatory Differential Equations - M-MATH-106682 ..... 195
2.146. Numerical Methods for Time-Dependent Partial Differential Equations - M-MATH-102928 ..... 197
2.147. Numerical Methods in Computational Electrodynamics - M-MATH-102894 ..... 198
2.148. Numerical Methods in Fluid Mechanics - M-MATH-102932 ..... 199
2.149. Numerical Methods in Mathematical Finance - M-MATH-102901 ..... 200
2.150. Numerical Optimisation Methods - M-MATH-102892 ..... 202
2.151. Numerical Simulation in Molecular Dynamics - M-MATH-105327 ..... 204
2.152. Optimal Control - M-ETIT-107497 ..... 205
2.153. Optimisation and Optimal Control for Differential Equations - M-MATH-102899 ..... 206
2.154. Optimization in Banach Spaces - M-MATH-102924 ..... 208
2.155. Parallel Computing - M-MATH-101338 ..... 209
2.156. Particle Physics I - M-PHYS-102114 ..... 210
2.157. Pattern Recognition - M-INFO-100825 ..... 212
2.158. Percolation - M-MATH-102905 ..... 214
2.159. Physical Foundations of Cryogenics - M-CIWVT-103068 ..... 215
2.160. Poisson Processes - M-MATH-102922 ..... 216
2.161. Potential Theory - M-MATH-102879 ..... 217
2.162. Practical Course: Mathematical and Computational Methods in Robotics and AI - M-INFO-107609 ..... 218
2.163. Probability Theory and Combinatorial Optimization - M-MATH-102947 ..... 219
2.164. Process Modeling in Downstream Processing - M-CIWVT-103066 ..... 221

2.165. Processing of Nanostructured Particles - M-CIWVT-103073 ... 222
2.166. Random Graphs and Networks - M-MATH-106052 ... 223
2.167. Real-Time Systems - M-INFO-100803 ... 225
2.168. Regularity for Elliptic Operators - M-MATH-106696 ... 226
2.169. Riemann Surfaces - M-MATH-106466 ... 227
2.170. Robotics I - Introduction to Robotics - M-INFO-107162 ... 228
2.171. Robotics II - Humanoid Robotics - M-INFO-102756 ... 229
2.172. Robotics III - Sensors and Perception in Robotics - M-INFO-104897 ... 230
2.173. Ruin Theory - M-MATH-104055 ... 231
2.174. Sampling Methods for Machine Learning - M-INFO-107090 ... 232
2.175. Scattering Theory - M-MATH-102884 ... 233
2.176. Scattering Theory for Time-dependent Waves - M-MATH-106664 ... 234
2.177. Selected Methods in Fluids and Kinetic Equations - M-MATH-105897 ... 235
2.178. Selected Topics in Harmonic Analysis - M-MATH-104435 ... 236
2.179. Semigroup Theory for the Navier-Stokes Equations - M-MATH-106663 ... 237
2.180. Seminar - M-MATH-102730 ... 238
2.181. Seminar Advanced Topics in Parallel Programming - M-INFO-101887 ... 239
2.182. Signal Processing Methods - M-ETIT-106899 ... 240
2.183. Signal Processing with Nonlinear Fourier Transforms and Koopman Operators - M-ETIT-106675 ... 242
2.184. Simulation and Optimization in Robotics and Biomechanics - M-INFO-106504 ... 244
2.185. Sobolev Spaces - M-MATH-102926 ... 245
2.186. Software Engineering II - M-INFO-107235 ... 246
2.187. Space and Time Discretization of Nonlinear Wave Equations - M-MATH-105966 ... 248
2.188. Spatial Stochastics - M-MATH-102903 ... 249
2.189. Special Topics of Numerical Linear Algebra - M-MATH-102920 ... 250
2.190. Spectral Theory - M-MATH-101768 ... 251
2.191. Spectral Theory of Differential Operators - M-MATH-102880 ... 253
2.192. Splitting Methods for Evolution Equations - M-MATH-105325 ... 254
2.193. Statistical Learning - M-MATH-105840 ... 255
2.194. Statistical Thermodynamics - M-CIWVT-103059 ... 257
2.195. Steins Method with Applications in Statistics - M-MATH-105579 ... 258
2.196. Stochastic Control - M-MATH-102908 ... 259
2.197. Stochastic Geometry - M-MATH-102865 ... 260
2.198. Stochastic Information Processing - M-INFO-100829 ... 261
2.199. Stochastic Simulation - M-MATH-106053 ... 262
2.200. Structural Graph Theory - M-MATH-105463 ... 263
2.201. Supplementary Studies on Science, Technology and Society - M-FORUM-106753 ... 264
2.202. Technical Optics - M-ETIT-100538 ... 268
2.203. Technomathematical Seminar - M-MATH-102863 ... 270
2.204. Telematics - M-INFO-107243 ... 271
2.205. Theoretical Nanooptics - M-PHYS-102295 ... 273
2.206. Theoretical Optics - M-PHYS-102277 ... 274
2.207. Thermodynamics III - M-CIWVT-103058 ... 275
2.208. Thermodynamics of Interfaces - M-CIWVT-103063 ... 276
2.209. Time Series Analysis - M-MATH-102911 ... 277
2.210. Topics in Algebraic Topology - M-MATH-107017 ... 278
2.211. Topics in Homotopy Theory - M-MATH-107484 ... 279
2.212. Topological Data Analysis - M-MATH-105487 ... 280
2.213. Translation Surfaces - M-MATH-105973 ... 281
2.214. Traveling Waves - M-MATH-102927 ... 282
2.215. Uncertainty Quantification - M-MATH-104054 ... 284
2.216. Variational Methods - M-MATH-105093 ... 286
2.217. Wavelets - M-MATH-102895 ... 287

**3. Module components ... 288**

3.1. Adaptive Finite Element Methods - T-MATH-105898 ... 288
3.2. Advanced Inverse Problems: Nonlinearity and Banach Spaces - T-MATH-105927 ... 289
3.3. Advanced Methods in Nonlinear Partial Differential Equations - T-MATH-113691 ... 290
3.4. Algebra - T-MATH-102253 ... 291
3.5. Algebraic Geometry - T-MATH-103340 ... 292
3.6. Algebraic Number Theory - T-MATH-103346 ... 293

3.7. Algebraic Topology - T-MATH-105915 ... 294
3.8. Algebraic Topology II - T-MATH-105926 ... 295
3.9. Analytical and Numerical Homogenization - T-MATH-111272 ... 296
3.10. Aspects of Geometric Analysis - T-MATH-106461 ... 297
3.11. Astroparticle Physics I - T-PHYS-102432 ... 298
3.12. Banach Algebras - T-MATH-105886 ... 299
3.13. Basic Seminar Supplementary Studies on Science, Technology and Society - Self Registration - T-FORUM-113579 ... 300
3.14. Basics of Nanotechnology I - T-PHYS-102529 ... 301
3.15. Basics of Nanotechnology II - T-PHYS-102531 ... 302
3.16. Batteries, Fuel Cells, and Electrolysis - T-ETIT-113986 ... 303
3.17. Batteries, Fuel Cells, and Electrolysis - Group Project - T-ETIT-114957 ... 304
3.18. Bayesian Inverse Problems with Connections to Machine Learning - T-MATH-112842 ... 305
3.19. Bifurcation Theory - T-MATH-106487 ... 306
3.20. Biopharmaceutical Purification Processes - T-CIWVT-106029 ... 307
3.21. Boundary and Eigenvalue Problems - T-MATH-105833 ... 308
3.22. Boundary Element Methods - T-MATH-109851 ... 309
3.23. Boundary Value Problems for Nonlinear Differential Equations - T-MATH-105847 ... 310
3.24. Brownian Motion - T-MATH-105868 ... 311
3.25. Class Field Theory - T-MATH-114500 ... 312
3.26. Classical Methods for Partial Differential Equations - T-MATH-105832 ... 313
3.27. Cognitive Systems - T-INFO-101356 ... 314
3.28. Combinatorics - T-MATH-105916 ... 315
3.29. Combustion Technology - T-CIWVT-106104 ... 316
3.30. Complex Analysis - T-MATH-105849 ... 317
3.31. Complex Geometry - T-MATH-113614 ... 318
3.32. Compressive Sensing - T-MATH-105894 ... 319
3.33. Computational Fluid Dynamics - T-CIWVT-106035 ... 320
3.34. Computational Fluid Dynamics and Simulation Lab - T-MATH-113373 ... 321
3.35. Computer Architecture - T-INFO-101355 ... 322
3.36. Computer Graphics - T-INFO-101393 ... 323
3.37. Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems - T-MATH-105854 ... 324
3.38. Condensed Matter Theory I, Fundamentals - T-PHYS-102559 ... 325
3.39. Condensed Matter Theory I, Fundamentals and Advanced Topics - T-PHYS-102558 ... 326
3.40. Condensed Matter Theory II: Many-Body Systems, Fundamentals - T-PHYS-104591 ... 327
3.41. Condensed Matter Theory II: Many-Body Systems, Fundamentals and Advanced Topics - T-PHYS-102560 ... 328
3.42. Continuous Time Finance - T-MATH-105930 ... 329
3.43. Control Theory - T-MATH-105909 ... 330
3.44. Convex Geometry - T-MATH-105831 ... 331
3.45. Curves on Surfaces - T-MATH-113364 ... 332
3.46. Deep Learning and Neural Networks - T-INFO-114219 ... 333
3.47. Differential Geometry - T-MATH-102275 ... 334
3.48. Discrete Dynamical Systems - T-MATH-110952 ... 335
3.49. Discrete Time Finance - T-MATH-105839 ... 336
3.50. Dispersive Equations - T-MATH-109001 ... 337
3.51. Dynamical Systems - T-MATH-106114 ... 338
3.52. Elective Specialization Supplementary Studies on Science, Technology and Society / About Knowledge and Science - Self-Registration - T-FORUM-113580 ... 339
3.53. Elective Specialization Supplementary Studies on Science, Technology and Society / Science in Public Debates - Self Registration - T-FORUM-113582 ... 340
3.54. Elective Specialization Supplementary Studies on Science, Technology and Society / Science in Society - Self-Registration - T-FORUM-113581 ... 341
3.55. Electromagnetics and Numerical Calculation of Fields - T-ETIT-100640 ... 342
3.56. Electronic Properties of Solids I, with Exercises - T-PHYS-102577 ... 343
3.57. Electronic Properties of Solids I, without Exercises - T-PHYS-102578 ... 344
3.58. Electronic Properties of Solids II, with Exercises - T-PHYS-104422 ... 345
3.59. Electronic Properties of Solids II, without Exercises - T-PHYS-104423 ... 346
3.60. Ergodic Theory - T-MATH-113086 ... 347
3.61. Evolution Equations - T-MATH-105844 ... 348
3.62. Exponential Integrators - T-MATH-107475 ... 349

3.63. Extremal Graph Theory - T-MATH-105931 ... 350
3.64. Extreme Value Theory - T-MATH-105908 ... 351
3.65. Finite Element Methods - T-MATH-105857 ... 352
3.66. Forecasting: Theory and Practice - T-MATH-105928 ... 353
3.67. Formal Systems - T-INFO-101336 ... 354
3.68. Foundations of Continuum Mechanics - T-MATH-107044 ... 355
3.69. Fractal Geometry - T-MATH-111296 ... 356
3.70. Functional Analysis - T-MATH-102255 ... 357
3.71. Functional Data Analysis - T-MATH-113102 ... 359
3.72. Functions of Matrices - T-MATH-105906 ... 360
3.73. Functions of Operators - T-MATH-105905 ... 361
3.74. Galerkin Methods for Time-dependent PDEs - T-MATH-114992 ... 362
3.75. Generalized Regression Models - T-MATH-105870 ... 363
3.76. Geometric Analysis - T-MATH-105892 ... 364
3.77. Geometric Group Theory - T-MATH-105842 ... 365
3.78. Geometric Group Theory II - T-MATH-105875 ... 366
3.79. Geometric Numerical Integration - T-MATH-105919 ... 367
3.80. Geometric Variational Problems - T-MATH-113418 ... 368
3.81. Geometry of Schemes - T-MATH-105841 ... 369
3.82. Global Differential Geometry - T-MATH-105885 ... 370
3.83. Graph Theory - T-MATH-102273 ... 371
3.84. Harmonic Analysis - T-MATH-111289 ... 372
3.85. Harmonic Analysis 2 - T-MATH-113103 ... 373
3.86. Heat Transfer II - T-CIWVT-106067 ... 374
3.87. High Temperature Process Engineering - T-CIWVT-106109 ... 375
3.88. Infinite dimensional dynamical systems - T-MATH-107070 ... 376
3.89. Information Security - T-INFO-112195 ... 377
3.90. Integral Equations - T-MATH-105834 ... 378
3.91. Integrated Photonics - T-ETIT-114418 ... 379
3.92. Internet Seminar for Evolution Equations - T-MATH-105890 ... 380
3.93. Internship - T-MATH-105888 ... 381
3.94. Interpolation Spaces - T-MATH-114639 ... 382
3.95. Introduction into Particulate Flows - T-MATH-105911 ... 383
3.96. Introduction to Artificial Intelligence - T-INFO-112194 ... 384
3.97. Introduction to Convex Integration - T-MATH-112119 ... 385
3.98. Introduction to Cosmology - T-PHYS-102384 ... 386
3.99. Introduction to Dynamical Systems - T-MATH-113263 ... 387
3.100. Introduction to Fluid Dynamics - T-MATH-111297 ... 388
3.101. Introduction to Fluid Mechanics - T-MATH-112927 ... 389
3.102. Introduction to Geometric Measure Theory - T-MATH-105918 ... 390
3.103. Introduction to Homogeneous Dynamics - T-MATH-110323 ... 391
3.104. Introduction to Kinetic Equations - T-MATH-111721 ... 392
3.105. Introduction to Kinetic Theory - T-MATH-108013 ... 393
3.106. Introduction to Microlocal Analysis - T-MATH-111722 ... 394
3.107. Introduction to Python - T-MATH-106119 ... 395
3.108. Introduction to Scientific Computing - T-MATH-105837 ... 396
3.109. Introduction to Stochastic Differential Equations - T-MATH-112234 ... 397
3.110. Inverse Problems - T-MATH-105835 ... 398
3.111. IT Security - T-INFO-113960 ... 399
3.112. Lecture Series Supplementary Studies on Science, Technology and Society - Self Registration - T-FORUM-113578 ... 400
3.113. Lie Groups and Lie Algebras - T-MATH-108799 ... 401
3.114. Lie-Algebras - T-MATH-113907 ... 402
3.115. Localization of Mobile Agents - T-INFO-115014 ... 403
3.116. Localization of Mobile Agents - Pass - T-INFO-115015 ... 405
3.117. Logical Foundations of Cyber-Physical Systems - T-INFO-112360 ... 407
3.118. Markov Decision Processes - T-MATH-105921 ... 408
3.119. Master's Thesis - T-MATH-105878 ... 409
3.120. Mathematical Methods in Signal and Image Processing - T-MATH-105862 ... 410
3.121. Mathematical Methods of Imaging - T-MATH-106488 ... 411

3.122. Mathematical Modelling and Simulation in Practise - T-MATH-105889 ... 412
3.123. Mathematical Statistics - T-MATH-105872 ... 413
3.124. Mathematical Topics in Kinetic Theory - T-MATH-108403 ... 414
3.125. Maxwell's Equations - T-MATH-105856 ... 415
3.126. Medical Imaging Technology - T-ETIT-113625 ... 416
3.127. Metric Geometry - T-MATH-111933 ... 417
3.128. Minimal Surfaces - T-MATH-113417 ... 418
3.129. Modelling and Simulation of Lithium-Ion Batteries - T-MATH-113382 ... 419
3.130. Models of Mathematical Physics - T-MATH-105846 ... 420
3.131. Modern Experimental Physics I, Atoms, Nuclei and Molecules - T-PHYS-112846 ... 421
3.132. Modern Experimental Physics II, Structure of Matter - T-PHYS-112847 ... 422
3.133. Modern Methods in Combinatorics - T-MATH-113911 ... 423
3.134. Modular Forms - T-MATH-105843 ... 424
3.135. Monotonicity Methods in Analysis - T-MATH-105877 ... 425
3.136. Neural Networks - T-INFO-101383 ... 426
3.137. Nonlinear Analysis - T-MATH-107065 ... 427
3.138. Nonlinear Control Systems - T-ETIT-114989 ... 428
3.139. Nonlinear Evolution Equations - T-MATH-105848 ... 429
3.140. Nonlinear Functional Analysis - T-MATH-105876 ... 430
3.141. Nonlinear Maxwell Equations - T-MATH-110283 ... 431
3.142. Nonlinear Wave Equations - T-MATH-110806 ... 432
3.143. Nonparametric Statistics - T-MATH-105873 ... 433
3.144. Numerical Analysis of Neural Networks - T-MATH-113470 ... 434
3.145. Numerical Analysis on Quantum Computers - T-MATH-114990 ... 435
3.146. Numerical Complex Analysis - T-MATH-112280 ... 436
3.147. Numerical Linear Algebra in Image Processing - T-MATH-108402 ... 437
3.148. Numerical Methods for Differential Equations - T-MATH-105836 ... 438
3.149. Numerical Methods for Hyperbolic Equations - T-MATH-105900 ... 439
3.150. Numerical Methods for Integral Equations - T-MATH-105901 ... 440
3.151. Numerical Methods for Maxwell's Equations - T-MATH-105920 ... 441
3.152. Numerical Methods for Oscillatory Differential Equations - T-MATH-113437 ... 442
3.153. Numerical Methods for Time-Dependent Partial Differential Equations - T-MATH-105899 ... 443
3.154. Numerical Methods in Computational Electrodynamics - T-MATH-105860 ... 444
3.155. Numerical Methods in Fluid Mechanics - T-MATH-105902 ... 445
3.156. Numerical Methods in Mathematical Finance - T-MATH-105865 ... 446
3.157. Numerical Optimisation Methods - T-MATH-105858 ... 447
3.158. Numerical Simulation in Molecular Dynamics - T-MATH-110807 ... 448
3.159. Optimal Control - T-ETIT-114701 ... 449
3.160. Optimisation and Optimal Control for Differential Equations - T-MATH-105864 ... 450
3.161. Optimization in Banach Spaces - T-MATH-105893 ... 451
3.162. Parallel Computing - T-MATH-102271 ... 452
3.163. Particle Physics I - T-PHYS-102369 ... 453
3.164. Pattern Recognition - T-INFO-101362 ... 454
3.165. Percolation - T-MATH-105869 ... 455
3.166. Physical Foundations of Cryogenics - T-CIWVT-106103 ... 456
3.167. Poisson Processes - T-MATH-105922 ... 457
3.168. Potential Theory - T-MATH-105850 ... 458
3.169. Practical Course: Mathematical and Computational Methods in Robotics and AI - T-INFO-114911 ... 459
3.170. Probability Theory and Combinatorial Optimization - T-MATH-105923 ... 460
3.171. Process Modeling in Downstream Processing - T-CIWVT-106101 ... 461
3.172. Processing of Nanostructured Particles - T-CIWVT-106107 ... 462
3.173. Project Lab Scientific Computing - T-MATH-114059 ... 463
3.174. Random Graphs and Networks - T-MATH-112241 ... 464
3.175. Real-Time Systems - T-INFO-101340 ... 465
3.176. Registration for Certificate Issuance - Supplementary Studies on Science, Technology and Society - T-FORUM-113587 ... 466
3.177. Regularity for Elliptic Operators - T-MATH-113472 ... 467
3.178. Riemann Surfaces - T-MATH-113081 ... 468
3.179. Robotics I - Introduction to Robotics - T-INFO-114190 ... 469
3.180. Robotics II - Humanoid Robotics - T-INFO-105723 ... 471

3.181. Robotics III - Sensors and Perception in Robotics - T-INFO-109931 ..... 473
3.182. Ruin Theory - T-MATH-108400 ..... 475
3.183. Sampling Methods for Machine Learning - T-INFO-114133 ..... 476
3.184. Sampling Methods for Machine Learning - Pass - T-INFO-114134 ..... 478
3.185. Scattering Theory - T-MATH-105855 ..... 479
3.186. Scattering Theory for Time-dependent Waves - T-MATH-113416 ..... 480
3.187. Selected Methods in Fluids and Kinetic Equations - T-MATH-111853 ..... 481
3.188. Selected Topics in Harmonic Analysis - T-MATH-109065 ..... 482
3.189. Self-Booking-HOC-SPZ-FORUM-1-Graded - T-MATH-111515 ..... 483
3.190. Self-Booking-HOC-SPZ-FORUM-2-Graded - T-MATH-111517 ..... 484
3.191. Self-Booking-HOC-SPZ-FORUM-5-Ungraded - T-MATH-111516 ..... 485
3.192. Self-Booking-HOC-SPZ-FORUM-6-Ungraded - T-MATH-111520 ..... 486
3.193. Self-Booking-HOC-SPZ-FORUM-PEBA-10-Ungraded - T-MATH-112652 ..... 487
3.194. Self-Booking-HOC-SPZ-FORUM-PEBA-9-Graded - T-MATH-112651 ..... 488
3.195. Semigroup Theory for the Navier-Stokes Equations - T-MATH-113415 ..... 489
3.196. Seminar Advanced Topics in Parallel Programming - T-INFO-103584 ..... 490
3.197. Seminar Mathematics - T-MATH-105686 ..... 491
3.198. Signal Processing Methods - T-ETIT-113837 ..... 492
3.199. Signal Processing with Nonlinear Fourier Transforms and Koopman Operators - T-ETIT-113428 ..... 493
3.200. Simulation and Optimization in Robotics and Biomechanics - T-INFO-113123 ..... 494
3.201. Simulation and Optimization in Robotics and Biomechanics - Pass - T-INFO-114838 ..... 496
3.202. Sobolev Spaces - T-MATH-105896 ..... 497
3.203. Software Engineering II - T-INFO-114259 ..... 498
3.204. Space and Time Discretization of Nonlinear Wave Equations - T-MATH-112120 ..... 499
3.205. Spatial Stochastics - T-MATH-105867 ..... 500
3.206. Special Topics of Numerical Linear Algebra - T-MATH-105891 ..... 501
3.207. Spectral Theory - Exam - T-MATH-103414 ..... 502
3.208. Spectral Theory of Differential Operators - T-MATH-105851 ..... 504
3.209. Splitting Methods for Evolution Equations - T-MATH-110805 ..... 505
3.210. Statistical Learning - T-MATH-111726 ..... 506
3.211. Statistical Thermodynamics - T-CIWVT-106098 ..... 507
3.212. Steins Method with Applications in Statistics - T-MATH-111187 ..... 508
3.213. Stochastic Control - T-MATH-105871 ..... 509
3.214. Stochastic Geometry - T-MATH-105840 ..... 510
3.215. Stochastic Information Processing - T-INFO-101366 ..... 511
3.216. Stochastic Simulation - T-MATH-112242 ..... 513
3.217. Structural Graph Theory - T-MATH-111004 ..... 514
3.218. Technical Optics - T-ETIT-100804 ..... 515
3.219. Technomathematical Seminar - T-MATH-105884 ..... 516
3.220. Telematics - T-INFO-114269 ..... 517
3.221. Theoretical Nanooptics - T-PHYS-104587 ..... 519
3.222. Theoretical Optics - T-PHYS-104578 ..... 520
3.223. Thermodynamics III - T-CIWVT-106033 ..... 521
3.224. Thermodynamics of Interfaces - T-CIWVT-106100 ..... 522
3.225. Time Series Analysis - T-MATH-105874 ..... 523
3.226. Topics in Algebraic Topology - T-MATH-114063 ..... 524
3.227. Topics in Homotopy Theory - T-MATH-114682 ..... 525
3.228. Topological Data Analysis - T-MATH-111031 ..... 526
3.229. Translation Surfaces - T-MATH-112128 ..... 527
3.230. Traveling Waves - T-MATH-105897 ..... 528
3.231. Uncertainty Quantification - T-MATH-108399 ..... 529
3.232. Variational Methods - T-MATH-110302 ..... 531
3.233. Wavelets - T-MATH-105838 ..... 532

# 1 Study Program Structure

| | |
|---|---|
| **Mandatory** | |
| Master's Thesis | 30 CP |
| Internship<br>*This field will not influence the calculated grade of its parent.* | 10 CP |
| Applied Mathematics | 24 CP |
| **Technical Field (Elective: 1 item)** | |
| Electrical Engineering / Information Technology | 18-27 CP |
| Experimental Physics | 18-27 CP |
| Chemical and Process Engineering | 18-27 CP |
| Wildcard Technical Field | 18-27 CP |
| **Mandatory** | |
| Computer Science | 8-17 CP |
| Mathematical Specialization | 19 CP |
| Interdisciplinary Qualifications<br>*This field will not influence the calculated grade of its parent.* | 2 CP |
| **Voluntary** | |
| Additional Examinations<br>*This field will not influence the calculated grade of its parent.* | |

## 1.1 Master's Thesis

**Credits**
30

| **Mandatory** | | | | |
|---|---|---|---|---|
| M-MATH-102917 | Master's Thesis | | WS+SS | 30 CP |

## 1.2 Internship

**Credits**
10

| **Mandatory** | | | | |
|---|---|---|---|---|
| M-MATH-102861 | Internship | | WS+SS | 10 CP |

## 1.3 Applied Mathematics

**Credits**
24

| | | | | |
|---|---|---|---|---|
| **Mandatory** | | | | |
| M-MATH-102891 | Finite Element Methods | EN | WS | 8 CP |
| **Analysis (Elective: at least 8 credits)** | | | | |
| M-MATH-101320 | Functional Analysis | DE | WS | 8 CP |
| M-MATH-101768 | Spectral Theory | DE | SS | 8 CP |
| M-MATH-102870 | Classical Methods for Partial Differential Equations | DE/EN | WS | 8 CP |
| M-MATH-102871 | Boundary and Eigenvalue Problems | | SS | 8 CP |
| M-MATH-102872 | Evolution Equations | DE/EN | see notes | 8 CP |
| M-MATH-102874 | Integral Equations | | Irreg. | 8 CP |
| M-MATH-102875 | Models of Mathematical Physics | | Irreg. | 8 CP |
| M-MATH-102876 | Boundary value problems for nonlinear differential equations | | Irreg. | 8 CP |
| M-MATH-102877 | Nonlinear Evolution Equations | DE/EN | Irreg. | 8 CP |
| M-MATH-102878 | Complex Analysis | | Irreg. | 8 CP |
| M-MATH-102879 | Potential Theory | | Irreg. | 8 CP |
| M-MATH-102880 | Spectral Theory of Differential Operators | DE/EN | Irreg. | 8 CP |
| M-MATH-102883 | Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems | DE/EN | Irreg. | 8 CP |
| M-MATH-102884 | Scattering Theory | | Irreg. | 8 CP |
| M-MATH-102885 | Maxwell's Equations | | Irreg. | 8 CP |
| M-MATH-102886 | Nonlinear Functional Analysis | | Irreg. | 3 CP |
| M-MATH-102887 | Monotonicity Methods in Analysis | | Irreg. | 3 CP |
| M-MATH-102890 | Inverse Problems | | WS | 8 CP |
| M-MATH-102913 | Banach Algebras | | Irreg. | 3 CP |
| M-MATH-102918 | Internet Seminar for Evolution Equations | DE/EN | WS | 8 CP |
| M-MATH-102923 | Geometric Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-102924 | Optimization in Banach Spaces | | Irreg. | 5 CP |
| M-MATH-102926 | Sobolev Spaces | DE/EN | Irreg. | 8 CP |
| M-MATH-102927 | Traveling Waves | EN | Irreg. | 6 CP |
| M-MATH-102941 | Control Theory | DE/EN | Irreg. | 6 CP |
| M-MATH-103080 | Dynamical Systems | DE | Irreg. | 8 CP |
| M-MATH-103259 | Bifurcation Theory | | Irreg. | 5 CP |
| M-MATH-103251 | Aspects of Geometric Analysis<br>*First usage possible until Apr 15, 2026.* | | Irreg. | 4 CP |
| M-MATH-103539 | Nonlinear Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-103544 | Infinite dimensional dynamical systems | | Irreg. | 4 CP |
| M-MATH-104059 | Mathematical Topics in Kinetic Theory | | Irreg. | 4 CP |
| M-MATH-104425 | Dispersive Equations | | Irreg. | 6 CP |
| M-MATH-104435 | Selected Topics in Harmonic Analysis | DE | Irreg. | 3 CP |
| M-MATH-105066 | Nonlinear Maxwell Equations | DE/EN | Irreg. | 8 CP |
| M-MATH-105101 | Introduction to Homogeneous Dynamics | | Irreg. | 6 CP |
| M-MATH-105093 | Variational Methods | | Irreg. | 8 CP |
| M-MATH-105324 | Harmonic Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-105326 | Nonlinear Wave Equations | DE/EN | Irreg. | 4 CP |
| M-MATH-105432 | Discrete Dynamical Systems | DE | Irreg. | 3 CP |
| M-MATH-105487 | Topological Data Analysis | DE/EN | Irreg. | 6 CP |
| M-MATH-105650 | Introduction to Fluid Dynamics | | Irreg. | 3 CP |
| M-MATH-105964 | Introduction to Convex Integration | EN | Irreg. | 3 CP |
| M-MATH-106401 | Introduction to Fluid Mechanics | EN | Irreg. | 6 CP |
| M-MATH-106486 | Harmonic Analysis 2 | EN | Irreg. | 8 CP |
| M-MATH-106591 | Introduction to Dynamical Systems | DE/EN | Irreg. | 6 CP |
| M-MATH-106667 | Geometric Variational Problems | DE/EN | Irreg. | 8 CP |

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|---|---|---|---|---|
| M-MATH-106666 | Minimal Surfaces | DE | Irreg. | 3 CP |
| M-MATH-106664 | Scattering Theory for Time-dependent Waves | DE/EN | Irreg. | 6 CP |
| M-MATH-106663 | Semigroup Theory for the Navier-Stokes Equations | EN | Irreg. | 6 CP |
| M-MATH-106696 | Regularity for Elliptic Operators | EN | Irreg. | 6 CP |
| M-MATH-106822 | Advanced Methods in Nonlinear Partial Differential Equations | EN | Irreg. | 3 CP |
| M-MATH-107456 | Interpolation Spaces | DE/EN | Irreg. | 6 CP |
| **Elective Field Applied Mathematics (Elective: at least 8 credits)** | | | | |
| M-MATH-102864 | Convex Geometry | | Irreg. | 8 CP |
| M-MATH-102883 | Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems | DE/EN | Irreg. | 8 CP |
| M-MATH-102890 | Inverse Problems | | WS | 8 CP |
| M-MATH-102904 | Brownian Motion | | Irreg. | 4 CP |
| M-MATH-102909 | Mathematical Statistics | | WS | 8 CP |
| M-MATH-102931 | Numerical Methods for Maxwell's Equations | | Irreg. | 6 CP |
| M-MATH-102936 | Functions of Operators | | Irreg. | 6 CP |
| M-MATH-102947 | Probability Theory and Combinatorial Optimization | | Irreg. | 8 CP |
| M-MATH-102956 | Forecasting: Theory and Practice | EN | Irreg. | 8 CP |
| M-MATH-102866 | Geometry of Schemes | | Irreg. | 8 CP |
| M-MATH-102872 | Evolution Equations | DE/EN | see notes | 8 CP |
| M-MATH-102879 | Potential Theory | | Irreg. | 8 CP |
| M-MATH-102888 | Numerical Methods for Differential Equations | DE | WS | 8 CP |
| M-MATH-102906 | Generalized Regression Models | | Irreg. | 4 CP |
| M-MATH-102910 | Nonparametric Statistics | | Irreg. | 4 CP |
| M-MATH-102913 | Banach Algebras | | Irreg. | 3 CP |
| M-MATH-102924 | Optimization in Banach Spaces | | Irreg. | 5 CP |
| M-MATH-102927 | Traveling Waves | EN | Irreg. | 6 CP |
| M-MATH-101724 | Algebraic Geometry | | Irreg. | 8 CP |
| M-MATH-101768 | Spectral Theory | DE | SS | 8 CP |
| M-MATH-102867 | Geometric Group Theory | EN | see notes | 8 CP |
| M-MATH-102894 | Numerical Methods in Computational Electrodynamics | DE | Irreg. | 6 CP |
| M-MATH-102899 | Optimisation and Optimal Control for Differential Equations | EN | Irreg. | 6 CP |
| M-MATH-102918 | Internet Seminar for Evolution Equations | DE/EN | WS | 8 CP |
| M-MATH-102930 | Numerical Methods for Integral Equations | | Irreg. | 8 CP |
| M-MATH-102941 | Control Theory | DE/EN | Irreg. | 6 CP |
| M-MATH-101315 | Algebra | | see notes | 8 CP |
| M-MATH-102874 | Integral Equations | | Irreg. | 8 CP |
| M-MATH-102876 | Boundary value problems for nonlinear differential equations | | Irreg. | 8 CP |
| M-MATH-102905 | Percolation | DE/EN | Irreg. | 5 CP |
| M-MATH-106634 | Computational Fluid Dynamics and Simulation Lab | DE/EN | SS | 4 CP |
| M-MATH-101725 | Algebraic Number Theory | | Irreg. | 8 CP |
| M-MATH-102865 | Stochastic Geometry | | SS | 8 CP |
| M-MATH-102915 | Numerical Methods for Hyperbolic Equations | DE/EN | Irreg. | 6 CP |
| M-MATH-102921 | Geometric Numerical Integration | | Irreg. | 6 CP |
| M-MATH-102950 | Combinatorics | EN | see notes | 8 CP |
| M-MATH-102953 | Algebraic Topology II | DE/EN | Irreg. | 8 CP |
| M-MATH-102955 | Advanced Inverse Problems: Nonlinearity and Banach Spaces | | Irreg. | 5 CP |
| M-MATH-101317 | Differential Geometry | DE/EN | Irreg. | 8 CP |
| M-MATH-102870 | Classical Methods for Partial Differential Equations | DE/EN | WS | 8 CP |
| M-MATH-102871 | Boundary and Eigenvalue Problems | | SS | 8 CP |
| M-MATH-102900 | Adaptive Finite Elemente Methods | | Irreg. | 8 CP |
| M-MATH-102903 | Spatial Stochastics | | WS | 8 CP |

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|---|---|---|---|---|
| M-MATH-102920 | Special Topics of Numerical Linear Algebra | EN | see notes | 8 CP |
| M-MATH-102928 | Numerical Methods for Time-Dependent Partial Differential Equations | | Irreg. | 8 CP |
| M-MATH-102932 | Numerical Methods in Fluid Mechanics | EN | SS | 4 CP |
| M-MATH-102957 | Extremal Graph Theory | EN | Irreg. | 8 CP |
| M-MATH-101320 | Functional Analysis | DE | WS | 8 CP |
| M-MATH-101336 | Graph Theory | EN | see notes | 8 CP |
| M-MATH-101338 | Parallel Computing | DE/EN | Irreg. | 5 CP |
| M-MATH-102878 | Complex Analysis | | Irreg. | 8 CP |
| M-MATH-102885 | Maxwell's Equations | | Irreg. | 8 CP |
| M-MATH-102889 | Introduction to Scientific Computing | | SS | 8 CP |
| M-MATH-102895 | Wavelets | | Irreg. | 8 CP |
| M-MATH-102868 | Modular Forms | | Irreg. | 8 CP |
| M-MATH-102877 | Nonlinear Evolution Equations | DE/EN | Irreg. | 8 CP |
| M-MATH-102908 | Stochastic Control | | Irreg. | 4 CP |
| M-MATH-102912 | Global Differential Geometry | DE/EN | Irreg. | 8 CP |
| M-MATH-102935 | Compressive Sensing | | Irreg. | 5 CP |
| M-MATH-102937 | Functions of Matrices | | Irreg. | 8 CP |
| M-MATH-102939 | Extreme Value Theory | | Irreg. | 4 CP |
| M-MATH-102943 | Introduction into Particulate Flows | | Once | 3 CP |
| M-MATH-102948 | Algebraic Topology | DE/EN | see notes | 8 CP |
| M-MATH-102949 | Introduction to Geometric Measure Theory | DE/EN | Irreg. | 6 CP |
| M-MATH-102886 | Nonlinear Functional Analysis | | Irreg. | 3 CP |
| M-MATH-102897 | Mathematical Methods in Signal and Image Processing | | Irreg. | 8 CP |
| M-MATH-102901 | Numerical Methods in Mathematical Finance | DE/EN | see notes | 8 CP |
| M-MATH-102907 | Markov Decision Processes | | Irreg. | 5 CP |
| M-MATH-102911 | Time Series Analysis | | SS | 4 CP |
| M-MATH-102923 | Geometric Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-102929 | Mathematical Modelling and Simulation in Practise | EN | Irreg. | 4 CP |
| M-MATH-102860 | Continuous Time Finance | | SS | 8 CP |
| M-MATH-102869 | Geometric Group Theory II | EN | Irreg. | 8 CP |
| M-MATH-102875 | Models of Mathematical Physics | | Irreg. | 8 CP |
| M-MATH-102880 | Spectral Theory of Differential Operators | DE/EN | Irreg. | 8 CP |
| M-MATH-102884 | Scattering Theory | | Irreg. | 8 CP |
| M-MATH-102887 | Monotonicity Methods in Analysis | | Irreg. | 3 CP |
| M-MATH-102892 | Numerical Optimisation Methods | DE/EN | Irreg. | 8 CP |
| M-MATH-102919 | Discrete Time Finance | | WS | 8 CP |
| M-MATH-102922 | Poisson Processes | | Irreg. | 5 CP |
| M-MATH-102926 | Sobolev Spaces | DE/EN | Irreg. | 8 CP |
| M-MATH-103260 | Mathematical Methods of Imaging | | Irreg. | 5 CP |
| M-MATH-103251 | Aspects of Geometric Analysis<br>*First usage possible until Apr 15, 2026.* | | Irreg. | 4 CP |
| M-MATH-103527 | Foundations of Continuum Mechanics | | Once | 4 CP |
| M-MATH-103539 | Nonlinear Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-103700 | Exponential Integrators | | Irreg. | 6 CP |
| M-MATH-103919 | Introduction to Kinetic Theory | EN | WS | 4 CP |
| M-MATH-104054 | Uncertainty Quantification | EN | SS | 4 CP |
| M-MATH-104055 | Ruin Theory | | Irreg. | 4 CP |
| M-MATH-104058 | Numerical Linear Algebra in Image Processing | | Irreg. | 6 CP |
| M-MATH-104059 | Mathematical Topics in Kinetic Theory | | Irreg. | 4 CP |
| M-MATH-104261 | Lie Groups and Lie Algebras | DE | see notes | 8 CP |
| M-MATH-103540 | Boundary Element Methods | | Irreg. | 8 CP |

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|---|---|---|---|---|
| M-MATH-105066 | Nonlinear Maxwell Equations | DE/EN | Irreg. | 8 CP |
| M-MATH-105101 | Introduction to Homogeneous Dynamics | | Irreg. | 6 CP |
| M-MATH-105093 | Variational Methods | | Irreg. | 8 CP |
| M-MATH-105325 | Splitting Methods for Evolution Equations | | Irreg. | 6 CP |
| M-MATH-105327 | Numerical Simulation in Molecular Dynamics | DE | Irreg. | 8 CP |
| M-MATH-105579 | Steins Method with Applications in Statistics | DE/EN | Irreg. | 4 CP |
| M-MATH-105636 | Analytical and Numerical Homogenization | EN | Irreg. | 6 CP |
| M-MATH-105649 | Fractal Geometry | DE/EN | Irreg. | 6 CP |
| M-MATH-105840 | Statistical Learning | | SS | 8 CP |
| M-MATH-105966 | Space and Time Discretization of Nonlinear Wave Equations | EN | Irreg. | 6 CP |
| M-MATH-106045 | Introduction to Stochastic Differential Equations | EN | Irreg. | 4 CP |
| M-MATH-106052 | Random Graphs and Networks | EN | Irreg. | 8 CP |
| M-MATH-106053 | Stochastic Simulation | EN | WS | 5 CP |
| M-MATH-106063 | Numerical Complex Analysis | DE | Irreg. | 6 CP |
| M-MATH-106328 | Bayesian Inverse Problems with Connections to Machine Learning | EN | SS | 4 CP |
| M-MATH-106485 | Functional Data Analysis | EN | Irreg. | 4 CP |
| M-MATH-106640 | Modelling and Simulation of Lithium-Ion Batteries | EN | Irreg. | 4 CP |
| M-MATH-106664 | Scattering Theory for Time-dependent Waves | DE/EN | Irreg. | 6 CP |
| M-MATH-106695 | Numerical Analysis of Neural Networks | EN | Irreg. | 6 CP |
| M-MATH-106682 | Numerical Methods for Oscillatory Differential Equations | DE/EN | see notes | 8 CP |
| M-MATH-107646 | Numerical Analysis on Quantum Computers neu | EN | Irreg. | 6 CP |
| M-MATH-107647 | Galerkin Methods for Time-dependent PDEs neu | EN | Irreg. | 5 CP |

## 1.4 Electrical Engineering / Information Technology

**Credits**
18-27

| | | | | |
|---|---|---|---|---|
| **Mandatory** | | | | |
| M-MATH-102863 | Technomathematical Seminar | | WS+SS | 3 CP |
| **Electrical Engineering / Information Technology (Elective: between 15 and 24 credits)** | | | | |
| M-ETIT-107644 | Nonlinear Control Systems neu | EN | SS | 6 CP |
| M-ETIT-100386 | Electromagnetics and Numerical Calculation of Fields | EN | WS | 4 CP |
| M-ETIT-107497 | Optimal Control | EN | WS | 6 CP |
| M-ETIT-107005 | Batteries, Fuel Cells, and Electrolysis | EN | WS | 6 CP |
| M-ETIT-100538 | Technical Optics | DE | WS | 5 CP |
| M-ETIT-106899 | Signal Processing Methods | EN | WS | 6 CP |
| M-ETIT-106675 | Signal Processing with Nonlinear Fourier Transforms and Koopman Operators | EN | SS | 6 CP |
| M-ETIT-106778 | Medical Imaging Technology | EN | SS | 6 CP |
| M-ETIT-107344 | Integrated Photonics | EN | WS | 6 CP |

## 1.5 Experimental Physics

**Credits**
18-27

| | | | | |
|---|---|---|---|---|
| **Mandatory** | | | | |
| M-MATH-102863 | Technomathematical Seminar | | WS+SS | 3 CP |
| **Experimental Physics (Elective: between 15 and 24 credits)** | | | | |
| M-PHYS-106331 | Modern Experimental Physics I, Atoms, Nuclei and Molecules | DE | SS | 8 CP |
| M-PHYS-106332 | Modern Experimental Physics II, Structure of Matter | DE | WS | 8 CP |
| M-PHYS-102053 | Condensed Matter Theory I, Fundamentals and Advanced Topics | EN | WS | 12 CP |
| M-PHYS-102054 | Condensed Matter Theory I, Fundamentals | EN | WS | 8 CP |
| M-PHYS-102075 | Astroparticle Physics I | EN | WS | 8 CP |
| M-PHYS-102089 | Electronic Properties of Solids I, with Exercises | EN | WS | 10 CP |
| M-PHYS-102090 | Electronic Properties of Solids I, without Exercises | EN | WS | 8 CP |
| M-PHYS-102097 | Basics of Nanotechnology I | EN | WS | 4 CP |
| M-PHYS-102100 | Basics of Nanotechnology II | EN | SS | 4 CP |
| M-PHYS-102108 | Electronic Properties of Solids II, with Exercises | EN | SS | 8 CP |
| M-PHYS-102109 | Electronic Properties of Solids II, without Exercises | EN | SS | 4 CP |
| M-PHYS-102114 | Particle Physics I | EN | WS | 8 CP |
| M-PHYS-102175 | Introduction to Cosmology | EN | WS | 6 CP |
| M-PHYS-102277 | Theoretical Optics | EN | SS | 6 CP |
| M-PHYS-102295 | Theoretical Nanooptics | EN | Irreg. | 6 CP |
| M-PHYS-102308 | Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics | EN | SS | 12 CP |
| M-PHYS-102313 | Condensed Matter Theory II: Many-Body Theory, Fundamentals | EN | SS | 8 CP |

## 1.6 Chemical and Process Engineering

**Credits**
18-27

| | | | | |
|---|---|---|---|---|
| **Mandatory** | | | | |
| M-MATH-102863 | Technomathematical Seminar | | WS+SS | 3 CP |
| **Chemical and Process Engineering (Elective: between 15 and 24 credits)** | | | | |
| M-CIWVT-103051 | Heat Transfer II | DE | WS | 6 CP |
| M-CIWVT-103058 | Thermodynamics III | DE | WS | 6 CP |
| M-CIWVT-103059 | Statistical Thermodynamics | DE/EN | SS | 6 CP |
| M-CIWVT-103063 | Thermodynamics of Interfaces | DE/EN | SS | 6 CP |
| M-CIWVT-103065 | Biopharmaceutical Purification Processes | DE | WS | 6 CP |
| M-CIWVT-103066 | Process Modeling in Downstream Processing | DE | SS | 4 CP |
| M-CIWVT-103068 | Physical Foundations of Cryogenics | EN | SS | 6 CP |
| M-CIWVT-103069 | Combustion Technology | DE | WS | 6 CP |
| M-CIWVT-103072 | Computational Fluid Dynamics | DE | WS | 6 CP |
| M-CIWVT-103073 | Processing of Nanostructured Particles | DE | WS | 6 CP |
| M-CIWVT-103075 | High Temperature Process Engineering | DE | SS | 6 CP |

## 1.7 Wildcard Technical Field

**Credits**
18-27

| | | | | |
|---|---|---|---|---|
| **Mandatory** | | | | |
| M-MATH-102863 | Technomathematical Seminar | | WS+SS | 3 CP |

## 1.8 Computer Science

**Credits**
8-17

| Computer Science (Elective: at least 1 item as well as between 8 and 17 credits) | | | | |
|---|---|---|---|---|
| M-INFO-100799 | Formal Systems | DE | WS | 6 CP |
| M-INFO-100803 | Real-Time Systems | DE | SS | 6 CP |
| M-INFO-104897 | Robotics III - Sensors and Perception in Robotics | EN | SS | 3 CP |
| M-INFO-100818 | Computer Architecture | DE | SS | 6 CP |
| M-INFO-100819 | Cognitive Systems | DE | SS | 6 CP |
| M-INFO-100825 | Pattern Recognition | DE | SS | 6 CP |
| M-INFO-100846 | Neural Networks | DE/EN | SS | 6 CP |
| M-INFO-100856 | Computer Graphics | DE | WS | 6 CP |
| M-INFO-107663 | Localization of Mobile Agents neu | EN | SS | 6 CP |
| M-INFO-101887 | Seminar Advanced Topics in Parallel Programming | DE/EN | SS | 3 CP |
| M-INFO-100829 | Stochastic Information Processing | DE | WS | 6 CP |
| M-INFO-106014 | Introduction to Artificial Intelligence | DE | WS | 5 CP |
| M-INFO-106015 | Information Security | DE | SS | 5 CP |
| M-INFO-102756 | Robotics II - Humanoid Robotics | EN | SS | 3 CP |
| M-INFO-106102 | Logical Foundations of Cyber-Physical Systems | EN | WS | 6 CP |
| M-INFO-106998 | IT Security | EN | WS | 6 CP |
| M-INFO-107162 | Robotics I - Introduction to Robotics | EN | WS | 6 CP |
| M-INFO-107197 | Deep Learning and Neural Networks | EN | SS | 6 CP |
| M-INFO-107235 | Software Engineering II | EN | SS | 6 CP |
| M-INFO-107243 | Telematics | EN | WS | 6 CP |
| M-INFO-107090 | Sampling Methods for Machine Learning | EN | SS | 6 CP |
| M-INFO-106504 | Simulation and Optimization in Robotics and Biomechanics | EN | WS | 6 CP |
| M-INFO-107609 | Practical Course: Mathematical and Computational Methods in Robotics and AI | EN | WS+SS | 6 CP |

## 1.9 Mathematical Specialization

**Credits**
19

| | | | | |
|---|---|---|---|---|
| **Mandatory** | | | | |
| M-MATH-102730 | Seminar | DE/EN | WS+SS | 3 CP |
| **Elective Field Mathematical Specialization (Elective: at least 16 credits)** | | | | |
| M-MATH-102864 | Convex Geometry | | Irreg. | 8 CP |
| M-MATH-102866 | Geometry of Schemes | | Irreg. | 8 CP |
| M-MATH-102872 | Evolution Equations | DE/EN | see notes | 8 CP |
| M-MATH-102879 | Potential Theory | | Irreg. | 8 CP |
| M-MATH-102883 | Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems | DE/EN | Irreg. | 8 CP |
| M-MATH-102888 | Numerical Methods for Differential Equations | DE | WS | 8 CP |
| M-MATH-102890 | Inverse Problems | | WS | 8 CP |
| M-MATH-102904 | Brownian Motion | | Irreg. | 4 CP |
| M-MATH-102906 | Generalized Regression Models | | Irreg. | 4 CP |
| M-MATH-102909 | Mathematical Statistics | | WS | 8 CP |
| M-MATH-102910 | Nonparametric Statistics | | Irreg. | 4 CP |
| M-MATH-102913 | Banach Algebras | | Irreg. | 3 CP |
| M-MATH-102918 | Internet Seminar for Evolution Equations | DE/EN | WS | 8 CP |
| M-MATH-102924 | Optimization in Banach Spaces | | Irreg. | 5 CP |
| M-MATH-102927 | Traveling Waves | EN | Irreg. | 6 CP |
| M-MATH-102931 | Numerical Methods for Maxwell's Equations | | Irreg. | 6 CP |
| M-MATH-102936 | Functions of Operators | | Irreg. | 6 CP |
| M-MATH-102947 | Probability Theory and Combinatorial Optimization | | Irreg. | 8 CP |
| M-MATH-102956 | Forecasting: Theory and Practice | EN | Irreg. | 8 CP |
| M-MATH-101315 | Algebra | | see notes | 8 CP |
| M-MATH-101724 | Algebraic Geometry | | Irreg. | 8 CP |
| M-MATH-101725 | Algebraic Number Theory | | Irreg. | 8 CP |
| M-MATH-101768 | Spectral Theory | DE | SS | 8 CP |
| M-MATH-102867 | Geometric Group Theory | EN | see notes | 8 CP |
| M-MATH-102874 | Integral Equations | | Irreg. | 8 CP |
| M-MATH-102876 | Boundary value problems for nonlinear differential equations | | Irreg. | 8 CP |
| M-MATH-102894 | Numerical Methods in Computational Electrodynamics | DE | Irreg. | 6 CP |
| M-MATH-102899 | Optimisation and Optimal Control for Differential Equations | EN | Irreg. | 6 CP |
| M-MATH-102905 | Percolation | DE/EN | Irreg. | 5 CP |
| M-MATH-102915 | Numerical Methods for Hyperbolic Equations | DE/EN | Irreg. | 6 CP |
| M-MATH-102930 | Numerical Methods for Integral Equations | | Irreg. | 8 CP |
| M-MATH-106634 | Computational Fluid Dynamics and Simulation Lab | DE/EN | SS | 4 CP |
| M-MATH-102941 | Control Theory | DE/EN | Irreg. | 6 CP |
| M-MATH-102953 | Algebraic Topology II | DE/EN | Irreg. | 8 CP |
| M-MATH-101317 | Differential Geometry | DE/EN | Irreg. | 8 CP |
| M-MATH-101320 | Functional Analysis | DE | WS | 8 CP |
| M-MATH-101336 | Graph Theory | EN | see notes | 8 CP |
| M-MATH-101338 | Parallel Computing | DE/EN | Irreg. | 5 CP |
| M-MATH-102865 | Stochastic Geometry | | SS | 8 CP |
| M-MATH-102870 | Classical Methods for Partial Differential Equations | DE/EN | WS | 8 CP |
| M-MATH-102871 | Boundary and Eigenvalue Problems | | SS | 8 CP |
| M-MATH-102878 | Complex Analysis | | Irreg. | 8 CP |
| M-MATH-102885 | Maxwell's Equations | | Irreg. | 8 CP |
| M-MATH-102889 | Introduction to Scientific Computing | | SS | 8 CP |
| M-MATH-102895 | Wavelets | | Irreg. | 8 CP |
| M-MATH-102900 | Adaptive Finite Elemente Methods | | Irreg. | 8 CP |
| M-MATH-102903 | Spatial Stochastics | | WS | 8 CP |

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|---|---|---|---|---|
| M-MATH-102920 | Special Topics of Numerical Linear Algebra | EN | see notes | 8 CP |
| M-MATH-102921 | Geometric Numerical Integration | | Irreg. | 6 CP |
| M-MATH-102928 | Numerical Methods for Time-Dependent Partial Differential Equations | | Irreg. | 8 CP |
| M-MATH-102932 | Numerical Methods in Fluid Mechanics | EN | SS | 4 CP |
| M-MATH-102937 | Functions of Matrices | | Irreg. | 8 CP |
| M-MATH-102939 | Extreme Value Theory | | Irreg. | 4 CP |
| M-MATH-102943 | Introduction into Particulate Flows | | Once | 3 CP |
| M-MATH-102950 | Combinatorics | EN | see notes | 8 CP |
| M-MATH-102955 | Advanced Inverse Problems: Nonlinearity and Banach Spaces | | Irreg. | 5 CP |
| M-MATH-102957 | Extremal Graph Theory | EN | Irreg. | 8 CP |
| M-MATH-102860 | Continuous Time Finance | | SS | 8 CP |
| M-MATH-102868 | Modular Forms | | Irreg. | 8 CP |
| M-MATH-102869 | Geometric Group Theory II | EN | Irreg. | 8 CP |
| M-MATH-102875 | Models of Mathematical Physics | | Irreg. | 8 CP |
| M-MATH-102877 | Nonlinear Evolution Equations | DE/EN | Irreg. | 8 CP |
| M-MATH-102884 | Scattering Theory | | Irreg. | 8 CP |
| M-MATH-102886 | Nonlinear Functional Analysis | | Irreg. | 3 CP |
| M-MATH-102887 | Monotonicity Methods in Analysis | | Irreg. | 3 CP |
| M-MATH-102897 | Mathematical Methods in Signal and Image Processing | | Irreg. | 8 CP |
| M-MATH-102901 | Numerical Methods in Mathematical Finance | DE/EN | see notes | 8 CP |
| M-MATH-102907 | Markov Decision Processes | | Irreg. | 5 CP |
| M-MATH-102908 | Stochastic Control | | Irreg. | 4 CP |
| M-MATH-102911 | Time Series Analysis | | SS | 4 CP |
| M-MATH-102912 | Global Differential Geometry | DE/EN | Irreg. | 8 CP |
| M-MATH-102919 | Discrete Time Finance | | WS | 8 CP |
| M-MATH-102922 | Poisson Processes | | Irreg. | 5 CP |
| M-MATH-102923 | Geometric Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-102926 | Sobolev Spaces | DE/EN | Irreg. | 8 CP |
| M-MATH-102929 | Mathematical Modelling and Simulation in Practise | EN | Irreg. | 4 CP |
| M-MATH-102935 | Compressive Sensing | | Irreg. | 5 CP |
| M-MATH-102948 | Algebraic Topology | DE/EN | see notes | 8 CP |
| M-MATH-102949 | Introduction to Geometric Measure Theory | DE/EN | Irreg. | 6 CP |
| M-MATH-102880 | Spectral Theory of Differential Operators | DE/EN | Irreg. | 8 CP |
| M-MATH-102892 | Numerical Optimisation Methods | DE/EN | Irreg. | 8 CP |
| M-MATH-103080 | Dynamical Systems | DE | Irreg. | 8 CP |
| M-MATH-103259 | Bifurcation Theory | | Irreg. | 5 CP |
| M-MATH-103260 | Mathematical Methods of Imaging | | Irreg. | 5 CP |
| M-MATH-103251 | Aspects of Geometric Analysis<br>*First usage possible until Apr 15, 2026.* | | Irreg. | 4 CP |
| M-MATH-103527 | Foundations of Continuum Mechanics | | Once | 4 CP |
| M-MATH-103539 | Nonlinear Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-103700 | Exponential Integrators | | Irreg. | 6 CP |
| M-MATH-103919 | Introduction to Kinetic Theory | EN | WS | 4 CP |
| M-MATH-104054 | Uncertainty Quantification | EN | SS | 4 CP |
| M-MATH-104055 | Ruin Theory | | Irreg. | 4 CP |
| M-MATH-104058 | Numerical Linear Algebra in Image Processing | | Irreg. | 6 CP |
| M-MATH-104059 | Mathematical Topics in Kinetic Theory | | Irreg. | 4 CP |
| M-MATH-104261 | Lie Groups and Lie Algebras | DE | see notes | 8 CP |
| M-MATH-104425 | Dispersive Equations | | Irreg. | 6 CP |
| M-MATH-104435 | Selected Topics in Harmonic Analysis | DE | Irreg. | 3 CP |
| M-MATH-103540 | Boundary Element Methods | | Irreg. | 8 CP |

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|---|---|---|---|---|
| M-MATH-105066 | Nonlinear Maxwell Equations | DE/EN | Irreg. | 8 CP |
| M-MATH-105101 | Introduction to Homogeneous Dynamics | | Irreg. | 6 CP |
| M-MATH-105093 | Variational Methods | | Irreg. | 8 CP |
| M-MATH-105324 | Harmonic Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-105325 | Splitting Methods for Evolution Equations | | Irreg. | 6 CP |
| M-MATH-105326 | Nonlinear Wave Equations | DE/EN | Irreg. | 4 CP |
| M-MATH-105327 | Numerical Simulation in Molecular Dynamics | DE | Irreg. | 8 CP |
| M-MATH-105432 | Discrete Dynamical Systems | DE | Irreg. | 3 CP |
| M-MATH-105463 | Structural Graph Theory | EN | Irreg. | 4 CP |
| M-MATH-105487 | Topological Data Analysis | DE/EN | Irreg. | 6 CP |
| M-MATH-105579 | Steins Method with Applications in Statistics | DE/EN | Irreg. | 4 CP |
| M-MATH-105636 | Analytical and Numerical Homogenization | EN | Irreg. | 6 CP |
| M-MATH-105649 | Fractal Geometry | DE/EN | Irreg. | 6 CP |
| M-MATH-105650 | Introduction to Fluid Dynamics | | Irreg. | 3 CP |
| M-MATH-105837 | Introduction to Kinetic Equations | EN | Irreg. | 3 CP |
| M-MATH-105838 | Introduction to Microlocal Analysis | EN | Irreg. | 3 CP |
| M-MATH-106950 | Lie-Algebras | DE | see notes | 8 CP |
| M-MATH-105840 | Statistical Learning | | SS | 8 CP |
| M-MATH-105897 | Selected Methods in Fluids and Kinetic Equations | EN | Irreg. | 3 CP |
| M-MATH-105931 | Metric Geometry | DE | see notes | 8 CP |
| M-MATH-105964 | Introduction to Convex Integration | EN | Irreg. | 3 CP |
| M-MATH-105966 | Space and Time Discretization of Nonlinear Wave Equations | EN | Irreg. | 6 CP |
| M-MATH-105973 | Translation Surfaces | DE | Irreg. | 8 CP |
| M-MATH-106045 | Introduction to Stochastic Differential Equations | EN | Irreg. | 4 CP |
| M-MATH-106052 | Random Graphs and Networks | EN | Irreg. | 8 CP |
| M-MATH-106053 | Stochastic Simulation | EN | WS | 5 CP |
| M-MATH-106063 | Numerical Complex Analysis | DE | Irreg. | 6 CP |
| M-MATH-106328 | Bayesian Inverse Problems with Connections to Machine Learning | EN | SS | 4 CP |
| M-MATH-106401 | Introduction to Fluid Mechanics | EN | Irreg. | 6 CP |
| M-MATH-106466 | Riemann Surfaces | DE | Irreg. | 8 CP |
| M-MATH-106473 | Ergodic Theory | DE | Irreg. | 8 CP |
| M-MATH-106485 | Functional Data Analysis | EN | Irreg. | 4 CP |
| M-MATH-106486 | Harmonic Analysis 2 | EN | Irreg. | 8 CP |
| M-MATH-106591 | Introduction to Dynamical Systems | DE/EN | Irreg. | 6 CP |
| M-MATH-106632 | Curves on Surfaces | EN | Irreg. | 3 CP |
| M-MATH-106640 | Modelling and Simulation of Lithium-Ion Batteries | EN | Irreg. | 4 CP |
| M-MATH-106664 | Scattering Theory for Time-dependent Waves | DE/EN | Irreg. | 6 CP |
| M-MATH-106667 | Geometric Variational Problems | DE/EN | Irreg. | 8 CP |
| M-MATH-106666 | Minimal Surfaces | DE | Irreg. | 3 CP |
| M-MATH-106663 | Semigroup Theory for the Navier-Stokes Equations | EN | Irreg. | 6 CP |
| M-MATH-106696 | Regularity for Elliptic Operators | EN | Irreg. | 6 CP |
| M-MATH-106695 | Numerical Analysis of Neural Networks | EN | Irreg. | 6 CP |
| M-MATH-106682 | Numerical Methods for Oscillatory Differential Equations | DE/EN | see notes | 8 CP |
| M-MATH-106776 | Complex Geometry | EN | Irreg. | 6 CP |
| M-MATH-106822 | Advanced Methods in Nonlinear Partial Differential Equations | EN | Irreg. | 3 CP |
| M-MATH-106957 | Modern Methods in Combinatorics | EN | Irreg. | 6 CP |
| M-MATH-107017 | Topics in Algebraic Topology | EN | Irreg. | 6 CP |
| M-MATH-107387 | Class Field Theory | DE | Irreg. | 8 CP |
| M-MATH-107484 | Topics in Homotopy Theory | EN | Irreg. | 6 CP |
| M-MATH-107456 | Interpolation Spaces | DE/EN | Irreg. | 6 CP |

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|---|---|---|---|---|
| M-MATH-107646 | Numerical Analysis on Quantum Computers neu | EN | Irreg. | 6 CP |
| M-MATH-107647 | Galerkin Methods for Time-dependent PDEs neu | EN | Irreg. | 5 CP |

## 1.10 Interdisciplinary Qualifications

**Credits**
2

| **Interdisciplinary Qualifications (Elective: at least 2 credits)** | | | | |
|---|---|---|---|---|
| M-MATH-102994 | Key Competences | DE | WS+SS | 2 CP |

## 1.11 Additional Examinations

| Additional Examinations (Elective: at least 30 credits) | | | | |
|---|---|---|---|---|
| M-MATH-101315 | Algebra | | see notes | 8 CP |
| M-MATH-101317 | Differential Geometry | DE/EN | Irreg. | 8 CP |
| M-MATH-101320 | Functional Analysis | DE | WS | 8 CP |
| M-MATH-101336 | Graph Theory | EN | see notes | 8 CP |
| M-MATH-101338 | Parallel Computing | DE/EN | Irreg. | 5 CP |
| M-MATH-101724 | Algebraic Geometry | | Irreg. | 8 CP |
| M-MATH-101725 | Algebraic Number Theory | | Irreg. | 8 CP |
| M-MATH-101768 | Spectral Theory | DE | SS | 8 CP |
| M-MATH-102730 | Seminar | DE/EN | WS+SS | 3 CP |
| M-MATH-102860 | Continuous Time Finance | | SS | 8 CP |
| M-MATH-102864 | Convex Geometry | | Irreg. | 8 CP |
| M-MATH-102865 | Stochastic Geometry | | SS | 8 CP |
| M-MATH-102866 | Geometry of Schemes | | Irreg. | 8 CP |
| M-MATH-102867 | Geometric Group Theory | EN | see notes | 8 CP |
| M-MATH-102868 | Modular Forms | | Irreg. | 8 CP |
| M-MATH-102869 | Geometric Group Theory II | EN | Irreg. | 8 CP |
| M-MATH-102870 | Classical Methods for Partial Differential Equations | DE/EN | WS | 8 CP |
| M-MATH-102871 | Boundary and Eigenvalue Problems | | SS | 8 CP |
| M-MATH-102872 | Evolution Equations | DE/EN | see notes | 8 CP |
| M-MATH-102874 | Integral Equations | | Irreg. | 8 CP |
| M-MATH-102875 | Models of Mathematical Physics | | Irreg. | 8 CP |
| M-MATH-102876 | Boundary value problems for nonlinear differential equations | | Irreg. | 8 CP |
| M-MATH-102877 | Nonlinear Evolution Equations | DE/EN | Irreg. | 8 CP |
| M-MATH-102878 | Complex Analysis | | Irreg. | 8 CP |
| M-MATH-102879 | Potential Theory | | Irreg. | 8 CP |
| M-MATH-102880 | Spectral Theory of Differential Operators | DE/EN | Irreg. | 8 CP |
| M-MATH-102883 | Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems | DE/EN | Irreg. | 8 CP |
| M-MATH-102884 | Scattering Theory | | Irreg. | 8 CP |
| M-MATH-102885 | Maxwell's Equations | | Irreg. | 8 CP |
| M-MATH-102886 | Nonlinear Functional Analysis | | Irreg. | 3 CP |
| M-MATH-102887 | Monotonicity Methods in Analysis | | Irreg. | 3 CP |
| M-MATH-102888 | Numerical Methods for Differential Equations | DE | WS | 8 CP |
| M-MATH-102889 | Introduction to Scientific Computing | | SS | 8 CP |
| M-MATH-102890 | Inverse Problems | | WS | 8 CP |
| M-MATH-102892 | Numerical Optimisation Methods | DE/EN | Irreg. | 8 CP |
| M-MATH-102894 | Numerical Methods in Computational Electrodynamics | DE | Irreg. | 6 CP |
| M-MATH-102895 | Wavelets | | Irreg. | 8 CP |
| M-MATH-102897 | Mathematical Methods in Signal and Image Processing | | Irreg. | 8 CP |
| M-MATH-102899 | Optimisation and Optimal Control for Differential Equations | EN | Irreg. | 6 CP |
| M-MATH-102900 | Adaptive Finite Elemente Methods | | Irreg. | 8 CP |
| M-MATH-102901 | Numerical Methods in Mathematical Finance | DE/EN | see notes | 8 CP |
| M-MATH-102903 | Spatial Stochastics | | WS | 8 CP |
| M-MATH-102904 | Brownian Motion | | Irreg. | 4 CP |
| M-MATH-102905 | Percolation | DE/EN | Irreg. | 5 CP |
| M-MATH-102906 | Generalized Regression Models | | Irreg. | 4 CP |
| M-MATH-102907 | Markov Decision Processes | | Irreg. | 5 CP |
| M-MATH-102908 | Stochastic Control | | Irreg. | 4 CP |
| M-MATH-102909 | Mathematical Statistics | | WS | 8 CP |
| M-MATH-102910 | Nonparametric Statistics | | Irreg. | 4 CP |

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|---|---|---|---|---|
| M-MATH-102911 | Time Series Analysis | | SS | 4 CP |
| M-MATH-102912 | Global Differential Geometry | DE/EN | Irreg. | 8 CP |
| M-MATH-102913 | Banach Algebras | | Irreg. | 3 CP |
| M-MATH-102915 | Numerical Methods for Hyperbolic Equations | DE/EN | Irreg. | 6 CP |
| M-MATH-102918 | Internet Seminar for Evolution Equations | DE/EN | WS | 8 CP |
| M-MATH-102919 | Discrete Time Finance | | WS | 8 CP |
| M-MATH-102920 | Special Topics of Numerical Linear Algebra | EN | see notes | 8 CP |
| M-MATH-102921 | Geometric Numerical Integration | | Irreg. | 6 CP |
| M-MATH-102922 | Poisson Processes | | Irreg. | 5 CP |
| M-MATH-102923 | Geometric Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-102924 | Optimization in Banach Spaces | | Irreg. | 5 CP |
| M-MATH-102926 | Sobolev Spaces | DE/EN | Irreg. | 8 CP |
| M-MATH-102927 | Traveling Waves | EN | Irreg. | 6 CP |
| M-MATH-102928 | Numerical Methods for Time-Dependent Partial Differential Equations | | Irreg. | 8 CP |
| M-MATH-102929 | Mathematical Modelling and Simulation in Practise | EN | Irreg. | 4 CP |
| M-MATH-102930 | Numerical Methods for Integral Equations | | Irreg. | 8 CP |
| M-MATH-102931 | Numerical Methods for Maxwell's Equations | | Irreg. | 6 CP |
| M-MATH-102932 | Numerical Methods in Fluid Mechanics | EN | SS | 4 CP |
| M-MATH-102935 | Compressive Sensing | | Irreg. | 5 CP |
| M-MATH-102936 | Functions of Operators | | Irreg. | 6 CP |
| M-MATH-102937 | Functions of Matrices | | Irreg. | 8 CP |
| M-MATH-106634 | Computational Fluid Dynamics and Simulation Lab | DE/EN | SS | 4 CP |
| M-MATH-102939 | Extreme Value Theory | | Irreg. | 4 CP |
| M-MATH-102941 | Control Theory | DE/EN | Irreg. | 6 CP |
| M-MATH-102943 | Introduction into Particulate Flows | | Once | 3 CP |
| M-MATH-102947 | Probability Theory and Combinatorial Optimization | | Irreg. | 8 CP |
| M-MATH-102948 | Algebraic Topology | DE/EN | see notes | 8 CP |
| M-MATH-102949 | Introduction to Geometric Measure Theory | DE/EN | Irreg. | 6 CP |
| M-MATH-102950 | Combinatorics | EN | see notes | 8 CP |
| M-MATH-102953 | Algebraic Topology II | DE/EN | Irreg. | 8 CP |
| M-MATH-102955 | Advanced Inverse Problems: Nonlinearity and Banach Spaces | | Irreg. | 5 CP |
| M-MATH-102956 | Forecasting: Theory and Practice | EN | Irreg. | 8 CP |
| M-MATH-102957 | Extremal Graph Theory | EN | Irreg. | 8 CP |
| M-MATH-103259 | Bifurcation Theory | | Irreg. | 5 CP |
| M-MATH-103260 | Mathematical Methods of Imaging | | Irreg. | 5 CP |
| M-MATH-103251 | Aspects of Geometric Analysis<br>*First usage possible until Apr 15, 2026.* | | Irreg. | 4 CP |
| M-MATH-104054 | Uncertainty Quantification | EN | SS | 4 CP |
| M-MATH-104055 | Ruin Theory | | Irreg. | 4 CP |
| M-MATH-104058 | Numerical Linear Algebra in Image Processing | | Irreg. | 6 CP |
| M-MATH-104059 | Mathematical Topics in Kinetic Theory | | Irreg. | 4 CP |
| M-MATH-103527 | Foundations of Continuum Mechanics | | Once | 4 CP |
| M-MATH-103539 | Nonlinear Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-103700 | Exponential Integrators | | Irreg. | 6 CP |
| M-MATH-103919 | Introduction to Kinetic Theory | EN | WS | 4 CP |
| M-MATH-104261 | Lie Groups and Lie Algebras | DE | see notes | 8 CP |
| M-MATH-104425 | Dispersive Equations | | Irreg. | 6 CP |
| M-MATH-104435 | Selected Topics in Harmonic Analysis | DE | Irreg. | 3 CP |
| M-MATH-103540 | Boundary Element Methods | | Irreg. | 8 CP |
| M-MATH-105066 | Nonlinear Maxwell Equations | DE/EN | Irreg. | 8 CP |
| M-MATH-105101 | Introduction to Homogeneous Dynamics | | Irreg. | 6 CP |

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|---|---|---|---|---|
| M-MATH-105093 | Variational Methods | | Irreg. | 8 CP |
| M-MATH-105324 | Harmonic Analysis | DE/EN | Irreg. | 8 CP |
| M-MATH-105325 | Splitting Methods for Evolution Equations | | Irreg. | 6 CP |
| M-MATH-105326 | Nonlinear Wave Equations | DE/EN | Irreg. | 4 CP |
| M-MATH-105327 | Numerical Simulation in Molecular Dynamics | DE | Irreg. | 8 CP |
| M-MATH-105432 | Discrete Dynamical Systems | DE | Irreg. | 3 CP |
| M-MATH-105463 | Structural Graph Theory | EN | Irreg. | 4 CP |
| M-MATH-105487 | Topological Data Analysis | DE/EN | Irreg. | 6 CP |
| M-MATH-105579 | Steins Method with Applications in Statistics | DE/EN | Irreg. | 4 CP |
| M-MATH-105636 | Analytical and Numerical Homogenization | EN | Irreg. | 6 CP |
| M-MATH-105649 | Fractal Geometry | DE/EN | Irreg. | 6 CP |
| M-MATH-105650 | Introduction to Fluid Dynamics | | Irreg. | 3 CP |
| M-MATH-105837 | Introduction to Kinetic Equations | EN | Irreg. | 3 CP |
| M-MATH-105838 | Introduction to Microlocal Analysis | EN | Irreg. | 3 CP |
| M-MATH-106950 | Lie-Algebras | DE | see notes | 8 CP |
| M-MATH-105840 | Statistical Learning | | SS | 8 CP |
| M-MATH-105897 | Selected Methods in Fluids and Kinetic Equations | EN | Irreg. | 3 CP |
| M-MATH-105931 | Metric Geometry | DE | see notes | 8 CP |
| M-MATH-105964 | Introduction to Convex Integration | EN | Irreg. | 3 CP |
| M-MATH-105966 | Space and Time Discretization of Nonlinear Wave Equations | EN | Irreg. | 6 CP |
| M-MATH-105973 | Translation Surfaces | DE | Irreg. | 8 CP |
| M-MATH-106045 | Introduction to Stochastic Differential Equations | EN | Irreg. | 4 CP |
| M-MATH-106052 | Random Graphs and Networks | EN | Irreg. | 8 CP |
| M-MATH-106053 | Stochastic Simulation | EN | WS | 5 CP |
| M-MATH-106063 | Numerical Complex Analysis | DE | Irreg. | 6 CP |
| M-MATH-106328 | Bayesian Inverse Problems with Connections to Machine Learning | EN | SS | 4 CP |
| M-MATH-106401 | Introduction to Fluid Mechanics | EN | Irreg. | 6 CP |
| M-MATH-106466 | Riemann Surfaces | DE | Irreg. | 8 CP |
| M-MATH-106473 | Ergodic Theory | DE | Irreg. | 8 CP |
| M-MATH-106485 | Functional Data Analysis | EN | Irreg. | 4 CP |
| M-MATH-106486 | Harmonic Analysis 2 | EN | Irreg. | 8 CP |
| M-MATH-106591 | Introduction to Dynamical Systems | DE/EN | Irreg. | 6 CP |
| M-MATH-106632 | Curves on Surfaces | EN | Irreg. | 3 CP |
| M-MATH-106640 | Modelling and Simulation of Lithium-Ion Batteries | EN | Irreg. | 4 CP |
| M-MATH-106664 | Scattering Theory for Time-dependent Waves | DE/EN | Irreg. | 6 CP |
| M-MATH-106667 | Geometric Variational Problems | DE/EN | Irreg. | 8 CP |
| M-MATH-106666 | Minimal Surfaces | DE | Irreg. | 3 CP |
| M-MATH-106663 | Semigroup Theory for the Navier-Stokes Equations | EN | Irreg. | 6 CP |
| M-MATH-106696 | Regularity for Elliptic Operators | EN | Irreg. | 6 CP |
| M-MATH-106695 | Numerical Analysis of Neural Networks | EN | Irreg. | 6 CP |
| M-MATH-106682 | Numerical Methods for Oscillatory Differential Equations | DE/EN | see notes | 8 CP |
| M-MATH-106776 | Complex Geometry | EN | Irreg. | 6 CP |
| M-MATH-106822 | Advanced Methods in Nonlinear Partial Differential Equations | EN | Irreg. | 3 CP |
| M-FORUM-106753 | Supplementary Studies on Science, Technology and Society | DE | WS+SS | 16 CP |
| M-INFO-106102 | Logical Foundations of Cyber-Physical Systems | EN | WS | 6 CP |
| M-MATH-106957 | Modern Methods in Combinatorics | EN | Irreg. | 6 CP |
| M-MATH-107017 | Topics in Algebraic Topology | EN | Irreg. | 6 CP |
| M-MATH-107387 | Class Field Theory | DE | Irreg. | 8 CP |
| M-MATH-107484 | Topics in Homotopy Theory | EN | Irreg. | 6 CP |
| M-MATH-107456 | Interpolation Spaces | DE/EN | Irreg. | 6 CP |

| | | | | |
|---|---|---|---|---|
| M-MATH-107646 | Numerical Analysis on Quantum Computers neu | EN | Irreg. | 6 CP |
| M-MATH-107647 | Galerkin Methods for Time-dependent PDEs neu | EN | Irreg. | 5 CP |

# 2 Modules

## M 2.1 Module: Adaptive Finite Elemente Methods [M-MATH-102900]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105898 | Adaptive Finite Element Methods | 8 CP | Dörfler |

**Assessment**
oral exam of ca. 30 minutes

**Prerequisites**
none

**Competence Goal**
Participants

- know the necessity for using adaptive methods
- are able to explain the basic methods, techniques and algorithms for the treatment of elliptic boundary value problems with adaptive finite element methods
- can describe different approaches for error estimation
- are able to solve simple initial boundary value problems numerically

**Content**

- necessity of adaptive methods
- residual error estimator
- aspects of implementions
- optimality of adaptive methods
- functional error estimator
- hp-Finite Elements
- adaptivity for time-dependent problems

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research on the course content
- preparation for the module examination

**Recommendations**
Basic knowledge in finite element methods, in programming and analysis of boundary value problems is strongly recommended. Knowledge in functional analysis is recommended.

# M 2.2 Module: Advanced Inverse Problems: Nonlinearity and Banach Spaces [M-MATH-102955]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105927 | Advanced Inverse Problems: Nonlinearity and Banach Spaces | 5 CP | Rieder |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
none

**Competence Goal**
Graduates are familiar with regularization methods for nonlinear ill-posed problems in Hilbert and Banach spaces and can discuss the underlying analytical and numerical aspects. They are also able to explain the conceptual differences between regularization methods in
Hilbert and Banach spaces.

**Content**
Inexact Newton methods in Hilbert spaces,

Approximate Inverse in Banach spaces

Tikhonov regularization with convex penalty

Kaczmarz-Newton methods in Banach spaces

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 150 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 90 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Inverse problems, Functional analysis

# M 2.3 Module: Advanced Methods in Nonlinear Partial Differential Equations [M-MATH-106822]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113691 | Advanced Methods in Nonlinear Partial Differential Equations | 3 CP | de Rijk, Reichel |

**Assessment**
The module examination takes place in form of an oral exam of about 30 minutes.

**Prerequisites**
none

**Competence Goal**
After successful completion of this module students

- know what amplitude or modulation equations are and can explain their significance;
- master several techniques to rigorously justify approximations by amplitude or modulation equations;
- have acquired miscellaneous methods to prove the existence of special solutions to nonlinear partial differential equations;
- can explain what the Ginzburg-Landau formalism is and how it can be employed to prove global existence of solutions.

**Content**
Nonlinear partial differential equations describing physical phenomena are often complex, making their qualitative and quantitative analysis challenging. Amplitude or modulation equations, such as the Ginzburg-Landau equation, the Korteweg-de Vries equation, and the nonlinear Schrödinger equation, play an important role in capturing the critical dynamics of spatially extended dissipative or conservative physical models. Mathematical theorems demonstrate that these well-understood asymptotic models accurately predict the behavior of the original system on sufficiently long time scales. Examples which can be described in such a way include pattern-forming systems close to their first instability, the long-wave limit of the water wave problem, and highly oscillatory regimes in nonlinear optics.

In the first part of this course, we develop several methods to rigorously justify approximations of complex physical systems by amplitude or modulation equations. Relevant tools include Fourier analysis, energy estimates, semigroup theory, mode filters, and normal form transformations. Often, amplitude or modulation equations admit special solutions, such as Turing patterns, solitary waves, or traveling (modulating) fronts. While approximation results yield solutions of the original system that are close to these special solutions, they are insufficient to conclude that such special solutions exist in the original system as well. In the second part of this course, we focus on techniques, such as Lyapunov-Schmidt reduction, spatial dynamics, and center manifold reduction, to construct these special solutions in the original system.

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 90 hours

Attendance: 30 hours

- lectures and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The following modules are recommended: Analysis 1-3, Functional Analysis, Evolution Equations

# M 2.4 Module: Algebra [M-MATH-101315]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-102253 | Algebra | 8 CP | Kühnlein, Sauer |

**Assessment**
Oral examination of ca. 30 minutes.

**Prerequisites**
None

**Competence Goal**
Students are able to

- understand essential concepts from Algebra,
- apply results from Galois theory to concrete situations,
- name basic results concerning discrete valuations and relate them to integral ring extensions.

They are prepared to write a thesis on a topic from algebra.

**Content**

- algebraic field extensions, Galois theory, roots of unit, applications of Galois theory
- discrete valuations, discrete valuation rings
- Tensor products of modules, integral ring extensions, normalization, noetherian rings, Hilbert's Basis Theorem

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Additional Information**
This course is one of the nine core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

**Workload**
Total worklaod : 240 hours.

Attendance: 90 h

- lectures and tutorials including the examination

Self studies: 150 h

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research on the course content
- preparation for the module examination

**Recommendations**
Basic knowledge on groups and rings is benefitial.

# M 2.5 Module: Algebraic Geometry [M-MATH-101724]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-103340 | Algebraic Geometry | 8 CP | Herrlich, Kühnlein |

**Assessment**
The module will be completed by an oral exam of about 30 minutes.

**Prerequisites**
None

**Competence Goal**
Participants are able to

- name and discuss basic concepts concerning algebraic varieties
- apply algebraic tools, in particular those from the theory of polynomial rings, to geometric questions
- explain important results from classical algebraic geometry and their application in specific examples
- start to read recent research papers from algebraic geometry and write a thesis in this area.

**Content**

- Hilbert's Nullstellensatz
- affine and projective varieties
- morphisms and rational maps
- non-singular varieties
- algebraic curves
- Riemann-Roch-Theorem

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total work load:

Attendance: 90 minutes

- lectures, problem classes an examination

Self studies: 150 hours

- follow-up and deepening of the course contents
- work on problem sheets
- literature study and internet research relating to the course contents
- Preparation of the oral exam

**Recommendations**
The contents of basic courses on algebra and number theory, including basic commutative algebra, should be well-understood.

# M 2.6 Module: Algebraic Number Theory [M-MATH-101725]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-103346 | Algebraic Number Theory | 8 CP | Herrlich, Kühnlein |

**Assessment**
oral examination of ca. 30 minutes

**Prerequisites**
none

**Competence Goal**
Students are able to

- understand basic structures and concepts from algebraic number theory,
- apply abstract concepts to concrete problems,
- read research papers and write a thesis in the field of algebraic number theory.

**Content**

- Algebraic number fields: rings of integers, Minkowski theory, class-groups and Dirichlet's unit theorem,
- Extensions of number fields: Ramified primes, Hilbert's ramification theory,
- Local fields: Ostrowski's theorem, valuation theory, Hensel's lemma, extensions of local fields,
- analytic methods: Dirichlet series, Dedekind's zeta function, L-series

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the module "Algebra" are strongly recommended.

# M 2.7 Module: Algebraic Topology [M-MATH-102948]

**Coordinators:** TT-Prof. Dr. Manuel Krannich
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105915 | Algebraic Topology | 8 CP | Krannich, Llosa Isenrich, Sauer |

**Assessment**
Written exam of 120 min.

**Prerequisites**
none

**Competence Goal**
Students

- are able to compute topological invariants of basic examples
- are able to work in a self-organized and reflective manner.

**Content**

- Basic homotopy-theoretic notions
- Examples of algebraic-topological invariants (e.g. fundamental groups or singular homology)

**Module Grade Calculation**
The module grade is the grade of the written exam.

**Additional Information**
This course is one of the nine core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The content of the course "Elementare Geometrie" is recommended.

# M 2.8 Module: Algebraic Topology II [M-MATH-102953]

**Coordinators:** TT-Prof. Dr. Manuel Krannich
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105926 | Algebraic Topology II | 8 CP | Krannich, Sauer |

**Assessment**
Written exam of 120 min.

**Prerequisites**
none

**Competence Goal**
Students

- are able to compute cohomology rings of basic examples
- are able to apply basic techniques of homological algebra
- are able to work in a self-organized and reflective manner.

**Content**

- Singular cohomology
- Product structures in cohomology
- Universal coefficient theorems in homological algebra
- Poincaré duality

**Module Grade Calculation**
The module grade is the grade of the written exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The content of the courses "Elementare Geometrie" and "Algebraic Topology" is recommended.

# M 2.9 Module: Analytical and Numerical Homogenization [M-MATH-105636]

**Coordinators:** TT-Prof. Dr. Roland Maier
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111272 | Analytical and Numerical Homogenization | 6 CP | Hochbruck, Maier |

**Assessment**
Oral examination of approximately 30 minutes.

**Prerequisites**
None.

**Competence Goal**
The topic of the lecture are numerical multiscale methods presented exemplarily for elliptic problems. Students know the basic analytical results for existence and uniqueness of solutions to multiscale problems and from homogenization theory. In addition, they know methods for the numerical approximation of the multiscale and the homogenized solution. They are able to analyze the convergence of these methods and to assess the advantages and disadvantages of the different approaches.

**Content**

- Analytical fundamentals (basic results from analysis for elliptic partial differential equations and from homogenization theory)
- Approximation of the homogenized solution(e.g., Heterogeneous Multiscale Method)
- Approximation of the multiscale solution (e.g., Localized Orthogonal Decomposition)

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Additional Information**
The course is offered in English. If everybody speaks German, the lecture will be held in German.

**Workload**
Total workload: 180 h

Attendance: 60 h

- Course including module examination during study.

Self-studies: 120 h

- Deepening the study content by working on the lecture content at home
- Working on exercises
- In-depth study of the course content using suitable literature and Internet research,
- preparation for the module examination during study.

**Recommendations**
Basic knowledge of ordinary and/or partial differential equations as well as the contents of the module "Numerical Methods for Differential Equations" are strongly recommended. Knowledge of functional analysis is also recommended.

# M 2.10 Module: Aspects of Geometric Analysis [M-MATH-103251]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis) (Usage until 4/15/2026)
Applied Mathematics (Elective Field Applied Mathematics) (Usage until 4/15/2026)
Mathematical Specialization (Elective Field Mathematical Specialization) (Usage until 4/15/2026)
Additional Examinations (Usage until 4/15/2026)

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-106461 | Aspects of Geometric Analysis | 4 CP | Lamm |

**Assessment**
oral exam; duration: about 20 minutes

**Prerequisites**
none

**Competence Goal**

- The students have got to know topics of Geometric analysis.
- They are able to use and explain the techniques they have learned in the course.

**Content**
Classical or recent topics of Geometric analysis, for example

- Geometric evolution equations,
- Geometric variational problems,
- The theory of minimal surfaces,
- Regularity of geometric objects,
- The isoperimetric problem,
- Spectral theory on manifolds.

**Recommendations**
Elementare Geometrie, Klassische Methoden partieller Differentialgleichungen/Partial differential equations, Functional analysis

# M 2.11 Module: Astroparticle Physics I [M-PHYS-102075]

**Coordinators:** Prof. Dr. Guido Drexlin
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102432 | Astroparticle Physics I | 8 CP | Drexlin, Valerius |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Competence Goal**
Students will be introduced to the basic concepts of astroparticle physics. The lecture teaches both the theoretical concepts and the experimental methods of this new dynamic field of work at the interface of elementary particle physics, cosmology and astrophysics. Students will learn to understand the concepts through concrete case studies from current research and will be enabled to apply the learned methods independently.

*Methodological skills acquisition*:

- Understanding of the fundamentals of experimental astroparticle physics.
- Recognition of methodological cross-connections to elementary particle physics, astrophysics, and cosmology.
- Acquisition of the ability to present a current research topic independently as well as in a team setting
- Acquisition of the ability to implement the concepts and experimental methods in the master thesis

**Content**
The topics covered include a general introduction to the field with its fundamental issues, theoretical concepts and experimental methods. Corresponding to the very different energy scales (meV - 1020 eV) of astroparticle physics, the lecture is divided into a discussion of the processes in the thermal (low energies) and non-thermal (high energies) universe. A special focus of the lecture is a comprehensive presentation of modern experimental techniques, e.g. in the search for very rare processes. Based on this, in the second part of the lecture a comprehensive introduction to the "dark universe" and the search for dark matter is given.

The lecture is the basis of further lectures on this topic (Astroparticle Physics II).

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises(180 hours)

**Recommendations**
Basic knowledge from the lecture "Nuclei and Particles".

**Literature**


- Donald Perkins, Particle Astrophysics (Oxford University Press, 2. Auflage, 2009)
- Claus Grupen, Astroparticle Physics (Springer, 2005)
- Lars Bergström & Ariel Goobar, Cosmology and Particle Astrophysics (Wiley, 2. Auflage, 2006)
- Malcolm Longair, High Energy Astrophysics (Cambridge University Press, 3. Auflage, 2011)

# M 2.12 Module: Banach Algebras [M-MATH-102913]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105886 | Banach Algebras | 3 CP | Herzog |

**Assessment**
The module will be completed by an oral exam (about 20 min).

**Prerequisites**
none

**Competence Goal**
At the end of the course, students can

- name, discuss and apply basic statements of the theory of Banach algebras,
- use specific techniques from ideal theory, spectral theory and functional calculus in Banach algebras.

**Content**

1. Banach and operator algebras
2. Multiplicative linear functionals
3. Spectrum and resolvents
4. Commutative Banach algebras
5. Corona Theorem
6. Functional calculus in Banach algebras
7. B*-algebras
8. Ordered Banach algebras

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 hours

- lectures, problem classes, and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Knowledge of complex analysis (e.g. from Analysis 4) is recommended.

# M 2.13 Module: Basics of Nanotechnology I [M-PHYS-102097]

**Coordinators:** apl. Prof. Dr. Gernot Goll
**Organisation:** KIT Department of Physics
**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102529 | Basics of Nanotechnology I | 4 CP | Goll |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Competence Goal**
Students deepen their knowledge in one area of nano-physics, master the relevant theoretical concepts and are familiar with basic techniques and measurement methods of nano-analytics and lithography.

**Content**
Introduction to central areas of nanotechnology;

Teaching of the conceptual, theoretical and, in particular, methodological fundamentals:

- Methods of imaging and characterization (nanoanalytics)
  Basic concepts of electron microscopy and associated analytical capabilities are covered in an introductory manner. Scanning probe techniques such as tunneling and force microscopy for the investigation and imaging of conductive and insulating sample surfaces, respectively, are discussed. Complementary spectroscopic capabilities of the scanning probe techniques will be explained.
- Methods of nanostructure fabrication (lithography and self-assembly)
  Along the individual process steps from coating and exposure to structure transfer by etching and vapor deposition, the methods used will be explained, their application limits discussed and current developments highlighted.

The lecture "Nanotechnology II" covers application areas and current research topics in the summer semester.

**Workload**
120 hours consisting of attendance time (30 hours), wrap-up of lecture incl. exam preparation. (90 hours)

**Recommendations**
Basic knowledge of solid state physics and quantum mechanics is expected.

**Literature**
For follow-up and consolidation of the lecture material, reference is made to various textbooks as well as original and review articles. A detailed list will be given in the lecture.

# M 2.14 Module: Basics of Nanotechnology II [M-PHYS-102100]

**Coordinators:** apl. Prof. Dr. Gernot Goll
**Organisation:** KIT Department of Physics
**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102531 | Basics of Nanotechnology II | 4 CP | Goll |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Competence Goal**
The student deepens his knowledge in the field of nanophysics, masters the relevant theoretical concepts and is familiar with the basic application areas of nanophysics. The student is able to interpret current data and figures from the scientific literature and to present the current state of research as well as important "open questions".

**Content**
Introduction to central areas of nanotechnology

Teaching of the conceptual, theoretical and especially methodological basics;

Applications and current developments in the fields of nanoelectronics, nanooptics, nanomechanics, nanotribology, biological nanostructures, self-organized nanostructures, among others.

In addition, the lecture "Fundamentals of Nanotechnology I" in the winter semester deals with methods of imaging, characterization and fabrication of nanostructures.

**Workload**
120 hours consisting of attendance time (30 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (90 hours)

**Recommendations**
Basic knowledge of solid state physics and quantum mechanics is expected.

**Literature**
For follow-up and consolidation of the lecture material, reference is made to various textbooks as well as original and review articles. A detailed list will be given in the lecture.

# M 2.15 Module: Batteries, Fuel Cells, and Electrolysis [M-ETIT-107005]

**Coordinators:** Prof. Dr.-Ing. Ulrike Krewer
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-113986 | Batteries, Fuel Cells, and Electrolysis | 5 CP | Krewer |
| T-ETIT-114957 | Batteries, Fuel Cells, and Electrolysis - Group Project<br>*This item will not influence the grade calculation of this parent.* | 1 CP | Krewer |

**Assessment**
Success control takes place in the form of:

1. an ungraded written technical report (approx. 7-10 pages).
2. a graded written examination lasting 120 minutes.

**Prerequisites**
none

**Competence Goal**
Students gain an understanding of batteries, fuel cells and electrolysis including their application, design, and behavior. They acquire in-depth knowledge of the transport and charge transfer processes in them, their impact on performance and design, and the characteristics of the most frequent types of batteries, fuel and electrolysis cells. They understand how to analyze and characterize them using measurement methods and modeling. A practical insight into current areas of application and research topics of electrochemical energy storage and conversion allows them to relate the course work to demands of the society and for R&D. They are able to communicate with specialists from related disciplines in the field of (application of) batteries, fuel cells and electrolysis and can actively contribute to the opinion-forming process in society with regard to energy technology issues.

**Content**
The course introduces batteries, fuel cells and electrolysis and their use for sustainable mobile and stationary energy supply and storage. The course is divided into five sections. The first part covers the role of batteries, fuel cells and electrolysis for renewable energy storage and electrification of the energy system and the present applications. This is followed by a fundamentals part, where the processes in electrochemical cells at open circuit and during operation and their relation to cell performance and behavior are discussed. It contains thermodynamics, kinetics, transport and performance measures. The third part deals with the working principle, design and operation of fuel cells and electrolysis and the particularities of the different cell types. This is followed by a similar part for batteries. Finally, dynamic and stationary methods for characterizing the cells are covered.

**Group project**

As part of the coursework, student groups work on the design of a battery, fuel cell or electrolyser for a given application during the semester. This includes literature research on cell type, materials and material data as well as the dimensioning and energetic evaluation of the cell. The results are documented in a short technical report.

**Module Grade Calculation**
The module grade is the grade of the written examination.

**Workload**

1. Lecture attendance time: 15 * 2 h = 30 h
2. Preparation and follow-up time for lecture: 15 * 5 h = 75 h
3. Exercise attendance time: 7 * 2 h = 14 h
4. Preparation and follow-up time for exercise: 7 * 4 h = 28 h
5. Group work including writing of a report: 33 h
6. Exam preparation and attendance: included in preparation and follow-up time.

Total: 180 h = 6 CP

# M 2.16 Module: Bayesian Inverse Problems with Connections to Machine Learning [M-MATH-106328]

**Coordinators:** Prof. Dr. Sebastian Krumscheid
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112842 | Bayesian Inverse Problems with Connections to Machine Learning | 4 CP | Krumscheid |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
None

**Competence Goal**
After completing the module's classes and the exam, students will be familiar with the theory of inverse problems. They will be able to apply the Bayesian framework to a given inverse problem and assess the
well-posedness of the Bayesian posterior. In addition, students will be able to describe the basics of several solution methods for accessing the Bayesian posterior, including approximation and machine-learning techniques, and their limitations. Finally, they will be able to name and discuss essential theoretical concepts for Bayesian inversion in Banach spaces and describe the suitable sampling-based solution techniques. In particular, the course prepares students to write a thesis in the field of Uncertainty Quantification.

**Content**
The course offers an introduction to the subject of statistical inversion, where, in its most basic form, the goal is to study how to estimate model parameters from data. We will introduce mathematical concepts and computational tools for systematically treating these inverse problems in a Bayesian framework, including an assessment of how uncertainties affect the solution. In the first part of the course, we will study the Bayesian framework for finite-dimensional inverse problems. While the first part will introduce some machine-learning ideas, the second part will address how machine learning is impacting, and has the potential to impact further on, the subject of inverse problems. In the final part of the course, we will generalize the Bayesian inverse problem theory to a Banach space setting and discuss sampling strategies for accessing the Bayesian posterior.

Topics covered include:

- Bayesian Inverse Problems and Well-Posedness
- The Linear-Gaussian Setting
- Optimization Perspective on Bayesian Inverse Problems
- Gaussian Approximation
- Markov Chain Monte Carlo
- Blending Inverse Problems and Machine-Learning
- Bayesian Inversion in Banach spaces

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
total workload: 120 hours

**Recommendations**
The contents of the modules 'M-MATH-101321 - Introduction to Stochastics', 'M-MATH-103214 – Numerical Mathematics 1+2', and 'M-MATH-106053 — Stochastic Simulation' are recommended.

# M 2.17 Module: Bifurcation Theory [M-MATH-103259]

**Coordinators:** Dr. Rainer Mandel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-106487 | Bifurcation Theory | 5 CP | Mandel |

**Prerequisites**
None

**Additional Information**
Course is held in English

# M 2.18 Module: Biopharmaceutical Purification Processes [M-CIWVT-103065]

**Coordinators:** Prof. Dr. Jürgen Hubbuch
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106029 | Biopharmaceutical Purification Processes | 6 CP | Hubbuch |

**Assessment**
Learning control is a written exam lasting 120 minutes

**Prerequisites**
None

**Competence Goal**
The students can

- evaluate and design process steps
- evaluate and design processes,
- explain the relationships between process parameters, product yield and purity.

**Content**
**Module objective:**
The module teaches the basic principles, methods and challenges of processing biopharmaceutical active ingredients. Students acquire knowledge of the processing of biopharmaceutical active ingredients, central reaction and purification processes and their application in industrial biopharmaceutical production.

**Contents:**

- Overview of biopharmaceutical products and process chains
- Biological mode of action of the pharmaceuticals presented
- Central purification processes
- Reactive processes
- Special features in the processing of biopharmaceutical products
- Processing of peptides, hormones, antibodies, vaccines, viruses, cell and gene therapy, etc.

**Module Grade Calculation**
The module grade ist the grade of the written exam.

**Workload**

- Attendance time (Lecture): 60 h
- Homework: 90 h
- Exam Preparation: 30 h

**Literature**
Vorlesungsskript

# M 2.19 Module: Boundary and Eigenvalue Problems [M-MATH-102871]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105833 | Boundary and Eigenvalue Problems | 8 CP | Frey, Hundertmark, Lamm, Plum, Reichel, Schnaubelt |

**Assessment**
The module will be completed by an oral exam (approx. 30 min).

**Prerequisites**
None

**Competence Goal**
Graduates will be able to

- assess the significance of boundary value and eigenvalue problems within mathematics and/or physics and illustrate them using examples,
- describe qualitative properties of solutions,
- prove the existence of solutions to boundary value problems using functional analysis methods,
- make statements about the existence of eigenvalues and eigenfunctions of elliptic differential operators and describe their properties.

**Content**

- Examples of boundary and eigenvalue problems
- Maximum principles for 2nd order equations
- Function spaces, e.g. Sobolev spaces
- Weak formulation of 2nd order linear elliptic equations
- Existence and regularity theory for elliptic equations
- Eigenvalue theory for weakly formulated elliptic eigenvalue problems

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

# M 2.20 Module: Boundary Element Methods [M-MATH-103540]

**Coordinators:** PD Dr. Tilo Arens
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-109851 | Boundary Element Methods | 8 CP | Arens |

**Assessment**
The examination is carried out by an oral examination (approx. 30 minutes).

**Prerequisites**
None

**Competence Goal**
Students are able to apply the analytic foundations of defining potentials and boundary operators, such as distributions, Sobolev spaces on boundaries of Lipschitz domains and trace operators to specific problems. They understand the definition of potentials, boundary operators and important mathematical statements about them. They are able to formulate boundary integral equations for concrete elliptic boundary value problems and to comprehend the proofs for their solvability.

Students are able to name and describe classes of boundary elements. They are familiar with the use of various boundary elements for numerically solving boundary integral equations by Galerkin methods. They can explain results on convergence of such methods. The students can describe techniques for improving practical handling of boundary element methods such as matrix compression schemes and preconditioning.

**Content**

- Sobolev spaces
- function spaces on Lipschitz boundaries
- boundary value problems for elliptic partial differential equations
- potentials and boundary operators
- boundary integral equations
- boundary elements
- Galerkin boundary element methods
- preconditioning
- matrix compression

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- increased understanding of module content by wrapping up lectures at home
- work on exercises
- increased understanding of module content by self study of literature and internet research
- preparing for the examination

**Recommendations**
We recommend attendance of the module "Numerical Methods for Integral Equations".

# M 2.21 Module: Boundary value problems for nonlinear differential equations [M-MATH-102876]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105847 | Boundary Value Problems for Nonlinear Differential Equations | 8 CP | Plum, Reichel |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
None

**Competence Goal**
Graduates will be able to

- assess the significance of non-linear boundary value problems in relation to their applications in the natural and engineering sciences and illustrate them using examples,
- describe qualitative properties of solutions,
- prove the existence of solutions using functional analytical methods,
- recognize and analyze non-linear phenomena (e.g. bifurcation, multiplicity of solutions) and illustrate them using prototypical examples.

**Content**

- Method of upper and lower solutions
- Existence using fixed point methods
- Qualitative properties
- Variational methods and/or bifurcation theory

**Module Grade Calculation**
The module grade is the grade of the oral/written exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the courses 'Functional Analysis', 'Classical Methods for Partial Differential Equations' and 'Boundary and Eigenvalue Problems' are recommend.

# M 2.22 Module: Brownian Motion [M-MATH-102904]

**Coordinators:** Prof. Dr. Nicole Bäuerle
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105868 | Brownian Motion | 4 CP | Bäuerle, Fasen-Hartmann, Last |

**Assessment**
The module will be completed by an oral exam (about 20 min).

**Prerequisites**
none

**Competence Goal**
At the end of the course, students

- can name, explain and justify properties of the Brownian motion,
- can use the Brownian motion to model stochastic phenomenon,
- can use specific probabilistic techniques,
- are able to work in a self-organized and reflective manner.

**Content**

- Existence and construction of Brownian motion,
- path properties of Brownian motion,
- strong Markov property of Brownian motion with applications,
- Skorokhod representation theorems with Brownian motion.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 hours

- lectures, problem classes, and examination

Self-studies: zz hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course 'Probability Theory' is strongly recommended.

# M 2.23 Module: Class Field Theory [M-MATH-107387]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-114500 | Class Field Theory | 8 CP | Herrlich, Kühnlein |

**Assessment**
The module examination takes the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
none

**Competence Goal**
Graduates

- are familiar with the issues and concepts of class field theory,
- know the basic results of class field theory and can relate them to each other,
- are prepared to write a thesis in the field of algebraic number theory

**Content**

- Abelian extensions of number fields, Kronecker-Weber theorem,
- Hilbert class fields, class fields for a group of ideal classes,
- Existence, completeness and isomorphism theorem for class fields,
- Dirichlet's L-series and generalization of the theorem on prime numbers in an arithmetic progression,
- Artin map and Artin's reciprocity law

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The modules "Algebra" and "Algebraic Number Theory" are strongly recommended.

# M 2.24 Module: Classical Methods for Partial Differential Equations [M-MATH-102870]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105832 | Classical Methods for Partial Differential Equations | 8 CP | Frey, Hundertmark, Lamm, Plum, Reichel, Schnaubelt |

**Assessment**
The module assessment takes the form of a comprehensive written examination (120 minutes).

**Prerequisites**
None

**Competence Goal**
By the end of the course, students will be familiar with fundamental concepts and ways of thinking in the field of partial differential equations. They will be able to calculate explicit solutions for certain classes of partial differential equations and will be familiar with methods for proving qualitative properties of solutions.

**Content**
- Examples of partial differential equations
- Wave equation
- Laplace and Poisson equations
- Heat equation
- Classical solution methods

**Module Grade Calculation**
The module grade is the grade of the examination.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- Course including the module examination

Self-studies: 150 hours

- Consolidation of course content through independent study of lecture material
- Completion of exercises
- Consolidation of course content using appropriate literature and internet research
- Preparation for the module examination

# M 2.25 Module: Cognitive Systems [M-INFO-100819]

**Coordinators:** Prof. Dr. Gerhard Neumann
Prof. Dr. Alexander Waibel
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-101356 | Cognitive Systems | 6 CP | Neumann, Waibel |

# M 2.26 Module: Combinatorics [M-MATH-102950]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | English | 4 | 4 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105916 | Combinatorics | 8 CP | Aksenovich |

**Assessment**
The final grade is given based on the written final exam (2h).

By successfully working on the problem sets, a bonus can be obtained. To obtain the bonus, one has to achieve 50% of the points on the solutions of the exercise sheets 1-6 and also of the exercise sheets 7-12. If the grade in the final written exam is between 4,0 and 1,3, then the bonus improves the grade by one step (0,3 or 0,4).

**Prerequisites**
none

**Competence Goal**
The students understand, describe, and use fundamental notions and techniques in combinatorics. They can analyze, structure, and formally describe typical combinatorial questions. The students can use the results and methods such as inclusion-exclusion, generating functions, Young tableaux, as well as the developed proof ideas, in solving combinatorial problems. In particular, they can analyze the existence and the number of ordered and unordered arrangements of a given size. The students understand and critically use the combinatorial methods. Moreover, the students can communicate using English technical terminology.

**Content**
The course is an introduction into combinatorics. Starting with counting problems and bijections, classical methods such as inclusion-exclusion principle and generating functions are discussed. Further topics include Catalan families, permutations, Young tableaux, partial orders, and combinatorial designs.

**Module Grade Calculation**
The grade of the module ist the grade of the written exam.

**Additional Information**

- Course is held in English
- This course is one of the nine core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination during the course of study

Self-study: 150 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
Knowledge of the modules Linear Algebra 1 and 2 and Analysis 1 and 2 is recommended.

# M 2.27 Module: Combustion Technology [M-CIWVT-103069]

**Coordinators:** Prof. Dr.-Ing. Dimosthenis Trimis
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106104 | Combustion Technology | 6 CP | Trimis |

**Assessment**
Learning Control is an oral examination with a duration of about 20 minutes (section 4 subsection 2 SPO). Grade of the module is the grade of the oral examination.

**Prerequisites**
None

**Competence Goal**

- The students are able to describe and explain the characteristics of the different flame types.
- The students can quantitatively estimate/calculate major combustion characteristics like flame temperature and flame velocity. They further understand the physicochemical mechanisms affecting flammability limits and quenching distances.
- The students understand and can assess the influence/interaction of turbulence, heat and mass transfer to reacting flows.
- The students understand the flame structure and the hierarchical structure of reaction kinetic mechanisms.
- The students understand and can assess the influence of interaction between different time scales of chemical kinetics and fluid flow in reacting flows.
- The students are able to assess and evaluate burner operability with regard to the application.

**Content**

- Introduction and significance of combustion technology
- Thermodynamics of combustion: Mass and energy/enthalpy balances
- Equilibrium composition
- Flame temperature
- Reaction mechanisms in combustion processes
- Laminar flame velocity and thermal flame theory
- Kinetics related combustion characteristics and experimental characterization: laminar flame velocity, flammability limits, ignition temperature, ignition energy, ignition delay time, quenching distance, flash point, octane and cetane number
- Turbulent flame propagation
- Industrial burner types

**Workload**

- Lectures and Exercises: 45 h
- Homework: 25 h
- Exam Preparation: 110 h

**Literature**


- K.K. Kuo: Principles of Combustion, John Wiley & Sons, Hoboken, New York 2005
- J. Warnatz, U. Maas, R.W. Dibble: Combustion, Spinger Verlag, Berlin, Heidelberg 2006
- S.R. Turns: An Introduction to Combustion - Concepts and Applications, McGraw-Hill, Boston 2000
- I. Glassman: Combustion, Academic Press, New York, London 1996

# M 2.28 Module: Complex Analysis [M-MATH-102878]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105849 | Complex Analysis | 8 CP | Herzog, Plum, Reichel, Schnaubelt, Tolksdorf |

**Assessment**
The module will be completed by an oral exam (about 30 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students can

- explain the basic concepts and results of the theory of infinite products and apply them in examples within the framework of Weierstrass's theorems
- reproduce the Mittag-Leffler theorem and derive conclusions from it
- explain Riemann's mapping theorem and are able to describe what Montel's theorem is and how this theorem is included in the proof of Riemann's theorem
- name the most important properties of class S of simple functions and formulate the (proven) Bieberbach conjecture
- can explain the basic concepts of the theory of harmonic functions and apply them in examples
- explain the Schwarz reflection principle.
- describe properties of regular and singular points in power series and discuss them with examples.

**Content**

- infinite products
- Mittag-Leffler's theorem
- Montel's theorem
- Riemann's mapping theorem
- conformal mappings
- univalent (schlicht) functions
- automorphisms of some domains
- harmonic functions
- Schwarz reflection principle
- regular and singular points of power series

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Basics of complex analysis, for example from the “Analysis 4” module, are recommended.

# M 2.29 Module: Complex Geometry [M-MATH-106776]

**Coordinators:** Jun.-Prof. Dr. Claudio Llosa Isenrich
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113614 | Complex Geometry | 6 CP | Llosa Isenrich |

**Assessment**
The module will be completed by an oral exam (of ca. 30 min).

**Prerequisites**
None

**Competence Goal**
Graduates

- can understand the structure of complex geometry and apply its results to specific problems;
- are able to explain important results on compact Kähler manifolds and their topology, relate them to each other and apply them to examples;
- can sketch proofs of important results from the lecture;
- can work in a self-organized and reflective manner.

**Content**

- Introduction to complex analysis in several variables
- Complex manifolds, vector bundles and forms
- Introduction to Kähler manifolds and important examples
- The Kähler identities and their consequences
- Dolbeaut cohomology and the Hodge decomposition theorem

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 hours

- lectures and examination

Self-studies: 120 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Knowledge of complex analysis (e.g. "Analysis 4") and differential geometry is strongly recommended. The same applies to the contents of the modules "Elementary Geometry" and "Introduction to Algebra and Number Theory".

# M 2.30 Module: Compressive Sensing [M-MATH-102935]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105894 | Compressive Sensing | 5 CP | Rieder |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Competence Goal**
Graduates can explain the ideas of compressive sensing and can name areas of application. They can apply and compare the basic algorithms and analyze their convergence behavior.

**Content**

- What is compressive sensing and where is it used?
- Sparse solutions of underdetermined linear systems of equations
- Basic algorithms
- Restricted isometry property
- Sparse solutions of underdetermined linear systems of equations with random matrices

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 150 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 90 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course "Introduction to stochastics" is recommended.

# M 2.31 Module: Computational Fluid Dynamics [M-CIWVT-103072]

**Coordinators:** Prof. Dr.-Ing. Hermann Nirschl
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106035 | Computational Fluid Dynamics | 6 CP | Nirschl |

**Assessment**
Learning control is a written examination lasting 90 minutes

**Prerequisites**
None

**Competence Goal**
Learning the fundamentals of CFD for the calculation of flow problems.

**Content**
Navier-Stokes equitations, numerical schemes, turbulence, multiphase flows.

**Module Grade Calculation**
The module grade is the grade of the written examination.

**Workload**

- Attendance time (Lecture): 64 h
- Homework: 56 h
- Exam Preparation: 601 h

**Literature**

- Nirschl: Skript zur Vorlesung CFD
- Ferziger, Peric: Numerische Strömungsmechanik
- Oertel, Laurien: Numerische Strömungsmechanik

# M 2.32 Module: Computational Fluid Dynamics and Simulation Lab [M-MATH-106634]

**Coordinators:** PD Dr. Mathias Krause
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each summer term | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113373 | Computational Fluid Dynamics and Simulation Lab | 4 CP | Frank, Krause, Simonis, Thäter |

**Assessment**
For their final project, students prepare a written report, usually 10-15 pages long, which is graded.

**Prerequisites**
none

**Competence Goal**
Students are able to jointly model problems beyond their own discipline and simulate them on high-performance computers. They have acquired a critical distance to results and their presentation. They can defend the results of projects in disputes. They have understood the importance of stability, convergence and parallelism of numerical methods from their own experience and are able to evaluate errors in modeling, approximation, computing and presentation.

**Content**
**Lecture part:** Introduction to modeling and simulations, introduction to associated numerical methods, introduction to associated software and high-performance computer hardware

**Own group work:** Working on 1-2 projects in which modelling, discretization, simulation and evaluation (e.g. visualization) are carried out for specific topics from the catalog. The catalog includes e.g: Diffusion processes, turbulent flows, multiphase flows, reactive flows, particle dynamics, optimal control and optimization under constraints, stabilization methods for advection-dominated transport problems.

**Module Grade Calculation**
The module grade is the grade of the final project.

**Workload**
Total workload: 120 hours

Attendance: 60 hours

- lectures and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- work on projects and report,
- literature study and internet research relating to the course content

**Recommendations**
Basic knowledge of the analysis of boundary value problems and of numerical methods for differential equations is recommended. Knowledge of a programming language is strongly recommened.

# M 2.33 Module: Computer Architecture [M-INFO-100818]

**Coordinators:** Prof. Dr. Wolfgang Karl
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-101355 | Computer Architecture | 6 CP | Karl |

# M 2.34 Module: Computer Graphics [M-INFO-100856]

**Coordinators:** Prof. Dr.-Ing. Carsten Dachsbacher
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-101393 | Computer Graphics | 6 CP | Dachsbacher |

# M 2.35 Module: Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems [M-MATH-102883]

**Coordinators:** Prof. Dr. Michael Plum
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105854 | Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems | 8 CP | Plum |

**Assessment**
The module examination takes the form of an oral examination (approx. 20 min).

**Prerequisites**
None.

**Competence Goal**
At the end of the module, students know the basics of computer-assisted analytical methods for proving the existence and enclosures of solutions of boundary value and eigenvalue problems, as well as the importance of such methods as a supplement to other (purely analytical) methods.

**Content**
Formulation of nonlinear boundary value problems as zero-finding and fixed-point problems; verification of the assumptions of a suitable fixed-point theorem using computer-assisted methods: explicit Sobolev inequalities, eigenvalue bounds using variational characterizations, interval arithmetic

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination

Self-study: 150 hours

- Consolidation by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet search
- Preparation for the module examination

**Recommendations**

- Classical methods for partial differential equations
- Boundary and eigenvalue problems
- Functional analysis

# M 2.36 Module: Condensed Matter Theory I, Fundamentals [M-PHYS-102054]

**Coordinators:** PD Dr. Robert Eder
Prof. Dr. Markus Garst
Prof. Dr. Alexander Mirlin
Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102559 | Condensed Matter Theory I, Fundamentals | 8 CP | Eder, Garst, Mirlin, Shnirman |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**
none

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-PHYS-102053 - Condensed Matter Theory I, Fundamentals and Advanced Topics must not have been started.

**Competence Goal**
Gaining understanding of phenomena and concepts in condensed matter theory, mastering basic theoretical tools for their description, and acquiring the ability to analyze and solve theoretically a limited class of problems in the field of condensed matter physics.

**Content**
Lectures and exercises convey and deepen the basic concepts of condensed matter theory, particular attention is paid to crystalline solids. The main subjects of the lecture are:

- Crystal lattices, electrons in periodic potentials, dynamics of Bloch electrons;
- Electronic transport properties of solids, Boltzmann equation;
- Solids in an external magnetic field: Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect;
- Electron-electron interaction, Stoner theory of ferromagnetism;
- Landau theory of Fermi liquids; Phonons and electron-phonon interaction

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (180 hours).

**Recommendations**
Basic knowledge of solid state physics, quantum mechanics, statistical physics and thermodynamics is required.

**Literature**


- C. Kittel, Einführung in die Festkörperphysik (Oldenburg, 1980) / Introduction to Solid State Physics.
- C. Kittel, Quantum Theory of Solids.
- N.W. Ashcroft and N.D. Mermin, Solid State Physics (Holt, Rinehart & Winston, N.Y 1976).
- J.H. Ziman, Principles of the Theory of Solids (Cambridge, Univ. Press, 1972).
- A. A. Abrikosov, Fundamentals of the Theory of Metals

# M 2.37 Module: Condensed Matter Theory I, Fundamentals and Advanced Topics [M-PHYS-102053]

**Coordinators:** PD Dr. Robert Eder
Prof. Dr. Markus Garst
Prof. Dr. Alexander Mirlin
Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 12 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102558 | Condensed Matter Theory I, Fundamentals and Advanced Topics | 12 CP | Eder, Garst, Mirlin, Shnirman |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**
none

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-PHYS-102054 - Condensed Matter Theory I, Fundamentals must not have been started.

**Competence Goal**
Gaining understanding of phenomena and concepts in condensed matter theory, mastering basic theoretical tools for their description, and acquiring the ability to analyze and solve theoretically a broader class of problems in the field of condensed matter physics.

**Content**
Lectures and exercises convey and deepen the basic concepts of condensed matter theory, particular attention is paid to crystalline solids. The main subjects of the lecture are:

- Crystal lattices, electrons in periodic potentials, dynamics of Bloch electrons;
- Electronic transport properties of solids, Boltzmann equation;
- Solids in the external magnetic field: Pauli paramagnetism, Landau diamagnetism, de Haas-van Alphen effect;
- Electron-electron interaction, Stoner theory of ferromagnetism;
- Landau theory of Fermi liquids; Phonons and electron-phonon interaction;
- Superconductivity: BCS theory, electrodynamics of superconductors, Ginzburg-Landau theory.

**Workload**
360 hours consisting of attendance time (90 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (270 hours)

**Recommendations**
Basic knowledge of solid state physics, quantum mechanics, statistical physics and thermodynamics is required.

**Literature**


- C. Kittel, Einführung in die Festkörperphysik (Oldenburg, 1980) / Introduction to Solid State Physics.
- C. Kittel, Quantum Theory of Solids.
- N.W. Ashcroft and N.D. Mermin, Solid State Physics (Holt, Rinehart & Winston, N.Y 1976).
- J.H. Ziman, Principles of the Theory of Solids (Cambridge, Univ. Press, 1972).
- A. A. Abrikosov, Fundamentals of the Theory of Metals

# M 2.38 Module: Condensed Matter Theory II: Many-Body Theory, Fundamentals [M-PHYS-102313]

**Coordinators:** Prof. Dr. Markus Garst
apl. Prof. Dr. Igor Gornyi
Prof. Dr. Alexander Mirlin
PD Dr. Boris Narozhnyy
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-104591 | Condensed Matter Theory II: Many-Body Systems, Fundamentals | 8 CP | Garst, Gornyi, Mirlin, Narozhnyy, Schmalian |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**
none

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-PHYS-102308 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics must not have been started.

**Competence Goal**
Mastering advanced field-theoretical approaches of condensed matter physics. Acquiring an ability to apply these methods for the solution of a limited class of advanced problems in the field of condensed matter physics.

**Content**
Estimated structure of the lecture:

1. Green's functions for non-interacting particles
2. Many-body Green's functions
3. Feynman diagrams (interacting fermions, Fermi fluids, collective excitations)
4. Green's functions and diagrammatic technique at finite temperatures (Matsubara diagrammatic technique)
5. Functional formulation of many-body theory
6. Superconducting systems
7. Non-equilibrium systems and Keldysh technique
8. Many-body systems in one dimension

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation and working on the exercises (180 hours).

**Recommendations**
In general this lecture should be attended after Theory of Condensed Matter I.

**Literature**


- A.A. Abrikosov, L.P. Gorkov, I.E. Dzyaloshinskii, Methods of QFT in statistical physics
- L.D. Landau, E.M. Lifschitz, Statistische Physik, Teil II (Lehrbuch der theoretischenPhysik, Bd IX)
- G.D. Mahan, Many-particle physics
- A.L. Fetter, J.D. Valecka, Quantum theory of many-particle systems.
- J.W. Negele, H. Orland, Quantum many-particle sysytems.
- J.R. Schrieffer, Theory of superconductivity.
- A. Altland, B. Simons, Condensed matter field theory.
- T. Giamarchi, Quantum physics in one dimension.
- A. Kamenev, Field theory of non-equilibrium systems.
- G. Giuliani, G. Vignale, Quantum Theory of the Electron Liquid.

# M 2.39 Module: Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics [M-PHYS-102308]

**Coordinators:** Prof. Dr. Markus Garst
apl. Prof. Dr. Igor Gornyi
Prof. Dr. Alexander Mirlin
PD Dr. Boris Narozhnyy
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 12 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102560 | Condensed Matter Theory II: Many-Body Systems, Fundamentals and Advanced Topics | 12 CP | Garst, Gornyi, Mirlin, Narozhnyy, Schmalian |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

Exercises are offered to complement the lecture. Prerequisite for the participation in the oral module final examination is the passing of the course work in the exercises. The course work takes place in the form of exercises. To pass, 50% of the exercises must be passed.

**Prerequisites**
none

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-PHYS-102313 - Condensed Matter Theory II: Many-Body Theory, Fundamentals must not have been started.

**Competence Goal**
Mastering advanced field-theoretical approaches of condensed matter physics. Acquiring an ability to apply these methods for the solution of a broader class of advanced problems in the field of condensed matter physics.

**Content**
Estimated structure of the lecture:

1. Green's functions for non-interacting particles
2. Many-body Green's functions
3. Feynman diagrams (interacting fermions, Fermi fluids, collective excitations)
4. Green's functions and diagrammatic technique at finite temperatures (Matsubara diagrammatic technique)
5. Functional formulation of many-body theory
6. Superconducting systems
7. Non-equilibrium systems and Keldysh technique
8. Many-body systems in one dimension
9. Kondo effect
10. Strongly correlated electrons: Hubbard model and Mott metal-insulator transition
11. Introduction to mesoscopic physics

**Workload**
360 hours consisting of attendance time (90 hours), follow-up of the lecture incl. exam preparation and working on the exercises (270 hours)

**Recommendations**
In general this lecture should be attended after Theory of Condensed Matter I.

**Literature**


- A.A. Abrikosov, L.P. Gorkov, I.E. Dzyaloshinskii, Methods of QFT in statistical physics
- L.D. Landau, E.M. Lifschitz, Statistische Physik, Teil II (Lehrbuch der theoretischenPhysik, Bd IX)
- G.D. Mahan, Many-particle physics
- A.L. Fetter, J.D. Valecka, Quantum theory of many-particle systems.
- J.W. Negele, H. Orland, Quantum many-particle sysytems.
- J.R. Schrieffer, Theory of superconductivity.
- A. Altland, B. Simons, Condensed matter field theory.
- T. Giamarchi, Quantum physics in one dimension.
- A. Kamenev, Field theory of non-equilibrium systems.
- G. Giuliani, G. Vignale, Quantum Theory of the Electron Liquid.

# M 2.40 Module: Continuous Time Finance [M-MATH-102860]

**Coordinators:** Prof. Dr. Nicole Bäuerle
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105930 | Continuous Time Finance | 8 CP | Bäuerle, Fasen-Hartmann, Trabs |

**Assessment**
oral examination of ca. 30 min.

**Prerequisites**
The module cannot be completed together with "Stochastic Calculus and Finance [T-WIWI-103129]".

**Competence Goal**
Students are able to

- understand, describe and use fundamental notions and techniques of modern continuous time finance,
- use specific probabilistic techniques,
- analyze mathematically economical questions in option pricing and optimization

**Content**

- Stochastic processes and filtrations
  - Martingales in continuous time
  - Stopping times
  - Quadratic variation
- Stochastic Ito-Integral w.r.t. continuous semimartingales
- Ito-calculus
  - Ito-Doeblin formula
  - Stochastic exponentials
  - Girsanov theorem
  - Martingale representation
- Black-Scholes financial market
  - Arbitrage and equivalent martingale measures
  - Options and no-arbitrage prices
  - market completeness
- Portfolio optimization
- Bonds, forwards and interest rate models

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The content of the module „Probability theory“ is strongly recommended. The module „Discrete time finance“ is recommended.

# M 2.41 Module: Control Theory [M-MATH-102941]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105909 | Control Theory | 6 CP | Schnaubelt |

**Assessment**
The module will be completed by an oral exam (ca. 20 min).

**Prerequisites**
none

**Competence Goal**
Students can explain the central concepts of the treatment of controlled linear ordinary differential equations (controllability, observability, stabilizability and discoverability) and the associated characterizations and apply them in examples. They are able to describe the basic features of the theory of transfer functions and realization theory. They can discuss the solution of the quadratic optimal control problem and apply it to feedback synthesis. They can describe the basic concepts of control theory including the associated criteria also for non-linear systems and apply them to examples.

**Content**

- controllabilty and observabilty of systems of linear ordinary differential equations
- stabilizability and detectability
- transfer functions
- realization theory,
- quadratic optimal control, feedback synthesis
- nonlinear controll theory: basic concepts, criteria via linearization, Lie brackets and Lyapunov functions

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the modules Analysis 1-2 und Lineare Algebra 1-2 are strongly recommended. Further knowledge of ordinary differential equations (as in Analysis 4) is useful.

**Literature**
J. Zabczyk, Mathematical Control Theory. An Introduction.

# M 2.42 Module: Convex Geometry [M-MATH-102864]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105831 | Convex Geometry | 8 CP | Hug |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
None

**Competence Goal**
The students

- know fundamental combinatorial, geometric and analytic properties of convex sets and convex functions and apply these to related problems,
- are familiar with fundamental geometric and analytic inequalities for functionals of convex sets and their applications to geometric extremal problems and can present central ideas and techniques of proofs,
- know selected integral formulas for convex sets and the required results on invariant measures.
- know how to work self-organized and self-reflexive.

**Content**

1. Convex Sets
   1.1. Combinatorial Properties
   1.2. Support and Separation Properties
   1.3. Extremal Representations
2. Convex Functions
   2.1. Basic Properties
   2.2. Regularity
   2.3. Support Function
3. Brunn-Minkowski Theory
   3.1. Hausdorff Metric
   3.2. Volume and Surface Area
   3.3. Mixed Volumes
   3.4. Geometric Inequalities
   3.5. Surface Area Measures
   3.6. Projection Functions
4. Integralgeometric Formulas
   4.1. Invariant Measures
   4.2. Projection and Section Formula
   4.3 Kinematic Formula

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research related to the course content
- preparation for the module exam.

**Literature**
D. Hug, W. Weil: Lectures on Convex Geometry. Graduate Texts in Mathematics, Vol. 286, Springer, Cham, 2020.

# M 2.43 Module: Curves on Surfaces [M-MATH-106632]

**Coordinators:** Dr. Elia Fioravanti
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113364 | Curves on Surfaces | 3 CP | Fioravanti |

**Assessment**
The module will be completed by an oral exam (of ca. 20 - 30 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students

- have a deeper understanding of the topology and geometry of surfaces, as well as of the structure of their homeomorphisms;
- are able to work independently and critically;
- are prepared to read recent research articles and work on a thesis on mapping class groups and related topics.

**Content**

- curves on surfaces up to homotopy and isotopy,
- mapping class groups of surfaces,
- Nielsen-Thurston classification of homeomorphisms of surfaces,
- Teichmüller space.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 hours

- lectures and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the courses 'Introduction into Geometry and Topology' and 'Elementary Geometry' are recommended. The courses 'Hyperbolic Geometry' and 'Algebraic Topology' can faciliate a deeper understanding of the course contents.

# M 2.44 Module: Deep Learning and Neural Networks [M-INFO-107197]

**Coordinators:** Prof. Dr. Jan Niehues
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-114219 | Deep Learning and Neural Networks | 6 CP | Niehues |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
Students will learn about the structure and function of different types of neural networks.

Students should learn the methods for training the various networks and their application to problems.

Students should learn the areas of application of the different types of networks.

Given a concrete scenario, students should be able to select the appropriate type of neural network.

**Content**
This module introduces the use of neural networks for the solution of solving various problems in the field of machine learning, such as classification, prediction, control or inference. or inference. Different types of neural networks are covered and their areas of application are illustrated using examples.

**Workload**
Lecture with 4 SWS, 6 CP.
6 LP corresponds to approx. 180 hours, of which
approx. 60 hours lecture attendance
approx. 90 hours post-processing (self-study)
approx. 30 hours exam preparation (self-study)

**Recommendations**
Prior successful completion of the core module "Cognitive Systems" is recommended.

# M 2.45 Module: Differential Geometry [M-MATH-101317]

**Coordinators:** Prof. Dr. Wilderich Tuschmann
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-102275 | Differential Geometry | 8 CP | Lytchak, Tuschmann |

**Assessment**
Performance will be assessed in the form of an oral examination lasting approximately 30 minutes. If the examination requires an unreasonable amount of preparation, the oral examination may be replaced by a written examination lasting 120 minutes. The decision will be announced at least six weeks before the examination.

**Prerequisites**
None.

**Competence Goal**
Participating students

- can discuss and apply fundamental concepts and techniques of modern differential geometry in detail,
- are familiar with exemplary applications of differential geometry,
- can attend advanced seminars and lectures in the field of differential geometry and topology.

**Content**

- Manifolds
- Tensors
- Riemannian metrics
- Linear relationships
- Covariant derivative
- Parallel translation
- Geodesics
- Curvature tensor and curvature notions

Optional:

- Fiber Bundles
- Differential forms
- Theorems of Stokes, Bonnet-Myers, and Hadamard-Cartan

**Module Grade Calculation**
The module grade is the grade for the written or oral exam.

**Additional Information**
This course is one of the core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

**Workload**
Total workload: 240 hours

Attendance time: 90 hours, by attending

- Course including module examination

Self-study: 150 hours

- Consolidation of course content through follow-up work on lecture content at home
- Completion of exercises
- Consolidation of course content using appropriate literature and internet research
- Preparation for the exam

**Recommendations**
In addition to the introductory lectures in calculus and linear algebra, ideally the module “Elementary Geometry” or a comparable course should also have been already completed.

# M 2.46 Module: Discrete Dynamical Systems [M-MATH-105432]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-110952 | Discrete Dynamical Systems | 3 CP | Herzog |

**Assessment**
The module will be completed by an oral exam (about 20 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students can

- name, discuss and apply fundamental statements of the theory of discrete dynamic systems,
- explain the meaning of dynamic systems using examples,
- describe and use specific techniques of topological dynamics.

**Content**

1. Discrete dynamical systems
2. Chaotic dynamical systems
3. Non-expansive mappings
4. The Fürstenberg-Weiss theorem
5. Cellular automata
6. (Weakly) mixing dynamical systems
7. Dynamics of linear operators

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 hours

- lectures, problem classes, and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Basics of complex analysis (e.g. from Analysis 4) and functional analysis are recommended.

# M 2.47 Module: Discrete Time Finance [M-MATH-102919]

**Coordinators:** Prof. Dr. Nicole Bäuerle
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105839 | Discrete Time Finance | 8 CP | Bäuerle, Fasen-Hartmann, Trabs |

**Assessment**
Written exam of 2h.

**Prerequisites**
none

**Competence Goal**
Students are able to

- understand, describe and use fundamental notions and techniques of modern discrete time finance,
- use specific probabilistic techniques,
- analyze mathematically economical questions in discrete option pricing and optimization,
- work self-organized and in a reflective manner.

**Content**

- Finite financial markets
- The Cox-Ross-Rubinstein-model
- Limit to Black-Scholes
- Characterizing no-arbitrage
- Characterizing completeness
- Incomplete markets
- American options
- Exotic options
- Portfolio optimization
- Preferences and stochastic dominance
- Mean-Variance portfolios
- Risk measures

**Module Grade Calculation**
The grade of the module is the grade of the written exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The content of the module „Probability theory“ is strongly recommended.

# M 2.48 Module: Dispersive Equations [M-MATH-104425]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-109001 | Dispersive Equations | 6 CP | Reichel |

**Assessment**
The module will be completed by an oral exam (ca. 20 min).

**Prerequisites**
None

**Competence Goal**
Graduates will be able to
- recognize the essential properties of dispersive partial differential equations and explain them using examples.
- name the particular difficulties of dispersive equations.
- use techniques to describe the short- and long-term behavior of solutions using the nonlinear Schrödinger equation as an example.
- analyze the stability of solitary waves.
- understand the concept of conservation variables and explain them for specific examples.

**Content**
- Strichartz estimates, Sobolev embeddings and conservation laws
- Well-posedness results
- Long-term behavior of solutions (virial and Morawetz identities)
- orbital stability of solitary waves (variational description and concentration compactness)
- Energy conservation (invariant transmission coefficients)

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 120 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the course 'Functional Analysis' are recommended.

# M 2.49 Module: Dynamical Systems [M-MATH-103080]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-106114 | Dynamical Systems | 8 CP | Reichel |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
none

**Competence Goal**
Graduates will be able to

- explain the significance of dynamical systems using examples,
- relate the concepts of a discrete-time and continuous-time dynamical system to each other,
- describe important methods for analyzing dynamical systems and use them to analyze the asymptotic behavior of solutions near equilibria for different dynamical systems,
- describe the behavior of invariant sets under discretization.

**Content**

- Examples of finite- and infinite-dimensional dynamical systems
- Fixed points, periodic orbits, limit sets
- Invariant sets
- Attractors
- Upper and lower continuity of attractors
- Stable and unstable manifolds
- Center manifolds

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The module 'Functional Analysis' is recommended.

# M 2.50 Module: Electromagnetics and Numerical Calculation of Fields [M-ETIT-100386]

**Coordinators:** Dr. Yongbo Deng
Prof. Dr. Ulrich Lemmer

**Organisation:** KIT Department of Electrical Engineering and Information Technology

**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each winter term | 1 term | English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-100640 | Electromagnetics and Numerical Calculation of Fields | 4 CP | Deng, Lemmer |

**Assessment**
Success control is carried out in the form of a written test of 120 minutes.

**Prerequisites**
none

**Competence Goal**
Students with very different background in electromagnetic field theory will be brought to a high level of comprehension. They will understand the concept of electric & magnetic fields and of electric potential & vector potential and they will be able to solve simple problems of electric & magnetic fields using mathematics. They will understand the equations and solutions of wave creation and wave propagation. Finally the student will have learnt the basics of numerical field calculation and be able to use software packages of numerical field calculation in a comprehensive and critical way.

The student will

- be able to deal with all quantities of electromagnetic field theory (E, D, B, H, J, M, P, ...), in particular: how to calculate and how to measure them,
- derive various equations from the Maxwell equations to solve simple field problems (electrostatics, magnetostatics, steady currents, electromagnetics),
- be able to deal with the concept of field energy density and solve practical problems using it (coefficients of capacitance and coefficients of inductance),
- be able to derive and use the wave equation, in particular: to solve problems how to create a wave and calculate solutions of wave propagation through various media,
- be able to outline the concepts, the main application areas and the limitations of methods of numerical field calculation (FDM, FDTD, FIM, FEM, BEM, MoM, TLM)
- be able to use one exemplary software package of numerical field calculation and solve simple practical problems with it.

**Content**
This course first gives a comprehensive recap of Maxwell equations and important equations of electromagnetic field theory. In the second part the most important methods of numerical field calculation are introduced.

Maxwell's equations, materials equations, boundary conditions, fields in ferroelectric and ferromagnetic materials

electric potentials, electric dipole, Coulomb integral, Laplace and Poisson's equation, separation of variables in cartesian, cylindrical and spherical coordinates

Dirichlet Problem, Neumann Problem, Greens function, Field energy density and Poynting vector,

electrostatic field energy, coefficients of capacitance, vector potential, Coulomb gauge, Biot-Savart-law, magnetic field energy, coefficients of inductance magnetic flux and coefficients of mutual inductance, field problems in steady electric currents,

law of induction, displacement current

general wave equation for E and H, Helmholtz equation

skin effect, penetration depth, eddy currents

retarded potentials, Coulomb integral with retarded potentials

wave equation for potential and Vector potential and A, Lorentz gauge, plane waves

Hertzian dipole, near field solution, far field solution

transmission lines, fields in coaxial transmission lines

waveguides, TM-waves, TE-waves

finite difference method FDM

finite difference - time domain FDTD, Yee ´s algorithm

finite difference - frequency domain

finite integration method FIM

finite element method FEM

boundary element method BEM, Method of Moments (MOM), Transmission LIne Matrix Methal (TLM),

solving large systems of linear equations

basic rules for good numerical field calculation

The lecturer reserves the right to alter the contents of the course without prior notification.

**Module Grade Calculation**
The module grade is the grade of the written exam.

**Workload**
Each credit point corresponds to approximately 25-30 hours of work (of the student). This is based on the average student who achieves an average performance. The workload includes:

Attendance time in lectures (3 h 15 appointments each) = 45 h

Self-study (4 h 15 appointments each) = 60 h

Preparation / post-processing = 20 h

Total effort approx. 125 hours = 4 LP

**Recommendations**
Fundamentals of electromagnetic field theory.

**Literature**
Matthew Sadiku (2001), Numerical Techniques in Electromagnetics.
CRC Press, Boca Raton, 0-8493-1395-3
Allen Taflove and Susan Hagness (2000), Computational electrodynamics: the finite-difference time-domain method.
Artech House, Boston, 1-58053-076-1
Nathan Ida and Joao Bastos (1997), Electromagnetics and calculation of fields.
Springer Verlag, New York, 0-387-94877-5
Z. Haznadar and Z. Stih (2000), Electromagnetic Fields, Waves and Numerical Methods.
IOS Press, Ohmsha, 1 58603 064 7
M.V.K. Chari and S.J. Salon (2000), Numerical Methods in Electromagnetism, Academic Press, 0 12 615760 X

# M 2.51 Module: Electronic Properties of Solids I, with Exercises [M-PHYS-102089]

**Coordinators:** Prof. Dr. Matthieu Le Tacon
Prof. Dr. Wolfgang Wernsdorfer
Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 10 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102577 | Electronic Properties of Solids I, with Exercises | 10 CP | Le Tacon, Wernsdorfer, Wulfhekel |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-PHYS-102090 - Electronic Properties of Solids I, without Exercises must not have been started.

**Competence Goal**
Students will be familiar with the most common experimental methods for studying the electronic properties of condensed matter and some of the key theoretical concepts that underlie them. They master the basic tools for studying and understanding heat transport, scattering mechanisms, phase transitions, and magnetism. Exercises will reinforce the acquired knowledge and apply it to classical condensed matter problems.

**Content**

- Metal and insulators: Band structure, Fermi surface
- Electronic and heat transport - scattering mechanisms
- Phase transitions: Landau theory, critical exponents
- Atomic magnetism and magnetic interactions
- Magnetic structures, dynamics

**Additional Information**
The course will be given in English. Questions and discussions in German are welcome as well.

**Workload**
300 hours consisting of attendance time (75 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (225 hours)

**Recommendations**
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics and statistical physics is assumed.

**Literature**

- R. Gross, A. Marx, Festkörperphysik
- N. W. Ashcroft, N. D. Mermin: Festkörperphysik
- H. Ibach, H. Lüth: Festkörperphysik
- C. Kittel: Einführung in die Festkörperphysik
- S. Blundell, Magnetism in Condensed Matter

# M 2.52 Module: Electronic Properties of Solids I, without Exercises [M-PHYS-102090]

**Coordinators:** Prof. Dr. Matthieu Le Tacon
Prof. Dr. Wolfgang Wernsdorfer
Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102578 | Electronic Properties of Solids I, without Exercises | 8 CP | Le Tacon, Wernsdorfer, Wulfhekel |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-PHYS-102089 - Electronic Properties of Solids I, with Exercises must not have been started.

**Competence Goal**
Students will be familiar with the most common experimental methods for studying the electronic properties of condensed matter and some of the key theoretical concepts that underlie them. They will master the basic tools for studying and understanding heat transport, scattering mechanisms, phase transitions, and magnetism.

**Content**

- Metal and insulators: Band structure, Fermi surface
- Electronic and heat transport - scattering mechanisms
- Phase transitions: Landau theory, critical exponents
- Atomic magnetism and magnetic interactions
- Magnetic structures, dynamics

**Additional Information**
The course will be given in English. Questions and discussions in German are welcome as well.

**Workload**
240 hours consisting of attendance time (60 hours), wrap-up of the lecture incl. exam preparation (180 hours)

**Recommendations**
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics and statistical physics is assumed.

**Literature**

- R. Gross, A. Marx, Festkörperphysik
- N. W. Ashcroft, N. D. Mermin: Festkörperphysik
- H. Ibach, H. Lüth: Festkörperphysik
- C. Kittel: Einführung in die Festkörperphysik
- S. Blundell, Magnetism in Condensed Matter

# M 2.53 Module: Electronic Properties of Solids II, with Exercises [M-PHYS-102108]

**Coordinators:** Prof. Dr. Matthieu Le Tacon
Dr. Johannes Rotzinger
Prof. Dr. Alexey Ustinov
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-104422 | Electronic Properties of Solids II, with Exercises | 8 CP | Le Tacon, Rotzinger, Ustinov, Wernsdorfer |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-PHYS-102109 - Electronic Properties of Solids II, without Exercises must not have been started.

**Competence Goal**
Students know the physical properties of superconductivity, a thermodynamic state of the electronic system of solids. They understand classical and modern experimental findings as well as basic theoretical models, such as the concept of the energy gap or the quasiparticle, which is also commonly used outside superconductivity. They apply the acquired knowledge to specific problems. The students are able to familiarize themselves with current literature on the subject of superconductivity.

**Content**
Foundations of superconductivity: thermodynamics, electrodynamics, flux quantization, Ginzburg-Landau theory, BCS theory, vortices, tunnel junctions, Josephson junctions, SQUIDs, superconducting electronics, superconducting qubits.

**Additional Information**
The course will be given in English. Questions and discussions in German are welcome as well.

**Workload**
240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (180 hours).

**Recommendations**
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**


- V.V. Schmidt, “The Physics of Superconductors: Introduction to Fundamentals and Applications”, Springer (1997), ISBN 978-3540612438
- M. Tinkham, „Introduction to Superconductivity: Vol I“, Dover Publ. (2004), ISBN: 978-0486435039
- W. Buckel und R. Kleiner, „Supraleitung: Grundlagen und Anwendungen“, Wiley-VCH (2004), ISBN: 978-3527403486

# M 2.54 Module: Electronic Properties of Solids II, without Exercises [M-PHYS-102109]

**Coordinators:** Prof. Dr. Matthieu Le Tacon
Dr. Johannes Rotzinger
Prof. Dr. Alexey Ustinov
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-104423 | Electronic Properties of Solids II, without Exercises | 4 CP | Le Tacon, Rotzinger, Ustinov, Wernsdorfer |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-PHYS-102108 - Electronic Properties of Solids II, with Exercises must not have been started.

**Competence Goal**
Students know the physical properties of superconductivity, a thermodynamic state of the electronic system of solids. They understand classical and modern experimental findings as well as basic theoretical models, such as the concept of the energy gap or the quasiparticle, which is also commonly used outside of superconductivity. Students are able to familiarize themselves with current literature on superconductivity.

**Content**
Foundations of superconductivity: thermodynamics, electrodynamics, flux quantization, Ginzburg-Landau theory, BCS theory, vortices, tunnel junctions, Josephson junctions, SQUIDs, superconducting electronics, superconducting qubits.

**Additional Information**
The course will be given in English. Questions and discussions in German are welcome as well.

**Workload**
120 hours consisting of attendance time (30 hours), wrap-up of the lecture incl. exam preparation (90 hours)

**Recommendations**
Basic knowledge of solid state physics, quantum mechanics, and thermodynamics is assumed.

**Literature**


- V.V. Schmidt, “The Physics of Superconductors: Introduction to Fundamentals and Applications”, Springer (1997), ISBN 978-3540612438
- M. Tinkham, „Introduction to Superconductivity: Vol I“, Dover Publ. (2004), ISBN: 978-0486435039
- W. Buckel und R. Kleiner, „Supraleitung: Grundlagen und Anwendungen“, Wiley-VCH (2004), ISBN: 978-3527403486

# M 2.55 Module: Ergodic Theory [M-MATH-106473]

**Coordinators:** PD Dr. Gabriele Link
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113086 | Ergodic Theory | 8 CP | Link |

**Assessment**
Oral examination of ca. 20-30 minutes.

**Prerequisites**
None

**Competence Goal**
Students

- know important examples of dynamical systems,
- can state and discuss substantial concepts of ergodic theory,
- can state important results on qualitative properties of dynamical systems and relate them,
- are prepared to read recent research articles and write a bachelor or master thesis in the field of ergodic theory.

**Content**

- Elementary examples of dynamical systems such as Bernoulli systems and billiards
- Poincare rekurrence and ergodic theorems
- mixing, weak mixing, equidistribution
- entropy
- advanced topic(s) (as for example hyperbolic dynamics, symbolic dynamics and coding, Furstenberg correspondence principle or unitary representations of SL(2,R))

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
Some basic knowledge of measure theory, topology, geometry, group theory and functional analysis is recommended.

# M 2.56 Module: Evolution Equations [M-MATH-102872]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105844 | Evolution Equations | 8 CP | Frey, Kunstmann, Schnaubelt |

**Assessment**
Oral examination of ca. 30 minutes.

**Prerequisites**
none

**Competence Goal**
The students

- can explain the basics of the theory of strongly continuous operator semigroups and their generators, in particular the theorems on generation and wellposedness, and they can apply it to examples.
- can also describe and use the solution and regularity theory of inhomogeneous Cauchy problems.
- are able to construct analytic semigroups and to characterize their generators. Using these results and perturbations theorems, they can solve partial differential equations.
- are able to explain main aspects of approximation theory of evolution equations.
- can discuss the core statements of stability and spectral theory of operator semigroups and discuss examples by means of them.
- have mastered the important techniques for proofs in evolution equations and are able to, at least, sketch the complicated proofs.

**Content**

- strongly continuous operator semigroups and their generators,
- generation results and wellposedness,
- inhomogeneous Cauchy problems,
- analytic semigroups,
- perturbation and approximation theory,
- stability and spectral theory of operator semigroups,
- applications to partial differential equations

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Additional Information**
Regular cycle: every 2nd year. The module "Nonlinear Evolution Equations"
is based on "Evolution Equations"

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The module “Functional Analysis” is strongly recommended.

**Literature**
K.-J. Engel und R. Nagel, One-Parameter Semigroups for Linear Evolution Equations.

# M 2.57 Module: Exponential Integrators [M-MATH-103700]

**Coordinators:** Prof. Dr. Marlis Hochbruck
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-107475 | Exponential Integrators | 6 CP | Hochbruck, Jahnke |

**Assessment**
Oral exam of approximately 20 minutes.

**Prerequisites**
None.

**Competence Goal**
Graduates will be able to name key concepts for the construction and analysis of exponential integrators and implement them efficiently.

**Content**
In this class we consider the construction, analysis, implementation and application of exponential integrators. The focus will be on two types of stiff problems.

The first one is characterized by a Jacobian that possesses eigenvalues with large negative real parts. Parabolic partial differential equations and their spatial discretization are typical examples. The second class consists of highly oscillatory problems with purely imaginary eigenvalues of large modulus.

Apart from motivating the construction of exponential integrators for various classes of problems, our main intention in this class is to present the mathematics behind these methods. We will derive error bounds that are independent of stiffness or highest frequencies in the system.

Since the implementation of exponential integrators requires the evaluation of the product of a matrix function with a vector, we will briefly discuss some possible approaches as well.

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 180 h

Attendance: 60 h

- Course including module examination during study.

Self-studies: 120 h

- Deepening the study content by working on the lecture content at home
- Working on exercises
- In-depth study of the course content using suitable literature and Internet research,
- preparation for the module examination during study.

**Recommendations**
Basic knowledge of ordinary and/or partial differential equations as well as the contents of the module "Numerical Methods for Differential Equations" are strongly recommended. Knowledge of functional analysis is also recommended.

# M 2.58 Module: Extremal Graph Theory [M-MATH-102957]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105931 | Extremal Graph Theory | 4 CP | Aksenovich |

**Assessment**
The final grade is given based on an oral exam (approx. 30 min.).

**Prerequisites**
None.

**Competence Goal**
The students understand, describe, and use fundamental notions and techniques in extremal graph theory. They can analyze, structure, and formally describe typical combinatorial questions. The students understand and use Szemeredi's regularity lemma and Szemeredi's theorem, can use probabilistic techniques, such as dependent random choice and multistep random colorings, know the best bounds for the extremal numbers of complete graphs, cycles, complete bipartite graphs, and bipartite graphs with bounded maximum degree. They understand and can use the Ramsey theorem for graphs and hypergraphs, as well as stepping-up techniques for bounding Ramsey numbers. Moreover, the students know and understand the behavior of Ramsey numbers for graphs with bounded maximum degree. The students can communicate using English technical terminology.

**Content**
The course is concerned with advanced topics in graph theory. It focuses on the areas of extremal functions, regularity, and Ramsey theory for graphs and hypergraphs. Further topics include Turán's theorem, Erdös-Stone theorem, Szemerédi's lemma, graph colorings and probabilistic techniques.

**Module Grade Calculation**
The module grade is the grade of the exam.

**Additional Information**
Course is held in English

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination

Self-study: 150 hours

- Consolidation by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
Basic knowledge of linear algebra, analysis and graph theory is recommended.

# M 2.59 Module: Extreme Value Theory [M-MATH-102939]

**Coordinators:** Prof. Dr. Vicky Fasen-Hartmann
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105908 | Extreme Value Theory | 4 CP | Fasen-Hartmann |

**Assessment**
The module will be completed by an oral exam (approx. 20 min).

**Prerequisites**
None.

**Competence Goal**
Students are able to

- name, explain, motivate and apply statistical methods for estimating risk measures,
- model and quantify extreme events,
- apply specific probabilistic techniques of extreme value theory,
- master proof techniques,
- work in a self-organised and reflective manner.

**Content**

- Theorem of Fisher and Tippett's
- Generalised extreme value and Pareto distribution (GED and GPD)
- Domain of attractions of generalised extreme value distributions
- Theorem of Pickands-Balkema-de Haan
- Estimation of risk measures
- Hill estimator
- Block maxima method
- POT method

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 hours

- lectures and problem classes including the examination.

Self studies: 75 hours

- follow-up and deepening of the course content
- work on problem sheets
- literature and internet research on the course content
- preparation for the module examination

**Recommendations**
The content of the module "Probability theory" is recommended.

# M 2.60 Module: Finite Element Methods [M-MATH-102891]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Christian Wieners
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (mandatory)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105857 | Finite Element Methods | 8 CP | Dörfler, Hochbruck, Jahnke, Maier, Rieder, Wieners |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes. If the examination is unreasonably time-consuming, the oral examination may be replaced by a written examination lasting 120 minutes. The decision will be announced at least six weeks before the examination.

**Prerequisites**
None.

**Competence Goal**
At the end of the course, students

- know the basic methods, techniques and algorithms for the numerical solution of elliptic boundary value problems with finite elements (especially stability, convergence and complexity of the discretisation)
- can explain concepts of modelling with differential equations
- are able to solve numerically boundary value problems with finite elements

**Content**

- Theory of finite element methods for elliptic boundary value problems of second order
- Basic concepts for the implementation
- Special topis like, e.g., elliptic eigenvalue problems
- Mixed methods

**Module Grade Calculation**
The module grade is the grade of the exam.

**Workload**
Total workload: 240 hours
Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Basic knowledge of numerical methods and the analysis for differential equations is strongly recommended. Knowledge in functional analysis is helpful.

# M 2.61 Module: Forecasting: Theory and Practice [M-MATH-102956]

**Coordinators:** Prof. Dr. Tilmann Gneiting
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 2 terms | English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105928 | Forecasting: Theory and Practice | 8 CP | Gneiting |

**Assessment**
The examination takes the form of an oral exam (30 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students

- can explain the measure theoretic and probabilistic foundations of the theory of forecasting and are able to apply this knowledge in examples
- can explain the decision theoretic foundations of forecast evaluation and are able to apply key concepts and key tools in examples
- can explain, adapt, interpret, and implement regression methods for forecasting
- can explain basic concepts of the generation and evaluation of meteorological and economic forecasts
- can develop and code simulation and real data studies for the generation and evaluation of forecasts in a self-organized and reflective manner
- are prepared to work on a thesis in the field of the theory and practice of forecasting

**Content**

- case studies from meteorology and economics
- point forecasts and probabilistic forecasts
- prediction spaces, calibration, and sharpness
- proper scoring rules and consistent scoring functions
- forecast aggregation
- predictive facets of regression

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**

- regular cycle: every 2nd year, next offering winter semester 26/27

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- course including lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course contents
- work on problem sheets
- literature study and internet research relating to the course contents
- preparation for the module examinaton

**Recommendations**
Familiarity with the contents of the module "Probability theory" is strongly recommended. Furthermore, familiarity with the contents of the module "Statistics" is recommended.

**Literature**
Gneiting, T, Katzfuss, M (2014). Probabilistic forecasting. Annual Review of Statistics and Its Application, 1, 125-151.
Further literature will be recommended in the course.

# M 2.62 Module: Formal Systems [M-INFO-100799]

**Coordinators:** Prof. Dr. Bernhard Beckert
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-101336 | Formal Systems | 6 CP | Beckert |

# M 2.63 Module: Foundations of Continuum Mechanics [M-MATH-103527]

**Coordinators:** Prof. Dr. Christian Wieners
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Once | 1 term | 4 | 2 |

**Election Notes**
by interest of international students the course will be in English

| Mandatory | | | |
|---|---|---|---|
| T-MATH-107044 | Foundations of Continuum Mechanics | 4 CP | Wieners |

**Assessment**
Oral exam of approx. 20 minutes.

**Prerequisites**
none

**Competence Goal**
Graduates can

- explain the basic concepts in continuum mechanics
- distinguish different models in continuum mechanics and analyze their properties
- applying methods and principles in mathematical modelling for solids and fluids

**Content**

- kinematic foundations
- balance relations for static problems, Cauchy theorem
- elastic materials
- hyperelastic materials
- balance relations for dynamic probleme, Reynolds theorem
- Newtonian Fluids
- Non-Newtonian Fluids

**Module Grade Calculation**
the grade points are the grade points of the oral exam

**Workload**
in presence: 45 hours

- lecture, exercises, including exam

own study time: 75 hours

- deeper learning of the lecture content by repeating the content at home
- solving the exercises
- deeper learning by reading literature and internet
- preparation of the exam

**Recommendations**
optimization theory

# M 2.64 Module: Fractal Geometry [M-MATH-105649]

**Coordinators:** PD Dr. Steffen Winter
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111296 | Fractal Geometry | 6 CP | Winter |

**Assessment**
The module will be completed with an oral exam (20 - 30 min).

**Prerequisites**
None

**Competence Goal**
Students

- can name and explain important terms and concepts of fractal geometry;
- know important results of dimension theory and can apply them to examples;
- have the ability to use specific methods for the analysis of fractal structures;
- are able to construct fractals and random fractals with certain prescribed properties;
- master important proof techniques in fractal geometry and are able to at least sketch the more difficult proofs;
- are able to work self-organized and in a reflective manner;
- are prepared, to write a thesis in the field of fractal geometry.

**Content**

- iterated function systems and self-similar sets
- chaos game algorithm
- random fractals
- fractal dimension theory
- Hausdorff measure and dimension
- packing measure and dimension
- Minkowski contents
- methods of computing dimension
- self-similar measures and multifractals
- dimension of measures

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the courses Analysis 3 (measure theory) and Probability theory are recommended.

# M 2.65 Module: Functional Analysis [M-MATH-101320]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | German | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-102255 | Functional Analysis | 8 CP | Frey, Herzog, Hundertmark, Lamm, Liao, Reichel, Schnaubelt, Tolksdorf |

**Assessment**
Written examination of 120 minutes.

**Prerequisites**
None

**Competence Goal**
The students can

- explain basic topological concepts such as compactness in the framework of metric spaces, and are able to apply these in examples.
- describe the structure of Hilbert spaces and can use them in applications.
- explain the principle of uniform boundedness, the open mapping theorem and the Hahn-Banach theorem, and are able to derive conclusions from them.
- describe the concepts of dual Banach spaces, in particular weak convergence, reflexivity and the Banach-Alaoglu theorem. They can discuss these concepts in examples.
- explain the spectral theorem for compact self-adjoint operators.
- come up with a proof for simple functional analytic statements.

**Content**

- Metric spaces (basic topological concepts, compactness),
- Hilbert spaces, Orthonormal bases, Sobolev spaces,
- Continuous linear operators on Banach spaces (principle of uniform boundedness, open mapping theorem),
- Dual spaces and representations, Hahn-Banach theorem, Banach-Alaoglu theorem, weak convergence, reflexivity,
- Spectral theorem for compact self-adjoint operators.

**Module Grade Calculation**
The grade of the module is the grade of the written exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

# M 2.66 Module: Functional Data Analysis [M-MATH-106485]

**Coordinators:** Dr. rer. nat. Bruno Ebner
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113102 | Functional Data Analysis | 4 CP | Ebner, Klar, Trabs |

**Assessment**
Oral examination of ca. 25 minutes.

**Prerequisites**
None

**Competence Goal**
The aim of the course is to give an introduction to weak convergence concepts in metric spaces and to highlight some statistical applications.

After successful participation students can

- model random elements in metric spaces,
- explain the concept of weak convergence in metric spaces and are familiar with structural problems in this context,
- apply limit laws for functionals of the empirical distribution function,
- model the normal distribution for random elements in Hilbert spaces,
- derive limit distributions of L2 type goodness-of-fit statistics,
- apply goodness-of-fit tests to functional data.

**Content**

- Theorem of Glivenko-Cantelli,
- weak convergence in metric spaces,
- Theorem of Prokhorov,
- Gaussian Processes,
- Donsker's Theorem,
- functional central limit theorem,
- empirical processes,
- random elements in separable Hilbert spaces,
- Goodness-of-fit tests.

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 h

- lectures and examination

Self studies: 75 h

- follow-up and deepening of the course content,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the modules "Probability Theory" and "Mathematical Statistics" are strongly recommended.

# M 2.67 Module: Functions of Matrices [M-MATH-102937]

**Coordinators:** PD Dr. Volker Grimm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105906 | Functions of Matrices | 8 CP | Grimm |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
none

**Competence Goal**
The students know the basic definitions and properties of matrix functions. They can evaluate methods for approximating matrix functions in terms of convergence and efficiency, independently solve exercises, present their own solutions and implement the methods discussed.

**Content**

- Definition of functions of matrices
- Approximations to functions of matrices for large sparse matrices
- Krylov subspace methods and rational Krylov subspace methods
- Application to the numerical solution of partial differential equations

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The courses Numerical Analysis 1 and 2 are strongly recommended.

# M 2.68 Module: Functions of Operators [M-MATH-102936]

**Coordinators:** PD Dr. Volker Grimm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105905 | Functions of Operators | 6 CP | |

**Assessment**
The module will be completed by an oral exam (ca. 20 min).

**Prerequisites**
None

**Competence Goal**
The students have basic knowledge of the approximation of functions of operators. They can examine the methods for convergence properties and efficiency. In the context of semigroups, they can analyze the procedures discussed, independently select the appropriate procedures and justify their choice.

**Content**

- Definition of functions of operators
- Strongly continuous and analytic semigroups
- Rational approximations to functions of operators with fixed poles
- Rational Krylov subspace method for the approximation of functions of operators
- Applications in the numerical analysis of semigroups

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 120 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The courses Numerical Analysis 1 and 2, and Functional Analysis are strongly recommended.

# M 2.69 Module: Galerkin Methods for Time-dependent PDEs [M-MATH-107647]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-114992 | Galerkin Methods for Time-dependent PDEs | 5 CP | Dörfler |

**Assessment**
Success is assessed in form of an oral examination.

**Prerequisites**
None.

**Competence Goal**
At the end of the course, students

- know the basic methods, techniques and algorithms for the numerical solution of parabolic boundary value problems with finite elements (especially stability, convergence and complexity of the discretisation),
- can explain concepts of modelling with time-dependend differential equations,
- are able to solve numerically initial boundary value problems with finite elements.

**Content**

- Theory of the solution for parabolic boundary value problems with continuous or discontinuous finite element methods,
- Basic concepts for the implementation,
- Adaptive time-stepping and adaptive finite elements in space.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 150 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 90 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Basic knowledge of numerical methods and the analysis for differential equations is strongly recommended. Knowlegde in functional analysis is helpful.

# M 2.70 Module: Generalized Regression Models [M-MATH-102906]

**Coordinators:** PD Dr. Bernhard Klar
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105870 | Generalized Regression Models | 4 CP | Ebner, Fasen-Hartmann, Klar, Trabs |

**Assessment**
The module will be completed by an oral exam (ca. 20 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students will

- be familiar with the most important regression models and their properties,
- be able to evaluate and interpret the results obtained using these models,
- be able to use the models to analyze more complex data sets.

**Content**
This course covers basic models of statistics that allow us to capture relationships between variables. Topics include

- Linear regression models:
  Model diagnostics
  Multicollinearity
  Variable selection
  Generalized least squares
- Nonlinear regression models:
  Parameter estimation
  Asymptotic normality of maximum likelihood estimators
- Regression models for count data
- Generalized linear models:
  Parameter estimation
  Model diagnostics
  Overdispersion and quasi-likelihood

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 hours

- lectures, problem classes, and examination

Self-studies: 75 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the course "Statistics" are strongly recommended.

# M 2.71 Module: Geometric Analysis [M-MATH-102923]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105892 | Geometric Analysis | 8 CP | Lamm |

**Assessment**
Oral examination lasting approx. 30 minutes.

**Prerequisites**
None.

**Competence Goal**
Students will be able to

- apply basic techniques of geometric analysis,
- recognize connections between differential geometry and partial differential equations.

**Content**
Geometric evolution equations

Geometric variational problems

Minimal surfaces

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Attendance time: 90 hours

- Course including module examination

Self-study: 150 hours

- Consolidation of the course content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
Introduction to geometry and topology or elementary geometry, classical methods of partial differential equations

# M 2.72 Module: Geometric Group Theory [M-MATH-102867]

**Coordinators:** Prof. Dr. Roman Sauer
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105842 | Geometric Group Theory | 8 CP | Herrlich, Link, Llosa Isenrich, Sauer, Tuschmann |

**Assessment**
The module examination takes the form of a written examination lasting 120 minutes.

**Prerequisites**
None.

**Competence Goal**
Graduates

- recognize the interplay between geometry and group theory,
- understand fundamental structures and techniques of geometric group theory and are able to identify, discuss, and apply them,
- are familiar with and understand concepts and results from coarse geometry,
- are prepared to read and engage with current research literature in geometric group theory.

**Content**

- Finitely generated groups and group presentations
- Cayley graphs and group actions
- Quasi-isometries of metric spaces, quasi-isometric invariants, and the Schwarz–Milnor Lemma
- Classes of groups, for example: hyperbolic groups, Fuchsian groups, amenable groups, braid groups, Thompson's group

**Module Grade Calculation**
The module grade is the grade of the examination.

**Additional Information**
This course is one of the nine core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination during the course of study

Self-study: 150 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
The contents of the modules "Introduction to Geometry and Topology" or "Elementary Geometry" and "Introduction to Algebra and Number Theory" are recommended.

# M 2.73 Module: Geometric Group Theory II [M-MATH-102869]

**Coordinators:** Prof. Dr. Roman Sauer
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105875 | Geometric Group Theory II | 8 CP | Herrlich, Llosa Isenrich, Sauer |

**Assessment**
The module examination takes the form of an oral examination (approx. 30 minutes).

The examination is offered every semester and can be repeated at any regular examination date.

**Prerequisites**
None.

**Competence Goal**
Graduates

- have a deeper understanding of exemplary objects and concepts in the field of geometric group theory,
- can work self-organized and reflexive,
- are prepared to read current research papers and write final theses in the field of geometric group theory.

**Content**
Selected topics of geometric group theory, e.g.

- Gromov-hyperbolic spaces,
- Lie groups and discrete subgroups,
- symmetrical spaces and arithmetic groups,
- automorphism groups of free groups,
- Teichmüller rooms and mapping class groups,
- non-positively curved groups,

**Module Grade Calculation**
The module grade is the grade of the oral examination

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination

Self-study: 150 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
The module "Geometric Group Theory I" is strongly recommended.

# M 2.74 Module: Geometric Numerical Integration [M-MATH-102921]

**Coordinators:** Prof. Dr. Tobias Jahnke
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105919 | Geometric Numerical Integration | 6 CP | Hochbruck, Jahnke |

**Assessment**
The module will be completed by an oral exam (about 25 min).

**Prerequisites**
none

**Competence Goal**
After attending the course, students understand the central properties of finite-dimensional Hamilton systems (energy conservation, symplectic flow, first integrals etc.). They know important classes of geometric time integrators such as, e.g., symplectic (partitioned) Runge-Kutta methods, splitting methods, SHAKE and RATTLE. They are not only able to implement these methods and apply them to practice-oriented problems, but also to analyze and explain the observed long-time behavior (e.g. approximative energy conservation over long times).

**Content**

- Newtonian equation of motion, Lagrange equations, Hamilton systems
- Properties of Hamilton systems: symplectic flow, energy conservation, other conserved quantities
- Symplectic numerical methods: symplectic Euler method, Störmer-Verlet method, symplectic (partitioned) Runge-Kutta methods
- Construction of symplectic methods, for example by composition and splitting
- Backward error analysis and energy conservation over long time intervals
- Mechanical systems with constraints

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**
The module is offered about every two years

**Workload**
Total workload: 180 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 120 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Familiarity with ordinary differential equations and Runge-Kutta methods (construction, order, stability, etc.) are strongly recommended. The course "Numerical methods for differential equations" provides an excellent basis. Moreover, programming skills in Python or MATLAB are strongly recommended.

# M 2.75 Module: Geometric Variational Problems [M-MATH-106667]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113418 | Geometric Variational Problems | 8 CP | Lamm |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
none

**Competence Goal**
The students

- can name basic results in the theory of geometric variational problems and relate them to each other;
- are prepared to write a thesis in the field of geometric analysis.

**Content**

- Harmonic maps
- Willmore surfaces
- Regularity theory
- Hardy and BMO spaces

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The modules *Classical Methods for Partial Differential Equations* and *Functional Analysis* are recommended.

# M 2.76 Module: Geometry of Schemes [M-MATH-102866]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105841 | Geometry of Schemes | 8 CP | Herrlich, Kühnlein |

**Assessment**
The modules is completed by an oral exam of about 30 minutes

**Prerequisites**
None

**Competence Goal**
At the end of the module, participants are able to

- relate the notion of algebraic schemes with that of algebraic varieties
- name and discuss basic properties of schemes
- deal with sheaves on schemes and investigate their properties
- start to read recent research papers in algebraic geometry and write a thesis in this field.

**Content**

- Sheaves of modules
- affine schemes
- varieties and schemes
- morphisms between schemes
- coherent and quasicoherent sheaves
- cohomology of sheaves

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total work load. 240 hours

Attendance: 90 hours

- lectures, problem classes and examination

Self studies: 150 hours

- follow-up and deepening of the course content
- work on problem sheets
- literature studies and internet research relating to the course content
- preparation for the module examination

**Recommendations**
The modules "Algebra" and "Algebraic Geometry" are strongly recommended.

# M 2.77 Module: Global Differential Geometry [M-MATH-102912]

**Coordinators:** Prof. Dr. Wilderich Tuschmann
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105885 | Global Differential Geometry | 8 CP | Tuschmann |

**Assessment**
The module examination takes the form of an oral examination lasting approximately 30 minutes.

**Prerequisites**
None.

**Competence Goal**
Graduates

- have acquired a deeper understanding of exemplary concepts and methods of global differential geometry and Riemannian geometry,
- are prepared for independent research and advanced seminars in the field of differential geometry.

**Content**

- Existence and obstacle theorems for metrics with special properties
- Geometric finiteness and classification results
- Geometric limits
- Gromov-Hausdorff and Lipschitz convergence of Riemannian manifolds
- Moduli Spaces of Riemannian Metrics

**Module Grade Calculation**
The module grade is the grade for the oral examination.

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including examination

Self-study: 150 hours

- Consolidation of course content through follow-up work on lecture content at home
- Completion of exercises
- Consolidation of course content using appropriate literature and internet research
- Preparation for the module examination

**Recommendations**
Prior knowledge gained in the lecture “Differential Geometry” is recommended.

# M 2.78 Module: Graph Theory [M-MATH-101336]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-102273 | Graph Theory | 8 CP | Aksenovich |

**Assessment**
The final grade is given based on the written final exam (3h).

By successfully working on the problem sets, a bonus can be obtained. To obtain the bonus, one has to achieve 50% of the points on the solutions of the exercise sheets 1-6 and also of the exercise sheets 7-12. If the grade in the final written exam is between 4,0 and 1,3, then the bonus improves the grade by one step (0,3 or 0,4).

**Prerequisites**
None.

**Competence Goal**
The students understand, describe and use fundamental notions and techniques in graph theory. They can represent the appropriate mathematical questions in terms of graphs and use the results such as Menger's theorem, Kuratowski's theorem, Turan's theorem, as well as the developed proof ideas, to solve these problems. The students can analyze graphs in terms of their characteristics such as connectivity, planarity, and chromatic number. They are well positioned to understand graph theoretic methods and use them critically. Moreover, the students can communicate using English technical terminology.

**Content**
The course Graph Theory treats the fundamental properties of graphs, starting with basic ones introduced by Euler and including the modern results obtained in the last decade. The following topics are covered: structure of trees, paths, cycles and walks in graphs, minors, unavoidable subgraphs in dense graphs, planar graphs, graph coloring, Ramsey theory, and regularity in graphs.

**Additional Information**

- Course is held in English
- This course is one of the nine core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination during the course of study

Self-study: 150 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

# M 2.79 Module: Harmonic Analysis [M-MATH-105324]

**Coordinators:** Prof. Dr. Dorothee Frey
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111289 | Harmonic Analysis | 8 CP | Frey, Kunstmann, Schnaubelt, Tolksdorf |

**Assessment**
The module will be completed by an oral exam of approx. 30 min.

**Prerequisites**
None.

**Competence Goal**
Students are familiar with the representation of (square-)integrable functions by Fourier series, the convergence theory of these series and the relationship between the smoothness of a function and the decay of the Fourier coefficients. They are able to apply the results to simple examples. They master the properties of the Fourier transform in the context of Lebesgue spaces and distributions. They recognize the importance of Fourier analysis for applied mathematics, based on explicit solutions for the heat equation, the wave equation and the Schrödinger equation. They master the basic statements on the boundedness singular integrals, e.g., for the Hilbert transform. They recognize the importance and applicability of interpolation methods and Fourier multiplier theorems.

**Content**

- Fourier series
- Fourier transform on L^1 and L^2
- Tempered distributions and their Fourier transform
- Explicit solutions of the Heat-, Schrödinger- and Wave equation on R^n
- the Hilbert transform
- the interpolation theorem of Marcinkiewicz
- Singular integral operators
- the Fourier multiplier theorem of Mihlin

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**
Every two years.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research relating to the course content
- preparation for the module examination

**Recommendations**
The contents of the course "Functional Analysis" are recommended.

# M 2.80 Module: Harmonic Analysis 2 [M-MATH-106486]

**Coordinators:** Prof. Dr. Dorothee Frey
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113103 | Harmonic Analysis 2 | 8 CP | Frey, Kunstmann, Tolksdorf |

**Assessment**
Oral examination of ca. 30 minutes.

**Prerequisites**
None

**Competence Goal**
The students

- can explain basic results on Riesz tranforms and in the Littlewood-Paley theory.
- can explain the basic results on Hardy spaces and BMO and put them into context.
- can describe fundamental results on oscillatory integrals and apply them to examples.
- can describe fundamental results for the study of dispersive equations and discuss them.
- master important techniques of proofs for singular integral operators and oscillatory integrals and can sketch central proofs.
- are prepared to write a thesis in the field of Harmonic Analysis or dispersive equations.

**Content**

- Riesz transforms and related singular integral operators
- Littlewood-Paley theory
- Hardy space H^1 and the space BMO
- sharp maximal functions and good-lambda inequalities
- oscillatory integrals, dispersive estimates, Strichartz estimates
- applications to various differential equations

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The following modules are strongly recommended: "Harmonic Analysis", "Functional Analysis".

# M 2.81 Module: Heat Transfer II [M-CIWVT-103051]

**Coordinators:** Prof. Dr.-Ing. Thomas Wetzel
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 4 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106067 | Heat Transfer II | 6 CP | Wetzel |

**Assessment**
Learning control is an oral examination lasting approx. 20 minutes.
Module grade is the grade of the oral examination.

**Prerequisites**
None

**Competence Goal**
Students can deduce the basic differential equations of thermofluiddynamics and know possible simplifications. They know different analytical and numerical solution methods for the transient temperature field equation in quiescent media and are able to use them actively. Students are able to apply these solution methods independently to other heat conduction problems such as the heat transfer in fins and needles.

**Content**
Advanced topics in heat transfer:

Thermo-fluid dynamic transport equations, transient heat conduction; thermal boundary conditions; analytical methods (combination and separation of variables, Laplace transform); numerical methods (finite difference and volume methods); heat transfer in fins and needles

**Module Grade Calculation**
The grade of the oral examination is the module grade.

**Workload**

- Attendance time (Lecture): 45 h
- Homework: 75 h
- Exam Preparation: 60 h

**Literature**

- Von Böckh/Wetzel: „Wärmeübertragung“, Springer, 6. Auflage 2015
- VDI-Wärmeatlas, Springer-VDI, 10. Auflage, 2011

# M 2.82 Module: High Temperature Process Engineering [M-CIWVT-103075]

**Coordinators:** Prof. Dr.-Ing. Dieter Stapf
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106109 | High Temperature Process Engineering | 6 CP | Stapf |

**Assessment**
Learning control is an oral examination lasting approx. 20 minutes.

**Prerequisites**
None

**Competence Goal**
Students identify requirements for high-temperature processes from the problem definition. They determine the required process parameters by means of suitable balancing, taking into account relevant kinetic processes. They are able to select suitable reactors and process components for this purpose. This enables students to critically evaluate different processes in the process industry and systematically develop solutions for new problems in High Temperature Process Engineering.

**Content**
Examples of high-temperature processes; combustion fundamentals; heat transfer by radiation; heat exchange calculation for high-temperature systems; metallic and ceramic high-temperature materials; examples of the design of high-temperature systems.

**Module Grade Calculation**
The grade of the oral examination is the module grade.

**Additional Information**
The module will exceptionally be offered in WS 26/27 in 2026 and not in SS 26.

This module deals with high-temperature process engineering as a cross-sectional topic of various process engineering disciplines. As part of the exercises, the fundamentals learned are applied in process assessment using specific examples of High Temperature Process Engineering.

**Workload**

- Attendance time (Lecture): 45 h
- Homework: 75 h
- Exam Preparation: 60 h

# M 2.83 Module: Infinite dimensional dynamical systems [M-MATH-103544]

**Coordinators:** Prof. Dr. Jens Rottmann-Matthes
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-107070 | Infinite dimensional dynamical systems | 4 CP | Rottmann-Matthes |

**Prerequisites**
None

# M 2.84 Module: Information Security [M-INFO-106015]

**Coordinators:** Prof. Dr. Hannes Hartenstein
Prof. Dr. Thorsten Strufe

**Organisation:** KIT Department of Informatics

**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 5 CP | graded | Each summer term | 1 term | German | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-112195 | Information Security | 5 CP | Hartenstein, Strufe |

# M 2.85 Module: Integral Equations [M-MATH-102874]

**Coordinators:** PD Dr. Frank Hettlich
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105834 | Integral Equations | 8 CP | Arens, Griesmaier, Hettlich |

**Assessment**
The module will be completed by an oral exam (~30min.).

**Prerequisites**
none

**Competence Goal**
The students can clarify integral equations and can show existence and uniqueness of solutions by perturbation theory and by Fredholm theory. Ideas of proofs for Fredholm theory and perturbation theory especially in case of convolution equations can be described and explained. Furthermore, the students can formulate classical boundary value problems for ordinary differential equations and from potential theory in terms of integral equations.

**Content**

- Riesz and Fredholm theory
- Fredholm and Volterra integral equations
- Applications in potential theory
- convolution equation

**Module Grade Calculation**
The module grade is the the grade of the oral exam

**Workload**
Total workload: 240h

Attendance: 90h

- Lecture, problem class, examination

Self studies: 150h

- follow-up and deepening of the course content
- work on problem sheets
- literature studies and internet research related to the course content
- preparation of the module examination

# M 2.86 Module: Integrated Photonics [M-ETIT-107344]

**Coordinators:** Prof. Dr.-Ing. Christian Koos
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-114418 | Integrated Photonics | 6 CP | Koos |

**Assessment**
The assessment takes place in the form of an oral examination (approx. 25 minutes); appointments individually on demand.

**Prerequisites**
none

**Competence Goal**
At the end of the course, students

- have a refreshed and deepened understanding of the basic principles of light-matter-interaction and wave propagation in dielectric media,
- know and understand the Lorentz model for frequency-dependent material properties and can use this knowledge to quantitatively analyze the dispersive properties of optical media using Sellmeier relations and scientific databases,
- understand and can quantitatively describe the formation and propagation of surface plasmon polaritons (SPP),
- know basic structures of integrated optical waveguides and understand the formation of guided modes in these structures,
- can quantitatively describe the propagation of signals in optical waveguides under the influence of dispersion,
- are familiar with state-of-the-art material systems and technology platforms of integrated photonics,
- understand basic analytical methods for modeling of photonic circuits such as eigenmode expansion (EME) methods, scattering-matrix formalisms, or coupled-mode theory and can apply these methods to specific use cases,
- understand the concepts and limitations of widely used computational techniques for integrated optical devices such as numerical mode solvers or finite-difference-time-domain (FDTD) simulators,
- know and can quantitatively analyze widely used building blocks and passive devices of integrated photonics, comprising, e.g., multi-mode interference (MMI) couplers, directional couplers, and waveguide gratings, as well as Mach-Zehnder interferometers (MZI), arrayed-waveguide gratings (AWG), lattice filters, and ring resonators.
- understand lasers and optical amplifiers and are familiar with the associated models, e.g., based on rate equations, and their predictions for dynamic behavior
- know material systems and device concepts used for electro-optic modulators
- understand photodetectors and the origin and quantitative description of noise in optoelectronic receiver systems.

**Content**
This course is geared towards engineering students that want to get a deeper insight into the vividly growing field of integrated photonics. The lecture and the associated tutorial provide an advanced understanding of the physical concepts and associated mathematical models of photonic integrated circuits, of the underlying material platforms and fabrication technologies, and of related application in optical communications, optical sensing, or microwave photonics. The concepts explained in the lecture are widely applicable also in fields outside integrated optics and can be a perfect complement to a variety of topics and adjacent fields such as communications engineering and high-speed data transmission, radio-frequency (RF) electronics, sensor system engineering and automation, photovoltaics, or quantum technologies.

The course covers the following aspects:

1. Review of fundamentals of wave propagation and light-matter interaction in photonics: Maxwell's equations in optical media, wave equation and plane waves; material dispersion; Lorentz and Drude model of refractive index; Sellmeier equations
2. Plasmonics: Fundamentals of surface-plasmonic polariton (SPP) propagation
3. Integrated optical waveguides: Basic structures; formation of guided modes; mathematical description; orthogonality of modes
4. Propagation of optical signals in waveguides: Group velocity; dispersion; outlook to nonlinear optical effects
5. Optical fibers: Step-index fibers and associated modes; micro-structured fibers
6. Overview of material systems and integration platforms: Silicon photonics, silicon-nitride-based photonic circuits; III-V compound semiconductors; thin-film lithium niobate; polymer-based photonic circuits
7. Eigenmode expansion (EME) method: Concept and applications
8. Numerical methods in integrated photonics: Basics of numerical mode solvers and finite-difference-time-domain (FDTD) simulators
9. Scattering-matrices (S-matrices) for optical devices: Definition and properties of S-matrices
10. Coupled-mode theory and building blocks of integrated photonics: Multi-mode interference (MMI) devices; directional couplers; waveguide gratings
11. Selected passive devices: Mach-Zehnder interferometers (MZI); arrayed-waveguide gratings (AWG); lattice filters; ring resonators
12. Lasers and optical amplifiers: Material systems; quantitative model and rate equations; dynamic behaviour of lasers
13. Electro-optic modulators: Material systems, device concepts, and figures of merit
14. Photodetectors and noise in optoelectronic receiver systems: Photodetector concepts and implementations; direct and coherent detection; shot noise; thermal noise; noise figures

**Module Grade Calculation**
The module grade is the grade of the oral exam under consideration of any bonuses that may apply

The module grade is the grade of the oral exam under consideration of bonuses based on the problem sets that are solved during the term – details will be given during the lecture. A bonus of 0.3 or 0.4 grades will be granted on the final mark of the oral exam, except for grades worse than 4.0. Bonus points do not expire and are retained for any examinations taken at a later date.

**Workload**
The workload amounts to approximately 180 h (6 CP), comprising the following items:

Attendance of lectures and tutorials: 15 × (2 h +2 h) = 60 h
Preparation and follow-up of lectures: 15 × 3 h = 45 h
Preparation and follow-up of tutorials: 15 × 3 h = 45 h
Preparation of oral exam: 30 h

**Recommendations**
Basics understanding of the underlying topics such as electromagnetic fields and waves, semiconductors and solid-state electronics, and advanced calculus. These skills can, e.g., be acquired in the modules "Höhere Mathematik I-III", "Elektromagnetische Felder und Wellen", "Festkörperelektronik und Bauelemente", and „Fundamentals of Photonics" or in comparable lectures.

# M 2.87 Module: Internet Seminar for Evolution Equations [M-MATH-102918]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105890 | Internet Seminar for Evolution Equations | 8 CP | Frey, Kunstmann, Schnaubelt, Tolksdorf |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
none

**Competence Goal**
Students can explain the basic ideas, concepts and statements of a sub-area of the theory of evolutionary equations and apply them to examples. They can work on this topic from a script and discuss it in a reading course.

**Content**
A part of the theory of evolution equations is introduced. The necessary basics (beyond the contents of an introductory lecture in functional analysis) are developed. The basic concepts, statements and methods of the respective subarea are treated systematically. Applications of the theory are discussed.

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Additional Information**
The internet seminar has different main organizers each year, who send out a manuscript with exercises and provide a website with discussion forums. In Karlsruhe, the material is discussed in a two-hour reading course in the winter semester, which is roughly equivalent to a four-hour lecture with exercises. There is the opportunity (outside of our modules) to work on a project during the summer semester and present it at a final workshop in June. Further information and details on the current content can be found on Roland Schnaubelt's website, http://www.math.kit.edu/iana3/~schnaubelt/en

**Workload**
Total workload: 240 hours

Attendance: 30 h

- lectures and examination

Self studies: 210 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the module "Functional Analysis" are strongly recommended.

# M 2.88 Module: Internship [M-MATH-102861]

**Coordinators:** Prof. Dr. Willy Dörfler
PD Dr. Markus Neher
**Organisation:** KIT Department of Mathematics
**Part of:** Internship

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 10 CP | pass/fail | Each term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105888 | Internship | 10 CP | Dörfler, Neher |

**Workload**
Gesamter Arbeitsaufwand: 300 Stunden.

Präsenzzeit: 270 Stunden im Unternehmen.

Selbststudium: 30 Stunden

- Ausarbeitung des Berichtes
- Vorbereitung und Halten der Präsentation

# M 2.89 Module: Interpolation Spaces [M-MATH-107456]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-114639 | Interpolation Spaces | 6 CP | Kunstmann, Lamm |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
none

**Competence Goal**
Graduates

- are able to state and discuss essential results on interpolation theory and maximum L^p regularity,
- can state and discuss basic results on Besov spaces and relate them to each other,
- can state basic results in the treatment of partial differential equations and relate them to each other,
- can outline central proofs,
- are prepared to write a thesis in the field of harmonic analysis or global analysis.

**Content**

- Real and complex interpolation,
- function spaces,
- maximal L^p regularity,
- applications to partial differential equations.

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Attendance time: 60 hours

- Course including module examination during the course of study

Self-study: 120 hours

- Consolidation of the course content by working on the lecture content at home
- completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
The modules 'Functional Analysis' and 'Classical Methods in PDE's' are strongly recommended.

# M 2.90 Module: Introduction into Particulate Flows [M-MATH-102943]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 3 CP | graded | Once | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105911 | Introduction into Particulate Flows | 3 CP | Dörfler |

**Assessment**
Oral exam of ca. 20 minutes

**Prerequisites**
none

**Competence Goal**
Participants

- can explain the basic mathematical models of fluid flows
- can explain the modeling of particulate fluid flows
- understand the numerical methods to compute particulate fluid flows

**Content**

- Mathematical description of fluid flows
- Models to describe particles in fluids
- Movement of rigid bodies in a flow
- Movement of rigid bodies in a viscous flow
- Different forces acting between fluid and particle, e.g. ionic flows

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 h

- lectures, problem classes and examination

Self studies: 60 h

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research on the course content
- preparation for the module examination

**Recommendations**
Basic knowledge in numerics of differential equations und numerical fluid dynamics is strongly recommended.

# M 2.91 Module: Introduction to Artificial Intelligence [M-INFO-106014]

**Coordinators:** Prof. Dr. Pascal Friederich
Prof. Dr. Gerhard Neumann
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 5 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-112194 | Introduction to Artificial Intelligence | 5 CP | Friederich, Neumann |

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-INFO-100819 - Cognitive Systems must not have been started.

# M 2.92 Module: Introduction to Convex Integration [M-MATH-105964]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112119 | Introduction to Convex Integration | 3 CP | Zillinger |

**Assessment**
The module will be completed with an oral exam (approx. 30 min).

**Prerequisites**
none

**Competence Goal**
The main aim of this lecture is to introduce students to convex integration as a tool to construct solutions to partial differential equations.
In particular, they will be able to

- discuss the structure of convex integration algorithms,
- state major theorems and their relation,
- discuss regularity of convex integration solutions and uniqueness,
- discuss building blocks of constructions and their properties.

**Content**
This lecture provides an introduction to the methods of convex integration and its applications:

- for isometric immersions,
- for the m-well problem in elasticity,
- for equations of fluid dynamics and
- higher regularity of convex integration solutions.

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 h

- lectures and examination

Self studies: 60 h

- follow-up and deepening of the course content,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The modules "Classical Methods for Partial Differential Equations" and "Functional Analysis" are recommended.

# M 2.93 Module: Introduction to Cosmology [M-PHYS-102175]

**Coordinators:** Prof. Dr. Guido Drexlin
Prof. Dr. Kathrin Valerius
**Organisation:** KIT Department of Physics
**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102384 | Introduction to Cosmology | 6 CP | Drexlin |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Competence Goal**
Students will be introduced to the basic concepts of cosmology. The lecture will provide both the theoretical concepts and an overview of modern experimental methods and observational techniques. The students will be enabled to understand the concepts by means of concrete case studies from modern cosmology and will be enabled to apply the learned methods in the context of later independent research.

*Methodological Competency Acquisition:*

- Understanding of the fundamentals of cosmology
- Recognition of methodological cross-connections to elementary particle physics and astroparticle physics.
- Acquisition of the ability to work independently on current research topics as preparation for the master thesis.

**Content**
The lecture offers an introduction to modern cosmology, which has taken an enormous upswing in recent years due to the use of state-of-the-art technologies (Planck satellite, galaxy surveys such as 2dF and SDSS) and accompanying computationally intensive simulations (Millennium). The large number of observations has led to the establishment of a so-called concordance model of cosmology, in which the contributions of dark energy and dark matter dominate the evolution of large-scale structures in the universe.

Starting from a description of the early universe with the supporting pillars of the Big Bang theory (Hubble expansion, nucleosynthesis, cosmic background radiation) and the phase transitions and symmetry breaking that occur in the process, the formation and evolution of large-scale structures in the universe up to today's "dark universe" is discussed (comparison of "top-down" with "bottom-up" models). Special attention is given to a detailed presentation of the most modern experimental techniques and methods of analysis, which have found their way into wide areas of physics.

The lecture thus provides a coherent picture of modern cosmology and discusses fundamental issues also in neighboring disciplines such as particle physics and astrophysics and can therefore be complemented with other lectures in the field of Experimental Astroparticle Physics and Experimental Particle Physics.

**Workload**
180 hours consisting of attendance time (45 hours), wrap-up of the lecture incl. exam preparation and preparation of the exercises (135 hours).

**Recommendations**
Basic knowledge from lecture "Nuclei and Particles

**Literature**
Will be mentioned in the lecture.

# M 2.94 Module: Introduction to Dynamical Systems [M-MATH-106591]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113263 | Introduction to Dynamical Systems | 6 CP | de Rijk, Reichel |

**Assessment**
The module will be completed with an oral exam of about 30 minutes.

**Prerequisites**
None

**Competence Goal**
After successful completion of this module students

- can explain the significance of dynamical systems and give several examples;
- have acquired miscellaneous tools to prove the existence of special solutions and to analyze the local dynamics around them;
- master several techniques to describe global dynamics in certain classes of dynamical systems;
- identify various bifurcations and explain how these change the dynamics of the system;
- outline the main steps in establishing chaotic behavior.

**Content**

- Flows
- Abstract dynamical systems
- Lyapunov functions
- Invariant sets
- Limit sets and attractors
- Hartman-Grobman theorem
- Local (un)stable manifold theorem
- Poincaré-Bendixson theorem
- Periodic orbits and Floquet theory
- Exponential dichotomies
- Melnikov functions
- Lin's method
- Hamiltonian dynamics
- Liénard systems
- Bifurcations
- Chaotic dynamics
- (Introduction to) Fenichel theory
- Center manifolds
- Dynamical systems associated with semilinear evolution equations

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The following modules are strongly recommended: Analysis 1-2 and Linear Algebra 1-2. The module Analysis 4 is recommended.

# M 2.95 Module: Introduction to Fluid Dynamics [M-MATH-105650]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111297 | Introduction to Fluid Dynamics | 3 CP | Reichel |

**Assessment**
The module will be completed by an oral exam (approx. 30 min).

**Prerequisites**
None

**Competence Goal**
The main aim of this lecture is to introduce students to mathematical fluid dynamics. In particular, by the end of the course students will be able to

- discuss and explain the various formulations of the Euler equations and when these formulations are equivalent,
- state major theorems and their relation,
- discuss weak formulations, existence and uniqueness results.

**Content**
Mathematical description and analysis of fluid dynamics:

- physical motivation of the incompressible Euler and Navier-Stokes equations,
- Vorticity-Stream formulation and Eulerian and Lagrangian coordinates,
- Local existence theory and energy methods,
- Weak solutions and the Beale-Kato-Majda criterion.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 hours

- lectures, problem classes, and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the courses "Classical Methods for Partial Differential Equations" or "Boundary and Eigenvalue Problems" are recommended.

# M 2.96 Module: Introduction to Fluid Mechanics [M-MATH-106401]

**Coordinators:** TT-Prof. Dr. Xian Liao
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112927 | Introduction to Fluid Mechanics | 6 CP | Liao |

**Assessment**
The module examination takes the form of an oral examination of approx. 25 minutes.

**Prerequisites**
None

**Competence Goal**
Graduates can

- recognize the essential formulations of the partial differential equations in fluid mechanics and explain them using examples,
- use techniques to describe the weak and strong solutions for the Euler and Navier-Stokes equations, and show the existence, uniqueness and regularity results,
- name the special difficulties in the three-dimensional case,
- understand the concept of stratification and explain it using concrete examples.

**Content**

- Derivation of models, modeling
- Euler equations, Navier-Stokes equations
- Biot-Savart law, Leray-Hopf decomposition
- Wellposedness results
- Regularity results

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
total work load: 180 hours

**Recommendations**
The module *Functional Analysis* is strongly recommended.

# M 2.97 Module: Introduction to Geometric Measure Theory [M-MATH-102949]

**Coordinators:** PD Dr. Steffen Winter
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105918 | Introduction to Geometric Measure Theory | 6 CP | Winter |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
None.

**Competence Goal**
Graduates

- know basic statements and proof techniques of geometric measure theory,
- are familiar with exemplary applications of methods of geometric measure theory and apply them,
- are able to work in a reflective and self-organized manner.

**Content**

- measure and integral
- Covering theorems
- Hausdorff measures
- Differentiation of measures
- Lipschitz functions and rectifiability
- Area and coarea formula
- Currents
- Applications

**Workload**
Total workload: 180 hours

Attendance time: 60 hours

- Course including module examination during the course of study

Self-study: 120 hours

- consolidation the study content by working on the lecture content at home
- completion of exercises
- In-depth study using suitable literature and internet research
- Preparation for the module examination

# M 2.98 Module: Introduction to Homogeneous Dynamics [M-MATH-105101]

**Coordinators:** Prof. Dr. Tobias Hartnick
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-110323 | Introduction to Homogeneous Dynamics | 6 CP | Hartnick |

**Prerequisites**
None

# M 2.99 Module: Introduction to Kinetic Equations [M-MATH-105837]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111721 | Introduction to Kinetic Equations | 3 CP | Zillinger |

**Assessment**
oral examination of approx. 30 minutes

**Prerequisites**
none

**Competence Goal**
The main aim of this lecture is to introduce students to the theory of kinetic transport equations. In particular, by the end of the course students will be able to

- discuss properties of the free transport, Boltzmann and Vlasov-Poisson equations,
- state major theorems and their relation,
- discuss notions of solutions and their properties,
- discuss the effects of phase mixing and challenges of nonlinear equations.

**Content**
Mathematical description and analysis of kinetic transport equations:

- the free transport, Boltzmann and Vlasov-Poisson equations,
- linear theory, phase mixing and Landau damping,
- equilibrium solutions and stability,
- nonlinear results and methods,
- renormalized solutions.

**Module Grade Calculation**
The module grade is the grade of the final oral exam.

**Workload**
Totel workload: 90 h

Attendance: 30 h

- lectures and examination

Self studies: 60 h

- follow-up and deepening of the course content,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the course "Classical Methods for Partial Differential Equations" are recommended.

# M 2.100 Module: Introduction to Kinetic Theory [M-MATH-103919]

**Coordinators:** Prof. Dr. Martin Frank
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-108013 | Introduction to Kinetic Theory | 4 CP | Frank |

**Prerequisites**
None

**Competence Goal**
After successfully taking part in the module's classes and exams, students have gained knowledge and abilities as described in the "Inhalt" section. Specifically, Students know common means of mesoscopic and macroscopic description of particle systems. Furthermore, students are able to describe the basics of multiscale methods, such as the asypmtotic analysis and the method of moments. Students are able to apply numerical methods to solve engineering problems related to particle systems. They can name the assumptions that are needed to be made in the process. Students can judge whether specific models are applicable to the specific problem and discuss their results with specialists and colleagues.

**Content**

- From Newton's equations to Boltzmann's equation
- Rigorous derivation of the linear Boltzmann equation
- Properties of kinetic equations (existence & uniqueness, H theorem)
- The diffusion limit
- From Boltzmann to Euler & Navier-Stokes
- Method of Moments
- Closure techniques
- Selected numerical methods

**Recommendations**
Partial Differential Equations, Functional Analysis

# M 2.101 Module: Introduction to Microlocal Analysis [M-MATH-105838]

**Coordinators:** TT-Prof. Dr. Xian Liao
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111722 | Introduction to Microlocal Analysis | 3 CP | Liao |

**Assessment**
oral examination of circa 30 minutes

**Prerequisites**
none

**Competence Goal**

- Students will become familiar with the notions of Fourier multipliers and pseudo-differential operators
- Students can state major theorems and their relation
- Students will understand the structure of the propagation of singularities by introducing the wave front set and apply them to the domain of partial differential equations, control theory, etc.

**Content**

1. Pseudo-differential operators
2. Symbolic calculus
3. Wavefront set
4. Propagation of singularities
5. Microlocal defective measure

**Module Grade Calculation**
The module grade is the grade of the final oral exam.

**Workload**
Totel workload: 90 h

Attendance: 30 h

- lectures and examination

Self studies: 60 h

- follow-up and deepening of the course content,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The following courses should be studied beforehand: "Classical Methods for Partial Differential Equations" und "Functional Analysis".

# M 2.102 Module: Introduction to Scientific Computing [M-MATH-102889]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Tobias Jahnke

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105837 | Introduction to Scientific Computing | 8 CP | Dörfler, Hochbruck, Jahnke, Rieder, Wieners |
| T-MATH-114059 | Project Lab Scientific Computing | 0 CP | Dörfler, Hochbruck, Jahnke, Rieder, Wieners |

**Assessment**
The module will be completed by an oral exam (about 30 min).

Requirement for exam: Successful Hands-on tutorial

**Prerequisites**
None

**Competence Goal**
At the end of the course, students

- are able to develop the interlinking of all aspects of scientific computing using simple examples: from modeling and algorithmic implementation to stability and error analysis.
- can explain concepts of modeling with differential equations
- are able to implement simple application examples algorithmically, evaluate the code and present and discuss the results.

**Content**

- Numerical methods for initial value problems, boundary value problems, and initial boundary value problems
- Modelling with differential equations
- Algorithmic realization of applications
- Presentation of results of scientific computations

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**
3 SWS lecture plus 3 SWS hands-on training

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets and coding,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
It is strongly recommended that participants have completed the modules "Numerische Mathematik 1 und 2" as well as "Programmieren: Einstieg in die Informatik und algorithmische Mathematik".

# M 2.103 Module: Introduction to Stochastic Differential Equations [M-MATH-106045]

**Coordinators:** Prof. Dr. Mathias Trabs
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112234 | Introduction to Stochastic Differential Equations | 4 CP | Janák, Trabs |

**Assessment**
The module will be completed with an oral exam (approx. 30 min).

**Prerequisites**
none

**Competence Goal**
The students will

- know fundamental examples for linear and non-linear stochastic differential equations,
- be able to apply basic solution concepts for stochastic differential equations,
- know fundamental theorems of stochastic calculus and will be able to apply these to stochastic differential equations.

**Content**

1. Introduction and recapitulation of stochastic integration, Itô's formula, Lévy Theorem
2. Burkholder-Davis-Gundy inequality
3. Existence and uniqueness of solutions of stochastic differential equations
4. Explicit solutions of linear stochastic differential equations
5. Change of the time scale of Brownian motion
6. Representation of continuous time martingales
7. Brownian martingales
8. Local and global solutions of stochastic differential equations
9. Girsanov Theorem

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 hours

- lectures, problem classes, and examination

Self-studies: 75 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the course "Probability Theory" are strongly recommended. The contents of the course "Continuous Time Finance" are recommended.

# M 2.104 Module: Inverse Problems [M-MATH-102890]

**Coordinators:** Prof. Dr. Roland Griesmaier
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105835 | Inverse Problems | 8 CP | Arens, Griesmaier, Hettlich, Rieder |

**Assessment**
The module will be completed by an oral exam (approx. 30 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students are able to distinguish well-posed from ill-posed problems. They acquire a systematic knowledge of the theory of linear inverse problems and their regularization in Hilbert spaces and can provide proof ideas. They are able to analyze regularization methods such as, e.g., Tikhonov regularization and assess their convergence properties.

**Content**

- Compact operator equations
- Ill-posed problems
- Regularization
- Tikhonov regularization
- Iterative regularization
- Examples for ill-posed problems

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course "Functional Analysis" or "Integral Equations" is recommended as a prerequisite.

# M 2.105 Module: IT Security [M-INFO-106998]

**Coordinators:** Prof. Dr. Jörn Müller-Quade
Prof. Dr. Christian Wressnegger
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-113960 | IT Security | 6 CP | Müller-Quade, Wressnegger |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
Students
• have in-depth knowledge of cryptography and IT security
• know and understands sophisticated techniques and security primitives to achieve the protection goals
• know and understand scientific evaluation and analysis methods of IT security (game-based formalization of confidentiality and integrity, security and anonymity notions)
• have a good understanding of types of data, personal data, legal and technical fundamentals of privacy protection
• know and understand the fundamentals of system security (buffer overflow, return-oriented programming, ...)
• know different mechanisms for anonymous communication (TOR, Nym, ANON) and can assess their effectivity

**Content**
This advanced mandatory module deepens different topics of IT security. These include in particular:
• Elliptic curve cryptography
• Threshold cryptography
• Zero-knowledge proofs
• Secret sharing
• Secure multi-party computation and homomorphic encryption
• Methods of IT security (game-based analysis and the UC model)
• Crypto-currencies and consensus through proof-of-work/stake
• Anonymity on the Internet, anonymity with online payments
• Privacy-preserving machine learning
• Security of machine learning
• System security and exploits
• Threat modeling and quantification of IT security

**Workload**
Course workload:
1. Attendance time: 56 h
2. Self-study: 56 h
3. Preparation for the exam: 68 h

**Recommendations**
Attendance of the lecture Information Security is recommended.

**Literature**
Literature:
• Katz/Lindell: Introduction to Modern Cryptography (Chapman & Hall)
• Schäfer/Roßberg: Netzsicherheit (dpunkt)
• Anderson: Security Engineering (Wiley, and online)
• Stallings/Brown: Computer Security (Pearson)
• Pfleeger, Pfleeger, Margulies: Security in Computing (Prentice Hall)

# M 2.106 Module: Key Competences [M-MATH-102994]

**Organisation:** KIT Department of Mathematics
**Part of:** Interdisciplinary Qualifications

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 2 CP | pass/fail | Each term | 1 term | German | 4 | 4 |

**Election Notes**
For self-assessment of interdisciplinary qualifications from HoC, FORUM or SPZ, the components with the title "Selbstverbuchung-HOC-SPZ-FORUM-..." must be selected according to the grading scale, ungraded or graded.

| Key Competences (Elective: at least 2 credits) | | | |
|---|---|---|---|
| T-MATH-106119 | Introduction to Python | 4 CP | Weiß |
| T-MATH-111515 | Self-Booking-HOC-SPZ-FORUM-1-Graded | 2 CP | |
| T-MATH-111517 | Self-Booking-HOC-SPZ-FORUM-2-Graded | 2 CP | |
| T-MATH-111516 | Self-Booking-HOC-SPZ-FORUM-5-Ungraded | 2 CP | |
| T-MATH-111520 | Self-Booking-HOC-SPZ-FORUM-6-Ungraded | 2 CP | |
| T-MATH-112651 | Self-Booking-HOC-SPZ-FORUM-PEBA-9-Graded | 2 CP | |
| T-MATH-112652 | Self-Booking-HOC-SPZ-FORUM-PEBA-10-Ungraded | 2 CP | |

**Prerequisites**
None

# M 2.107 Module: Lie Groups and Lie Algebras [M-MATH-104261]

**Coordinators:** Prof. Dr. Tobias Hartnick
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-108799 | Lie Groups and Lie Algebras | 8 CP | Hartnick |

**Additional Information**
This course is one of the nine core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

# M 2.108 Module: Lie-Algebras [M-MATH-106950]

**Coordinators:** Prof. Dr. Tobias Hartnick
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | German | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113907 | Lie-Algebras | 8 CP | Hartnick |

**Assessment**
The module exam takes the form of a 30-minute oral exam.

**Competence Goal**
Students who completed this module

- understand how methods of linear algebra can be applied to families of linear maps that do not necessarily commute with one another;
- are familiar with the fundamental structural properties of complex and real Lie algebras;
- are familiar with key concepts of semisimple theory, such as root systems and finite reflection groups, and can use these to describe Lie algebras;
- are familiar with the abstract classification of representations of semisimple Lie algebras and can identify concrete representations within this classification;
- have an understanding of the significance of Lie algebras in various areas of mathematics and theoretical physics;
- are prepared to write a thesis in algebraic Lie theory.

**Content**

- Lie algebras of linear Lie groups
- Solvable and nilpotent Lie algebras
- Reductive and semisimple Lie algebras
- Root systems and Weyl groups
- Classification of complex simple Lie algebras
- General structure theory
- Representations of semisimple Lie algebras and character formulas
- Selected applications

**Module Grade Calculation**
The grade is the grade of the oral exam.

**Additional Information**
This course is one of the nine core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

**Workload**
Total workload: 240 hours

Class time: 90 hours

- Lecture including oral exam

Self-study: 150 hours

- Deepening understanding of course content through independent review of lecture material at home
- Completion of homework exercises
- Deepening understanding of course content through appropriate literature and internet research
- Exam preparation

**Recommendations**
A solid understanding of linear algebra is essential. Connections to the courses “Elementary Geometry” and “Introduction to Algebra and Number Theory,” as well as to “Theoretical Physics,” will be mentioned in the lecture, but they are not required for understanding the module and are not included in the exam.

# M 2.109 Module: Localization of Mobile Agents [M-INFO-107663]

**Coordinators:** Prof. Dr.-Ing. Uwe Hanebeck
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-115014 | Localization of Mobile Agents | 6 CP | Hanebeck |
| T-INFO-115015 | Localization of Mobile Agents - Pass | 0 CP | Hanebeck |

**Assessment**
See Partial Achievements (Teilleistung).

**Prerequisites**
See Partial Achievements (Teilleistung).

**Competence Goal**
Participants in this course will gain a broad overview of probabilistic machine learning tools and learn how to creatively combine them to solve a wide variety of problems.

**Content**
This module provides a systematic introduction to the field of localization methods. To facilitate entry, the module is divided into four central topics. Dead reckoning (1) deals with the step-by-step determination of a vehicle's position from dynamic parameters such as speed or steering angle, as well as intertial measurement unit (IMU) data. Localization with the aid of measurements to external, known landmarks is part of static localization (2). Specifically, signal times of arrival (multilateration and GPS), distance measurements, and angle measurements (bearings) are covered. In addition to closed-form solutions for special measurements, the method of least squares for fusing arbitrary measurements is introduced. This also includes nonlinear optimization methods and certifiable global optimization. Dynamic localization (3) deals with the combination of dead reckoning and static localization using the Kalman filter, which is used in virtually all object tracking scenarios and other state estimation problems. General estimator properties are also discussed. The course concludes with simultaneous localization and mapping (SLAM) (4), which allows localization even when the location of landmarks is partially unknown. Thereby the measurement association problem is also addressed.

**Workload**
Per week:
2 SWS Presence
2h Follow-up
6h Digital exercise with computation tasks
2h exam preparation
= 12h/week und 180h/semester

**Recommendations**
Knowledge of a higher-level programming language with mature libraries for scientific and numerical computing (e.g., Julia, Matlab, Python) is an advantage.

# M 2.110 Module: Logical Foundations of Cyber-Physical Systems [M-INFO-106102]

**Coordinators:** Prof. Dr. André Platzer
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-112360 | Logical Foundations of Cyber-Physical Systems | 6 CP | Platzer |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
**In modeling and control**, successful students will

– understand core principles behind CPS. A solid understanding of these principles is important for anyone who wants to integrate cyber and physical components to solve problems that no part could solve alone.
– develop models and controls. In order to understand, design, and analyze CPS, it is important to be able to develop models for the relevant aspects of a CPS design and to design controllers for the intended functionalities based on appropriate specifications, including modeling with differential equations.
– identify relevant dynamical aspects. It is important to be able to identify which types of phenomena influence a property of a system. These allow us to judge, for example, where it is important to manage adversarial effects, or where a nondeterministic model is sufficient.

**In computational thinking**, successful students should be able to

– identify safety specifications and critical properties. In order to develop correct CPS designs, it is important to identify what “correctness” means, how a design may fail to be correct, and how to make it correct.
– understand abstraction in system designs. The power of abstraction is essential for the modular organization of CPS, and the ability to reason about separate parts of a system independently.
– express pre- and post-conditions and invariants for CPS models. Pre- and post-conditions allow us to capture under which circumstance it is safe to run a CPS or a part of a CPS design, and what safety entails. They allow us to achieve what abstraction and hierarchies achieve at the system level: decompose correctness of a full CPS into correctness of smaller pieces. Invariants achieve a similar decomposition by establishing which relations of variables remain true no matter how long and how often the CPS runs.
– reason rigorously about CPS models. Reasoning is required to ensure correctness and find flaws in CPS designs. Both informal and formal reasoning in a logic are important objectives for being able to establish correctness, which includes rigorous reasoning about differential equations.

**In CPS skills**, successful students will be able to

– understand the semantics of a CPS model. What may be easy in a classical isolated program becomes very demanding when that program interfaces with effects in the physical world.
– develop an intuition for operational effects. Intuition for the joint operational effect of a CPS is crucial, e.g., about what the effect of a particular discrete computer control algorithm on a continuous plant will be.
– understand opportunities and challenges in CPS and verification. While the beneficial prospects of CPS for society are substantial, it is crucial to also develop an understanding of their inherent challenges and of approaches for minimizing the impact of potential safety hazards. Likewise, it is important to understand the ways in which formal verification can best help improve the safety of system designs.

**Content**
Cyber-physical systems (CPSs) combine cyber capabilities (computation and/or communication) with physical capabilities (motion or other physical processes). Cars, aircraft, and robots are prime examples, because they move physically in space in a way that is determined by discrete computerized control algorithms. Designing these algorithms to control CPSs is challenging due to their tight coupling with physical behavior. At the same time, it is vital that these algorithms be correct, since we rely on CPSs for safety-critical tasks like keeping aircraft from colliding. In this course we will strive to answer the fundamental question posed by Jeannette Wing:

“How can we provide people with cyber-physical systems they can bet their lives on?”

The cornerstone of this course design are hybrid programs (HPs), which capture relevant dynamical aspects of CPSs in a simple programming language with a simple semantics. One important aspect of HPs is that they directly allow the programmer to refer to real-valued variables representing real quantities and specify their dynamics as part of the HP.

This course will give you the required skills to formally analyze the CPSs that are all around us—from power plants to pacemakers and everything in between—so that when you contribute to the design of a CPS, you are able to understand important safety-critical aspects and feel confident designing and analyzing system models. It will provide an excellent foundation for students who seek industry positions and for students interested in pursuing research.

**Additional Information**
Course web page: https://lfcps.org/course/lfcps.html

**Workload**
6 ECTS from 180h of coursework consisting of
45h = 15 * 3 from 3 SWS lectures
15h = 15 * 1 from 1 SWS exercises
68h preparation, reading textbook, studying
40h solving exercises
12h exam preparation

**Recommendations**
The course assumes prior exposure to basic computer programming and mathematical reasoning. This course covers the basic required mathematical and logical background of cyber-physical systems. You will be expected to follow the textbook as needed: André Platzer. Logical Foundations of Cyber-Physical Systems. Springer 2018. DOI:10.1007/978-3-319-63588-0

# M 2.111 Module: Markov Decision Processes [M-MATH-102907]

**Coordinators:** Prof. Dr. Nicole Bäuerle
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105921 | Markov Decision Processes | 5 CP | Bäuerle |

**Assessment**
The module will be completed by an oral exam (about 20 min).

**Prerequisites**
none

**Competence Goal**
At the end of the course, students

- can name the mathematical foundations of Markov Decision Processes and apply solution algorithm,
- can formulate stochastic, dynamic optimization problems as Markov Decision Processes,
- are able to work in a self-organized and reflective manner.

**Content**

- MDPs with finite time horizon
  - Bellman equation
  - Problems with structure
  - Applications
- MDPs with infinite time horizon
  - contracting MDPs
  - positive MDPs
  - Howards policy improvement
  - Solution by linear programs
- Stopping problems
  - finite and infinite time horizon
  - One-step-look-ahead rule

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 150 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 90 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course 'Probability theory' is strongly recommended and 'Markov chains' is recommended.

# M 2.112 Module: Master's Thesis [M-MATH-102917]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Master's Thesis

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 30 CP | graded | Each term | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105878 | Master's Thesis | 30 CP | Kühnlein |

**Assessment**
The Master's Thesis is graded according to the regulations from §14 (7) of Studien- und Prüfungsordnung. The handling time is six months. On submission of the Master's Thesis, according to §14 (5) the students have to confirm, that the thesis has been written independently without using undisclosed sources and tools, that passages which have been copied literally or in content have clearly been marked as such, and that the by-laws to implement scientific integrity at KIT in the recent version have been taken into account. If this confirmation is not contained, the thesis gets rejected. In case of a wrong confirmation, the thesis is graded with "not sufficient" (5.0). The thesis may be written in English.

Electronic submission of the Thesis is compulsory. Technical information concerning the process of electronic submission can be found here: https://koala.kit.edu/goto.php/pg/1322_1911

If the thesis is planned to be written outside the KIT-department of mathematics, the approval by the examination board is required.

Further details are regulated by §14 of Studien- und Prüfungsordnung.

**Prerequisites**
For admission to the module Master's Thesis it is required that the student has successfully accomplished module examinations of at least 70 credit points.

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. You need to have earned at least 70 credits in the following fields:
   - Wildcard Technical Field
   - Applied Mathematics
   - Internship
   - Chemical and Process Engineering
   - Electrical Engineering / Information Technology
   - Experimental Physics
   - Computer Science
   - Mathematical Specialization
   - Interdisciplinary Qualifications

**Competence Goal**
The students are able to work on a given topic independently and in a limited time, using scientific methods from the state of the art. They master the necessary scientific methods and techniques, modify them if necessary and develop them further if required. Alternative approaches are compared critically. In their thesis, the students write up their results clearly structured and in a way adequate to academic standards.

**Content**
Following §14 SPO the thesis should demonstrate that the students are able to work on a given topic from their course of studies independently and in a bounded time, using scientific methods from the state of the art. The students should have the opportunity to make suggestions for their topic. If the student petitions, in exceptional cases the head of the examination board takes care that the student receives a topic for a master thesis within four weeks. In that case, the topic is given by the head of the examination board. Further details are regulated by §14 of Studien- und Prüfungsordnung.

**Workload**
Total work load: 900 hours

Attendance: 0 hours

Self studies: 900 hours

# M 2.113 Module: Mathematical Methods in Signal and Image Processing [M-MATH-102897]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105862 | Mathematical Methods in Signal and Image Processing | 8 CP | Rieder |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
none

**Competence Goal**
Graduates know the essential mathematical tools of signal and image processing and their properties. They are able to apply these tools appropriately and to scrutinize and evaluate the results obtained.

**Content**

- Digital and analog systems
- Integral Fourier transform
- Sampling and resolution
- Discrete and fast Fourier transform
- Non-uniform sampling
- Anisotropic diffusion filters
- Variational methods

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course "Functional analysis" is recommended.

# M 2.114 Module: Mathematical Methods of Imaging [M-MATH-103260]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-106488 | Mathematical Methods of Imaging | 5 CP | Rieder |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
None

**Competence Goal**
Graduates become familiar with some imaging methods and are able to discuss and analyze the underlying mathematical aspects. In particular, they will be able to explain the functional-analytical properties of the imaging operators. They can implement the corresponding reconstruction algorithms and they can explain and evaluate the artifacts that appear. They are able to apply the techniques they have learned to related problems.

**Content**

- Variants of tomography (X-ray, impedance, seismic, etc.)
- Properties of (generalized) Radon transforms
- Microlocal analysis/Pseudodifferential operators
- Ill-Posedness and regularization
- Reconstruction algorithms

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total work load: 150 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 90 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course „Functional Analysis“ is recommended.

# M 2.115 Module: Mathematical Modelling and Simulation in Practise [M-MATH-102929]

**Coordinators:** PD Dr. Gudrun Thäter
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105889 | Mathematical Modelling and Simulation in Practise | 4 CP | Thäter |

**Assessment**
The module will be completed by an oral exam (ca. 20 min).

**Prerequisites**
None

**Competence Goal**
The general aim of this lecture course is threefold:

1) to interconnect different mathematical fields,
2) to connect mathematics and real life problems,
3) to learn to be critical and to ask relevant questions.

At the end of the course, students can

- work Project-orientated,
- link knowledge from different fields,
- develop typical modelling approaches on their own.

**Content**
Mathematical thinking (as modelling) and mathematical techniques (as tools) meet application problems such as:

- Differential equations
- Population models
- Traffic flow
- Game theory
- Chaos
- Mechanics and fluids

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**
The lecture is always in English.

To earn the credits you have to attend the lecture, finish the work on one project during the term in a group of 2-3 persons and pass the exam. The topic of the project is up to the choice of each group.

**Workload**
Total workload: 120 hours

Attendance: 45 hours

- lectures, problem classes, and examination
- Project presentations

Self-studies: 75 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination,
- work on the project

**Recommendations**
Some basic knowledge of numerical mathematics is recommended.

**Literature**
Hans-Joachim Bungartz e.a.: Modeling and Simulation: An Application-Oriented Introduction,
Springer, 2013

# M 2.116 Module: Mathematical Statistics [M-MATH-102909]

**Coordinators:** PD Dr. Bernhard Klar
Prof. Dr. Mathias Trabs

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105872 | Mathematical Statistics | 8 CP | Ebner, Fasen-Hartmann, Klar, Trabs |

**Assessment**
The module will be completed by an oral exam (approx. 30 min).

**Prerequisites**
none

**Competence Goal**
By the end of the course, students will

- know the basic concepts of mathematical statistics,
- be able to apply them independently to simple problems and examples,
- know specific probabilistic techniques and be able to use them for the mathematical analysis of estimation and test procedures,
- know the asymptotic behavior of maximum likelihood estimators and the generalized likelihood ratio for parametric test problems.

**Content**
The course covers basic concepts of mathematical statistics, in particular the finite optimality theory of estimators and tests, and the asymptotic behavior of estimators and test statistics. Topics are:

- Optimal and best linear unbiased estimators,
- Cramér-Rao bound in exponential families,
- sufficiency, completeness and the Lehmann-Scheffé theorem,
- the multivariate normal distribution,
- convergence in distribution and multivariate central limit theorem,
- Glivenko-Cantelli theorem,
- limit theorems for U-statistics,
- asymptotic estimation theory (maximum likelihood estimator),
- asymptotic relative efficiency of estimators,
- Neyman-Pearson tests and optimal unbiased tests,
- asymptotic tests in parametric models (likelihood ratio tests).

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the courses "Probability theory" and "Statistics" are strongly recommended.

# M 2.117 Module: Mathematical Topics in Kinetic Theory [M-MATH-104059]

**Coordinators:** PD Dr. Ioannis Anapolitanos
Prof. Dr. Dirk Hundertmark

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-108403 | Mathematical Topics in Kinetic Theory | 4 CP | Hundertmark |

**Assessment**
The module examination takes the form of an oral examination (30 min.)

**Prerequisites**
None

**Competence Goal**
The students are familiar with the basic questions in kinetic theory and methodical approaches to their solutions. With the acquired knowledge they are able to understand the required analytical methods and are able to apply them to the basic equations in kinetic theory.

**Content**

- Boltzmann equation: Cauchy problem and properties of solutions
- entropy and H theorem
- equilibrium and convergence to equilibrium
- other models of kinetic theory

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 120 hours

Attendance time: 45 hours

- Course including module examination

Self studies: 75 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
Knowledge of functional analysis is recommended.

# M 2.118 Module: Maxwell's Equations [M-MATH-102885]

**Coordinators:** PD Dr. Frank Hettlich
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105856 | Maxwell's Equations | 8 CP | Arens, Griesmaier, Hettlich |

**Assessment**
The module will be completed by an oral exam (~30min.).

**Prerequisites**
none

**Competence Goal**
The students can explain mathematical questions from the theory of Maxwell's equations. They can formulate and prove the main theorems on properties and existence of solutions, can apply these to specific cases, and can compare results with simpler differential equations (like the Helmholtz equation).

**Content**
Specific examples of solutions to Maxwell's equations, properties of solutions (e.g. representation theorems), specific cases like E-mode and H-mode, corresponding boundary value problems.

**Module Grade Calculation**
The module grade is the grade of the oral exam

**Workload**
Total workload: 240h

Attendace: 90h

- lecture, problem class, examination

Self-studies: 150h

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research related to the course content
- preparation of the course content

**Recommendations**
Desirable is basic knowledge from functional analysis

# M 2.119 Module: Medical Imaging Technology [M-ETIT-106778]

**Coordinators:** Prof. Dr.-Ing. Maria Francesca Spadea
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-113625 | Medical Imaging Technology | 6 CP | Spadea |

**Assessment**
The examination takes place in form of a written examination lasting 120 minutes.

**Prerequisites**
none

**Competence Goal**
For each imaging modality students will be able to:

- identify required energy source;
- analyze the interactions between the form of energy and biological tissue distinguishing desired signal from noise contribution;
- critically interpret the image content to derive knowledge
- evaluate image quality and implementing strategies to improve it.

Moreover, the students will be able to communicate in technical and clinical English languange.

**Content**

- Basic knowledge of mathematical and physical principles of medical imaging formation, including X-ray based modalities, nuclear medicine imaging, magnetic resonance imaging and ultrasound
- Components of medical imaging devices.
- Assessment of image quality in terms of signal-to-noise-ratio, presence of artifact, spatial, Spectral and temporal resolution
- Safety and protection for patients and workers.

**Module Grade Calculation**
The module grade is the grade of the written exam.

A bonus can be earned for voluntary tasks such as:

- presentation and discussion of a specific topic,
- participation to writing the lecture minutes
- implementation of educational tools

The exact criteria for awarding a bonus will be announced at the beginning of the lecture period. If the grade in the oral exam is between 4.0 and 1.3, the bonus improves the grade by 0.3 or 0.4.

Bonus points do not expire and are retained for any examinations taken at a later date.

**Workload**

1. attendance in lectures an exercises: 15*4 h = 60 h
2. preparation / follow-up: 15*6 h = 90 h
3. preparation of and attendance in examination: 30 h

A total of 180 h = 6 CR

**Recommendations**
Basic knowledge in the field of physics and signal processing is helpful.

# M 2.120 Module: Metric Geometry [M-MATH-105931]

**Coordinators:** Prof. Dr. Alexander Lytchak
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | German | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111933 | Metric Geometry | 8 CP | Lytchak, Nepechiy |

**Assessment**
Oral examination of circa 20 minutes.

**Prerequisites**
None.

**Competence Goal**
Understanding of fundamental concepts of metric geometry

Preparation for a thesis in the area of metric geometry

**Content**
Convergence of metric spaces, Spaces of metric spaces, comparison geometry, curvature-free geometry of manifolds

**Module Grade Calculation**
The module grade is the grade of the final oral exam.

**Additional Information**
This course is one of the nine core courses in the subject area Algebra and Geometry, from which at least six courses are offered within every two years (at least four different ones).

**Workload**
Total workload: 240 hours

Contact hours: 90 hours

Course, including the accompanying module examination

Independent study: 150 hours

- Consolidation of course content through at-home review of the lecture material
- Completion of exercise assignments
- Further study of course content using appropriate literature and online research
- Preparation for the accompanying module examination

**Recommendations**
Basic knowledge of set-theoretical topology and elementary geometry, as taught in the module "M-MATH-103152 - Elementary Geometry", is recommended.

# M 2.121 Module: Minimal Surfaces [M-MATH-106666]

**Coordinators:** Dr. Peter Lewintan
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113417 | Minimal Surfaces | 3 CP | Lewintan |

**Assessment**
The module will be completed by an oral exam (about 30 min).

**Prerequisites**
None

**Competence Goal**
Graduates

- are able to mathematically understand and solve a practical problem;
- can explain important results of the theory of minimal surfaces and apply them to examples;
- are prepared to write a thesis in the field of the theory of minimal surfaces or the calculus of variations.

**Content**
Minimal surfaces are critical points of the area functional and locally minimize its area. They can also be described by having zero mean curvature. In this course we consider two dimensional minimal surfaces in R^3 and discuss their properties. We will use arguments from differential geometry, the calculus of variations, the theory of partial differential equations and functions of a complex variable. Our goal is to prove the classical Plateau's problem.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 hours

- lectures, problem classes, and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course "Classical Methods for Partial Differential Equations" is recommended.

# M 2.122 Module: Modelling and Simulation of Lithium-Ion Batteries [M-MATH-106640]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113382 | Modelling and Simulation of Lithium-Ion Batteries | 4 CP | Dörfler |

**Assessment**
oral exam of ca. 20 minutes

**Prerequisites**
None

**Competence Goal**
Participants know about the modelling and physical basics that lead to the model equations. They can explain (at least for simplified problems) their well-posedness. They are able to analyze stability and convergence of the presented methods.

**Content**

- Derivation of the model equations,
- Existence for simplified model problems,
- Discretization of the initial boundary value problems with fiite elements,
- Nonlinear diffusion equations, Cahn-Hilliard equation, linear elasticity and contact problems,
- Stability and convergence of the discrete models,
- Applications

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 h

- lectures, problem classes and examination

Self studies: 75 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
Basic knowledge in the numerical treatment of differential equations, such as boundary value problems or initial value problems is strongly recommended.

# M 2.123 Module: Models of Mathematical Physics [M-MATH-102875]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105846 | Models of Mathematical Physics | 8 CP | Hundertmark, Plum, Reichel |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
None

**Competence Goal**
Graduates will be able to

- understand the modeling of fundamental physical effects,
- understand the most important mathematical properties of these differential equation models,
- calculate exemplary solutions,
- draw conclusions regarding the models from the provable properties of the differential equations and the solutions.

**Content**

- Reaction-diffusion models
- Wave phenomena
- Maxwell equations and electrodynamics
- Schrödinger equation and quantum mechanics
- Navier-Stokes equation and fluid dynamics
- Elasticity
- Surface tension

**Module Grade Calculation**
The module grade is the grade of the oral/written exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

# M 2.124 Module: Modern Experimental Physics I, Atoms, Nuclei and Molecules [M-PHYS-106331]

**Coordinators:** Studiendekan/in Physik
**Organisation:** KIT Department of Physics
**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-112846 | Modern Experimental Physics I, Atoms, Nuclei and Molecules | 8 CP | Studiendekan/in Physik |

**Assessment**
See components of this module

**Prerequisites**
none

# M 2.125 Module: Modern Experimental Physics II, Structure of Matter [M-PHYS-106332]

**Coordinators:** Studiendekan/in Physik
**Organisation:** KIT Department of Physics
**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-112847 | Modern Experimental Physics II, Structure of Matter | 8 CP | Studiendekan/in Physik |

**Assessment**
See components of this module

**Prerequisites**
none

# M 2.126 Module: Modern Methods in Combinatorics [M-MATH-106957]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113911 | Modern Methods in Combinatorics | 6 CP | Aksenovich |

**Assessment**
The module examination takes the form of an oral examination (approx. 30 min).

**Prerequisites**
None

**Competence Goal**
The students understand and are able to use powerful modern methods in Combinatorics.

**Content**
The course is concerned with modern methods in Combinatorics including probabilistic or algebraic ones. Every presented method is illustrated with several applications.

The probabilistic part includes the following topics: random graphs, linearity of expectation, second moment method, and Lovasz Local Lemma. The algebraic part includes: polynomial methods, spectral methods, and linear algebraic techniques.

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 180 hours

Attendance time: 60 hours

- Course including module examination during the course of study

Self-study: 120 hours

- Deepening the study content by working on the lecture content at home
- completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
Some knowledge of linear algebra and probability theory is strongly recommended. The courses *Graph Theory* and *Combinatorics* are recommended but not required.

# M 2.127 Module: Modular Forms [M-MATH-102868]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105843 | Modular Forms | 8 CP | Kühnlein |

**Assessment**
The exam is an oral exam of about 30 minutes.

**Prerequisites**
None

**Competence Goal**
Participants are able to

- understand basic questions discussed in the theory of modular forms
- see the relevance of analytic results for solving certain arithmetic problems
- start reading a recent research paper and write a thesis in the area of modular forms.

**Content**

- Modular Group: Upper half plane, Mobius transforms, fundamental regions, Eisenstein series, modular forms, dimension formula
- congruence subgroups: Petersson scalar product, Hecke operators, Atkin-Lehner-theory of new forms
- L-series: Mellin transform, functional equation, Euler product decomposition of the L-series of a Hecke-eigenform

**Module Grade Calculation**
Grade of the oral exam

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classe and examination

Self studies: 150 hours

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research on the course content
- preparation for the module examination

**Recommendations**
The basic notions of algebra and number theory should be well-understood, and also basic principles of complex analysis.

# M 2.128 Module: Monotonicity Methods in Analysis [M-MATH-102887]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105877 | Monotonicity Methods in Analysis | 3 CP | Herzog |

**Assessment**
The module will be completed by an oral exam (about 20 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students can

- name, discuss and apply basic techniques of the order-theoretical methods of analysis,
- apply specific order theory techniques to fixed point problems and differential equations.

**Content**

- Fixed point theorems in ordered sets and ordered metric spaces.
- Ordered Banach spaces.
- Quasimonotone increasing functions.
- Differential equations and differential inequalities in ordered Banach spaces.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 hours

- lectures, problem classes, and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course "Functional Analysis" is recommended.

# M 2.129 Module: Neural Networks [M-INFO-100846]

**Coordinators:** Prof. Dr. Alexander Waibel
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-101383 | Neural Networks | 6 CP | Waibel |

# M 2.130 Module: Nonlinear Analysis [M-MATH-103539]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-107065 | Nonlinear Analysis | 8 CP | Lamm |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
None.

**Competence Goal**
Graduates

- have gained an insight into topics of nonlinear analysis,
- are able to recognize and explain connections between the theory of partial differential equations and functional analysis.

**Content**
Classical and/or current research topics in nonlinear analysis, e.g.

- Nonlinear analysis in Banach spaces,
- mapping degree,
- Selected topics in calculus of variations.

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination

Self-study: 150 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**

- Classical methods of partial differential equations
- Functional analysis

# M 2.131 Module: Nonlinear Control Systems [M-ETIT-107644]

**Coordinators:** Prof. Dr.-Ing. Sören Hohmann
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-114989 | Nonlinear Control Systems | 6 CP | Kluwe |

**Assessment**
The examination takes place in form of a written examination lasting 120 minutes.

**Prerequisites**
none

**Competence Goal**

- The students are able to describe nonlinear systems in time domain, in particular they are familiar with the state space representation.
- The students are able to analyze the behavior of nonlinear systems on the basis of the respective trajectory plots in state space.
- They master the stability analysis of equilibrium points with the fundamental Lyapunov theory and its extensions.
- They are familiar with the passivity concept in nonlinear systems.
- They are as well familiar with dissipativity as the generalization of passivity.
- They are able to design controllers with control Lyapunov functions.
- They master the controller design with the back-stepping principle.
- They are able to design sliding-mode control in nonlinear systems.
- They are able to synthesize passivity-based controllers.
- They are able to use design compensation control methods with feedback linearization on the basis of relative degree.
- They can design controllers based on the concept of flatness.

**Module Grade Calculation**
The module grade is the grade of the written examination.

**Workload**
The workload includes (4 SWS):

1. attendance in lectures and exercises: 15*4 h = 60 h
2. preparation / follow-up: 15*4 h = 60 h
3. preparation of and attendance in examination: 60 h

A total of 180 h

**Recommendations**
Basic and advanced knowledge knowledge in the field of control theory is recommended (for example the contents of the bachelor module M-ETIT-106339 “Mess- und Regelungstechnik” and the master module M-ETIT-107515 “Multivariable Control Systems”)

**Teaching and Learning Methods**
Lecture (3 SWS) + exercises (1 SWS)

# M 2.132 Module: Nonlinear Evolution Equations [M-MATH-102877]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105848 | Nonlinear Evolution Equations | 8 CP | Frey, Schnaubelt |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
None

**Competence Goal**
Students can explain the well-posedness theory of semilinear evolution equations in the locally Lipschitz case and apply it to cubic wave equations in 3D. They can also examine these for global existence and blow-up. Based on the fundamentals of interpolation theory for generators, they can also deal with more general nonlinearities in the parabolic case. In this case, they can determine the long-term behaviour with the help of Lyapunov functions and the principle of linearized stability, and apply these results to reaction-diffusion systems. They can derive basic Strichartz inequalities. They can use them to treat the well-posedness and long-term behavior of the nonlinear Schrödinger and wave equations. They master the important proof techniques in the theory of semilinear evolution equations and can at least sketch more complex proofs.

**Content**

- semilinear evolution equations
- wellposedness, global existence versus blow-up
- interpolation theory for generators
- Lyapunov functions, linearized stability
- reaction diffusion systems
- semilinear wave and Schrödinger equations
- Strichartz inequalities

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the modules Functional Analysis and Evolution Equations are strongly recommended. However, the relevant parts of Evolution Equations will be briefly recalled.

# M 2.133 Module: Nonlinear Functional Analysis [M-MATH-102886]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105876 | Nonlinear Functional Analysis | 3 CP | Herzog |

**Assessment**
The module will be completed by an oral exam (about 20 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students can

- name, discuss and apply basic techniques of nonlinear functional analysis,
- explain the construction of the Brouwer- and Schauder-degree,
- apply specific techniques of degree theory to nonlinear problems.

**Content**

- The Brouwer degree and its applications
- The Leray-Schauder degree and its applications
- Odd mappings
- Measures of non-compactness and their applications

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 hours

- lectures, problem classes, and examination

Self-studies: 60 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

# M 2.134 Module: Nonlinear Maxwell Equations [M-MATH-105066]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-110283 | Nonlinear Maxwell Equations | 8 CP | Schnaubelt |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
none

**Competence Goal**
Students can explain some basic types of nonlinear Maxwell equations and the physical significance of the variables that occur. They are able to prove and discuss local wellposedness theorems in the whole space using energy methods. They can derive Strichartz inequalities for linear Maxwell equations. With their help, they can show improved wellposedness results.

**Content**

- Maxwell equations with nonlinear material laws
- local wellposedness theory in the whole space using linearisation, apriori estimates and regularisation
- Strichartz inequalities and improved wellposedness theory

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the module "Functional Analysis" are strongly recommended.

# M 2.135 Module: Nonlinear Wave Equations [M-MATH-105326]

**Coordinators:** Prof. Dr. Wolfgang Reichel
Prof. Dr. Roland Schnaubelt

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-110806 | Nonlinear Wave Equations | 4 CP | Reichel, Schnaubelt |

**Assessment**
The module will be completed by an oral exam (ca. 20 min).

**Prerequisites**
None

**Competence Goal**
Graduates will be able to

- name important properties of nonlinear wave equations,
- describe essential difficulties in the analysis of the initial value problem,
- analyze the short- and long-term behavior of solutions of semilinear wave equations using modern techniques.

**Content**
The aim of the course is an introduction to methods for analyzing nonlinear wave equations. The aim is to get to know the basics of various important techniques and to apply them to simple models. The following topics will be covered:

- Symmetries and conservation laws
- Fourier transformation, Sobolev spaces
- Energy estimates
- Strichartz estimates
- Local and global well-posedness results
- Vector field methods
- Longtime behavior

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 h

- lectures, problem classes and examination

Self studies: 75 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the module "Functional Analysis" are strongly recommended.

# M 2.136 Module: Nonparametric Statistics [M-MATH-102910]

**Coordinators:** PD Dr. Bernhard Klar
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105873 | Nonparametric Statistics | 4 CP | Ebner, Fasen-Hartmann, Klar, Trabs |

**Assessment**
The module will be completed with an oral exam (ca. 20 min).

**Prerequisites**
None

**Competence Goal**
By the end of the course, students will be able to

- explain nonparametric statistical tests based on location problems and distinguish them from parametric methods,
- name and explain nonparametric estimation methods for nonparametric regression and density estimation,
- know and apply optimality criteria for the statistical methods covered.

**Content**

- Introduction to nonparametric models
- Nonparametric tests, especially rank statistics
- Nonparametric density and regression estimation
- Dependence measures or optimal convergence rates

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 h

- lectures, problem classes and examination

Self studies: 75 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the module 'Probability Theory' are strongly recommended. The module 'Mathematical Statistics' is recommended.

# M 2.137 Module: Numerical Analysis of Neural Networks [M-MATH-106695]

**Coordinators:** TT-Prof. Dr. Roland Maier
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113470 | Numerical Analysis of Neural Networks | 6 CP | Maier |

**Assessment**
The module will be completed by an oral exam (about 30 min).

**Prerequisites**
None.

**Competence Goal**
The goal of the lecture is to provide a mathematical foundation of neural networks from the perspective of numerical analysis. Students know basic definitions and terminology as well as classical approximation results for neural networks. They are familiar with numerical methods for the efficient training of neural networks and can analyze them. Moreover, students can apply the concepts to popular applications (such as physics-informed neural networks, Deep Ritz method, etc.).

**Content**

- Neural networks
- Approximation results
- Connections to finite element methods
- Numerical methods for the efficient learning
- Datasets

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Additional Information**
The course is offered in English. If everybody speaks German, the lecture will be held in German.

**Workload**
Total workload: 180 hours

Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
Basic knowledge of ordinary and/or partial differential equations as well as the contents of the module "Numerical Methods for Differential Equations" are recommended. Basic knowledge of functional analysis and finite element methods is helpful, but not required.

# M 2.138 Module: Numerical Analysis on Quantum Computers [M-MATH-107646]

**Coordinators:** TT-Prof. Dr. Roland Maier
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-114990 | Numerical Analysis on Quantum Computers | 6 CP | Maier |

**Assessment**
Oral examination of approximately 30 minutes.

**Prerequisites**
None.

**Competence Goal**
This lecture introduces a purely mathematical view on quantum computing. Students learn elementary concepts that describe operations on quantum computers. They are able to combine them and to implement numerical algorithms, e.g., to solve linear systems or differential equations. Students can also theoretically analyze the errors of the algorithms.

**Content**

- Basics of quantum computers
- Classical quantum algorithms
- Solving linear systems
- Solving linear differential equations

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance time: 60 hours

- Course including module examination during the course of study

Self-study: 120 hours

- Deepening the study content by working on the lecture content at home
- completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
A solid background in numerical mathematics is recommended.

# M 2.139 Module: Numerical Complex Analysis [M-MATH-106063]

**Coordinators:** Prof. Dr. Marlis Hochbruck
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112280 | Numerical Complex Analysis | 6 CP | Hochbruck |

**Assessment**
Oral exam of approximately 20 minutes.

**Prerequisites**
None.

**Competence Goal**
Graduates

- can apply techniques and concepts from complex analysis in numerical analysis,
- are prepared to write a thesis in numerical analysis.

**Content**
In this lecture we consider numerical methods for problems in complex analysis and complex analysis techniques to analyze numerical methods. It provides the chance to rediscover theorems known from the complex analysis lecture in applications.

The following topics are planned

- Calculations with power series: formal Newton's method and FFT,
- control systems and convolution quadrature (Cauchy integral formula, Laplace transform, argument principle),
- rational approximation to the exponential: order stars (maximum principle, argument principle),
- convergence of iterative methods for linear systems of equations an approximation of the matrix exponential operator (conformal mappings, Cauchy integral formula),
- numerical conformal mapping.

**Module Grade Calculation**
The module grade ist the grade of the oral exam.

**Workload**
Total workload: 180 h

Attendance: 60 h

- lectures, problem classes, and examination

Self-studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination.

**Recommendations**
Basic knowledge of complex analysis is highly recommended.

**Literature**
Lecture notes with references.

# M 2.140 Module: Numerical Linear Algebra in Image Processing [M-MATH-104058]

**Coordinators:** PD Dr. Volker Grimm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-108402 | Numerical Linear Algebra in Image Processing | 6 CP | Grimm |

**Assessment**
The module will be completed by an oral exam (ca. 20 min).

**Prerequisites**
None

**Competence Goal**
Graduates can name essential concepts of image processing using numerical linear algebra methods and implement them efficiently.

**Content**

- Linear models of optical devices
- Point spread function and discrete convolution
- Structured matrices and fast transformations
- Large, ill-conditioned linear systems of equations
- Krylov subspace methods, preconditioning
- Several applications

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 120 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

# M 2.141 Module: Numerical Methods for Differential Equations [M-MATH-102888]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Tobias Jahnke

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | German | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105836 | Numerical Methods for Differential Equations | 8 CP | Dörfler, Hochbruck, Jahnke, Rieder, Wieners |

**Assessment**
The module will be completed by an oral examination with a duration of approximately 30 minutes. If this would require an unreasonable amount of time, the oral examination may be replaced by a written exam with a duration of approximately 120 minutes. The decision will be announced at least six weeks before the examination.

**Prerequisites**
None.

**Competence Goal**
At the end of the course, students

- know important examples of numerical methods for ordinary differential equations as well as the underlying construction principles
- are able to analyze the properties of these methods (in particular their stability, convergence and complexity)
- are able to analyze basic numerical methods for linear partial differential equations
- can explain concepts of modelling with differential equations

**Content**

- Numerical methods for initial value problems (Runge-Kutta methods, multistep methods, order, stability, stiff problems)
- Numerical methods for boundary value problems (finite difference methods for second-order elliptic equations)
- Numerical methods for initial boundary value problems (finite difference methods for parabolic equations and hyperbolic equations)

**Module Grade Calculation**
The module grade is the grade of the oral or written exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
It is highly recommended that participants have completed the modules "Numerische Mathematik 1 und 2" as well as "Programmieren: Einstieg in die Informatik und algorithmische Mathematik".

# M 2.142 Module: Numerical Methods for Hyperbolic Equations [M-MATH-102915]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105900 | Numerical Methods for Hyperbolic Equations | 6 CP | Dörfler |

**Assessment**
Oral exam of ca. 25 minutes

**Prerequisites**
none

**Competence Goal**
Absolventinnen und Absolventen können

- die grundlegenden Methoden, Techniken und Algorithmen der Behandlung hyperbolischer Anfangswertprobleme erklären
- Konzepte der Modellierung mit hyperbolischen Differentialgleichungen wiedergeben
- Einfache skalare oder vektorwertige hyperbolische Gleichungen numerisch lösen

**Content**

- Modelling with conservation laws
- Shocks, Rarefaction waves and weak solutions
- Aspects of existence and regularity theorie of scalar problems
- Discretisation of conservation laws in space and time
- Properties and discretisation of hyperbolic systems

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research on the course content
- preparation for the module examination

**Recommendations**
Basic knowledge in numerics of differential equations is strongly recommended. Knowledge in functional analysis is recommended.

# M 2.143 Module: Numerical Methods for Integral Equations [M-MATH-102930]

**Coordinators:** PD Dr. Tilo Arens
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105901 | Numerical Methods for Integral Equations | 8 CP | Arens, Hettlich |

**Assessment**
The module examination is carried out by one oral examination (approx. 30 minutes).

By successfully participating in the problem classes by correctly completing 60% of the programming exercise assignments, students will obtain a bonus to the grade of the oral examination. This bonus amounts to an improvement of the grade to the next marking step (a decrease by 0.3 or 0.4, respectively), if the original grade is between 4.0 and 1.3.

**Prerequisites**
None

**Competence Goal**
Students are able to name and describe basic methods for numerically solving linear integral equations of the second kind, such as the Nyström method, collocation method and Galerkin method, as well as their underlying principles such as interpolation and numerical integration. They are able to apply these methods for numerically solving integral equations and to implement concrete examples on a computer. Students are able to state convergence results concerning these methods and have mastered the application of methods of proof for such results. They can independently derive corresponding results for simple variations of these methods and perform the analysis of the convergence behavior for specific applications.

**Content**

- Boundary integral operators
- Interpolation and quadrature formulae
- Nyström methods
- Projection methods and boundary element methods

**Module Grade Calculation**
The grade of the module is the grade of the oral examination, modified by the bonus from the problem class assignments.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- increased understanding of module content by wrapping up lectures at home
- work on exercises
- increased understanding of module content by self study of literature and internet research
- preparing for the examination

**Recommendations**
Numerical Analysis I

Integral Equations

# M 2.144 Module: Numerical Methods for Maxwell's Equations [M-MATH-102931]

**Coordinators:** Prof. Dr. Marlis Hochbruck
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105920 | Numerical Methods for Maxwell's Equations | 6 CP | Hochbruck, Jahnke |

**Assessment**
Oral examination of approximately 20 minutes.

**Prerequisites**
None.

**Competence Goal**
The students can interpret the terms arising in the time-dependent Maxwell equations physically and prove the existence and uniqueness of the solution under appropriate assumptions. They know numerical methods and techniques to approximate these solutions and they are able to perform an error analysis. From the practical point of view they are able to evaluate advantages and disadvantages of different methods.

**Content**
Maxwell equations are a set of vector valued partial differential equations that are fundamental for the propagation of electromagnetic waves in media. In this lecture we start to derive Maxwell equations in integral- and differential form, discuss examples of material laws, boundary conditions, and study the well-posedness in suitable function spaces. For the numerical solution of Maxwell equations, we employ finite element methods for the spatial discretization. Our emphasis is on discontinuous Galerkin methods. Favorable methods for time discretization are splitting methods, (locally) implicit schemes, and exponential integrators. We construct and analyse these methods and discuss their efficient implementation.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 h

Attendance: 60 h

- lectures, problem classes, and examination

Self-studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination.

**Recommendations**
Basic knowledge of ordinary and/or partial differential equations is recommended.

The module "Numerical Methods for Differential Equations" is strongly recommended.

**Teaching and Learning Methods**
Lecture and tutorial with the active contribution of the students; problem sheets every 2 weeks.

**Literature**
Lecture notes with many references will be provided.

# M 2.145 Module: Numerical Methods for Oscillatory Differential Equations [M-MATH-106682]

**Coordinators:** Prof. Dr. Tobias Jahnke
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113437 | Numerical Methods for Oscillatory Differential Equations | 8 CP | Jahnke |

**Assessment**
The module will be completed by an oral exam (about 30 min).

**Prerequisites**
none

**Competence Goal**
The central topic of the lecture are numerical time-integrators for highly oscillatory ordinary and partial differential equations.

After participation, students

- know selected classes of ordinary and partial differential equations with oscillatory solutions and can explain the reason for the oscillatons.
- can explain why time-integration of such problems with traditional methods is usually inefficient.
- know different techniques which can be used to construct more efficient methods for selected problems.
- can explain error bounds for such integrators and know the ideas, techniques and assumptions used in the error analysis.

**Content**

- Oscillatory ordinary and partial differential equations: examples and applications
- Construction of time integrators
- Oscillations and resonances
- Error analysis
- Space discretization by Fourier collocation methods

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Additional Information**
The module will be offered about every second summer semester.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
Participants are expected to be familiar with numerical methods for ordinary differential equations (e.g. Runge-Kutta methods) and with concepts required for their analysis (stability, order, local and global error, etc.).

# M 2.146 Module: Numerical Methods for Time-Dependent Partial Differential Equations [M-MATH-102928]

**Coordinators:** Prof. Dr. Marlis Hochbruck
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105899 | Numerical Methods for Time-Dependent Partial Differential Equations | 8 CP | Hochbruck, Jahnke |

**Assessment**
Success is assessed in form of an oral examination lasting approx. 25 minutes.

**Prerequisites**
None.

**Competence Goal**
Students can analyze numerical methods for abstract evolution equations. They can understand current research results and master various techniques for proving stability and error estimates of time integration methods. They can independently solve exercises, and present and discuss solutions.

**Content**

- Time integration methods for linear, semilinear, and quasilinear evolution equations and their semi-discretization in place, in particular, implicit Runge-Kutta and multistep methods,
- rigorous error estimates and stability proofs.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 h

Attendance: 90 h

- lectures, problem classes, and examination

Self-studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination.

**Recommendations**
Numerical methods for differential equations, finite element methods, functional analysis.

# M 2.147 Module: Numerical Methods in Computational Electrodynamics [M-MATH-102894]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105860 | Numerical Methods in Computational Electrodynamics | 6 CP | Dörfler, Hochbruck, Jahnke, Rieder, Wieners |

**Assessment**
Oral exam of ca. 25 minutes

**Prerequisites**
None

**Competence Goal**
Participants

- are able to explain electrostatic or electrodynamic effects with mathematical models,
- know the basic problems to construct correct approximations,
- are able to describe stable discretisations of Maxwell equations.

**Content**

- Maxwell equations, special cases
- Boundary and transmission conditions
- Analytical tools
- The electromagnetic source problem
- The eigenvalue problem
- Finite elements for the Maxwell equations
- Interpolation estimates

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research on the course content
- preparation for the module examination

**Recommendations**
Basic knowledge in analysis of boundary value problems and the finite element method is strongly recommended.

# M 2.148 Module: Numerical Methods in Fluid Mechanics [M-MATH-102932]

**Coordinators:** Prof. Dr. Willy Dörfler
PD Dr. Gudrun Thäter

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105902 | Numerical Methods in Fluid Mechanics | 4 CP | Dörfler, Thäter |

**Assessment**
Oral exam of about 20 minutes.

**Prerequisites**
None

**Competence Goal**
Participants know about the modelling and physical basics that lead to the model equations. They know how to discretize fluidmechanical problems with the finite element method and know especiallly how to treat the incompressibility condition. They are able to analyze stability and convergence of the presented methods.

**Content**

- Modelling and derivation of the Navier-Stokes equations
- Mathematical and physical representation of energy and stress
- Lax-Milgram theorem, Céa lemma and saddle point theory
- Analytical and numerical treatment of the potential and Stokes flow
- Stability and convergence of the discrete models
- Numerical treatment of the stationary nonlinear equation
- Numerical treatment of the instationary problems
- Applications

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 h

- lectures, problem classes and examination.

Self studies: 75 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination.

**Recommendations**
Basic knowledge in the numerical treatment of differential equations, such as boundary value problems or initial value problems is strongly recommended. Knowledge in functional analysis is recommended.

# M 2.149 Module: Numerical Methods in Mathematical Finance [M-MATH-102901]

**Coordinators:** Prof. Dr. Tobias Jahnke
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105865 | Numerical Methods in Mathematical Finance | 8 CP | Jahnke |

**Assessment**
oral exam of ca. 30 minutes

**Prerequisites**
none

**Competence Goal**
The lecture concentrates on option pricing with numerical methods.

After participation, students

- know how to model the price dynamics of different types of options by stochastic or partial differential equations, and to evaluate the differences between these models.
- know, in particular, the assumptions on which these models are based, which enables them to discuss and question the meaningfulness and reliability of the models.
- know different methods for solving stochastic and partial differential equations numerically, and for solving high-dimensional integration problems.
- are able to implement and apply these methods to different types of options, and to analyze their stability and convergence.

**Content**

- Options, arbitrage and other basic concepts,
- Black-Scholes equation und Black-Scholes formulas,
- Numerical methods for stochastic differential equations,
- (Multilevel) Monte Carlo methods,
- (Quasi-)Monte Carlo integration,
- Numerical methods for Black-Scholes equations,
- Numerical methods for American options

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Additional Information**
The module is offered every second winter term.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
Familiarity with stochastic differential equations, the Ito integral, and the Ito formula is strongly recommended. MATLAB skills are strongly recommended for the programming exercises.

# M 2.150 Module: Numerical Optimisation Methods [M-MATH-102892]

**Coordinators:** TT-Prof. Dr. Benjamin Unger
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105858 | Numerical Optimisation Methods | 8 CP | Dörfler, Hochbruck, Jahnke, Rieder, Unger, Wieners |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
None.

**Competence Goal**
The subject of the course is numerical methods for constrained and unconstrained optimization problems. Upon successful completion of this module, students will be able to:

- describe and analyze numerical methods for both constrained and unconstrained optimization problems,
- explain and assess results concerning local and global convergence properties of optimization algorithms, and
- illustrate the application of optimization methods in selected practical contexts.

**Content**

- General methods for unconstrained minimization
- Newton-type methods
- Inexact Newton methods
- Quasi-Newton methods
- Nonlinear conjugate gradient methods
- Trust-region methods
- Interior-point methods
- Penalty methods
- Active-set strategies
- Sequential quadratic programming (SQP) methods
- Nonsmooth optimization

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination

Self-study: 150 hours

- Consolidation of the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
The module Optimization Theory is recommended.

# M 2.151 Module: Numerical Simulation in Molecular Dynamics [M-MATH-105327]

**Coordinators:** PD Dr. Volker Grimm
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-110807 | Numerical Simulation in Molecular Dynamics | 8 CP | Grimm |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
None

**Competence Goal**
Graduates know the basic concepts for implementing numerical simulations in molecular dynamics on serial and parallel computer architectures. They can name the numerical results and procedures required for simulation in molecular dynamics, apply them to specific problems and implement them.

**Content**

- Linked-cell method for short-range potentials
- Parallel programming with MPI
- Various potentials and molecules
- Time integration methods
- Aspects of numerical geometric integration
- Methods for the simulation of long-range potentials

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-study: 150 hours

- follow-up and deepening of course content,
- work on problem sheets,
- literature study and internet research relating to the course content
- preparation for the module examination

**Recommendations**
The module M-MATH-102888 (Numerical Methods for Differential Equations) and some programming skills in C (or C++) are recommended.

# M 2.152 Module: Optimal Control [M-ETIT-107497]

**Coordinators:** Prof. Dr.-Ing. Sören Hohmann
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-114701 | Optimal Control | 6 CP | Hohmann |

**Assessment**
The assessment consists of a written exam (120 min) taking place in the recess period.

**Prerequisites**
none

**Competence Goal**

- The students know as well the mathematical basics as the fundamental methods and algorithms to solve constraint and unconstraint nonlinear static optimization problems.
- They can solve constraint and unconstraint dynamic optimization by using the calculus of variations approach and the Dynamic Programming method.
- The students understand and can apply the Bellman Principle, including its theoretical foundations and practical relevance.
- Also they are able to transfer dynamic optimization problem to static problems.
- They are proficient in formulating Optimal Control Problems and applying Model Predictive Control techniques
- The students know the mathematic relations, the pros and cons and the limits of the particular optimization methods.
- They can transfer problems from other fields of their studies in a convenient optimization problem formulation and they are able to select and implement suitable optimization algorithms for them by using common software tools.

**Content**
The module teaches the mathematical basics that are required to solve optimization problems. The first part of the lecture treats methods for solving dynamic optimization problems, including Dynamic Programming and methods derived from the calculus of variations, such as the Hamilton method.

This is followed by a section on optimal control problems. After presenting techniques to transform dynamic optimization problems into static ones, the final part of the lecture addresses methods for solving static optimization problems, both constrained and unconstrained.

**Module Grade Calculation**
The module grade is the grade of the written exam.

**Additional Information**
Successor of "M-ETIT-100531 - Optimization of Dynamic Systems"

**Workload**
The amount of work includes

1. presence in lecture/exercises/tutorial(optional) (2+2 SWS: 60h)
2. preparation/postprocessing of lecture/exercises (90h)
3. preparation/presence in the written exam (30h)

**Teaching and Learning Methods**
lecture (2 SWS), excercise (2 SWS)

# M 2.153 Module: Optimisation and Optimal Control for Differential Equations [M-MATH-102899]

**Coordinators:** TT-Prof. Dr. Benjamin Unger
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105864 | Optimisation and Optimal Control for Differential Equations | 6 CP | Unger |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 20 minutes.

**Prerequisites**
None.

**Competence Goal**
The subject of the course is the modeling and analysis of optimal control problems with a particular emphasis on time-dependent systems. Graduates are familiar with the principles of modeling dynamical systems within the framework of optimal control and possess a solid understanding of the underlying functional analytic setting. They know fundamental concepts from control theory, including controllability and observability, and are acquainted with the linear–quadratic regulator (LQR) framework in both finite and infinite time horizon settings.
In addition, they are able to derive and analyze optimality conditions, including the Pontryagin maximum principle and associated adjoint equations, and understand the role of Riccati equations in optimal control. They are capable of assessing questions of existence, uniqueness, and optimality (both necessary and sufficient conditions), and are familiar with corresponding numerical solution methods. Furthermore, they understand how key concepts and results can be transferred from finite-dimensional systems to infinite-dimensional settings, in particular to parabolic partial differential equations.

**Content**

- Introduction and motivation: modeling with optimal control
- Time-dependent systems in finite dimensions
- Controllability and observability
- Linear–quadratic regulator (finite and infinite horizon)
- Pontryagin maximum principle and adjoint equations
- Riccati equations
- Existence, uniqueness, and optimality conditions
- Numerical methods for optimal control problems
- Optimal control of parabolic partial differential equations

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 180 hours

Attendance time: 60 hours

- Course including module examination

Self-study: 120 hours

- Consolidation of the course content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
The modules Optimization Theory and Numerical Optimization Methods are recommended.

# M 2.154 Module: Optimization in Banach Spaces [M-MATH-102924]

**Coordinators:** Prof. Dr. Roland Griesmaier
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105893 | Optimization in Banach Spaces | 5 CP | Griesmaier, Hettlich |

**Assessment**
The module will be completed by an oral exam (approx. 30 min).

**Prerequisites**
none

**Competence Goal**
The students can transfer properties from finite dimensional optimization problems to infinite dimensional cases. Furthermore, they can apply these results to problems from approximation theory, calculus of variation and optimal control. The students know about the main theorems and their proofs and can explain conclusions with the help of examples.

**Content**
Basics from Functional Analysis (in particular separation theorems, properties of convex functions and generalized derivatives), duality theory of convex problems, differentiable optimization problems (Lagrange multiplier), sufficient optimality conditions, existence results, applications in approximation theory, calculus of variation, and optimal control theory.

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 150 hours

Attendance: 60 hours

- lecture including course related examinations

Self-studies: 90 hours

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research relating to the course content
- preparation for the module examination

**Recommendations**
Some basic knowledge of finite dimensional optimization theory and functional analysis is desirable.

# M 2.155 Module: Parallel Computing [M-MATH-101338]

**Coordinators:** PD Dr. Mathias Krause
Prof. Dr. Christian Wieners

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-102271 | Parallel Computing | 5 CP | Krause, Wieners |

**Assessment**
Examination prerequisite: passed computer lab

Success is assessed in the form of an oral examination lasting approx. 20 minutes.

**Prerequisites**
None

**Competence Goal**
Graduates

- know the fundamentals of parallel computing,
- have an overview of scientific computing concepts on parallel computers,
- have theoretical and practical experience with parallel programming models and parallel solution methods,
- can independently implement simple practical tasks in a scalable manner

**Content**

- Parallel programming models
- Parallel solving of linear equation systems
- Parallel finite differences, finite elements, finite volumes methods
- Domain decomposition methods
- Parallel matrix-matrix and matrix-vector operations
- Convergence and performance analysis
- Load balance techniques
- Applications from the natural sciences and engineering

**Module Grade Calculation**
The module grade is the grade for the oral examination.

**Workload**
Total workload: 150 hours

Attendance time: 60 hours

- Course including module examination during the course of study

Self-study: 90 hours

- Consolidation of course content through follow-up work on lecture content at home
- Completion of exercises
- Consolidation of course content using appropriate literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
Knowledge of a higher-level programming language (C++, Java, Fortran) and basic knowledge of the numerical treatment of differential equations (finite differences or finite elements) are recommended.

# M 2.156 Module: Particle Physics I [M-PHYS-102114]

**Coordinators:** Prof. Dr. Torben Ferber
Prof. Dr. Ulrich Husemann
Prof. Dr. Markus Klute
Prof. Dr. Günter Quast
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-102369 | Particle Physics I | 8 CP | Ferber, Husemann, Klute, Quast, Rabbertz |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Competence Goal**
Students can classify elementary particles and qualitatively analyze interactions between elementary particles using symmetries, Feynman diagrams and Lagrangian densities. Combining this knowledge with knowledge of elementary particle detection, students will be able to discuss the operation of modern particle physics detectors. Students will be able to interpret current data and figures from the scientific literature on particle physics and present the current state of research and important "open questions". Students will be able to apply techniques of statistical data analysis and Monte Carlo simulation to simple particle physics problems and perform basic characterization of silicon track detectors in the laboratory.

**Content**
Lecture:

- Basic concepts of particle physics
- Detectors and accelerators
- Basics of the Standard Model
- Tests of the electroweak theory
- Flavour physics
- QCD
- Physics at high transverse momenta
- Higgs physics
- Physics of massive neutrinos
- Physics beyond the Standard Model

Practical exercises:

- Current methods of Monte Carlo simulation and data analysis in particle physics.
- Measurements on modern silicon track detectors.

**Additional Information**
For students of the KIT Faculty of Computer Science: The exams in this module have to be registered via admissions from ISS (KIT Faculty of Computer Science). For this, an e-mail with matriculation numbers and name of the desired exam to Beratung-informatik@informatik.kit.edu is sufficient.

**Workload**
approx. 240 hours consisting of attendance time (60 hours), follow-up of the lecture incl. exam preparation and preparation of the exercises (180 hours)

**Recommendations**
Basic knowledge of experimental particle physics from the lecture Modern Experimental Physics III in the bachelor's program in physics.

**Literature**
M. Thomson: Modern Particle Physics, Cambridge University Press (2013). D. Griffith: Introduction to Elementary Particles, Wiley (2008). A. Bettini: Introduction to Elementary Particle Physics, Cambridge University Press (2008). C. Berger: Elementarteilchenphysik, Springer (2006).

Additional references will be given in lecture.

# M 2.157 Module: Pattern Recognition [M-INFO-100825]

**Coordinators:** Prof. Dr.-Ing. Jürgen Beyerer
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | German | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-101362 | Pattern Recognition | 6 CP | Beyerer, Zander |

**Assessment**
See Partial Achievements (Teilleistung)

**Prerequisites**
See Partial Achievements (Teilleistung)

**Competence Goal**

- Students have a sound knowledge of the selection, extraction and properties of features used to characterize objects to be classified. Students know how the feature space can be examined, how features can be transformed and how distances in the feature space can be determined. Furthermore, they can normalize features and construct features. In addition, students know how to reduce the dimension of the feature space.
- Students have a sound knowledge of how to select and adapt suitable classifiers for different tasks. They are familiar with Bayesian decision theory, parameter estimation and parameter-free methods, linear discriminant functions, support vector machines and matched filters. Students are also proficient in classification with nominal features.
- Students are able to solve pattern recognition problems, taking into account the efficiency of classifiers and the relationships in the processing chain object - pattern - feature - classifier on a task-specific basis. To this end, students are familiar with the principle for determining the performance of classifiers and the principle of boosting.

**Content**
Features:

- Feature types
- Examination of the feature space
- Transformation of the features
- Distance measurement in the feature space
- Normalization of features
- Selection and construction of features
- Reduction of the dimension of the feature space

Classifiers:

- Bayesian decision theory
- Parameter estimation
- Parameter-free methods
- Linear discriminant functions
- Support Vector Machine
- Matched Filter, Template Matching
- Classification with nominal features

General principles:

- Vapnik-Chervonenki's theory
- Performance determination of classifiers
- Boosting

**Workload**
Total: approx. 180h, of which

Lecture attendance time 31h
Preparation and follow-up 40h
Exercise attendance time 10h
Preparation, solving exercises, follow-up 40h
Exam preparation and attendance 59h

**Recommendations**
See Partial Achievements (Teilleistung)

# M 2.158 Module: Percolation [M-MATH-102905]

**Coordinators:** PD Dr. Steffen Winter
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105869 | Percolation | 5 CP | Hug, Winter |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
none

**Competence Goal**
The students

- are acquainted with basic models of discrete and continuum percolation,
- acquire the skills needed to use specific probabilistic and graph-theoretical methods for the analysis of these models,
- know how to work self-organised and self-reflexive.

**Content**

- Bond and site percolation on graphs
- Infinite clusters and critical probabilities
- Asymptotics of cluster sizes
- Uniqueness of the infinite cluster
- Continuous percolation

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 150 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 90 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the module *Probability Theory* are recommended.

# M 2.159 Module: Physical Foundations of Cryogenics [M-CIWVT-103068]

**Coordinators:** Prof. Dr.-Ing. Steffen Grohmann
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106103 | Physical Foundations of Cryogenics | 6 CP | Grohmann |

**Assessment**
Learning control is an oral examination lasting approx. 30 minutes.

**Prerequisites**
None

**Competence Goal**
Understanding of the mechanisms of entropy generation, and the interaction of the first and the second law in thermodynamic cycles; understanding of cryogenic material properties; application, analysis and assessment of real gas models for classical helium I; understanding of quantum fluid properties of helium II based on Bose-Einstein condensation, understanding of cooling principles at lowest temperatures.

**Content**
Relation between energy and temperature, energy transformation on microscopic and on macroscopic scales, physical definitions of entropy and temperature, thermodynamic equlibria, reversibility of thermodynamic cycles, helium as classical and as quantum fluid, low-temperature material properties, cooling methods at temperatures below 1 K.

**Module Grade Calculation**
The grade of the oral examination is the module grade.

**Workload**

- Attendance time (Lecture): 45 h
- Homework: 45 h
- Exam Preparation: 90 h

**Literature**
Schroeder, D.V.: An introduction to thermal physics. Addison Wesley Longman (2000)

Pobell; F.: Matter and methods at low temperatures. 3rd edition, Springer (2007)

# M 2.160 Module: Poisson Processes [M-MATH-102922]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 5 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105922 | Poisson Processes | 5 CP | Fasen-Hartmann, Hug, Nestmann, Winter |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
none

**Competence Goal**
The students know about important properties of the Poisson process. The focus is on probabilistic methods and results which are independent of the specific phase space. The students understand the central role of the Poisson process as a specific point process and as a random measure.

**Content**

- The Poisson process as particular point process
- Multivariate Mecke equation
- Superpositions, markings and thinnings
- Characterizations of the Poisson process
- Stationary Poisson and point processes
- Balanced allocations and the Gale-Shapley algorithm
- Compound Poisson processes
- Wiener-Ito integrals
- Fock space representation

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 150 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 90 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the module *Probability Theory* are recommended.

# M 2.161 Module: Potential Theory [M-MATH-102879]

**Coordinators:** Prof. Dr. Roland Griesmaier
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105850 | Potential Theory | 8 CP | Arens, Griesmaier, Hettlich, Reichel |

**Assessment**
The module will be completed by an oral exam (30 min).

**Prerequisites**
None

**Competence Goal**
Students can explain basic properties of harmonic functions and prove existence and uniqueness of solutions to boundary value problems for the Laplace equation in interior and exterior domains using integral equation techniques. They master representation theorems and are able to apply single- and double layer potentials to solver boundary value problems.

**Content**

- Properties of harmonic functions
- Existence and uniqueness of boundary value problems for the Laplace equation
- Fundamental solutions and Green's functions
- Single- and double layer potentials
- Integral equations

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research relating to the course content
- preparation for the module examination

# M 2.162 Module: Practical Course: Mathematical and Computational Methods in Robotics and AI [M-INFO-107609]

**Coordinators:** Prof. Dr. Katja Mombaur
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-114911 | Practical Course: Mathematical and Computational Methods in Robotics and AI | 6 CP | Mombaur |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
Students learn to understand scientific topics. They will learn how to address specific project tasks and solve them in a structured way. They will obtain deepened knowledge about fundamental mathematical and computational methods, including their potential, strengths and limitations and in which areas they are suited to be applied. Students learn to present their results to a an audience, as well as suitably documenting their results in form or in addition to a scientific paper and being capable of assessing the advantages and disadvantages of the methods used.

**Content**
Efficient mathematical and computational methods are an irreplaceable cornerstone of modern research and industrial applications in forms such as numerical simulation, optimization or inference, ranging from the generation of task-specific trajectories for robotic systems over stabilization of existing robots to data-driven prediction and inference as well as AI-applications.
In this practical course, students learn, on the basis of an individual programming project, how to implement and apply fundamental mathematical and computational methods to solve an existing task in a robotics application or related fields and gain experience leveraging methods from this area in said real-world context.

**Additional Information**
Limited number of projects and participants. Specific project topics will be different each term and will be announced in a presentation during the first semester week or can be indivdually agreed upon with people supervising the practical. Students can propose topics on their own as well.

**Workload**
Estimated effort for this module is 180 hours:
20h – In person events (kickoff meeting, individual meetings with supervisor, presentations)
130h – Individual project work
30h - Writing report and preparing presentation

**Recommendations**
Basic mathematical knowledge will be helpful, depending on topic. For Projects in the context of robotics, knowledge of robotics is recommended, but not strictly necessary.

# M 2.163 Module: Probability Theory and Combinatorial Optimization [M-MATH-102947]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105923 | Probability Theory and Combinatorial Optimization | 8 CP | Hug |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
None.

**Competence Goal**
The students

- know basic problems of combinatorial optimization as discussed in the lectures and are able to explain them,
- know typical methods for the probabilistic analysis of algorithms and combinatorial optimization problems and are able to use them for the solution of specific optimization problems,
- are familiar with the essential techniques of proof and are able to explain them,
- know how to work in a self-organized and self-reflexive manner.

**Content**
This course is devoted to the analysis of algorithms and combinatorial optimization problems in a probabilistic framework. A natural setting for the investigation of such problems is often provided by a (geometric) graph. For a given system (graph), the average or most likely behavior of an objective function of the system will be studied. In addition to asymptotic results, which describe a system as its size increases, quantitative laws for systems of fixed size will be described. Among the specific problems to be explored are

- the long-common-subsequence problem,
- packing problems,
- the Euclidean traveling salesperson problem,
- minimal Euclidean matching,
- minimal Euclidean spanning tree.

For the analysis of problems of this type, several techniques and concepts have been developed and will be introduced and applied in this course. Some of these are

- concentration inequalities and concentration of measure,
- subadditivity and superadditivity,
- martingale methods,
- isoperimetry,
- entropy.

**Module Grade Calculation**
The modul grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research related to the course content
- preparation for the module exam.

**Recommendations**
The contents of the module "Probability Theory" are strongly recommended.

# M 2.164 Module: Process Modeling in Downstream Processing [M-CIWVT-103066]

**Coordinators:** apl. Prof. Dr. Matthias Franzreb
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each summer term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106101 | Process Modeling in Downstream Processing | 4 CP | Franzreb |

**Assessment**
Learning control is an oral exam lasting approx. 20 minutes.

**Prerequisites**
None

**Competence Goal**
Students are able to sum up and explain equilibrium and kinetic equations relevant for chromatography modeling. They are able to explain the methods used for determination of equilibrium and kinetic parameters and can discuss examples. They are familiar with the principle of complex downstream processes, e.g. simulated moving beds, and can explain the differences to conventional chromatography. Using commercial software they are able to simulate chromatography processes and to analyze the results. On this basis they can optimize process parameters and fit them in order to meet given targets such as purity or yield. They can evaluate different processes and choose the variant for a given task.

**Content**
Fundamentals and practical examples of chromatography modeling,

Design rules for Simulated Moving Beds, Design of Experiments (DOE)

**Module Grade Calculation**
The grade of the oral examination is the module grade.

**Workload**

- Attendance time (Lecture): 30 h
- Homework: 60 h
- Exam Preparation: 30 h

# M 2.165 Module: Processing of Nanostructured Particles [M-CIWVT-103073]

**Coordinators:** Prof. Dr.-Ing. Hermann Nirschl
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106107 | Processing of Nanostructured Particles | 6 CP | Nirschl |

**Assessment**
Learning control is an oranl examination lasting approx. 25 minutes.

**Prerequisites**
None

**Competence Goal**
Ability to design a process technology for the manufacturing and production of nanoscale particles

**Content**
Development of technical process in particle engineering; particle characterisation, interface engineering, particle synthesis;
Typical processes: grinding, mixing, ganulation, selective separation,
classifying; fundamentals of apparatus and devices; simulation techniques, simulation tools

**Module Grade Calculation**
The grade of the oral examination is the module grade.

**Workload**

- Attendance time (Lecture): 60 h
- Homework: 60 h
- Exam Preparation: 60 h

**Literature**
Skriptum zur Vorlesung

# M 2.166 Module: Random Graphs and Networks [M-MATH-106052]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112241 | Random Graphs and Networks | 8 CP | Hug |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
none

**Competence Goal**
Students

- know the basic models of random graphs and their properties,
- are familiar with probabilistic techniques for the investigation of random graphs,
- are able to work in a self-organized and reflexive manner.

**Content**
In the course, models of random graphs and networks are presented and methods will be developed which allow to state and prove results about the structure of such models.

In particular, the following models are treated:

- Erdös--Renyi graphs
- Configuration models
- Preferential-Attachment graphs
- Generalized inhomogeneous random graphs
- Geometric random graphs

and the following methods are addressed:

- Branching processes
- Coupling arguments
- Probabilistic bounds
- Martingales
- Local convergence of random graphs

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Additional Information**
can not be completed together with M-MATH-102951 - Random Graphs

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination during the course of study

Self-study: 150 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
The contents of the module 'Probability Theory' are strongly recommended.

# M 2.167 Module: Real-Time Systems [M-INFO-100803]

**Coordinators:** Prof. Dr.-Ing. Thomas Längle
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-101340 | Real-Time Systems | 6 CP | Längle |

# M 2.168 Module: Regularity for Elliptic Operators [M-MATH-106696]

**Coordinators:** apl. Prof. Dr. Peer Kunstmann
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113472 | Regularity for Elliptic Operators | 6 CP | Kunstmann |

**Assessment**
The module will be completed by an oral exam (about 30 min).

**Prerequisites**
none

**Competence Goal**
The students

- can explain methods for definition of elliptic operators,
- can name results on spectral properties in L^q and relate them,
- can explain the relevance of heat kernel estimates and sketch corresponding methods of proof,
- can sketch the construction of the H^\infty calculus and name classes of elliptic operators for which it is bounded,
- can explain the concept of L^p maximal regularity and its relation to other parts of the theory and can name exmaples,
- have mastered the important techniques of proofs for regulariy properties of elliptic operators,
- are able to start a master thesis in the field.

**Content**

- elliptic operators in divergence and non-divergence form
- elliptic operators on domains with boundary conditions
- heat kernel estimates for elliptic operators
- spectrum of elliptic operators in Lebesgue spaces L^q
- maximal L^p regularity for the parabolic problem
- H^\infty functional calculus for elliptic operators
- L^q theory for parabolic boundary value problems

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The modules “Functional Analysis” and "Spectral Theory" are strongly recommended.

# M 2.169 Module: Riemann Surfaces [M-MATH-106466]

**Coordinators:** Prof. Dr. Frank Herrlich
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113081 | Riemann Surfaces | 8 CP | Herrlich |

**Assessment**
Oral examination of ca. 30 minutes.

**Prerequisites**
None

**Competence Goal**
Students know

- essential structural properties of Riemann surfaces,
- topological, analytic and algebraic methods for the investigation of Riemann surfaces, and are able to apply them.

**Content**

- Definition of Riemann surfaces
- holomorphic and meromorphic functions on Riemann surfaces
- Compact Riemann surfaces
- The Riemann-Roch theorem
- Uniformization, Fuchsian groups and hyperbolic metric
- Classification of compact Riemann surfaces

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
Some knowledge of complex analysis (e.g. *"Analysis 4"*) is strongly recommended as well as the modules *"Elementary Geometry"* and "*Introduction to Algebra and Number Theory*".

# M 2.170 Module: Robotics I - Introduction to Robotics [M-INFO-107162]

**Coordinators:** Prof. Dr.-Ing. Tamim Asfour
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-114190 | Robotics I - Introduction to Robotics | 6 CP | Asfour |

**Assessment**
See partial achivements (Teilleistung)

**Prerequisites**
See partial achivements (Teilleistung)

**Competence Goal**
The students are able to apply the presented concepts to simple and realistic tasks from robotics. This includes mastering and deriving the mathematical concepts relevant for robot modeling. Furthermore, the students master the kinematic and dynamic modeling of robot systems, as well as the modeling and design of simple controllers. The students know the algorithmic basics of motion and grasp planning and can apply these algorithms to problems in robotics. They know algorithms from the field of image processing and are able to apply them to problems in robotics. They are able to model and solve tasks as a symbolic planning problem. The students have knowledge about intuitive programming procedures for robots and know procedures for programming and learning by demonstration.

**Content**
The lecture provides an overview of the fundamentals of robotics using the examples of industrial robots, service robots and autonomous humanoid robots. An insight into all relevant topics is given. This includes methods and algorithms for robot modeling, control and motion planning, image processing and robot programming. First, mathematical basics and methods for kinematic and dynamic robot modeling, trajectory planning and control as well as algorithms for collision-free motion planning and grasp planning are covered. Subsequently, basics of image processing, intuitive robot programming especially by human demonstration and symbolic planning are presented.

In the exercise, the theoretical contents of the lecture are further illustrated with examples. Students deepen their knowledge of the methods and algorithms by independently working on problems and discussing them in the exercise. In particular, students can gain practical programming experience with tools and software libraries commonly used in robotics.

**Workload**
Lecture with 3 SWS + 1 SWS Tutorial, 6 LP
6 LP corresponds to 180 hours, including
15 * 3 = 45 hours attendance time (lecture)
15 * 1 = 15 hours attendance time (tutorial)
15 * 6 = 90 hours self-study and exercise sheets
30 hours preparation for the exam

# M 2.171 Module: Robotics II - Humanoid Robotics [M-INFO-102756]

**Coordinators:** Prof. Dr.-Ing. Tamim Asfour
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Each summer term | 1 term | English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-105723 | Robotics II - Humanoid Robotics | 3 CP | Asfour |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
The students have an overview of current research topics in autonomous learning robot systems using the example of humanoid robotics. They are able to classify and evaluate current developments in the field of cognitive humanoid robotics.

The students know the essential problems of humanoid robotics and are able to develop solutions on the basis of existing research.

**Content**
The lecture presents current work in the field of humanoid robotics that deals with the implementation of complex sensorimotor and cognitive abilities. In the individual topics different methods and algorithms, their advantages and disadvantages, as well as the current state of research are discussed.

The topics addressed are: Applications and real world examples of humanoid robots; biomechanical models of the human body, biologically inspired and data-driven methods of grasping, imitation learning and programming by demonstration; semantic representations of sensorimotor experience as well as cognitive software architectures of humanoid robots.

**Workload**
Lecture with 2 SWS, 3 CP.
3 LP corresponds to approx. 90 hours, thereof:
approx. 15 * 2h = 30 Std. Attendance time
approx. 15 * 2h = 30 Std. Self-study prior/after the lecture
approx. 30 Std. Preparation for the exam and exam itself

**Recommendations**
Having visited the lectures on Robotics I - Introduction to Robotics and Mechano-Informatics and Robotics is recommended.

# M 2.172 Module: Robotics III - Sensors and Perception in Robotics [M-INFO-104897]

**Coordinators:** Prof. Dr.-Ing. Tamim Asfour
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-109931 | Robotics III - Sensors and Perception in Robotics | 3 CP | Asfour |

**Assessment**
See partial achivements (Teilleistung)

**Prerequisites**
See partial achivements (Teilleistung)

**Competence Goal**
Students can name the main sensor principles used in robotics.

Students can explain the data flow from physical measurement through digitization to the use of the recorded data for feature extraction, state estimation and semantic scene understanding.

Students are able to propose and justify suitable sensor concepts for common tasks in robotics.

**Content**
The lecture supplements the lecture Robotics I with a broad overview of sensors used in robotics. The lecture focuses on visual perception, object recognition, semantic scene interpretation, and (inter-)active perception. The lecture is divided into two parts:

In the first part a comprehensive overview of current sensor technologies is given. A basic distinction is made between sensors for the perception of the environment (exteroceptive) and sensors for the perception of the internal state (proprioceptive).

The second part of the lecture concentrates on the use of exteroceptive sensors in robotics. The topics covered include tactile exploration and visual data processing, including advanced topics such as feature extraction, object localization,semantic scene interpretation, and (inter-)active perception.

**Workload**
Lecture with 2 SWS, 3 LP
3 LP corresponds to 90 hours, including
15 * 2 = 30 hours attendance time
15 * 2 = 30 hours self-study
30 hours preparation for the exam

**Recommendations**
Attending the lecture Robotics I – Introduction to Robotics is recommended.

# M 2.173 Module: Ruin Theory [M-MATH-104055]

**Coordinators:** Prof. Dr. Vicky Fasen-Hartmann
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-108400 | Ruin Theory | 4 CP | Fasen-Hartmann |

**Assessment**
The module will be completed by an oral exam (approx. 20 min).

**Prerequisites**
None

**Competence Goal**
Students are able to

- name and discuss key concepts and results of ruin theory with applications in actuarial mathematics and can apply them to examples,
- apply specific probabilistic methods to analyse risk processes,
- master proof techniques,
- work in a self-orientated and reflective manner.

**Content**

- renewal theory
- classical risk process of Cramér and Lundberg
- asymptotic behaviour of the probability of ruin probability if the Lundberg constant exists (losses with light tailed distributions)
- subexponential distributions
- asymptotic behaviour of the probability of ruin if the losses are subexponentially distributed (losses with heavy tailed distributions)
- approximation of the ruin probability
- integrated risk processes
- portfolio of risk processes

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance time: 45 hours

- Course and exercises including module examination during the course

Self-study: 75 hours

- Consolidation of the course content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
The content of the module "Probability Theory" is recommended.

# M 2.174 Module: Sampling Methods for Machine Learning [M-INFO-107090]

**Coordinators:** Prof. Dr.-Ing. Uwe Hanebeck
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-114133 | Sampling Methods for Machine Learning | 6 CP | Hanebeck |
| T-INFO-114134 | Sampling Methods for Machine Learning - Pass | 0 CP | Hanebeck |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
Students will understand and be able to implement various sampling techniques, from basic random number generation to advanced methods like normalizing flows. They will develop the ability to evaluate sampling quality, optimize procedures, and select appropriate methods for specific machine learning tasks. Graduates will be capable of independently developing sampling solutions for complex problems and critically assessing different approaches. Their comprehensive understanding will enable them to engage with current developments in the field and apply their knowledge effectively in both research and practical applications. This will be supported via a digital exercise.

**Content**
Sample-based inference is the de-facto standard for solving otherwise infeasible problems in machine learning, estimation, and control under (unavoidable) uncertainties. Thus, it is an important foundation for further studies. This lecture gives a thorough overview of state-of-the-art sampling methods and discusses current developments from the research frontier.

The first part shows how to efficiently sample large numbers of random samples from given densities starting with the special cases of uniform and Gaussian distributions. For sampling from arbitrary densities, important techniques such as inverse transform sampling, Knothe-Rosenblatt maps, Markov chain Monte Carlo, normalizing flows, and Langevin equations are introduced.

The second part is concerned with deterministic or low-discrepancy sampling, where the goal is to find a set of representative samples of a given density. These are usually obtained by optimization, which, in contrast to random samples, leads to good coverage, high homogeneity, and reproducible results. To analyze and synthesize such samples, various statistical tests and discrepancy measures are presented. This includes scalar tests such as the Cramér-von Mises test, Kolmogorov-Smirnov test, and multivariate generalizations based on Localized Cumulative Distributions and Stein discrepancy.

Finally, advanced topics such as importance sampling and sampling from the posterior density in a Bayesian update are discussed. Typical applications of sample-based inference include Bayesian neural networks, information fusion, and reinforcement learning.

**Workload**
Per week:
2 SWS Presence
2h Follow-up
6h Digital exercise with programming tasks
2h Exam preparation
= 12h/week und 180h/semester

**Recommendations**
Knowledge of a higher programming language with sophisticated libraries for scientific-numerical computing (e.g. Julia, Matlab, Python) is advantageous.

# M 2.175 Module: Scattering Theory [M-MATH-102884]

**Coordinators:** PD Dr. Frank Hettlich
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105855 | Scattering Theory | 8 CP | Arens, Griesmaier, Hettlich |

**Assessment**
The module will be completed by an oral exam (~30min.)

**Prerequisites**
none

**Competence Goal**
The students can prove and apply basic properties of solutions of the Helmholtz equation in the interior and in the exterior of a domain. They know about the representation theorems for such solutions. Students can explain the existence theory of corresponding boundary value problems by integral equations and/or variational formulations including appropriate proofs. Furthermore, the students can show and apply the dependence of a scattered field on the scattering object and the wave number as well as the relationship with its far field pattern.

**Content**

- Helmholtz equation and elementary soultions
- Greens representation theorems
- Existence and uniqueness of scattering problems
- Radiation condition and far field pattern

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240h

Attendance: 90h

- lecture, problem class, examination

Self-studies: 150h

- follow-up and deepening of the course content
- work on problem sheets
- literature study and internet research related to the course content
- preparation for the module exam

**Recommendations**
One of the following modules should already be covered: functional analysis or integral equations

# M 2.176 Module: Scattering Theory for Time-dependent Waves [M-MATH-106664]

**Coordinators:** Prof. Dr. Roland Griesmaier
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113416 | Scattering Theory for Time-dependent Waves | 6 CP | Griesmaier |

**Assessment**
The module will be completed with an oral exam of about 30 minutes.

**Prerequisites**
None

**Competence Goal**
The students can prove and apply basic properties of solutions of the wave equation in interior or exterior domains. They know about representation theorems for such solutions and can apply the Fourier-Laplace-transform to analyze causal solutions. Students master the existence and uniqueness theory of associated boundary value problems using integral equations and retarded single and double layer potentials including proofs. Furthermore, the students can apply these results to scattering problems and explain the depence of scattered waves on the scattering object as well as the relationship with its far field pattern.

**Content**

- Wave equations and elementary solutions
- Representation theorems
- Fourier-Laplace-transform
- Boundary element formulations of boundary value problems for the wave equation
- Existence and uniqueness of solutions to interior and exterior boundary value problems
- Scattering problems and far field patterns

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 h

Self studies: 120 h

**Recommendations**
The modules *Functional Analysis* and/or *Integral Equations* are recommended.

# M 2.177 Module: Selected Methods in Fluids and Kinetic Equations [M-MATH-105897]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111853 | Selected Methods in Fluids and Kinetic Equations | 3 CP | |

**Assessment**
The module will be completed with an oral exam (approx. 30 min).

**Prerequisites**
none

**Competence Goal**
The main aim of this lecture is to introduce students to tools and techniques developed in recent years to analyze the evolution of fluids and kinetic equations.
The students will learn how to use these techniques and how to apply them to families of equations.

**Content**
In this lecture we discuss selected techniques and tools that have lead to significant progress in the analysis of fluids and kinetic eqautions.
These, for instance, include:
- energy methods and local well-posedness results (e.g. fixed point results, Osgood lemma)
- Newton iteration
- Cauchy-Kowalewskaya and ghost energy approaches

No prior knowledge of fluids or kinetic equations is required.

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 90 hours

Attendance: 30 h

- lectures and examination

Self studies: 60 h

- follow-up and deepening of the course content,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The modules "Classical Methods for Partial Differential Equations" and "Functional Analysis" are recommended.

# M 2.178 Module: Selected Topics in Harmonic Analysis [M-MATH-104435]

**Coordinators:** PD Dr. Ioannis Anapolitanos
Prof. Dr. Dirk Hundertmark

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Irregular | 1 term | German | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-109065 | Selected Topics in Harmonic Analysis | 3 CP | Hundertmark |

**Assessment**
Oral examination with a duration of approx. 30 minutes.

**Prerequisites**
None

**Competence Goal**
The students are familiar with the concepts of singular integral operators and weighted estimates in Harmonic Analysis. They know the relations between the BMO space and the Muckenhoupt weights and also how to use dyadic analysis operators to obtain estimates for Calderon-Zygmund operators.

**Content**

- Calderon-Zygmund and Singular Integral operators
- BMO space and Muckenhoupt weights
- Reverse Holder Inequality and Factorisation of Ap weights
- Extrapolation Theory and weighted norm inequalities for singular integral operators

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 90 hours

Contact hours: 30 hours

- Course including module examination

Self studies: 60 hours

- Deepening the study content by working on the lecture content at home
- completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
Knowledge of the following topics is strongly recommended: Measure theory, Lebesgue spaces, Fourier transform, Distributions and Functional Analysis

# M 2.179 Module: Semigroup Theory for the Navier-Stokes Equations [M-MATH-106663]

**Coordinators:** Dr. rer. nat. Patrick Tolksdorf
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-113415 | Semigroup Theory for the Navier-Stokes Equations | 6 CP | Tolksdorf |

**Assessment**
The module will be completed with an oral exam of about 30 minutes.

**Prerequisites**
None

**Competence Goal**
After a successful participation of the course, students are familiar with essential concepts of semigroup theory, such as analytic semigroups and fractional powers of sectorial operators. They are able to apply these concepts to the Stokes operator and derive basic regularity properties of solutions to the Stokes equations. Furthermore, they can use these concepts to construct solutions to the Navier-Stokes equations in critical spaces through an iteration scheme.

**Content**
Content from abstract semigroup theory:

- Sectorial operators
- Analytic semigroups
- Fractional powers

Content from fluid mechanics:

- Helmholtz decomposition
- Bogovskii operator
- Stokes operator
- Mapping properties of the Stokes semigroup
- Solvability of the Navier-Stokes equations in critical spaces

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The following modules are strongly recommended: *Functional Analysis* and *Classical Methods for Partial Differential Equations.*

# M 2.180 Module: Seminar [M-MATH-102730]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (mandatory)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | pass/fail | Each term | 1 term | German/English | 4 | 3 |

| Elective Seminar (Elective: 1 item) | | | |
|---|---|---|---|
| T-MATH-105686 | Seminar Mathematics | 3 CP | Kühnlein |

**Assessment**
The control of success (pass/fail) is based on a seminar talk lasting at least 45 minutes.

**Prerequisites**
None

**Competence Goal**
At the end of the module, participants should

- have analyzed a specific problem in a mathematical area
- be able to discuss subject-specific problems in the given context and present as well as defend them, using suitable media
- have summarized the most relevant results of their topic
- have communicative, organizational and didactic skills in complex problem analyses at their disposal. They can use techniques of scientific work.

**Content**
The specific content is based on the seminar topics being offered.

**Module Grade Calculation**
Omitted, as ungraded (pass/fail)

**Workload**
Total work load: 90 hours

Attendance: 30 hours

Self studies: 60 hours

- Preparation of the scientific content of the talk
- Preparation of a didactical concept for the talk
- Preparation of the presentation (blackboard, beamer, etc.)
- getting practice for the talk, creating a hand-out

# M 2.181 Module: Seminar Advanced Topics in Parallel Programming [M-INFO-101887]

**Coordinators:** Prof. Dr. Achim Streit
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 3 CP | graded | Each summer term | 1 term | German/English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-103584 | Seminar Advanced Topics in Parallel Programming | 3 CP | Streit |

# M 2.182 Module: Signal Processing Methods [M-ETIT-106899]

**Coordinators:** Prof. Dr.-Ing. Sander Wahls
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-113837 | Signal Processing Methods | 6 CP | Wahls |

**Assessment**
Written exam, approx. 120 minutes.

**Prerequisites**
none

**Competence Goal**
Students can

- choose appropriate estimation methods based on theoretical properties and practical considerations
- determine estimators for specific problems
- can weight the pros and cons of data decomposition methods; apply them to given problems; interpret the results
- understand the advantages and limitations of the considered time-frequency analysis methods
- interpret time-frequency representations
- choose appropriate analysis and synthesis windows/wavelets
- determine time-frequency transforms of given signals

**Content**
This module introduces students to advanced signal processing methods that are widely employed in engineering. The three main topic areas are

1. Parameter estimation
2. Decomposition of data into components and modes
3. Time-frequency analysis

The following topics are treated:

- Best linear unbiased estimator
- Maximum likelihood estimation
- General Bayesian estimators
- Linear Bayesian estimators
- Principal component analysis
- Independent component analysis
- Dynamic and empirical mode decomposition
- Hilbert spaces and frames
- Short-time Fourier transform
- Wavelets
- Analytic signals
- Wigner-Ville-Distribution
- Huang-Hilbert transform

Illustrating examples from diverse application areas are discussed.

**Module Grade Calculation**
The module grade is the grade of the written exam.

**Workload**
The workload includes:

1. attendance in lectures and tutorials: 15*4 h = 60 h
2. preparation / follow-up: 15*4 h = 60 h
3. preparation of and attendance in examination: 60 h

A total of 180 h = 6 CR

**Recommendations**
Familiarity with signals and systems (in particular, Fourier transforms) and probability theory at the Bachelor level is assumed.

# M 2.183 Module: Signal Processing with Nonlinear Fourier Transforms and Koopman Operators [M-ETIT-106675]

**Coordinators:** Prof. Dr.-Ing. Sander Wahls
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-113428 | Signal Processing with Nonlinear Fourier Transforms and Koopman Operators | 6 CP | Wahls |

**Assessment**
The examination in this module consists of programming assessments and a graded written examination of 120 minutes.

The programming assignments are either pass or fail. They must be passed during the lecture period for admission to the written examination.

**Prerequisites**
none

**Competence Goal**
Students

- understand the basic theory of linear operator on Hilbert spaces and can analyze simple operators analytically
- know the use cases for selected integrable partial differential equations (PDEs) and can apply them under non-ideal circumstances (small non-integrable terms)
- can determine the PDE corresponding to a given Lax-pair and check if the PDE is actually integrable (i.e. check if the Lax pair is “fake”)
- understand the theory of nonlinear Fourier analysis for selected PDEs and can compute nonlinear (inverse) Fourier transforms numerically and, in simple cases, analytically
- know and implement practical engineering applications of nonlinear Fourier transforms
- understand the theory of the Koopman operator including selected engineering applications
- compute Koopman spectra numerically using data-driven methods and use them in practical engineering applications

**Content**
This module introduces students to signal processing methods that rely on nonlinear Fourier transforms and Koopman operators. These methods allow us to transform large classes of nonlinear systems such that they essentially behave like linear systems. They can also be used to decompose signals driven by such systems into physically meaningful nonlinear wave components (for example, solitons).

While these methods originated in mathematical physics, there has been a growing interesting of exploiting their unique capabilities in engineering contexts. The goal of this module is to give engineering students a practical introduction to this area. It provides the necessary theoretical background, enables students to apply the methods in practice via computer assignments, and discusses recent research from the engineering literature.

The following topics will be discussed:

- Introduction to linear operators on Hilbert spaces
- Integrable model systems (Korteweg-de Vries equation, Nonlinear Schrödinger equation)
- Lax-integrable systems (representations of Lax pairs, fake Lax pairs, conserved quantities)
- Solution of integrable model systems using nonlinear Fourier transforms (inverse scattering method) and the unified transform method
- Physical interpretation of nonlinear Fourier spectra (in particular, solitons)
- Practical applications of nonlinear Fourier transforms
- Theoretical properties of Koopman operators
- Data-driven computation of Koopman operators (residual dynamic mode decomposition)
- Practical applications of Koopman operators

**Module Grade Calculation**
The module grade is the grade of the written exam.

**Additional Information**
Some tutorial sessions will be classically devoted to solving pen and paper problems, but in others students will be working on their practical computer assignments. For the latter, students have to bring their own laptops with Matlab installed. The solutions of the computer assignments must be submitted by the provided deadlines, which are typically one week after the corresponding tutorial has taken place.

**Workload**
The workload includes:

1. attendance in lectures and tutorials: 15*4 h = 60 h
2. preparation / follow-up: 30*3 h = 60 h
3. finishing programming assignments: 30 h
4. preparation of and attendance in examination: 30 h

A total of 180 h = 6 CR

**Recommendations**
Familiarity with signals and systems at the Bachelor level (Fourier and Laplace transforms, linear systems, etc.) is assumed.

# M 2.184 Module: Simulation and Optimization in Robotics and Biomechanics [M-INFO-106504]

**Coordinators:** Prof. Dr. Katja Mombaur
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-113123 | Simulation and Optimization in Robotics and Biomechanics | 6 CP | Mombaur |
| T-INFO-114838 | Simulation and Optimization in Robotics and Biomechanics - Pass | 0 CP | Mombaur |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
The students
- can explain advanced principles of modeling, optimization and control of dynamic processes, in particular mechanical systems and can apply them
- can model, classify and analyze complex motions in robotics or biomechanics, and investigate specific properties such as stability.
- can apply nonlinear optimization and optimal control methods and can compare and evaluate different mathematical approaches.
- know how to use software tools based on C++ and Lua for modeling, simulation, optimization and visualization of humanoid and robotic systems

are capable of solving optimal control problems numerically and to evaluate the quality of the solution.

**Content**
The goal of this course is to give a practical introduction into simulation and optimization of motions in robotics and biomechanics. Simulation and optimization play an important role in generating and controlling motions in complex robotics systems and in predicting and analyzing motions of humans. Theory and methods will be covered, but the focus is on the use software tools for modeling, simulation, optimization and visualization of multibody systems. Topics covered include:
- Dynamic process modeling
- Transforming real world problems into mathematical models
- Modeling of complex robotics and biomechanics systems (e.g. humanoids), based on previous modeling knowledge
- Common template models for bipedal walking and running in robotics and biomechanics
- Simulation of mechanical / robotics systems (Integrators and Initial value problems)
- Boundary value problems
- Nonlinear optimization problems
- Optimal control problems
- Direct and indirect methods for optimal control problems, focus on direct methods, especially direct multiple shooting
- Stability of dynamical systems, stability in biomechanics and robotics

**Additional Information**
Limitation to 30 participants

**Workload**
Estimated effort for this module is 180 hours:
60h - Lecture and exercises (2+2 SWS)
80h - Independent work (repetition of lecture contents, preparation of assignments
40h - Exam preparation

# M 2.185 Module: Sobolev Spaces [M-MATH-102926]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105896 | Sobolev Spaces | 8 CP | Frey, Schnaubelt |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
None

**Competence Goal**
Students can explain the significance of Sobolev spaces for partial differential equations and apply the theory to examples. They are able to reproduce and prove the basic properties of the spaces and to describe the central methods. They can discuss the central theorems and their significance and describe the main ideas of the proofs.

**Content**
Definition of Sobolev spaces for functions on Lipschitz domains; density and extension results; product, composition and interpolation estimates; embeddings including compactness, traces, duality; Helmholtz decomposition in R^3; simple applications to partial differential equations.

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The module "Functional Analysis" is strongly recommended.

# M 2.186 Module: Software Engineering II [M-INFO-107235]

**Coordinators:** Prof. Dr.-Ing. Anne Koziolek
Prof. Dr. Raffaela Mirandola
Prof. Dr. Ralf Reussner

**Organisation:** KIT Department of Informatics

**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-114259 | Software Engineering II | 6 CP | Koziolek, Mirandola, Reussner |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
Software processes: Students understand evolutionary and incremental development and can describe the advantages over the sequential approach. They can describe the phases and disciplines of the unified process.

Requirements engineering: Students can describe the terms of requirements engineering and name activities in the requirements engineering process. They can classify and assess requirements according to the facets of type and representation. They can apply basic guidelines for specifying natural language requirements and describe prioritization procedures for requirements. Describe the purpose and elements of use case models. You can classify use cases according to their granularity and objectives. You can create use case diagrams and use cases. They can derive system sequence diagrams and operation contracts from use cases and can describe their role in the software development process.

Software architecture: Students can reproduce and explain the definition of software architecture and software components. They can explain the difference between software architecture and software architecture documentation. They can describe the advantages of explicit architecture and the factors influencing architecture decisions. You can assign design decisions and elements to the layers of an architecture. You will be able to describe what component models define. They can describe the components of the Palladio component model and discuss some of the design decisions made.

Enterprise Software Patterns: Students can characterize enterprise applications and decide for a described application which properties it fulfills. They know patterns for structuring domain logic, architectural patterns for data access and object-relational structure patterns. They can select a suitable pattern for a design problem and justify the selection based on the advantages and disadvantages of the patterns.

Software design: Students can assign the responsibilities resulting from system operations to classes or objects in object-oriented design using the GRASP patterns and thus design object-oriented software.

Software quality: Students know the principles for readable program code, can identify violations of these principles and develop proposals for solutions.

Model-driven software development: Students can describe the goals and the idealized division of labor of model-driven software development (MDSD) and reproduce and explain the definitions for model and metamodel. They can discuss the goals of modeling. You will be able to describe the model-driven architecture and express constraints in the Object Constraint Language. You can express simple transformation fragments of model-to-text transformations in a template language. You can weigh up the advantages and disadvantages of MDSD.

Embedded systems: Students will be able to explain the principle of a real-time system and why they are usually implemented as parallel processes. They can describe a rough design process for real-time systems. They can describe the role of a real-time operating system. They can distinguish between different classes of real-time systems.

Reliability: Students can describe the various dimensions of reliability and categorize a given requirement. They can illustrate that unit tests are not sufficient to evaluate software reliability and can describe how usage profile and realistic error data have an influence.

Domain-driven design (DDD): Students are familiar with the design metaphor of ubiquitous language, Closed Contexts, and Strategic Design. They can describe a domain using the DDD concepts, entity, value objects, services, and improve the resulting domain model using the patterns of aggregates, factories, and depots. They know the different types of interactions between Closed Contexts and can apply them.

Security (in the sense of security): Students can describe the basic ideas and challenges of security assessment. They can recognize common security problems and propose solutions.

**Content**
Requirements engineering, software development processes, software quality, software architectures, MDD, Enterprise Software Patterns software maintainability, software security, dependability, embedded software, middleware, domain-driven design

**Additional Information**
The Software Engineering II module is a basic module.

**Workload**
Preparation and follow-up time 1.5 h / 1 SWS

Total workload:
(4 SWS + 1.5 x 4 SWS) x 15 + 30 h exam preparation = 180 h = 6 ECTS

# M 2.187 Module: Space and Time Discretization of Nonlinear Wave Equations [M-MATH-105966]

**Coordinators:** Dr. rer. nat. Benjamin Dörich
Prof. Dr. Marlis Hochbruck

**Organisation:** KIT Department of Mathematics

**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112120 | Space and Time Discretization of Nonlinear Wave Equations | 6 CP | Hochbruck |

**Assessment**
Oral exam of approximately 20 minutes.

**Prerequisites**
None.

**Competence Goal**
Graduates

- can name and discuss essential concepts of error analysis of space and time discretizations for nonlinear wave equations,
- are prepared to write a thesis in the field of numerics of partial differential equations.

**Content**
The topic of the lecture is a unified error analysis of the space and time discretization of nonlinear wave-like equations. For this purpose, evolution equations with monotone operators on Hilbert spaces and different types of space discretization are considered, e.g. finite elements, discontinuous Galerkin methods or spectral methods, and, in particular, non-conformal discretizations.

After the analysis of the space discretization errors, this is combined with time integration methods such as the Crank-Nicolson and an implicit-explicit method.

The abstract analysis is illustrated with concrete examples.

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 180 h

Attendance: 60 h

- lectures, problem classes, and examination

Self-studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination.

**Recommendations**
Basic knowledge of partial differential equations and the contents of the modules M-MATH-102888 - Numerische Methoden für Differentialgleichungen and M-MATH-102891 - Finite Elemente Methoden are strongly recommended. Knowledge of functional analysis is also recommended.

# M 2.188 Module: Spatial Stochastics [M-MATH-102903]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each winter term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105867 | Spatial Stochastics | 8 CP | Hug, Last, Winter |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
none

**Competence Goal**
The students are familiar with some basic spatial stochastic processes. They do not only understand how to deal with general properties of distributions, but also know how to describe and apply specific models (Poisson process, Gaussian random fields). They know how to work self-organised and self-reflexive.

**Content**

- Random sets
- Point processes
- Random measures
- Palm distributions
- Random fields
- Gaussian fields
- Spectral theory of random fields
- Spatial ergodic theorem

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the module *Probability Theory* are recommended.

# M 2.189 Module: Special Topics of Numerical Linear Algebra [M-MATH-102920]

**Coordinators:** Prof. Dr. Marlis Hochbruck
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | see Annotations | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105891 | Special Topics of Numerical Linear Algebra | 8 CP | Grimm, Hochbruck, Neher |

**Assessment**
Oral exam of approximately 30 minutes.

**Prerequisites**
None.

**Competence Goal**
At the end of the course, students possess informed knowledge of methods and concepts of numerical linear algebra for large matrices. For various applications, they choose and implement the right numerical methods and they are able to assess and establish convergence properties of these methods. Students are able to solve problems in a self-organized and reflective manner, and to present and discuss solutions.

**Content**

- Direct methods for sparse linear systems
- Krylov subspace methods for large linear systems and eigenvalue problems
- matrix functions

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**
Bi-yearly course.

**Workload**
Total workload: 240 h

Attendance: 90 h

- lectures, problem classes, and examination

Self-studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination.

**Recommendations**
Numerical analysis 1 and 2.

# M 2.190 Module: Spectral Theory [M-MATH-101768]

**Coordinators:** Prof. Dr. Dorothee Frey
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-103414 | Spectral Theory - Exam | 8 CP | Frey, Herzog, Hundertmark, Kunstmann, Schnaubelt, Tolksdorf |

**Assessment**
Oral examination of approx. 30 minutes.

**Prerequisites**
none

**Competence Goal**
After participation, students

- understand the concepts of spectrum and resolvent of closed operators on Banach spaces.
- know their basic properties and are able to explain them in simple examples.
- can explain and justify the special features of compact operators and the Fredholm Alternative.
- can deduce algebraic identities and norm bounds for operators by means of the Dunford functional calculus and the spectral calculus for self-adjoint operators. This in particular includes spectral projections and spectral mapping theorems.
- are able to apply this general theory to integral and differential equations, and recognize the importance of spectral theoretic methods in Analysis.

**Content**

- Closed operators on Banach spaces,
- Spectrum and resolvent,
- Compact operators and Fredholm alternative,
- Dunford functional calculus, spectral projections,
- Fourier transform,
- Unbounded self-adjoint operators on Hilbert spaces,
- Spectral theorem,
- Sesquilinear forms and sectorial operators,
- Applications to partial differential equations.

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 h

- lectures, problem classes and examination

Self studies: 150 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The module „Functional Analysis“ is strongly recommended.

# M 2.191 Module: Spectral Theory of Differential Operators [M-MATH-102880]

**Coordinators:** Prof. Dr. Michael Plum
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105851 | Spectral Theory of Differential Operators | 8 CP | Plum |

**Assessment**
Oral examination lasting approx. 30 minutes.

**Prerequisites**
None.

**Competence Goal**
At the end of the module, students know the meaning of spectral problems and can deal with basic spectral concepts. They are able to apply these to various spectral problems arising in connection with differential equations.

**Content**
Spectral properties of self-adjoint operators, application to ordinary and elliptic differential operators of regular type, singular type (Weyl theory) as well as to periodic differential operators (Floquet-Bloch theory); supplementary: non-self-adjoint differential operators.

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination

Self-study: 150 hours

- Consolidation by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet search
- Preparation for the module examination

**Recommendations**
The modules Boundary and Eigenvalue Problems and Functional Analysis are recommended.

# M 2.192 Module: Splitting Methods for Evolution Equations [M-MATH-105325]

**Coordinators:** Prof. Dr. Tobias Jahnke
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-110805 | Splitting Methods for Evolution Equations | 6 CP | Jahnke |

**Assessment**
The module will be completed by an oral exam (about 30 min).

**Prerequisites**
None

**Competence Goal**
After attending the course, students can explain the concept and the advantages of splitting methods. They know important examples of such methods and typical problem classes to which these methods can be applied. They can explain the relation between classical order and accuracy, and they know the (classical) order conditions of such methods. Students can reproduce and explain error estimates for splitting methods for linear and nonlinear evolution equations, and to explain the essential steps of the proof as well as the relevance of the made assumptions.

**Content**

- Concept and advantages of splitting methods
- Splitting methods for ordinary differential equations
- Baker-Campbell-Hausdorff formula and order conditions
- Tools from operator theory
- Splitting methods for linear evolution equations (Schrödinger equation, parabolic problems)
- Splitting methods for nonlinear evolution equations (nonlinear Schrödinger equation, Gross-Pitaevskii equation, Korteweg-de Vries equation)

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**
The module will be offered about every second summer semester.

**Workload**
Total workload: 180 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 120 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Familiarity with ordinary differential equations and Runge-Kutta methods (construction, order, stability) is strongly recommended.

# M 2.193 Module: Statistical Learning [M-MATH-105840]

**Coordinators:** Prof. Dr. Mathias Trabs
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111726 | Statistical Learning | 8 CP | Trabs |

**Assessment**
The module will be completed with an oral exam (approx. 30 min).

**Prerequisites**
none

**Competence Goal**
At the end of the course, students

- know the fundamental principles and problems of machine learning and can relate learning methods to these,
- are able to explain how selected machine learning methods work and can apply these,
- are able to derive and to discuss a statistical analysis of selected learning methods,
- are able to independently develop and apply new learning methods.

**Content**
The course aims for a rigorous and mathematical analysis of some popular machine learning methods with a focus is on statistical aspects. Topics are:

- Regression
  - Empirical risk minimization
  - Lasso
  - Regression trees and Random forests
- Classification
  - Bayes classifier
  - model based classifiers (e.g. logistic regression, discriminant analysis)
  - model-free classifiers (e.g. k nearest neighbors, support vector machines)
- Neural networks
  - training
  - approximation properties
  - statistical analysis
- Unsupervised learning
  - principle component analysis
  - clustering
  - generative models

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The modules "Probability Theory" and "Statistics" (M-MATH-103220) are recommended.

# M 2.194 Module: Statistical Thermodynamics [M-CIWVT-103059]

**Coordinators:** Prof. Dr. Sabine Enders
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | German/English | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106098 | Statistical Thermodynamics | 6 CP | Enders |

**Assessment**
Learning control is an oral examination lasting approx. 30 minutes.

**Prerequisites**
Thermodynamics III

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module M-CIWVT-103058 - Thermodynamics III must have been passed.

**Competence Goal**
students will be able to

- explain and apply the basic principles of statistical mechanics (Boltzmann and Gibbs methods),
- establish the connection between microscopic properties and macroscopic material properties,
- develop and apply equations of state and activity coefficient models for complex material systems, and evaluate their advantages and disadvantages in process engineering.

**Content**
Boltzmann-method, Gibbs-method, real gases, quations of state, polymers

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**
If required, the course will be offered in English.

**Workload**

- Lectures and exercises: 60 hrs
- Homework, wrap-up of lectures and exercises: 60 hrs
- Exam preparation: 60 hrs

**Literature**


- J. Blahous, Statistische Thermodynamik, Hirzel Verlag Stuttgart, 2007.
- H.T. Davis, Statistical Mechanics of Phases, Interfaces, and Thin Films, Wiley-VCH, New York, 1996.
- G.G, Gray, K.E. Gubbins, Theory of Molecular Fluids Fundamentals. Clarendon, Press Oxford, 1984.
- J.P. Hansen, I.R. McDonald, Theory of Simple Liquids with Application to Soft Matter. Fourth Edition, Elsevier, Amsterdam, 2006.
- G.H. Findenegg, T. Hellweg, Statistische Thermodynamik, 2. Auflage,
- Springer Verlag, 2015.
- J.O. Hirschfelder, C.F. Curtis, R.B. Bird, Molecular Theory of Gases and Liquids. John-Wiley & Sons, New York, 1954.

# M 2.195 Module: Steins Method with Applications in Statistics [M-MATH-105579]

**Coordinators:** Dr. rer. nat. Bruno Ebner
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111187 | Steins Method with Applications in Statistics | 4 CP | Ebner, Hug |

**Assessment**
The module assessment takes the form of an oral comprehensive examination (approx. 25 minutes).

**Prerequisites**
None.

**Competence Goal**
Graduates can

- name and discuss the fundamentals of Stein's method and its applications to selected problems,
- prove central limit theorems and Poisson limit theorems using Stein's method,
- describe applications in statistics,
- work in a self-organized and reflective manner.

**Content**

- Stein equations for the univariate and multivariate normal distribution as well as for the Poisson distribution,
- local dependencies and dependency graphs,
- application of the above techniques to selected problems such as random graphs,
- Stein operators; characterization of distribution families,
- density and generator approaches,
- application of the above approaches to goodness-of-fit tests and minimum-distance estimators

**Module Grade Calculation**
The module grade is the grade awarded for the oral examination.

**Workload**
Total workload: 120 hours

Contact hours: 45 hours

Course, including the exam

Independent study: 75 hours

- Deepening of course content through at-home review of the lecture material,
- Completion of exercise assignments,
- Deepening of course content using suitable literature and online research,
- Preparation for the exam.

**Recommendations**
The contents of the module "Probability Theory" are strongly recommended. Knowledge of the module "Mathematical Statistics" is recommended.

# M 2.196 Module: Stochastic Control [M-MATH-102908]

**Coordinators:** Prof. Dr. Nicole Bäuerle
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105871 | Stochastic Control | 4 CP | Bäuerle |

**Assessment**
The module will be completed by an oral exam (about 20 min).

**Prerequisites**
none

**Competence Goal**
At the end of the course, students

- can name the mathematical foundations of stochastic control and and are able to apply solution techniques,
- can formulate continuous-time dynamic stochastic optimization problems as stochastic control problems,
- are able to work in a self-organized and reflective manner,

**Content**

- Verification techniques, Hamilton-Jacobi-Bellman equation
- Viscosity solution
- Singular control
- Feynman-Kac representations
- Applications from finance and insurance

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 hours

- lectures, problem classes, and examination

Self-studies: 75 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course 'Probably Theory' is strongly recommended. The courses 'Brownian motion' and 'Continuous time finance' are recommended.

# M 2.197 Module: Stochastic Geometry [M-MATH-102865]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Each summer term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105840 | Stochastic Geometry | 8 CP | Hug, Winter |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Prerequisites**
None.

**Competence Goal**
The students

- know the fundamental geometric models and characteristics in stochastic geometry,
- are familiar with properties of Poisson processes of geometric objects,
- know examples of applications of models of stochastic geometry,
- know how to work self-organised and self-reflexive.

**Content**

- Random Sets
- Geometric Point Processes
- Stationarity and Isotropy
- Germ Grain Models
- Boolean Models
- Foundations of Integral Geometry
- Geometric densities and characteristics
- Random Tessellations

**Module Grade Calculation**
The modul grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance time: 90 hours

- Course including module examination during the course of study

Self-study: 150 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
The contents of the module "Spatial Stochastics" are recommended.

# M 2.198 Module: Stochastic Information Processing [M-INFO-100829]

**Coordinators:** Prof. Dr.-Ing. Uwe Hanebeck
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-101366 | Stochastic Information Processing | 6 CP | Hanebeck |

**Assessment**
See Partial Achievements (Teilleistung).

**Prerequisites**
See Partial Achievements (Teilleistung).

**Competence Goal**
Qualification objective: Students can describe a given nonlinear dynamic model probabilistically and set up the equations for Bayesian inference. If no analytical solution exists, they can estimate the strength of the nonlinearity and select and implement a suitable practical filter for real-time state estimation.

Learning objective: Students are familiar with dynamic state models and methods for recursively estimating the state. The advantages and disadvantages of the various practical filters can be assessed in a problem-oriented manner.

**Content**
To deal with complex dynamic systems, as they occur for example in robotics, one typically requires both system models and the temporal evolution of the system states. For both system identification and state reconstruction, however, usually only noisy data are available.
For continuous state spaces, an exact calculation of the probability densities is only possible in a few special cases. In practice, general nonlinear systems are often traced back to these special cases by simplifying assumptions. One extreme is linearization with subsequent application of linear estimation theory. However, this often leads to unsatisfactory results and requires additional heuristic measures. At the other extreme are numerical approximation methods, which only evaluate the desired probability densities at discrete points in the state space. Although the basic principle of these methods is usually quite simple, their practical implementation is often difficult and, in particular for higher-dimensional systems, computationally demanding.

As a middle ground, analytical nonlinear estimation methods would therefore often be desirable. In this lecture the main difficulties in the development of such estimation methods are outlined and corresponding solution modules are presented. Based on these building blocks, some analytical estimation methods are discussed in detail as examples, which are very suitable for practical implementation and offer a good compromise between computing effort and performance. Useful applications of these estimation methods are also discussed. Both known methods and the results of current research are presented.

**Additional Information**
As a theoretical foundation lecture, "Stochastic Information Systems" is an ideal introduction to the ISAS lectures. Conversely, prior knowledge of "Localization of Mobile Agents" (LMA) [course no. 24613] and "Information Processing in Sensor Networks" (IIS) [course no. 24102],
, may nevertheless be helpful depending on the type of learner - more concrete applications are highlighted there. In all of our lectures, the content is always derived and explained in detail from the beginning; it is therefore possible to start with SI, LMA or IIS.

**Workload**
[1.5 h lecture + 1.5 h exercise (3 SWS)] x 15
+ [4.5 h follow-up lecture + 3.5 h preparation exercise] x 15
+ 15 h exam preparation
= 180 h ≙ 6 ECTS

**Recommendations**
Knowledge of the basics of probability theory is helpful.

# M 2.199 Module: Stochastic Simulation [M-MATH-106053]

**Coordinators:** Prof. Dr. Sebastian Krumscheid
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 5 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112242 | Stochastic Simulation | 5 CP | Krumscheid |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
None

**Competence Goal**
After successfully taking part in the module's classes and the exam, students will be acquainted with sampling-based computational tools used to analyze systems with uncertainty arising in engineering,
physics, chemistry, and economics. Specifically, by the end of this course, students will be able to analyze the convergence of sampling algorithms and implement the discussed sampling methods for different
stochastic processes as computer codes. Understanding the advantages and disadvantages of different sampling-based methods, the students can, in particular, choose appropriate stochastic simulation
techniques and propose efficient sampling methods for a specific stochastic problem. In particular, they can name and discuss essential theoretical concepts, and understand the structure of the sampling-based computational methods. Finally, the course prepares students to write a thesis in the field of Uncertainty Quantification.

**Content**
The course covers mathematical concepts and computational tools used to analyze systems with uncertainty arising across various application domains. First, we will address stochastic modelling strategies to represent uncertainty in such systems. Then we will discuss sampling-based methods to assess uncertain system outputs via stochastic simulation techniques. The focus of this course will be on
the theoretical foundations of the discussed techniques, as well as their methodological realization as efficient computational tools. Topics covered include:

- Random variable generation
- Simulation of random processes
- Simulation of Gaussian random fields
- Monte Carlo method; output analysis
- Variance reduction techniques
- Rare event simulations
- Quasi Monte Carlo methods
- Markov Chain Monte Carlo methods (Metropolis-Hasting, Gibbs sampler)

**Module Grade Calculation**
The grade of the module is the grade of the oral exam.

**Workload**
total workload: 150 hours

**Recommendations**
The contents of the modules 'M-MATH-101321 - Introduction to Stochastics' and 'M-MATH-103214 – Numerical Mathematics 1+2' are recommended.

# M 2.200 Module: Structural Graph Theory [M-MATH-105463]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Irregular | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111004 | Structural Graph Theory | 4 CP | Aksenovich |

**Assessment**
Success is assessed in an oral examination (approx. 30 minutes).

**Prerequisites**
None.

**Competence Goal**
After successful completion of the course, the participants are able to present and analyse main results in Structural Graph Theory. They are able to establish connections between graph minors and other graph parameters, give examples, and apply fundamental results to related problems.

**Content**
The purpose of this course is to provide an introduction to some of the central results and methods of structural graph theory. Our main point of emphasis will be on graph minor theory and the concepts devised in Robertson and Seymour's intricate proof of the Graph Minor Theorem: in every infinite set of graphs there are two graphs such that one is a minor of the other.

Our second point of emphasis (time permitting) will be on Hadwiger's conjecture: that every graph with chromatic number at least r has a K_r minor. We shall survey what is known about this conjecture, including some very recent progress.

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 120 hours

Attendance time: 45 hours

- Course including module examination

Self-study: 75 hours

- Consolidation by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination

**Recommendations**
A solid background in the fundamentals of graph theory is recommended.

# M 2.201 Module: Supplementary Studies on Science, Technology and Society [M-FORUM-106753]

**Coordinators:** Dr. Christine Mielke
Christine Myglas

**Organisation:** General Studies. Forum Science and Society (FORUM)

**Part of:** Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 16 CP | graded | Each term | 3 terms | German | 4 | 1 |

**Election Notes**
Students have to self-record the achievements obtained in the Supplementary Studies on Science, Technology and Society in their study plan. FORUM (formerly ZAK) records the achievements as "non-assigned" under "ÜQ/SQ-Leistungen". Further instructions on self-recording of achievements can be found in the FAQ at https://campus.studium.kit.edu/ and on the FORUM homepage at https://www.forum.kit.edu/english/. The title of the examination and the amount of credits override the modules placeholders.

If you want to use FORUM achievements for both your Interdisciplinary Qualifications and for the Supplementary Studies, please record them in the Interdisciplinary Qualifications first. You can then get in contact with the FORUM study services (stg@forum.kit.edu) to also record them in your Supplementary Studies.

In the Advanced Unit you can choose examinations from three subject areas: "About Knowledge and Science", "Science in Society" and "Science in Social Debates". It is advised to complete courses from each of the three subject areas in the Advanced Unit.

To self-record achievements in the Advanced Unit, you have to select a free placeholder partial examination first. The placeholders' title do *not* affect which achievements the placeholder can be used for!

| | | | |
|---|---|---|---|
| **Mandatory** | | | |
| T-FORUM-113578 | Lecture Series Supplementary Studies on Science, Technology and Society - Self Registration | 2 CP | Mielke, Myglas |
| T-FORUM-113579 | Basic Seminar Supplementary Studies on Science, Technology and Society - Self Registration | 2 CP | Mielke, Myglas |
| **Advanced Unit Supplementary Studies on Science, Technology and Society (Elective: at least 12 credits)** | | | |
| T-FORUM-113580 | Elective Specialization Supplementary Studies on Science, Technology and Society / About Knowledge and Science - Self-Registration | 3 CP | Mielke, Myglas |
| T-FORUM-113581 | Elective Specialization Supplementary Studies on Science, Technology and Society / Science in Society - Self-Registration | 3 CP | Mielke, Myglas |
| T-FORUM-113582 | Elective Specialization Supplementary Studies on Science, Technology and Society / Science in Public Debates - Self Registration | 3 CP | Mielke, Myglas |
| **Mandatory** | | | |
| T-FORUM-113587 | Registration for Certificate Issuance - Supplementary Studies on Science, Technology and Society | 0 CP | Mielke, Myglas |

**Assessment**
The monitoring is explained in the respective partial achievement.

They are composed of:
- Protocols
- Reflection reports
- Presentations
- Preparation of a project work
- An individual term paper
- An oral examination
- A written exam

Upon successful completion of the supplementary studies, graduates receive a graded report and a certificate issued by the FORUM.

**Prerequisites**
The course is offered during the course of study and does not have to be completed within a defined period. Enrollment is required for all assessments of the modules in the supplementary studies.
Participation in the supplementary studies is regulated by § 3 of the statutes. KIT students register for the supplementary studies by selecting this module in the student portal and booking a performance themselves. Registration for courses, assessments, and exams is regulated by § 8 of the statutes and is usually possible shortly before the start of the semester.
The course catalog, module description (module manual), statutes (study regulations), and guidelines for creating the various written performance requirements can be downloaded from the FORUM homepage at **https://www.forum.kit.edu/begleitstudium-wtg.php**.

**Registration and exam modalities**
**PLEASE NOTE:**
Registration on the FORUM, i.e. additionally via the module selection in the student portal, enables students to receive up-to-date information about courses or study modalities. In addition, registering on the FORUM ensures that you have proof of the credits you have earned. As it is currently (as of winter semester 24-25) not yet possible to continue additional credits acquired in the Bachelor's programme electronically in the Master's programme, we strongly advise you to digitally secure the credits you have earned by archiving the Bachelor's transcript of records yourself and by registering on FORUM.
In the event that a transcript of records of the Bachelor's certificate is no longer available - we can only assign the achievements of registered students and thus take them into account when issuing the certificate.

**Competence Goal**
Graduates of the Supplementary Studies on Science, Technology, and Society gain a solid foundation in understanding the interplay between science, the public, business, and politics. They develop practical skills essential for careers in media, political consulting, or research management. The program prepares them to foster innovation, influence social processes, and engage in dialogue with political and societal entities. Participants are introduced to interdisciplinary perspectives, encompassing social sciences and humanities, to enhance their understanding of science, technology, and society. The teaching objectives of this supplementary degree program include equipping participants with both subject-specific knowledge and insights from epistemological, economic, social, cultural, and psychological perspectives on scientific knowledge and its application in various sectors. Students are trained to critically assess and balance the implications of their actions at the intersection of science and society. This training prepares them for roles as students, researchers, future decision-makers, and active members of society.

Through the program, participants learn to contextualize in-depth content within broader frameworks, independently analyze and evaluate selected course materials, and communicate their findings effectively in both written and oral formats. Graduates are adept at analyzing social issues and problem areas, reflecting on them critically from a socially responsible and sustainable standpoint.

**Content**
The Supplementary Studies on Science, Technology and Society can be started in the 1st semester of the enrolled degree programme and is not limited in time. The wide range of courses offered by FORUM makes it possible to complete the program usually within three semesters. The supplementary studies comprises 16 or more credit points (LP). It consists of **two modules: the Basic Module (4 LP) and the Advanced Module (12 LP).**

The **basic Module** comprises the compulsory courses 'Lecture Series Supplementary Studies on Science, Technology and Society' and a basic seminar with a total of 4 LP.

The **Advanced Module** comprises courses totalling 12 LP in the humanities and social sciences subject areas 'On Knowledge and Science', 'Science in Society' and 'Science in Public Debates'. The allocation of courses to the accompanying study programme can be found on the homepage https://www.forum.kit.edu/wtg-aktuelland in the printed FORUM course catalogue.

The 3 thematic subject areas:

**Subject area 1: About Knowledge and Science**

This is about the internal perspective of science: students explore the creation of knowledge, distinguishing between scientific and non-scientific statements (e.g., beliefs, pseudo-scientific claims, ideological statements), and examining the prerequisites, goals, and methods of knowledge generation. They investigate how researchers address their own biases, analyze the structure of scientific explanatory and forecasting models in various disciplines, and learn about the mechanisms of scientific quality assurance.

After completing courses in the "Knowledge and Science" area, students can critically reflect on the ideals and realities of contemporary science. They will be able to address questions such as: How robust is scientific knowledge? What are the capabilities and limitations of predictive models? How effective is quality assurance in science, and how can it be improved? What types of questions can science answer, and what questions remain beyond its scope?

**Subject area 2: Science in Society**

This focuses on the interactions between science and different areas of society, such as how scientific knowledge influences social decision-making and how social demands impact scientific research. Students learn about the specific functional logics of various societal sectors and, based on this understanding, estimate where conflicts of goals and actions might arise in transfer processes—for example, between science and business, science and politics, or science and journalism. Typical questions in this subject area include: How and under what conditions does an innovation emerge from a scientific discovery? How does scientific policy advice work? How do business and politics influence science, and when is this problematic? According to which criteria do journalists incorporate scientific findings into media reporting? Where does hostility towards science originate, and how can social trust in science be strengthened?

After completing courses in the "Sciene in Society" area, students can understand and assess the goals and constraints of actors in different societal sectors. This equips them to adopt various perspectives of communication and action partners in transfer processes and to act competently at various social interfaces with research in their professional lives.

**Subject area 3: Science in Public Debates**

The courses in this subject area provide insights into current debates on major social issues such as sustainability, digitalization, artificial intelligence, gender equality, social justice, and educational opportunities. Public debates on complex challenges are often polarized, leading to oversimplifications, defamation, or ideological thinking. This can hinder effective social solution-finding processes and alienate people from the political process and from science. Debates about sustainable development are particularly affected, as they involve a wide range of scientific and technological knowledge in both problem diagnosis (e.g., loss of biodiversity, climate change, resource consumption) and solution development (e.g., nature conservation, CCS, circular economy).

By attending courses in "Science in Public Debates," students are trained in an application-oriented way to engage in factual debates—exchanging arguments, addressing their own prejudices, and handling contradictory information. They learn that factual debates can often be conducted more deeply and with more nuance than is often seen in public discourse. This training enables them to handle specific factual issues in their professional lives independently of their own biases and to be open to differentiated, fact-rich arguments.

**Supplementary credits:**
Additional LP (supplementary work) totalling a maximum of 12 LP can also be acquired from the complementary study programme (see statutes for the WTG complementary study programme § 7). § 4 and § 5 of the statutes remain unaffected by this. These supplementary credits are not included in the overall grade of the accompanying study programme. At the request of the participant, the supplementary work will be included in the certificate of the accompanying study programme and marked as such. Supplementary coursework is listed with the grades provided for in § 9.

**Module Grade Calculation**
The overall grade of the supplementary course is calculated as a credit-weighted average of the grades that were achieved in the advanced module.

**Additional Information**
Climate change, biodiversity crisis, antibiotic resistance, artificial intelligence, carbon capture and storage, and gene editing are just a few areas where science and technology can diagnose and address numerous social and global challenges. The extent to which scientific findings are considered in politics and society depends on various factors, such as public understanding and trust, perceived opportunities and risks, and ethical, social, or legal considerations.
To enable students to use their expertise as future decision-makers in solving social and global challenges, we aim to equip them with the skills to navigate the interfaces between science, business, and politics competently and reflectively. In the Supplementary Studies, they acquire foundational knowledge about the interactions between science, technology, and society.

They learn:
- How reliable scientific knowledge is produced,
- how social expectations and demands influence scientific research, and
- how scientific knowledge is adopted, discussed, and utilized by society.

The program integrates essential insights from psychology, philosophy, economics, social sciences, and cultural studies into these topics. After completing the supplementary studies programme, students can place the content of their specialized studies within a broader social context. This prepares them, as future decision-makers, to navigate competently and reflectively at the intersections between science and various sectors of society, such as politics, business, or journalism, and to contribute effectively to innovation processes, public debates, or political decision-making.

**Workload**
The workload is made up of the number of hours of the individual modules:

- Basic Module approx. 120 hours
- Advanced Module approx. 360 hours
> Total: approx. 480 hours

In the form of supplementary services, up to approximately 360 hours of work can be added.

**Recommendations**
It is recommended to complete the supplementary study program in three or more semesters, beginning with the lecture series on science, technology, and society in the summer semester. Alternatively, you can start with the basic seminar in the winter semester and then attend the lecture series in the summer semester.

Courses in the Advanced Module can be taken simultaneously. It is also advised to complete courses from each of the three subject areas in the advanced unit.

**Teaching and Learning Methods**
- Lectures
- Seminars/Project Seminars
- Workshops

# M 2.202 Module: Technical Optics [M-ETIT-100538]

**Coordinators:** Prof. Dr. Cornelius Neumann
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** Electrical Engineering / Information Technology (Electrical Engineering / Information Technology)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 5 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-ETIT-100804 | Technical Optics | 5 CP | Neumann |

**Assessment**
Success is assessed in the form of a written examination lasting 120 minutes. The module grade is the grade of the written examination.

**Prerequisites**
none

**Competence Goal**
Students learn the basics of imaging and non-imaging optics, as well as their applications using examples of optical observation and measurement methods, data storage, micro- and nano-optics, as well as the manufacturing methods for optical components. The course allows students to gain an overview of the many possible applications of optical technology.

They are able to apply what they have learned to the design of various optical systems and develop their own concepts.

Based on the examples learned, they are aware of the social and societal influence of new optical technologies and are able to assess the effects of new developments in research and industrial applications.

**Content**
Technical optics deals with the essential physical principles of optics, as well as a variety of technical applications of optical systems. These range from applications in the automobile, medicine, measurement technology, printing, optical data storage, to micro/nano optics and manufacturing processes for plastic and glass optics.

The following chapters are covered:

- Motivation
- Fundamentals
- Reflection & Refraction
- Absorption
- Mirrors
- Prisms & lenses
- Applications: Prism pole, Fresnel lens, telescope, camera
- Diffraction & Interference
- Application: Microscope
- Paraxial beam matrices
- Application: Focusing of beams
- Application: Distance & angle measurement
- Optics in data storage
- Micro- and nano-optics
- Production of optics

The lecturer reserves the right to deviate from the content given here in the context of the current lecture without special notice.

**Module Grade Calculation**
The module grade is the grade of the written examination.

**Workload**
1. attendance time lecture: 15 * 2 h = 30 h
2. preparation and follow-up time lecture: 15 * 2 h = 30 h
3. attendance time exercise: 15 * 2 = 30 h
4. preparation and follow-up time for exercise: 15 * 2 h = 30 h
5. exam preparation and attendance: 30 h

Total: 150 h = 5 LP

**Recommendations**
Previous attendance of the lecture on lighting technology.

# M 2.203 Module: Technomathematical Seminar [M-MATH-102863]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** Experimental Physics (mandatory)
Wildcard Technical Field
Electrical Engineering / Information Technology (mandatory)
Chemical and Process Engineering (mandatory)

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 3 CP | pass/fail | Each term | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105884 | Technomathematical Seminar | 3 CP | Jahnke, Kühnlein |

**Prerequisites**
None

**Competence Goal**
At the end of the module, the participants can

- analyze a specific problem in a scientific area
- discuss, present and defend subject-specific problems in the given context
- summarize the most important results concerning the topic

They have communicative, organizational and didactical skills in complex problem analyses at their disposal. They can apply techniques of scientific work.

**Content**
The technomathematical seminar optionally can be completed in mathematics, in computer sciences or in the technical subject. The specific content depends on the offered seminar courses. The chosen topic must possess a significant connection to applications. Admissible are seminar talks of at least 45 minutes as in the other mathematical seminar courses as well as the treatment of small projects with a project report and short presentation at the end, for instance in the technical field.

**Workload**
Total work load: 90 minutes.

The specific workload in attendance and self studies depends on the specific choice.

# M 2.204 Module: Telematics [M-INFO-107243]

**Coordinators:** Prof. Dr. Martina Zitterbart
**Organisation:** KIT Department of Informatics
**Part of:** Computer Science

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-INFO-114269 | Telematics | 6 CP | Zitterbart |

**Assessment**
See partial achievements (Teilleistung)

**Prerequisites**
See partial achievements (Teilleistung)

**Competence Goal**
Students

- master protocols, architectures, and methods and algorithms that are used on the Internet for routing and for establishing a reliable end-to-end connection, as well as various media allocation procedures in local networks.
- have an understanding of the systems and the problems that appear in a global, dynamic network as well as the mechanisms used to remedy them.
- are familiar with current developments such as SDN and data center networking.
- know methods to manage and administrate networks.

Students master the basic protocol mechanisms for establishing reliable end-to-end communication. Students have detailed knowledge of the mechanisms used in TCP for congestion and flow control and can discuss the issue of fairness with multiple parallel transport streams. Students can analytically determine the performance of transport protocols and know methods that fulfill special requirements of TCP, such as high data rates and short latencies. Students are familiar with current topics such as problems introduced by utilization of middle boxes in the Internet, the use of TCP in data centers and multipath TCP. Students can use transport protocols in practice.

Students know the functions of routers in the Internet and can reproduce and apply common routing algorithms. Students can reproduce the architecture of a router and know different approaches to buffer placement as well as their advantages and disadvantages.

Students understand the distinction of routing protocols into interior and exterior gateway protocols and have detailed knowledge of the functionality and properties of common protocols such as RIP, OSPF and BGP. The students are familiar with current topics such as SDN.

Students know the function of media allocation and can classify and analytically evaluate media allocation processes. Students have in-depth knowledge of Ethernet and are familiar with various Ethernet forms and their differences, especially current developments such as real-time Ethernet and data center Ethernet. Students can reproduce and apply the spanning tree protocol.
Students can reproduce the technical characteristics of DSL. Students are familiar with the concept of label switching and can compare existing approaches such as MPLS.

**Content**

- Introduction
- End-to-end data transport
- Routing protocols and architectures
- Media allocation
- Bridges
- Data transmission
- Further selected examples
- Network management

**Workload**
Lecture with 3 SWS plus follow-up/exam preparation, 6 CP.
6 CP corresponds to approx. 180 working hours, of which
approx. 60 hours lecture attendance
approx. 60 hours preparation/follow-up work
approx. 60 hours exam preparation

# M 2.205 Module: Theoretical Nanooptics [M-PHYS-102295]

**Coordinators:** Prof. Dr. Markus Garst
Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-104587 | Theoretical Nanooptics | 6 CP | Garst, Rockstuhl |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Competence Goal**
The properties of light at the nanoscale can be controlled by various means. The aim of this lecture is to familiarize the students with the different possibilities that rely on nanostructured dielectric or metallic materials and to outline on solid mathematical grounds the analytical description of observable effects. The lecture is meant as a complementary source of education to experimental lecture. It shall provide the students with the necessary skills to work themselves in the field of theoretical nanooptics.

**Content**

- Dispersion relation to describe light in extended systems such as free space, interfaces, planar waveguides and waveguides with complicated geometrical cross sections.
- Description of the interaction of light with isolated objects such as spheres, cylinders, ellipsoids and prolates and oblates.
- Properties of plasmonic nanoparticles and the ability to tune their properties
- Notion of optical antennas and the discussion of their basic characteristics
- Description of the dynamics of wave propagation by perturbed eigenstates, i.e. coupled mode theory. Application to optical waveguide arrays.
- Discussion of metamaterials (unit cells, homogenization, light propagation, applications)
- Transformation optics
- Analytical modeling and phenomenological tools to describe nanooptical systems

**Workload**
180 hours composed of active time (45), wrap-up of the lecture incl. preparation of the examination and the excercises (135)

**Recommendations**
Solid mathematical background, good knowledge of classical electromagnetism and theoretical optics.

**Literature**

- L. Novotny and B. Hecht, Principle of Nano-Optics, Cambridge
- S. A. Maier, Plasmonics, Springer
- J. D. Joannopoulos, S. G. Johnson, J. N. Winn and R. D. Meade, Photonic Crystals: Molding the Flow of Light, University Press

# M 2.206 Module: Theoretical Optics [M-PHYS-102277]

**Coordinators:** PD Dr. Boris Narozhnyy
Prof. Dr. Carsten Rockstuhl
**Organisation:** KIT Department of Physics
**Part of:** Experimental Physics (Experimental Physics)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-PHYS-104578 | Theoretical Optics | 6 CP | Narozhnyy, Rockstuhl |

**Assessment**
Oral Exam. In the MSc Physics, this module is examined together with further modules attended as part of the major in physics. The total duration of the oral exam is approx. 60 minutes.

**Prerequisites**
none

**Competence Goal**
The students deepen their knowledge about the theory and the mathematical tools in optics and photonics. They learn how to apply these tools to describe fundamental phenomena and how to predict observable quantities that reflect the actual physics from the theory by way of a corresponding purposeful mathematical analyses. They learn how to solve problems of both, interpretative and predictive nature with regards to model systems and real life situations.

**Content**

- Review of Electromagnetism (Maxwell's Equations, Stress Tensor, Material Properties, Kramers-Kronig Relation, Wave Propagation, Poynting's Theorem)
- Diffraction Theory (The Principles of Huygens and Fresnel, Scalar Diffraction Theory: Green's Function, Helmholtz-Kirchhoff Theorem, Kirchhoff Formulation of Diffraction, Fresnel-Kirchhoff Diffraction Formula, Rayleigh-Sommerfeld Formulation of Diffraction, Angular Spectrum Method, Fresnel and Fraunhofer Diffraction, Method of Stationary Phases, Basics og Holography)
- Crystal Optics (Polarization, Anisotropic Media, Fresnel Equation, Applications)
- Classical Coherence Theory (Elementary Coherence Phenomena, Theory of Stochastic Processes, Correlation Functions)
- Quantum Optics and Quantum Optical Coherence Theory (Review of Quantum Mechanics, Quantization of the EM Field, Quantum Coherence Functions)

**Additional Information**
For students of the KIT Faculty of Computer Science: The exams in this module have to be registered via admissions from ISS (KIT Faculty of Computer Science). For this, an e-mail with matriculation numbers and name of the desired exam to Beratung-informatik@informatik.kit.edu is sufficient.

**Workload**
180 hours composed of active time (45 hours), wrap-up of the lecture incl. preparation of the examination (135 hours)

**Recommendations**
Solid mathematical background, good knowledge of classical electromagnetism and basic knowledge of quantum mechanics.

**Literature**

- "Classical Electrodynamics" John David Jackson
- "Theoretical Optics: An Introduction" Hartmann Römer
- "Introduction to Fourier Optics" Joseph W. Goodman
- "Introduction to the Theory of Coherence and Polarization of Light" Emil Wolf
- "The Quantum Theory of Light " Rodney Loudon

# M 2.207 Module: Thermodynamics III [M-CIWVT-103058]

**Coordinators:** Prof. Dr. Sabine Enders
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each winter term | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106033 | Thermodynamics III | 6 CP | Enders |

**Assessment**
Learning control is a written examination lasting 90 minutes.

**Prerequisites**
None

**Competence Goal**
Students are familiar with the basic principles for the description of complex, multicomponent mixtures and thermodynamic equilibria including equilibria with chemical reactions. They are able to select suitable models and to calculate the properties of multicomponent real systems.

**Content**
Phase- and reaction equilibria of real systems, equations of state for real mixtures, models for activity coefficients, polymer solutions, protein solutions, elektrolyte solutions.

**Module Grade Calculation**
The module grade is the grade of the written exam.

**Workload**

- Attendance time (Lecture): 60 h
- Homework: 90 h
- Exam Preparation: 30 h

**Literature**

1. Stephan, P., Schaber, K., Stephan, K., Mayinger, F.: Thermodynamik, Band 2, 15. Auflage, Springer Verlag, 2010.
2. Sandler, S. I.: Chemical, Biochemical and Engineering Thermodynamics, J. Wiley & Sons, 2008.
3. Gmehling, J, Kolbe, B., Kleiber, M., Rarey, J.: Chemical Thermodynamics for Process Simulations, Wiley-VCG Verlag, 2012

# M 2.208 Module: Thermodynamics of Interfaces [M-CIWVT-103063]

**Coordinators:** Prof. Dr. Sabine Enders
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** Chemical and Process Engineering (Chemical and Process Engineering)

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Each summer term | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-CIWVT-106100 | Thermodynamics of Interfaces | 6 CP | Enders |

**Assessment**
Learning control is an oral examination lasting approx. 30 minutes.

**Prerequisites**
None

**Competence Goal**
The students to be familiar with the peculiarities on fluid-fluid and fluid-solid interfacial properties. They are able to calculate interfacial properties (interfacial tension, density - and concentration profils, adsorption isotherms) using macroscopic and local-dependent methods.

**Content**
Gibbs-method, density functional theory, experimental methods for characterization of interfaces, adsorption

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Additional Information**
If required, the course will be offered in English.

**Workload**

- Lectures and exercises: 45 h
- Homework: 90 h
- Exam preparation: 45 h

# M 2.209 Module: Time Series Analysis [M-MATH-102911]

**Coordinators:** PD Dr. Bernhard Klar
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 4 CP | graded | Each summer term | 1 term | 4 | 3 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105874 | Time Series Analysis | 4 CP | Ebner, Fasen-Hartmann, Gneiting, Klar, Trabs |

**Assessment**
The module will be completed by an oral exam (ca. 20 min).

**Prerequisites**
None

**Competence Goal**
At the end of the course, students will

- know and understand the standard models of time series analysis,
- know exemplary statistical methods for model selection and model validation,
- independently apply models and methods from the lecture to real and simulated data,
- know specific mathematical techniques and be able to use them to analyze time series models.

**Content**
The lecture covers the basic concepts of classical time series analysis:

- Stationary time series
- Trends and seasonality
- Autocorrelation
- Autoregressive models
- ARMA models
- Parameter estimation
- Forecasting
- Spectral density and periodogram

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 120 hours

Attendance: 45 hours

- lectures, problem classes, and examination

Self-studies: 75 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the course "Probability Theory" are strongly recommended. The contents of the course "Statistics" are recommended.

# M 2.210 Module: Topics in Algebraic Topology [M-MATH-107017]

**Coordinators:** TT-Prof. Dr. Manuel Krannich
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-114063 | Topics in Algebraic Topology | 6 CP | Krannich |

**Assessment**
The module examination takes the form of a written exam (120 min).

**Prerequisites**
none

**Competence Goal**
Students

- are able to calculate the discussed topological invariants in concrete examples;
- have mastered advanced techniques of algebraic topology;
- are able to work in a self-organized and reflective manner.

**Content**

- Examples of advanced invariants of algebraic topology (e.g. cohomology rings, higher homotopy groups)
- applications to the topology of manifolds (e.g. Poincaré duality)
- advanced homotopy theoretical concepts (e.g. fibrations and cofibrations, homotopy fibres)

**Module Grade Calculation**
The module grade is the grade of the written examination.

**Workload**
Total workload: 180 hours

Attendance time: 60 hours

- Course including module examination during the course of study

Self-study: 120 hours

- Deepening the study content by working on the lecture content at home
- completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
The contents of the modules "Elementary Geometry" and "Algebraic Topology" are recommended.

# M 2.211 Module: Topics in Homotopy Theory [M-MATH-107484]

**Coordinators:** TT-Prof. Dr. Manuel Krannich
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-114682 | Topics in Homotopy Theory | 6 CP | Krannich |

**Assessment**
The module examination takes the form of an oral examination (30 min.)

**Prerequisites**
None

**Competence Goal**
Graduates

- are able to calculate the homotopy-theoretic invariants discussed in concrete examples;
- are proficient in advanced techniques of homotopy theory;
- are able to work in a self-organized and reflective manner.

**Content**

- examples of advanced homotopy-theoretic invariants (e.g. cohomology operations, characteristic classes),
- advanced homotopy-theoretic concepts and methods (e.g. spectral sequences, spectra, obstruction theory, classification of fibrations and fiber bundles, Thom isomorphism),
- applications to the topology of manifolds (e.g. Wu formula, existence of exotic spheres)

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Attendance: 60 h

- lectures, problem classes and examination

Self studies: 120 h

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research on the course content,
- preparation for the module examination

**Recommendations**
The contents of the modules "Elementary Geometry", "Algebraic Topology" and "Topics in Algebraic Topology" are recommended.

# M 2.212 Module: Topological Data Analysis [M-MATH-105487]

**Coordinators:** Prof. Dr. Tobias Hartnick
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | German/English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-111031 | Topological Data Analysis | 6 CP | Hartnick, Sauer |

**Assessment**
The module exam is an oral exam (20 minutes).

**Prerequisites**
Basic knowledge of linear algebra and analysis.

**Competence Goal**
Students who completed the module succesfully

- understand fundamental concepts of simplicial homology and can apply them to simple examples
- understand fundamental concepts of persistent homology and can apply them to simple examples
- are familiar with algorithms for computing persistent homology and can implement them on a computer
- are familiar with specific application examples of topological data analysis and can explain them
- have an overview of the current literature on topological data analysis.

**Content**

- Review of basic concepts in topology
- Homology of simplicial complexes
- Persistent homology
- Algorithms for computing persistent homology
- Computer implementations of these algorithms
- Applications to real-world examples, e.g., phylogenetics (mutations of the SARS-CoV-2 coronavirus)
- All of the topics listed above will be introduced and illustrated using concrete examples.

**Module Grade Calculation**
The grade for the module is the grade of the oral exam.

**Workload**
Total workload: 180 hours

Class time: 60 hours

- Class-time including exam

Self-study: 120 hours

- Deepening understanding of course content through independent review of lecture material at home
- Completing homework exercises
- Deepening understanding of course content through appropriate literature and internet research
- Exam preparation

**Recommendations**
Basic knowledge of topology and programming

# M 2.213 Module: Translation Surfaces [M-MATH-105973]

**Coordinators:** Prof. Dr. Frank Herrlich
**Organisation:** KIT Department of Mathematics
**Part of:** Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | German | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-112128 | Translation Surfaces | 8 CP | Herrlich |

**Assessment**
The module will be completed by an oral exam of about 30 min.

**Prerequisites**
None

**Competence Goal**
At the end of the module, participants are able to

- name and discuss basic concepts to study translation surfaces,
- describe and use in examples essential methods for the classification of translation surfaces,
- read recent research papers on translation surfaces and write a thesis in this field.

**Content**

- Chararcterization of finite translation surfaces
- Riemann surfaces and algebraic curves
- Moduli space of Riemann surfaces
- Classification of translation surfaces
- Strata and the action of SL(2,R)
- Period coordinates

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
Basic knowledge in surface topology and complex analysis is strongly recommended. The module "Algebraic Geometry" is also recommended.

# M 2.214 Module: Traveling Waves [M-MATH-102927]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 6 CP | graded | Irregular | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105897 | Traveling Waves | 6 CP | de Rijk, Reichel |

**Assessment**
The module examination takes place in form of an oral exam of about 30 minutes. Please see under "Modulnote" for more information about the bonus regulation.

**Prerequisites**
none

**Competence Goal**
After successful completion of this module students:

- can explain the significance of traveling waves and their dynamic stability;
- know basic methods to study the existence of traveling waves;
- outline the main steps in a stability analysis and address potential complications;
- have acquired several mathematical tools to compute or approximate the spectrum;
- master several techniques to derive (in)stability of the wave from spectral information;
- understand how spectrum and stability might depend on the class of perturbations.

**Content**
Traveling waves are solutions to nonlinear partial differential equations (PDEs) that propagate over time with a fixed speed without changing their profiles. These special solutions arise in many applied problems where they model, for instance, water waves, nerve impulses in axons or light in optical fibers. Therefore, their existence and the naturally associated question of their dynamic stability is of interest, because only those waves which are stable can be observed in practice.

The first step in the stability analysis is to linearize the underlying PDE about the wave and compute the associated spectrum, which is in general a nontrivial task. To approximate spectra associated with various waves, such as fronts, pulses and periodic wave trains, we introduce the following tools:

- Sturm-Liouville theory
- exponential dichotomies
- Fredholm theory
- the Evans function
- parity arguments
- essential spectrum, point spectrum and absolute spectrum
- exponential weights

The next step is to derive useful bounds on the linear solution operator, or semigroup, based on the spectral information. A complicating factor is that any non-constant traveling wave possesses spectrum up to the imaginary axis. For various dissipative PDEs, such as reaction-diffusion systems, we employ the bounds on the linear solution operator to close a nonlinear argument via iterative estimates on the Duhamel formula. For traveling waves in Hamiltonian PDEs, such as the NLS or KdV equation, we describe a different route towards stability based on the variational arguments of Grillakis, Shatah and Strauss.

**Module Grade Calculation**
After passing the oral exam at the end of the semester, the final grade is min(0.7X + 0.3Y, X), where X is the grade for the oral exam and Y is the grade obtained by voluntarily working out and presenting a model problem during one of the exercise classes.

**Workload**
Total workload: 180 hours

Attendance: 60 hours

- lectures, problem classes, and examination

Self-studies: 120 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The following background is strongly reommended: Analysis 1-4.

**Literature**
Kapitula, Todd; Promislow, Keith. Spectral and dynamical stability of nonlinear waves. Applied Mathematical Sciences, 185. Springer, New York, 2013.

# M 2.215 Module: Uncertainty Quantification [M-MATH-104054]

**Coordinators:** Prof. Dr. Martin Frank
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Language | Level | Version |
|---|---|---|---|---|---|---|
| 4 CP | graded | Each summer term | 1 term | English | 4 | 2 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-108399 | Uncertainty Quantification | 4 CP | Frank |

**Assessment**
The module will be completed by an oral exam (approx. 30 min).

**Prerequisites**
None

**Competence Goal**
After successfully taking part in the module's classes and exams, students have gained knowledge and abilities as described in the "Inhalt" section.

Specifically, students know several parametrization methods for uncertainties. Furthermore, students are able to describe the basics of several solution methods (stochastic collocation, stochastic Galerkin, Monte-Carlo). Students can explain the so-called curse of dimensionality.

Students are able to apply numerical methods to solve engineering problems formulated as algebraic or differential equations with uncertainties. They can name the advantages and disadvantages of each method. Students can judge whether specific methods are applicable to the specific problem and discuss their results with specialists and colleagues. Finally, students are able to implement the above methods in computer codes.

**Content**
In this class, we learn to propagate uncertain input parameters through differential equation models, a field called Uncertainty Quantification (UQ). Given uncertain input (parameter values, initial or boundary conditions), how uncertain is the output? The first part of the course ("how to do it") gives an overview on techniques that are used. Among these are:

- Sensitivity analysis
- Monte-Carlo methods
- Spectral expansions
- Stochastic Galerkin method
- Collocation methods, sparse grids

The second part of the course ("why to do it like this") deals with the theoretical foundations of these methods. The so-called "curse of dimensionality" leads us to questions from approximation theory. We look back at the very standard numerical algorithms of interpolation and quadrature, and ask how they perform in many dimensions.

**Module Grade Calculation**
The module grade is the grade of the oral examination.

**Workload**
Total workload: 120 hours

Attendance time: 45 hours

- Course including module examination during the course of study

Self-study: 75 hours

- Deepening the study content by working on the lecture content at home
- Completion of exercises
- In-depth study of the course content using suitable literature and internet research
- Preparation for the module examination during the course of study

**Recommendations**
Numerical methods for differential equations

# M 2.216 Module: Variational Methods [M-MATH-105093]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Analysis)
Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-110302 | Variational Methods | 8 CP | Reichel |

**Assessment**
The module will be completed by an oral exam (ca. 30 min).

**Competence Goal**
Graduates will be able to

- assess the significance of variational problems in relation to their applications in the natural sciences, engineering or geometry and illustrate them using examples,
- formulate variational problems independently,
- recognize the specific difficulties within the calculus of variations,
- analyze and solve concrete, prototypical problems,
- use techniques to prove the existence of solutions to certain classes of variational problems and calculate these solutions in special cases.

**Content**

- one-dimensional variational problems
- Euler-Lagrange equation
- necessary and sufficient criteria
- multidimensional variational problems
- direct methods of the calculus of variations
- existence of critical points of functionals

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The contents of the courses Functional Analysis, Classical Methods for Partial Differential Equations, or Boundary and Eigenvalue problems are recommended.

# M 2.217 Module: Wavelets [M-MATH-102895]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** Applied Mathematics (Elective Field Applied Mathematics)
Mathematical Specialization (Elective Field Mathematical Specialization)
Additional Examinations

| Credits | Grading | Recurrence | Duration | Level | Version |
|---|---|---|---|---|---|
| 8 CP | graded | Irregular | 1 term | 4 | 1 |

| Mandatory | | | |
|---|---|---|---|
| T-MATH-105838 | Wavelets | 8 CP | Rieder |

**Assessment**
Success is assessed in the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
none

**Competence Goal**
Graduates are able

- to name, discuss and analyze the functional-analytical principles of continuous and discrete wavelet transforms,
- to apply the wavelet transform as an analysis tool in signal and image processing and evaluate the results obtained,
- to explain design aspects for wavelet systems.

**Content**

- Short-time Fourier transform
- Integral wavelet transform
- Wavelet frames
- Wavelet basis
- Fast wavelet transform
- Construction of orthogonal and bi-orthogonal wavelet systems
- Applications in signal and image processing

**Module Grade Calculation**
The module grade is the grade of the oral exam.

**Workload**
Total workload: 240 hours

Attendance: 90 hours

- lectures, problem classes, and examination

Self-studies: 150 hours

- follow-up and deepening of the course content,
- work on problem sheets,
- literature study and internet research relating to the course content,
- preparation for the module examination

**Recommendations**
The course "Functional analysis" is recommended.

# 3 Module components

## T 3.1 Module component: Adaptive Finite Element Methods [T-MATH-105898]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102900 - Adaptive Finite Elemente Methods

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 2 |

**Assessment**
oral exam of ca. 30 minutes

**Prerequisites**
none

**Recommendations**
Basic knowledge of finite element methods, a programming language and the analysis of boundary value problems is strongly recommended. Knowledge of functional analysis is recommended.

**Workload**
240 hours

# T 3.2 Module component: Advanced Inverse Problems: Nonlinearity and Banach Spaces [T-MATH-105927]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102955 - Advanced Inverse Problems: Nonlinearity and Banach Spaces

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 5 CP | graded | 1 |

**Prerequisites**
none

# T 3.3 Module component: Advanced Methods in Nonlinear Partial Differential Equations [T-MATH-113691]

**Coordinators:** Dr. Björn de Rijk
Prof. Dr. Wolfgang Reichel

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-106822 - Advanced Methods in Nonlinear Partial Differential Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 3 CP | graded | 1 |

**Assessment**
The module examination takes place in form of an oral exam of about 30 minutes.

**Prerequisites**
none

**Recommendations**
The following modules are recommended: Analysis 1-3, Functional Analysis, Evolution Equations.

**Workload**
90 hours

# T 3.4 Module component: Algebra [T-MATH-102253]

**Coordinators:** PD Dr. Stefan Kühnlein
Prof. Dr. Roman Sauer

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-101315 - Algebra

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 2 |

| | | | | | |
|---|---|---|---|---|---|
| **Courses** | | | | | |
| WT 25/26 | 0102200 | Algebra | 4 SWS | Lecture / 🗣 | Kühnlein |
| WT 25/26 | 0102210 | Tutorial for 0102200 (Algebra) | 2 SWS | Practice / 🗣 | Kühnlein |
| **Exams** | | | | | |
| WT 25/26 | 7700080 | Algebra | | | Kühnlein |
| ST 2026 | 7700079 | Algebra | | | Kühnlein |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

# T 3.5 Module component: Algebraic Geometry [T-MATH-103340]

**Coordinators:** Prof. Dr. Frank Herrlich
PD Dr. Stefan Kühnlein

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-101724 - Algebraic Geometry

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.6 Module component: Algebraic Number Theory [T-MATH-103346]

**Coordinators:** Prof. Dr. Frank Herrlich
PD Dr. Stefan Kühnlein

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-101725 - Algebraic Number Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

**Assessment**
oral examination of ca. 30 minutes

**Prerequisites**
none

**Workload**
240 hours

# T 3.7 Module component: Algebraic Topology [T-MATH-105915]

**Coordinators:** TT-Prof. Dr. Manuel Krannich
Jun.-Prof. Dr. Claudio Llosa Isenrich
Prof. Dr. Roman Sauer

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102948 - Algebraic Topology

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700140 | Algebraic Topology | Llosa Isenrich |

**Prerequisites**
none

# T 3.8 Module component: Algebraic Topology II [T-MATH-105926]

**Coordinators:** TT-Prof. Dr. Manuel Krannich
Prof. Dr. Roman Sauer

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102953 - Algebraic Topology II

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 8 CP | graded | Irregular | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0157400 | Algebraic Topology II | 4 SWS | Lecture | Sauer |
| ST 2026 | 0157410 | Tutorial for 0157400 (Algebraic Topology II) | 2 SWS | Practice | Sauer |

**Prerequisites**
none

*Below you will find excerpts from courses related to this module component:*

## V Algebraic Topology II

0157400, SS 2026, 4 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**
The course deepens the understanding of singular (co-)homology of spaces.

The course covers product structures on the cohomology which are interesting per se but also enable more computations. Fundamental ideas ofhomological algebra will be an important part of the course. A highlight will be the proof of Poincare duality for manifolds and the geometric interpretation of the product structure via intersections of submanifolds.

# T 3.9 Module component: Analytical and Numerical Homogenization [T-MATH-111272]

**Coordinators:** Prof. Dr. Marlis Hochbruck
TT-Prof. Dr. Roland Maier

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-105636 - Analytical and Numerical Homogenization

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.10 Module component: Aspects of Geometric Analysis [T-MATH-106461]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103251 - Aspects of Geometric Analysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0176600 | AG Geometrische Analysis | 2 SWS | Seminar | Lamm |

**Prerequisites**
Keine

# T 3.11 Module component: Astroparticle Physics I [T-PHYS-102432]

**Coordinators:** Prof. Dr. Guido Drexlin
Prof. Dr. Kathrin Valerius

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102075 - Astroparticle Physics I

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4022011 | Astroparticle Physics I: Dark Matter | 3 SWS | Lecture / 🗣 | Valerius, Biondi, Schlösser |
| WT 25/26 | 4022012 | Exercises to Astroparticle Physics I: Dark Matter | 1 SWS | Practice / 🗣 | Valerius, Heyns, Kovac |

Legend: 📱 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

# T 3.12 Module component: Banach Algebras [T-MATH-105886]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102913 - Banach Algebras

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 3 CP | graded | 1 |

**Prerequisites**
none

**Workload**
90 hours

# T 3.13 Module component: Basic Seminar Supplementary Studies on Science, Technology and Society - Self Registration [T-FORUM-113579]

**Coordinators:** Dr. Christine Mielke
Christine Myglas
**Organisation:** General Studies. Forum Science and Society (FORUM)
**Part of:** M-FORUM-106753 - Supplementary Studies on Science, Technology and Society

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Coursework | 2 CP | pass/fail | Each summer term | 1 semesters | 1 |

**Assessment**
Study achievement in the form of a presentation or a term paper or project work in the selected course.

**Prerequisites**
None

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)
- FORUM (ehem. ZAK) Begleitstudium

**Recommendations**
It is recommended that the basic seminar be completed during the same semester as the lecture series "Science in Society". If it is not possible to attend the lecture series and the basic seminar in the same semester, the basic seminar can also be attended in the semesters before the lecture series.
However, attending courses in the advanced unit before attending the basic seminar should be avoided.

# T 3.14 Module component: Basics of Nanotechnology I [T-PHYS-102529]

**Coordinators:** apl. Prof. Dr. Gernot Goll
**Organisation:** KIT Department of Physics
**Part of:** M-PHYS-102097 - Basics of Nanotechnology I

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4021041 | Basics of Nanotechnology I | 2 SWS | Lecture / | Goll |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**
none

# T 3.15 Module component: Basics of Nanotechnology II [T-PHYS-102531]

**Coordinators:** apl. Prof. Dr. Gernot Goll
**Organisation:** KIT Department of Physics
**Part of:** M-PHYS-102100 - Basics of Nanotechnology II

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 4021151 | Basics of Nanotechnology II | 2 SWS | Lecture / 🗣 | Goll |

Legend: 📱 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

# T 3.16 Module component: Batteries, Fuel Cells, and Electrolysis [T-ETIT-113986]

**Coordinators:** Prof. Dr.-Ing. Ulrike Krewer
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** M-ETIT-107005 - Batteries, Fuel Cells, and Electrolysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 5 CP | graded | Each winter term | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2304240 | Batteries, Fuel Cells and Electrolysis | 2 SWS | Lecture / | Krewer |
| WT 25/26 | 2304241 | Practical Exercise to 2304240 Batteries, Fuel Cells and Electrolysis | 2 SWS | Practice / | Krewer, Sonder |
| **Exams** | | | | | |
| WT 25/26 | 7304240 | Batteries, Fuel Cells, and Electrolysis | | | Krewer |
| ST 2026 | 7304240 | Batteries, Fuel Cells, and Electrolysis | | | Krewer |

Legend: Online, Blended (On-Site/Online), On-Site, × Cancelled

**Assessment**
Success control takes place in the form of a graded written examination lasting 120 minutes.

**Prerequisites**
The following module components **must not** have started:

- T-ETIT-100983 - Batterien und Brennstoffzellen
- T-ETIT-114097 - Batterien, Brennstoffzellen und ihre Systeme

The following module components **must** have started:

- T-ETIT-114957 - Batteries, Fuel Cells, and Electrolysis - Group Project

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-ETIT-100983 - Batteries and Fuel Cells must not have been started.
2. The module component T-ETIT-114957 - Batteries, Fuel Cells, and Electrolysis - Group Project must have been started.

**Additional Information**
For details on content and qualification objectives see "M-ETIT-107005 - Batteries, Fuel Cells, and Electrolysis".

The course is offered in English.

**Workload**
150 hours

# T 3.17 Module component: Batteries, Fuel Cells, and Electrolysis - Group Project [T-ETIT-114957]

**Coordinators:** Prof. Dr.-Ing. Ulrike Krewer
**Organisation:** KIT Department of Electrical Engineering and Information Technology
KIT Department of Mechanical Engineering
**Part of:** M-ETIT-107005 - Batteries, Fuel Cells, and Electrolysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Coursework | 1 CP | pass/fail | Each winter term | 1 |

**Assessment**
Success control takes place in the form of an ungraded written technical report (approx. 7-10 pages).

**Prerequisites**
none

**Additional Information**
For details on content and qualification objectives see "M-ETIT-107005 - Batteries, Fuel Cells, and Electrolysis".
The course is offered in English.

**Workload**
30 hours

# T 3.18 Module component: Bayesian Inverse Problems with Connections to Machine Learning [T-MATH-112842]

**Coordinators:** Prof. Dr. Sebastian Krumscheid
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106328 - Bayesian Inverse Problems with Connections to Machine Learning

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 4 CP | graded | Each summer term | 1 semesters | 1 |

| Exams | | | |
|---|---|---|---|
| ST 2026 | 7700131 | Bayesian Inverse Problems with Connections to Machine Learning | Krumscheid |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
none

**Workload**
120 hours

# T 3.19 Module component: Bifurcation Theory [T-MATH-106487]

**Coordinators:** Dr. Rainer Mandel
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103259 - Bifurcation Theory

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 5 CP | graded | Irregular | 1 |

**Prerequisites**
None

# T 3.20 Module component: Biopharmaceutical Purification Processes [T-CIWVT-106029]

**Coordinators:** Prof. Dr. Jürgen Hubbuch
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103065 - Biopharmaceutical Purification Processes

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 6 CP | graded | 1 |

| **Courses** | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2214010 | Biopharmaceutical Purification Processes | 3 SWS | Lecture / 🗣 | Hubbuch, Franzreb |
| WT 25/26 | 2214011 | Exercises on 2214010 Biopharmaceutical Purification Processes | 1 SWS | Practice / 🗣 | Hubbuch, Franzreb |
| **Exams** | | | | | |
| WT 25/26 | 7214010 | Biopharmaceutical Purification Processes (written exam) | | | Hubbuch |
| ST 2026 | 7214010 | Biopharmaceutical Purification Processes | | | Hubbuch |

Legend: 💻 Online, 🎲 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The examination is a written examination with a duration of 120 minutes (section 4 subsection 2 number 1 SPO).

# T 3.21 Module component: Boundary and Eigenvalue Problems [T-MATH-105833]

**Coordinators:** Prof. Dr. Dorothee Frey
Prof. Dr. Dirk Hundertmark
Prof. Dr. Tobias Lamm
Prof. Dr. Michael Plum
Prof. Dr. Wolfgang Reichel
Prof. Dr. Roland Schnaubelt

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102871 - Boundary and Eigenvalue Problems

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0157500 | Boundary and Eigenvalue Problems | 4 SWS | Lecture | Knopf |
| ST 2026 | 0157510 | Tutorial for 0157500 (Boundary and Eigenvalue Problems) | 2 SWS | Practice | Knopf |
| **Exams** | | | | | |
| WT 25/26 | 7700153 | Boundary and Eigenvalue Problems | | | Reichel, Lamm, Hundertmark |

*Below you will find excerpts from courses related to this module component:*

## V Boundary and Eigenvalue Problems

0157500, SS 2026, 4 SWS, Open in study portal **Lecture (V)**

**Content**
We consider boundary value and eigenvalue problems within mathematics and physics, describe qualitative properties of solutions, prove the existence of solutions to boundary value problems using functional analytical methods and will work in more general function spaces, e.g. Sobolev spaces. Further contents are the weak formulation of 2nd order linear elliptic equations, existence and regularity theory of elliptic equations, as well as, eigenvalue theory for weakly formulated elliptic eigenvalue problems.

# T 3.22 Module component: Boundary Element Methods [T-MATH-109851]

**Coordinators:** PD Dr. Tilo Arens
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103540 - Boundary Element Methods

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.23 Module component: Boundary Value Problems for Nonlinear Differential Equations [T-MATH-105847]

**Coordinators:** Prof. Dr. Michael Plum
Prof. Dr. Wolfgang Reichel

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102876 - Boundary value problems for nonlinear differential equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.24 Module component: Brownian Motion [T-MATH-105868]

**Coordinators:** Prof. Dr. Nicole Bäuerle
Prof. Dr. Vicky Fasen-Hartmann
Prof. Dr. Günter Last

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102904 - Brownian Motion

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0155700 | Brownsche Bewegung | 2 SWS | Lecture | Last |
| WT 25/26 | 0155710 | Übungen zu 0155700 (Brownsche Bewegung) | 1 SWS | Practice | Last |
| **Exams** | | | | | |
| WT 25/26 | 7700150 | Brownian Motion | | | Last |
| ST 2026 | 7700086 | Brownian Motion | | | Last |

**Prerequisites**
none

**Workload**
120 hours

# T 3.25 Module component: Class Field Theory [T-MATH-114500]

**Coordinators:** Prof. Dr. Frank Herrlich
PD Dr. Stefan Kühnlein

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-107387 - Class Field Theory

| Type | Credits | Grading | Expansion | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | 1 semesters | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700147 | Class Field Theory | Herrlich |

**Assessment**
The module examination takes the form of an oral examination lasting approx. 30 minutes.

**Prerequisites**
none

**Workload**
240 hours

# T 3.26 Module component: Classical Methods for Partial Differential Equations [T-MATH-105832]

**Coordinators:** Prof. Dr. Dorothee Frey
Prof. Dr. Dirk Hundertmark
Prof. Dr. Tobias Lamm
Prof. Dr. Michael Plum
Prof. Dr. Wolfgang Reichel
Prof. Dr. Roland Schnaubelt

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102870 - Classical Methods for Partial Differential Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0105300 | Classical Methods for Partial Differential Equations | 4 SWS | Lecture | Knopf |
| WT 25/26 | 0105310 | Tutorial for 0105300 (Classical Methods for Partial Differential Equations) | 2 SWS | Practice | Knopf |
| **Exams** | | | | | |
| WT 25/26 | 7700045 | Classical Methods for Partial Differential Equations | | | Knopf, Reichel, Lamm, Hundertmark |
| ST 2026 | 7700052 | Classical Methods for Partial Differential Equations | | | Reichel, Hundertmark, Tolksdorf, Knopf |

**Prerequisites**
None.

**Workload**
240 hours

# T 3.27 Module component: Cognitive Systems [T-INFO-101356]

**Coordinators:** Prof. Dr. Gerhard Neumann
Prof. Dr. Alexander Waibel

**Organisation:** KIT Department of Informatics

**Part of:** M-INFO-100819 - Cognitive Systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 1 |

# T 3.28 Module component: Combinatorics [T-MATH-105916]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102950 - Combinatorics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 8 CP | graded | 4 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0150300 | Combinatorics | 4 SWS | Lecture | Aksenovich, Sagdeev |
| ST 2026 | 0150310 | Tutorial for Combinatorics (0150300) | 2 SWS | Practice | Aksenovich, Sagdeev |

**Prerequisites**
none

*Below you will find excerpts from courses related to this module component:*

## V Combinatorics

0150300, SS 2026, 4 SWS, Open in study portal **Lecture (V)**

**Content**
Combinatorics is an area of mathematics primarily concerned with counting finite structures such as sets, groups, and graphs. While combinatorial problems are often very basic and easy to describe, solving them requires special knowledge and skills. This course is devoted to main concepts and techniques in combinatorics. These include counting principles such as inclusion-exclusion and bijective mappings, twelvefold way, generating functions, arrangements, Young tableaux, partitions, recursions, partially ordered sets, extremal set theory, and combinatorial designs.

## T 3.29 Module component: Combustion Technology [T-CIWVT-106104]

**Coordinators:** Prof. Dr.-Ing. Dimosthenis Trimis
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103069 - Combustion Technology

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2232010 | Fundamentals of Combustion Technology | 2 SWS | Lecture / 🗣 | Trimis |
| WT 25/26 | 2232011 | Exercises for 2232010 Fundamentals of Combustion Technology | 1 SWS | Practice / 🗣 | Trimis, und Mitarbeitende |
| **Exams** | | | | | |
| WT 25/26 | 7232010 | Combustion Technology | | | Trimis |
| ST 2026 | 7232010 | Combustion Technology | | | Trimis |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Prerequisites
None

# T 3.30 Module component: Complex Analysis [T-MATH-105849]

**Coordinators:** PD Dr. Gerd Herzog
Prof. Dr. Michael Plum
Prof. Dr. Wolfgang Reichel
Prof. Dr. Roland Schnaubelt
Dr. rer. nat. Patrick Tolksdorf

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102878 - Complex Analysis

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.31 Module component: Complex Geometry [T-MATH-113614]

**Coordinators:** Jun.-Prof. Dr. Claudio Llosa Isenrich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106776 - Complex Geometry

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Assessment**
oral exam (ca. 30 min)

**Prerequisites**
none

**Workload**
180 hours

# T 3.32 Module component: Compressive Sensing [T-MATH-105894]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102935 - Compressive Sensing

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 5 CP | graded | Irregular | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0154000 | Compressive Sensing | 2 SWS | Lecture | Rieder |

# T 3.33 Module component: Computational Fluid Dynamics [T-CIWVT-106035]

**Coordinators:** Prof. Dr.-Ing. Hermann Nirschl
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103072 - Computational Fluid Dynamics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2245020 | Computational Fluid Dynamics | 2 SWS | Lecture / 🗣 | Nirschl, und Mitarbeitende |
| WT 25/26 | 2245021 | Exercises for 2245020 Computational Fluid Dynamics | 1 SWS | Practice / 🗣 | Nirschl, und Mitarbeitende |
| **Exams** | | | | | |
| WT 25/26 | 7245020 | Computational Fluid Dynamics | | | Nirschl |
| ST 2026 | 7245020 | Computational Fluid Dynamics | | | Nirschl |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Learning control is a written examination lasting 90 minutes.

**Prerequisites**
None

# T 3.34 Module component: Computational Fluid Dynamics and Simulation Lab [T-MATH-113373]

**Coordinators:** Prof. Dr. Martin Frank
PD Dr. Mathias Krause
Dr. Stephan Simonis
PD Dr. Gudrun Thäter

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-106634 - Computational Fluid Dynamics and Simulation Lab

| Type | Credits | Grading | Version |
|---|---|---|---|
| Examination of another type | 4 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0161700 | Computational Fluid Dynamics and Simulation Lab | 4 SWS | Practical course | Thäter, Krause, Simonis |

**Prerequisites**
none

**Workload**
120 hours

*Below you will find excerpts from courses related to this module component:*

## V Computational Fluid Dynamics and Simulation Lab

0161700, SS 2026, 4 SWS, Language: German/English, Open in study portal

**Practical course (P)**

**Content**
The course is held in two parts. The lecture part contains introductions to modeling and simulations, to associated numerical methods, and to associated software and high-performance computer hardware, respectively. The second part is based on supervised group work of the students. Participants work on projects in which modelling, discretization, simulation and evaluation (e.g. visualization) are carried out for specific topics from the catalog. The catalog includes e.g: Diffusion processes, turbulent flows, multiphase flows, reactive flows, particle dynamics, optimal control and optimization under constraints, stabilization methods for advection-dominated transport problems.

At the end of the course, the students are able to jointly model problems beyond their own discipline and simulate them on high-performance computers. They have acquired a critical distance to results and their presentation. They can defend the results of projects in disputes. They have understood the importance of stability, convergence and parallelism of numerical methods from their own experience and are able to evaluate errors in modeling, approximation, computing and presentation.

Basic knowledge of the analysis of boundary value problems and of numerical methods for differential equations is recommended. Knowledge of a programming language is strongly recommened.

# T 3.35 Module component: Computer Architecture [T-INFO-101355]

**Coordinators:** Prof. Dr. Wolfgang Karl
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-100818 - Computer Architecture

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 1 |

| **Courses** | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2424570 | Computer Architecture | 3 SWS | Lecture / | Karl |
| **Exams** | | | | | |
| WT 25/26 | 7500034 | Computer Architecture | | | Karl |
| ST 2026 | 7500190 | Computer Architecture | | | Karl |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

# T 3.36 Module component: Computer Graphics [T-INFO-101393]

**Coordinators:** Prof. Dr.-Ing. Carsten Dachsbacher
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-100856 - Computer Graphics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2424081 | Computergraphics | 4 SWS | Lecture / | Grauer, Dachsbacher |
| **Exams** | | | | | |
| WT 25/26 | 7500430 | Computer Graphics | | | Dachsbacher |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Assessment**
Success is assessed in the form of a written examination lasting 90 minutes in accordance with Section 4 (2) No. 1 SPO.

A grade bonus for first attempt examinations can be obtained by successfully completing exercises. If the grade of the written examination is between 4.0 and 1.3, the bonus improves the grade by up to one grade level (0.3 or 0.4). Details will be announced in the lecture. This bonus is only valid within one year for an examination in the same semester or in the following semester. After that, the grade bonus expires.

# T 3.37 Module component: Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems [T-MATH-105854]

**Coordinators:** Prof. Dr. Michael Plum
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102883 - Computer-Assisted Analytical Methods for Boundary and Eigenvalue Problems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Assessment**
Oral examination lasting approx. 30 minutes.

**Prerequisites**
None.

**Workload**
240 hours

# T 3.38 Module component: Condensed Matter Theory I, Fundamentals [T-PHYS-102559]

**Coordinators:** PD Dr. Robert Eder
Prof. Dr. Markus Garst
Prof. Dr. Alexander Mirlin
Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102054 - Condensed Matter Theory I, Fundamentals

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4024011 | Condensed Matter Theory I | 4 SWS | Lecture / 🗣 | Shnirman |
| WT 25/26 | 4024012 | Exercises to Condensed Matter Theory I | 2 SWS | Practice / 🗣 | Shnirman, Reich |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

# T 3.39 Module component: Condensed Matter Theory I, Fundamentals and Advanced Topics [T-PHYS-102558]

**Coordinators:** PD Dr. Robert Eder
Prof. Dr. Markus Garst
Prof. Dr. Alexander Mirlin
Prof. Dr. Alexander Shnirman

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102053 - Condensed Matter Theory I, Fundamentals and Advanced Topics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 12 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4024011 | Condensed Matter Theory I | 4 SWS | Lecture / 🗣 | Shnirman |
| WT 25/26 | 4024012 | Exercises to Condensed Matter Theory I | 2 SWS | Practice / 🗣 | Shnirman, Reich |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

# T 3.40 Module component: Condensed Matter Theory II: Many-Body Systems, Fundamentals [T-PHYS-104591]

**Coordinators:** Prof. Dr. Markus Garst
apl. Prof. Dr. Igor Gornyi
Prof. Dr. Alexander Mirlin
PD Dr. Boris Narozhnyy
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Mathematics
KIT Department of Physics

**Part of:** M-PHYS-102313 - Condensed Matter Theory II: Many-Body Theory, Fundamentals

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 4024111 | Condensed Matter Theory II: Many-Body Theory | 4 SWS | Lecture / 🗣 | Gornyi, Poboiko |
| ST 2026 | 4024112 | Exercises to Condensed Matter Theory II | 2 SWS | Practice / 🗣 | Poboiko, Gornyi |

Legend: 🖥 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

## T 3.41 Module component: Condensed Matter Theory II: Many-Body Systems, Fundamentals and Advanced Topics [T-PHYS-102560]

**Coordinators:** Prof. Dr. Markus Garst
apl. Prof. Dr. Igor Gornyi
Prof. Dr. Alexander Mirlin
PD Dr. Boris Narozhnyy
Prof. Dr. Jörg Schmalian

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102308 - Condensed Matter Theory II: Many-Body Theory, Fundamentals and Advanced Topics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 12 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 4024111 | Condensed Matter Theory II: Many-Body Theory | 4 SWS | Lecture / 🗣 | Gornyi, Poboiko |
| ST 2026 | 4024112 | Exercises to Condensed Matter Theory II | 2 SWS | Practice / 🗣 | Poboiko, Gornyi |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

# T 3.42 Module component: Continuous Time Finance [T-MATH-105930]

**Coordinators:** Prof. Dr. Nicole Bäuerle
Prof. Dr. Vicky Fasen-Hartmann
Prof. Dr. Mathias Trabs

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102860 - Continuous Time Finance

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0159400 | Continuous Time Finance | 4 SWS | Lecture | Bäuerle |
| ST 2026 | 0159410 | Tutorial for 0159400 (Continuous Time Finance) | 2 SWS | Practice | Bäuerle |

**Assessment**
oral exam of ca. 30 minutes

**Prerequisites**
none

**Workload**
240 hours

*Below you will find excerpts from courses related to this module component:*

## V Continuous Time Finance

0159400, SS 2026, 4 SWS, Open in study portal **Lecture (V)**

**Content**
The lecture covers central topics in continuous-time finance. The first part of the course is an introduction to stochastic analysis. First, we introduce Brownian motion and important topics in the theory of martingales. We then develop the stochastic integral and describe its importance in finance. The second part of the course focuses on the analysis of the Black-Scholes model where the asset process is modelled by a geometric Brownian motion. In this market we price and hedge options. We derive the first and second fundamental theorems of asset pricing, which describe the relationships between arbitrage freedom, equivalent martingale measures and completeness. Finally, we study portfolio optimisation problems and term structure models.

Topics:

- Stochastic processes
- Total variation and quadratic variation
- Ito integral
- Black-Scholes model
- Bonds, futures, term structure models

# T 3.43 Module component: Control Theory [T-MATH-105909]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102941 - Control Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

**Prerequisites**
none

# T 3.44 Module component: Convex Geometry [T-MATH-105831]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102864 - Convex Geometry

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.45 Module component: Curves on Surfaces [T-MATH-113364]

**Coordinators:** Dr. Elia Fioravanti
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106632 - Curves on Surfaces

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 |

**Assessment**
oral exam (ca. 20-30 min)

**Prerequisites**
none

**Workload**
90 hours

# T 3.46 Module component: Deep Learning and Neural Networks [T-INFO-114219]

**Coordinators:** Prof. Dr. Jan Niehues
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-107197 - Deep Learning and Neural Networks

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2400024 | Deep Learning and Neural Networks | 4 SWS | Lecture / 🗣 | Niehues |
| **Exams** | | | | | |
| WT 25/26 | 7500400 | Deep Learning and Neural Networks (Nachklausur) | | | Niehues |
| ST 2026 | 7500044 | Deep Learning and Neural Networks | | | Niehues, Waibel |

Legend: 📱 Online, 🎲 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) lasting 60 minutes.

**Prerequisites**
T-INFO-101383 - Neural networks must not be started.

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-INFO-101383 - Neural Networks must not have been started.
2. The module component T-INFO-109124 - Deep Learning and Neural Networks must not have been started.

**Recommendations**
Prior successful completion of the core module "Cognitive Systems" is recommended.

# T 3.47 Module component: Differential Geometry [T-MATH-102275]

**Coordinators:** Prof. Dr. Alexander Lytchak
Prof. Dr. Wilderich Tuschmann

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-101317 - Differential Geometry

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700120 | Differential Geometry | Lytchak |

**Prerequisites**
none

# T 3.48 Module component: Discrete Dynamical Systems [T-MATH-110952]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105432 - Discrete Dynamical Systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 |

**Prerequisites**
none

**Workload**
90 hours

# T 3.49 Module component: Discrete Time Finance [T-MATH-105839]

**Coordinators:** Prof. Dr. Nicole Bäuerle
Prof. Dr. Vicky Fasen-Hartmann
Prof. Dr. Mathias Trabs

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102919 - Discrete Time Finance

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 8 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0108400 | Finanzmathematik in diskreter Zeit | 4 SWS | Lecture / 🗣 | Bäuerle |
| WT 25/26 | 0108500 | Übungen zu 0108400 (Finanzmathematik in diskreter Zeit) | 2 SWS | Practice / 🗣 | Bäuerle |
| **Exams** | | | | | |
| WT 25/26 | 0100025 | Discrete Time Finance | | | Bäuerle |
| WT 25/26 | 6700054 | Discrete Time Finance | | | Bäuerle |

Legend: 🖥 Online, 💠 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Written exam of 2h.

**Prerequisites**
none

**Recommendations**
The contents of the module „Probability theory“ are strongly recommended.

**Workload**
240 hours

# T 3.50 Module component: Dispersive Equations [T-MATH-109001]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-104425 - Dispersive Equations

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.51 Module component: Dynamical Systems [T-MATH-106114]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103080 - Dynamical Systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.52 Module component: Elective Specialization Supplementary Studies on Science, Technology and Society / About Knowledge and Science - Self-Registration [T-FORUM-113580]

**Coordinators:** Dr. Christine Mielke
Christine Myglas

**Organisation:** General Studies. Forum Science and Society (FORUM)

**Part of:** M-FORUM-106753 - Supplementary Studies on Science, Technology and Society

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Examination of another type | 3 CP | graded | Each term | 1 |

**Assessment**
Another type of examination assessment under § 5, section 3 involves a presentation, term paper, or project work within the chosen course.

**Prerequisites**
None

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)
- FORUM (ehem. ZAK) Begleitstudium

**Recommendations**
The contents of the basic module are helpful. The basic module should be completed or attended in parallel, but not after the advanced module.
The reading recommendations for primary and specialist literature are determined individually by the respective lecturers according to the subject area and course.

**Additional Information**
This placeholder can be used for any achievement in the Advanced Unit of the Supplementary Studies.

In the Advanced Module, students can choose their own individual focus, e.g. sustainable development, data literacy, etc. The focus should be discussed with the module coordinator at the FORUM.

# T 3.53 Module component: Elective Specialization Supplementary Studies on Science, Technology and Society / Science in Public Debates - Self Registration [T-FORUM-113582]

**Coordinators:** Dr. Christine Mielke
Christine Myglas

**Organisation:** General Studies. Forum Science and Society (FORUM)

**Part of:** M-FORUM-106753 - Supplementary Studies on Science, Technology and Society

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Examination of another type | 3 CP | graded | Each term | 1 |

**Assessment**
Another type of examination assessment under § 5, section 3 involves a presentation, term paper, or project work within the chosen course.

**Prerequisites**
None

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)
- FORUM (ehem. ZAK) Begleitstudium

**Recommendations**
The contents of the basic module are helpful. The basic module should be completed or attended in parallel, but not after the advanced module.
The reading recommendations for primary and specialist literature are determined individually by the respective lecturers according to the subject area and course.

**Additional Information**
This placeholder can be used for any achievement in the Advanced Unit of the Supplementary Studies.

# T 3.54 Module component: Elective Specialization Supplementary Studies on Science, Technology and Society / Science in Society - Self-Registration [T-FORUM-113581]

**Coordinators:** Dr. Christine Mielke
Christine Myglas
**Organisation:** General Studies. Forum Science and Society (FORUM)
**Part of:** M-FORUM-106753 - Supplementary Studies on Science, Technology and Society

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Examination of another type | 3 CP | graded | Each term | 1 |

**Assessment**
Another type of examination assessment under § 5, section 3 involves a presentation, term paper, or project work within the chosen course.

**Prerequisites**
None

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)
- FORUM (ehem. ZAK) Begleitstudium

**Recommendations**
The contents of the basic module are helpful. The basic module should be completed or attended in parallel, but not after the advanced module.
The reading recommendations for primary and specialist literature are determined individually by the respective lecturers according to the subject area and course.

**Additional Information**
This placeholder can be used for any achievement in the Advanced Unit of the Supplementary Studies.

# T 3.55 Module component: Electromagnetics and Numerical Calculation of Fields [T-ETIT-100640]

**Coordinators:** Dr. Yongbo Deng
Prof. Dr. Ulrich Lemmer

**Organisation:** KIT Department of Electrical Engineering and Information Technology

**Part of:** M-ETIT-100386 - Electromagnetics and Numerical Calculation of Fields

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 4 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2141110 | Electromagnetics and Numerical Calculation of Fields | 2 SWS | Lecture / 🗣 | Deng |
| WT 25/26 | 2141111 | Exercise for 2308263 Electromagnetics and Numerical Calculation of Fields | 1 SWS | Practice / 🗣 | Deng |
| **Exams** | | | | | |
| WT 25/26 | 7308263 | Electromagnetics and Numerical Calculation of Fields | | | Deng |
| ST 2026 | 7600003 | Electromagnetics and Numerical Calculation of Fields | | | Deng |

Legend: 💻 Online, 🎲 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Success control is carried out in the form of a written test of 120 minutes.

**Prerequisites**
none

**Recommendations**
Fundamentals of electromagnetic field theory.

# T 3.56 Module component: Electronic Properties of Solids I, with Exercises [T-PHYS-102577]

**Coordinators:** Prof. Dr. Matthieu Le Tacon
Prof. Dr. Wolfgang Wernsdorfer
Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102089 - Electronic Properties of Solids I, with Exercises

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 10 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4021011 | Electronic Properties of Solids I | 4 SWS | Lecture / 🗣 | Le Tacon, Wernsdorfer |
| WT 25/26 | 4021012 | Exercises to Electronic Properties of Solids I | 1 SWS | Practice / 🗣 | Le Tacon, Wernsdorfer, Cubaynes |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

# T 3.57 Module component: Electronic Properties of Solids I, without Exercises [T-PHYS-102578]

**Coordinators:** Prof. Dr. Matthieu Le Tacon
Prof. Dr. Wolfgang Wernsdorfer
Prof. Dr. Wulf Wulfhekel

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102090 - Electronic Properties of Solids I, without Exercises

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4021011 | Electronic Properties of Solids I | 4 SWS | Lecture / | Le Tacon, Wernsdorfer |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Prerequisites**
none

# T 3.58 Module component: Electronic Properties of Solids II, with Exercises [T-PHYS-104422]

**Coordinators:** Prof. Dr. Matthieu Le Tacon
Dr. Johannes Rotzinger
Prof. Dr. Alexey Ustinov
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102108 - Electronic Properties of Solids II, with Exercises

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 4021111 | Electronic Properties of Solids II | 2 SWS | Lecture / 🗣 | Ustinov |
| ST 2026 | 4021112 | Exercises to Electronic Properties of Solids II | 2 SWS | Practice / 🗣 | Ustinov, Fischer |

Legend: 💻 Online, 🌸 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

# T 3.59 Module component: Electronic Properties of Solids II, without Exercises [T-PHYS-104423]

**Coordinators:** Prof. Dr. Matthieu Le Tacon
Dr. Johannes Rotzinger
Prof. Dr. Alexey Ustinov
Prof. Dr. Wolfgang Wernsdorfer

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102109 - Electronic Properties of Solids II, without Exercises

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 4021111 | Electronic Properties of Solids II | 2 SWS | Lecture / 🗣 | Ustinov |

Legend: 🖥 Online, 🔀 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

# T 3.60 Module component: Ergodic Theory [T-MATH-113086]

**Coordinators:** PD Dr. Gabriele Link
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106473 - Ergodic Theory

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
Oral examination of ca. 20-30 minutes.

**Prerequisites**
none

**Recommendations**
Some basic knowledge of measure theory, topology, geometry, group theory and functional analysis is recommended.

**Workload**
240 hours

# T 3.61 Module component: Evolution Equations [T-MATH-105844]

**Coordinators:** Prof. Dr. Dorothee Frey
apl. Prof. Dr. Peer Kunstmann
Prof. Dr. Roland Schnaubelt

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102872 - Evolution Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0105900 | Evolution equations | 4 SWS | Lecture | de Rijk |
| WT 25/26 | 0105910 | Tutorial for 0105900 (Evolution Equations) | 2 SWS | Practice | de Rijk |
| **Exams** | | | | | |
| WT 25/26 | 7700002 | Evolution Equations | | | de Rijk, Reichel |
| ST 2026 | 7700117 | Evolution Equations | | | Kunstmann, de Rijk |

*Below you will find excerpts from courses related to this module component:*

## V Evolution equations

0105900, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**
See ILIAS page

**Literature**
We will follow the lecture notes of Roland Schnaubelt (see ILIAS page)

* Engel, Nagel: One-Parameter Semigroups for Linear Evolution Equations
* Pazy: Semigroups of Linear Operators and Applications to Partial Differential Equations

* Arendt, Batty, Hieber, Neubrander: Vector-valued Laplace Transforms and Cauchy Problems
* Davies: One-Parameter Semigroups
* Engel, Nagel: A Short Course of Operator Semigroups
* Fattorini: The Cauchy Problem
* Goldstein: Semigroups of Linear Operators and Applications
* Hille, Phillips: Functional Analysis and Semi-groups
* Lunardi: Analytic Semigroups and Optimal Regularity in Parabolic Problems
* Tanabe: Equations of Evolution

# T 3.62 Module component: Exponential Integrators [T-MATH-107475]

**Coordinators:** Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-103700 - Exponential Integrators

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.63 Module component: Extremal Graph Theory [T-MATH-105931]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102957 - Extremal Graph Theory

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 2 |

**Prerequisites**
none

# T 3.64 Module component: Extreme Value Theory [T-MATH-105908]

**Coordinators:** Prof. Dr. Vicky Fasen-Hartmann
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102939 - Extreme Value Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 2 |

# T 3.65 Module component: Finite Element Methods [T-MATH-105857]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke
TT-Prof. Dr. Roland Maier
Prof. Dr. Andreas Rieder
Prof. Dr. Christian Wieners

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102891 - Finite Element Methods

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0110300 | Finite Element Methods | 4 SWS | Lecture / 🗣 | Hochbruck, Dörich |
| WT 25/26 | 0110310 | Tutorial for 0110300 (Finite Element Methods) | 2 SWS | Practice | Hochbruck, Dörich |
| **Exams** | | | | | |
| WT 25/26 | 7700046 | Finite Element Methods | | | Hochbruck, Dörich |
| WT 25/26 | 7700047 | Finite Element Methods | | | Hochbruck, Dörich |

Legend: 💻 Online, Blended (On-Site/Online), 🗣 On-Site, × Cancelled

**Prerequisites**
none

*Below you will find excerpts from courses related to this module component:*

## V Finite Element Methods

0110300, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture (V)**
**On-Site**

**Content**
This course is about numerically solving elliptic boundary value problems using the finite element method. We will introduce necessary basic definitions and then discuss the method in its various aspects. In particular, we will study grid generation, error estimates, and the practical realization of the approach.

**Literature**
Complete lecture notes will be provided

# T 3.66 Module component: Forecasting: Theory and Practice [T-MATH-105928]

**Coordinators:** Prof. Dr. Tilmann Gneiting
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102956 - Forecasting: Theory and Practice

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 2 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700110 | Forecasting: Theory and Practice | Gneiting |

**Prerequisites**
None.

# T 3.67 Module component: Formal Systems [T-INFO-101336]

**Coordinators:** Prof. Dr. Bernhard Beckert
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-100799 - Formal Systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each winter term | 1 |

| **Courses** | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2424086 | Formale Systeme | 4 SWS | Lecture / Practice | Beckert, Ulbrich, Weigl |
| **Exams** | | | | | |
| WT 25/26 | 7500036 | Formal Systems | | | Beckert |
| ST 2026 | 7500009 | Formal Systems | | | Beckert |

# T 3.68 Module component: Foundations of Continuum Mechanics [T-MATH-107044]

**Coordinators:** Prof. Dr. Christian Wieners
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103527 - Foundations of Continuum Mechanics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Once | 2 |

**Assessment**
Oral exam of approx. 20 minutes.

**Prerequisites**
none

# T 3.69 Module component: Fractal Geometry [T-MATH-111296]

**Coordinators:** PD Dr. Steffen Winter
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105649 - Fractal Geometry

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.70 Module component: Functional Analysis [T-MATH-102255]

**Coordinators:** Prof. Dr. Dorothee Frey
PD Dr. Gerd Herzog
Prof. Dr. Dirk Hundertmark
Prof. Dr. Tobias Lamm
TT-Prof. Dr. Xian Liao
Prof. Dr. Wolfgang Reichel
Prof. Dr. Roland Schnaubelt
Dr. rer. nat. Patrick Tolksdorf

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-101320 - Functional Analysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 8 CP | graded | Each winter term | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0104800 | Functional Analysis | 4 SWS | Lecture / 🗣 | Hundertmark |
| WT 25/26 | 0104810 | Tutorial for 0104800 (Functional Analysis) | 2 SWS | Practice / 🗣 | Hundertmark |
| **Exams** | | | | | |
| WT 25/26 | 0100047 | Functional Analysis | | | Lamm, Hundertmark, Kunstmann, Schnaubelt, Frey, Reichel, Tolksdorf |

Legend: 💻 Online, 🌐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Written examination of 120 minutes.

**Prerequisites**
none

**Workload**
240 hours

*Below you will find excerpts from courses related to this module component:*

## V Functional Analysis

0104800, WS 25/26, 4 SWS, Open in study portal

**Lecture (V)**
**On-Site**

**Content**
The lecture deals with Banach and Hilbert spaces and the linear operators on these spaces. Typical examples are spaces of continuous or integrable functions, and linear operators on these spaces occur in the study of integral and differential equations. The development of functional analysis in the 20th century contributed significantly to the modern theory of differential equations. Today, functional analysis is a fundamental discipline of modern analysis and is widely used, for example, in the theory of partial differential equations, numerical mathematics, mathematical physics and many other areas of application.

Topics of the lecture:
basic properties and examples of metric spaces and Banach spaces, continuous linear operators on Banach spaces, uniform boundedness principle, homomorphism theorem, Hilbert spaces, orthonormal bases, Sobolev spaces, dual spaces, Hahn-Banach theorem, weak convergence, Banach-Alaoglu theorem, reflexivity, compact linear operators

The contents of the basic lectures Analysis 1-3 and Linear Algebra 1+2 are assumed.

**Literature**

- D. Werner: Funktionalanalysis.

- H.W. Alt: Lineare Funktionalanalysis.
- H. Brezis: Functional Analysis, Sobolev Spaces and Partial Differential Equations.
- J.B. Conway: A Course in Functional Analysis.
- M. Reed, B. Simon: Functional Analysis.
- W. Rudin: Functional Analysis.
- A.E. Taylor, D.C. Lay: Introduction to Functional Analysis.
- J. Wloka: Funktionalanalysis und Anwendungen.

# T 3.71 Module component: Functional Data Analysis [T-MATH-113102]

**Coordinators:** Dr. rer. nat. Bruno Ebner
PD Dr. Bernhard Klar
Prof. Dr. Mathias Trabs

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-106485 - Functional Data Analysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700112 | Functional Data Analysis | Ebner |

**Assessment**
Oral examination of ca. 25 minutes.

**Prerequisites**
none

**Recommendations**
The contents of the modules "Probability Theory" and "Mathematical Statistics" are strongly recommended.

**Workload**
120 hours

# T 3.72 Module component: Functions of Matrices [T-MATH-105906]

**Coordinators:** PD Dr. Volker Grimm
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102937 - Functions of Matrices

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

**Prerequisites**
none

# T 3.73 Module component: Functions of Operators [T-MATH-105905]

**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102936 - Functions of Operators

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

# T 3.74 Module component: Galerkin Methods for Time-dependent PDEs [T-MATH-114992]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-107647 - Galerkin Methods for Time-dependent PDEs

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 5 CP | graded | 1 |

**Assessment**
Success is assessed in form of an oral examination.

**Prerequisites**
None.

**Workload**
150 hours

# T 3.75 Module component: Generalized Regression Models [T-MATH-105870]

**Coordinators:** Dr. rer. nat. Bruno Ebner
Prof. Dr. Vicky Fasen-Hartmann
PD Dr. Bernhard Klar
Prof. Dr. Mathias Trabs

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102906 - Generalized Regression Models

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0161400 | Generalisierte Regressionsmodelle | 2 SWS | Lecture | Klar |
| ST 2026 | 0161410 | Übungen zu 0161400 (generalisierte Regressionsmodelle) | 1 SWS | Practice | Klar |

**Workload**
120 hours

# T 3.76 Module component: Geometric Analysis [T-MATH-105892]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102923 - Geometric Analysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Prerequisites**
none

**Workload**
240 hours

# T 3.77 Module component: Geometric Group Theory [T-MATH-105842]

**Coordinators:** Prof. Dr. Frank Herrlich
PD Dr. Gabriele Link
Jun.-Prof. Dr. Claudio Llosa Isenrich
Prof. Dr. Roman Sauer
Prof. Dr. Wilderich Tuschmann

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102867 - Geometric Group Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700079 | Geometric Group Theory | Link |
| ST 2026 | 7700149 | Geometric Group Theory | Link |

**Prerequisites**
None.

**Workload**
240 hours

# T 3.78 Module component: Geometric Group Theory II [T-MATH-105875]

**Coordinators:** Prof. Dr. Frank Herrlich
Jun.-Prof. Dr. Claudio Llosa Isenrich
Prof. Dr. Roman Sauer

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102869 - Geometric Group Theory II

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0102900 | Geometric Group Theory II | 4 SWS | Lecture | Fioravanti |
| WT 25/26 | 0102910 | Tutorial for 0102900 (Geometric Group Theory II) | 2 SWS | Practice | Fioravanti |
| **Exams** | | | | | |
| WT 25/26 | 7700149 | Geometric Group Theory II | | | Fioravanti |
| WT 25/26 | 7700156 | Geometric Group Theory II | | | Fioravanti |

*Below you will find excerpts from courses related to this module component:*

## V Geometric Group Theory II

0102900, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**

Geometric Group Theory studies algebraic and computational aspects of infinite, finitely generated groups by means of their isometric actions on metric spaces. Arbitrary finitely generated groups can be "arbitrarily wild", and many computational problems are unsolvable in general. For instance, Adyan and Rabin showed in the 1950s that, given a finite presentation of a general finitely presented group, there cannot exist an algorithm telling whether a word in the generators represents the trivial element in the group.

At the same time, most groups naturally arising in geometry and topology are not wild at all. In fact, quite a lot can be said about a group if we know that it admits a "nice" action on a "nice" metric space. Here both occurrences of the word "nice" can be taken to mean quite a lot of different things.

The course will focus on two of the most important classes of "nice" metric spaces, namely CAT(0) spaces and Gromov-hyperbolic spaces. These provide two different ways of formalising the concept of non-positive (or negative) sectional curvature in a purely synthetic way, which avoids any use of differential geometry and applies to "singular" spaces that can fail to be manifolds.

Time permitting, topics covered will include:

- boundaries of hyperbolic groups;
- CAT(0), CAT(+1) and CAT(-1) spaces;
- algebraic and algorithmic properties of hyperbolic and CAT(0) groups;
- Coxeter groups;
- CAT(0) cube complexes.

We will build on the material already covered in the course Geometric Group Theory (SS 2025), including the basics of Gromov-hyperbolic spaces developed there. Familiarity with these concepts is recommended.

**Literature**

M.Bridson, A.Haefliger, *"Metric spaces of non-positive curvature"*. (Freely available online, among the first results of any search engine.)

# T 3.79 Module component: Geometric Numerical Integration [T-MATH-105919]

**Coordinators:** Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102921 - Geometric Numerical Integration

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0154100 | Geometric Numerical Integration | 3 SWS | Lecture | Jahnke |
| ST 2026 | 0154200 | Tutorial for 0154100 (Geometric Numerical Integration) | 1 SWS | Practice | Jahnke, Kirn |

**Prerequisites**
none

**Workload**
180 hours

*Below you will find excerpts from courses related to this module component:*

## V Geometric Numerical Integration

0154100, SS 2026, 3 SWS, Language: English, Open in study portal — **Lecture (V)**

**Content**
Simulating time-dependent processes in science and technology often requires to solve a system of ordinary differential equations with a suitable numerical method. In many applications it can be shown that the exact flow of the differential equation exhibits certain qualitative or “geometric” properties. For example, it is well-known that the flow of a Hamiltonian system is symplectic, and that the energy remains constant along the solution although the solution itself changes as time evolves.

When the solution or the flow is approximated by a numerical integrator, it is desirable or even crucial to preserve these geometric properties. It turns out, however, that only selected methods respect the geometric properties of the dynamics. These methods are called geometric numerical integrators. In this lecture we will investigate

• why certain methods are (or are not) geometric numerical integrators,
• how to construct geometric numerical integrators, and
• which properties are conserved, and in which sense.

The lecture will be suited for Master students in mathematics, physics and other sciences with a basic knowledge in ordinary differential equations and Runge-Kutta methods. In particular, students should be familiar with concepts such as, e.g., order, consistency, convergence, A-stability, and so on. The course “Numerische Methoden für Differentialgleichungen” provides a good basis. Moreover, participants are expected to be familiar with Matlab or Python. In some of the exercises discussed in the tutorial, students will be asked to write short programs in order to test the behaviour of numerical methods.

Both the lecture and the exercise classes will be given in English.

# T 3.80 Module component: Geometric Variational Problems [T-MATH-113418]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106667 - Geometric Variational Problems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
none

**Workload**
240 hours

# T 3.81 Module component: Geometry of Schemes [T-MATH-105841]

**Coordinators:** Prof. Dr. Frank Herrlich
PD Dr. Stefan Kühnlein

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102866 - Geometry of Schemes

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.82 Module component: Global Differential Geometry [T-MATH-105885]

**Coordinators:** Prof. Dr. Wilderich Tuschmann
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102912 - Global Differential Geometry

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

**Prerequisites**
none

**Workload**
240 hours

# T 3.83 Module component: Graph Theory [T-MATH-102273]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-101336 - Graph Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 8 CP | graded | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0104500 | Graph Theory | 4 SWS | Lecture | Aksenovich, Liu |
| WT 25/26 | 0104510 | Tutorial for 0104500 (Graph Theory) | 2 SWS | Practice | Aksenovich, Liu |
| **Exams** | | | | | |
| WT 25/26 | 7700050 | Graph Theory | | | Aksenovich |

**Prerequisites**
None

*Below you will find excerpts from courses related to this module component:*

## V Graph Theory

0104500, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**
Graphs are structures in discrete mathematics that in particular model various networks. The course starts with basic concepts in graph theory such as trees, cycles, matchings, factors, connectivity, and their interconnections. Further topics include properties of graphs with forbidden subgraphs, planar graphs, graph colorings, random graphs, Ramsey theory, and graph minors. Not only classical, but very recent results in the field will be discussed. The class is oriented towards problem solving. Particular attention to proof writing techniques will be paid in the problem class. The final grade will be based on the written exam. Bonus points will be given for weekly or biweekly homework assignments.

# T 3.84 Module component: Harmonic Analysis [T-MATH-111289]

**Coordinators:** Prof. Dr. Dorothee Frey
apl. Prof. Dr. Peer Kunstmann
Prof. Dr. Roland Schnaubelt
Dr. rer. nat. Patrick Tolksdorf

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-105324 - Harmonic Analysis

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| ST 2026 | 7700081 | Harmonic Analysis | Frey, Tolksdorf, Kunstmann |

**Prerequisites**
None.

**Workload**
240 hours

# T 3.85 Module component: Harmonic Analysis 2 [T-MATH-113103]

**Coordinators:** Prof. Dr. Dorothee Frey
apl. Prof. Dr. Peer Kunstmann
Dr. rer. nat. Patrick Tolksdorf

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-106486 - Harmonic Analysis 2

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700144 | Harmonic Analysis 2 | Frey |

**Assessment**
oral examination of ca. 30 minutes.

**Prerequisites**
none

**Recommendations**
The following modules are strongly recommended: "Harmonic Analysis", "Functional Analysis".

**Workload**
240 hours

# T 3.86 Module component: Heat Transfer II [T-CIWVT-106067]

**Coordinators:** Prof. Dr.-Ing. Thomas Wetzel
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103051 - Heat Transfer II

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 3 |

| **Courses** | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2260020 | Heat Transfer II | 2 SWS | Lecture / 🗣 | Wetzel, Dietrich |
| WT 25/26 | 2260021 | Exercises on 2260020 Heat Transfer II | 1 SWS | Practice / 🗣 | Wetzel, Dietrich |
| **Exams** | | | | | |
| WT 25/26 | 7260020 | Heat Transfer II | | | Wetzel, Dietrich |
| ST 2026 | 7260020 | Heat Transfer II | | | Wetzel, Dietrich |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

# T 3.87 Module component: High Temperature Process Engineering [T-CIWVT-106109]

**Coordinators:** Prof. Dr.-Ing. Dieter Stapf
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103075 - High Temperature Process Engineering

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each summer term | 1 |

| **Courses** | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2232210 | High Temperature Process Engineering | 2 SWS | Lecture / ✕ | Stapf |
| ST 2026 | 2232211 | High Temperature Process Engineering - Exercises | 1 SWS | Practice / ✕ | Stapf, und Mitarbeitende |
| **Exams** | | | | | |
| WT 25/26 | 7232210 | High Temperature Process Engineering | | | Stapf |
| ST 2026 | 7232210 | High Temperature Process Engineering | | | Stapf |

Legend: Online, Blended (On-Site/Online), On-Site, ✕ Cancelled

**Prerequisites**
None

# T 3.88 Module component: Infinite dimensional dynamical systems [T-MATH-107070]

**Coordinators:** Prof. Dr. Jens Rottmann-Matthes
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103544 - Infinite dimensional dynamical systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.89 Module component: Information Security [T-INFO-112195]

**Coordinators:** Prof. Dr. Hannes Hartenstein
Prof. Dr. Thorsten Strufe
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-106015 - Information Security

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 5 CP | graded | Each summer term | 6 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2400199 | Informationssicherheit | 3 SWS | Lecture / Practice / 🗣 | Müller-Quade, Strufe, Hartenstein |
| **Exams** | | | | | |
| WT 25/26 | 7500003 | Information Security | | | Wressnegger, Müller-Quade, Strufe, Hartenstein |
| WT 25/26 | 7500408 | Information Security | | | Strufe, Hartenstein |
| ST 2026 | 7500028 | Information Security | | | Müller-Quade, Strufe, Hartenstein |

Legend: 🖥 Online, 🌸 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-INFO-101371 - Security must not have been started.

# T 3.90 Module component: Integral Equations [T-MATH-105834]

**Coordinators:** PD Dr. Tilo Arens
Prof. Dr. Roland Griesmaier
PD Dr. Frank Hettlich

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102874 - Integral Equations

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0160510 | Übungen zu 0160500 (Integralgleichungen) | 2 SWS | Practice | Arens |

## T 3.91 Module component: Integrated Photonics [T-ETIT-114418]

**Coordinators:** Prof. Dr.-Ing. Christian Koos
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** M-ETIT-107344 - Integrated Photonics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2309440 | Integrated Photonics | 2 SWS | Lecture / 🗣 | Koos, N.N. |
| WT 25/26 | 2309441 | Tutorial to Integrated Photonics | 2 SWS | Practice / 🗣 | Koos, N.N., Khairy |
| **Exams** | | | | | |
| WT 25/26 | 7300021 | Integrated Photonics | | | Koos |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Assessment
The assessment takes place in the form of an oral examination (approx. 25 minutes); appointments individually on demand.

### Prerequisites
none

# T 3.92 Module component: Internet Seminar for Evolution Equations [T-MATH-105890]

**Coordinators:** Prof. Dr. Dorothee Frey
apl. Prof. Dr. Peer Kunstmann
Prof. Dr. Roland Schnaubelt
Dr. rer. nat. Patrick Tolksdorf

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102918 - Internet Seminar for Evolution Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0105000 | Internetseminar für Evolutionsgleichungen | 2 SWS | Lecture / 🗣 | Schnaubelt, Kunstmann, Frey, Tolksdorf |

Legend: 💻 Online, 🎲 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
oral examination of ca. 30 minutes

**Prerequisites**
none

**Workload**
240 hours

# T 3.93 Module component: Internship [T-MATH-105888]

**Coordinators:** Prof. Dr. Willy Dörfler
PD Dr. Markus Neher

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102861 - Internship

| Type | Credits | Grading | Version |
|---|---|---|---|
| Coursework | 10 CP | pass/fail | 1 |

# T 3.94 Module component: Interpolation Spaces [T-MATH-114639]

**Coordinators:** apl. Prof. Dr. Peer Kunstmann
Prof. Dr. Tobias Lamm

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-107456 - Interpolation Spaces

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Assessment**
Oral examination lasting approx. 30 minutes.

**Prerequisites**
none

**Workload**
180 hours

# T 3.95 Module component: Introduction into Particulate Flows [T-MATH-105911]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102943 - Introduction into Particulate Flows

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 3 CP | graded | 1 |

**Prerequisites**
none

# T 3.96 Module component: Introduction to Artificial Intelligence [T-INFO-112194]

**Coordinators:** Prof. Dr. Pascal Friederich
Prof. Dr. Gerhard Neumann

**Organisation:** KIT Department of Informatics

**Part of:** M-INFO-106014 - Introduction to Artificial Intelligence

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 5 CP | graded | Each winter term | 7 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2400158 | Introduction to Artificial Intelligence | 3 SWS | Lecture / Practice / | Schäfer, Nowack, Friederich, Neumann |
| **Exams** | | | | | |
| WT 25/26 | 7500136 | Introduction to Artificial Intelligence | | | Nowack, Friederich, Schäfer, Neumann |
| ST 2026 | 7500058 | Introduction to Artificial Intelligence | | | Friederich, Schäfer, Nowack |

Legend: Online, Blended (On-Site/Online), On-Site, × Cancelled

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-INFO-101356 - Cognitive Systems must not have been started.

# T 3.97 Module component: Introduction to Convex Integration [T-MATH-112119]

**Coordinators:** Dr. Christian Zillinger
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105964 - Introduction to Convex Integration

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
oral examination of approx. 30 minutes

**Prerequisites**
none

**Recommendations**
The courses "Classical Methods for Partial Differential Equations" and "Functional Analysis" are recommended.

**Workload**
90 hours

# T 3.98 Module component: Introduction to Cosmology [T-PHYS-102384]

**Coordinators:** Prof. Dr. Guido Drexlin
**Organisation:** KIT Department of Physics
**Part of:** M-PHYS-102175 - Introduction to Cosmology

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4022021 | Introduction to Cosmology | 2 SWS | Lecture / 🗣 | Valerius, Lokhov |
| WT 25/26 | 4022022 | Exercises to Introduction to Cosmology | 1 SWS | Practice / 🗣 | Valerius, Hinz, Seday |

Legend: 💻 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

*Below you will find excerpts from courses related to this module component:*

## V Introduction to Cosmology

4022021, WS 25/26, 2 SWS, Language: English, Open in study portal

**Lecture (V)**
**On-Site**

**Content**
An Introduction to cosmology from the Big Bang to the present universe

# T 3.99 Module component: Introduction to Dynamical Systems [T-MATH-113263]

**Coordinators:** Dr. Björn de Rijk
Prof. Dr. Wolfgang Reichel

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-106591 - Introduction to Dynamical Systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
none

**Workload**
180 hours

# T 3.100 Module component: Introduction to Fluid Dynamics [T-MATH-111297]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105650 - Introduction to Fluid Dynamics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.101 Module component: Introduction to Fluid Mechanics [T-MATH-112927]

**Coordinators:** TT-Prof. Dr. Xian Liao
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106401 - Introduction to Fluid Mechanics

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
The module examination takes the form of an oral examination of approx. 25 minutes.

**Prerequisites**
none

**Recommendations**
The module *Functional Analysis* is strongly recommended.

**Workload**
180 hours

# T 3.102 Module component: Introduction to Geometric Measure Theory [T-MATH-105918]

**Coordinators:** PD Dr. Steffen Winter
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102949 - Introduction to Geometric Measure Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

**Prerequisites**
none

# T 3.103 Module component: Introduction to Homogeneous Dynamics [T-MATH-110323]

**Coordinators:** Prof. Dr. Tobias Hartnick
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105101 - Introduction to Homogeneous Dynamics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.104 Module component: Introduction to Kinetic Equations [T-MATH-111721]

**Coordinators:** Dr. Christian Zillinger
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105837 - Introduction to Kinetic Equations

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
oral examination of circa 30 minutes

**Prerequisites**
none

**Recommendations**
The course "Classical Methods for Partial Differential Equations" should be studied beforehand.

# T 3.105 Module component: Introduction to Kinetic Theory [T-MATH-108013]

**Coordinators:** Prof. Dr. Martin Frank
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103919 - Introduction to Kinetic Theory

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0155450 | Introduction to Kinetic Theory | 2 SWS | Lecture | Loevbak |
| WT 25/26 | 0155460 | Tutorial for 0155450 (Introduction to Kinetic Theory) | 1 SWS | Practice | Loevbak |
| **Exams** | | | | | |
| WT 25/26 | 7700078 | Introduction to Kinetic Theory | | | Frank, Loevbak |

**Prerequisites**
none

*Below you will find excerpts from courses related to this module component:*

## V Introduction to Kinetic Theory

0155450, WS 25/26, 2 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**
Kinetic descriptions play an important role in a variety of physical, biological, and even social applications, for instance, in the description of gases, radiations, bacteria or financial markets. Typically, these systems are described locally not by a finite set of variables but instead by a probability density describing the distribution of a microscopic state. Its evolution is typically given by an integro-differential equation. Unfortunately, the large phase space associated with the kinetic description has made simulations impractical in most settings in the past. However, recent advances in computer resources, reduced-order modeling and numerical algorithms are making accurate approximations of kinetic models more tractable, and this trend is expected to continue in the future. On the theoretical mathematical side, two rather recent Fields medals (Pierre-Louis Lions 1994, Cédric Villani 2010) also indicate the continuing interest in this field, which was already the subject of Hilbert's sixth out of the 23 problems presented at the World Congress of Mathematicians in 1900.

This course gives an introduction to kinetic theory. Our purpose is to discuss the mathematical passage from a microscopic description of a system of particles, via a probabilistic description to a macroscopic view. This is done in a complete way for the linear case of particles that are interacting with a background medium. The nonlinear case of pairwise interacting particles is treated on a more phenomenological level.

An extremely broad range of mathematical techniques is used in this course. Besides mathematical modeling, we make use of statistics and probability theory, ordinary differential equations, hyperbolic partial differential equations, integral equations (and thus functional analysis) and infinite-dimensional optimization. Among the astonishing discoveries of kinetic theory are the statistical interpretation of the Second Law of Thermodynamics, induced by the Boltzmann-Grad limit, and the result that the macroscopic equations describing fluid motion (namely the Euler and Navier-Stokes equations) can be inferred from abstract geometrical properties of integral scattering operators.

# T 3.106 Module component: Introduction to Microlocal Analysis [T-MATH-111722]

**Coordinators:** TT-Prof. Dr. Xian Liao
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105838 - Introduction to Microlocal Analysis

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
oral examination of circa 30 minutes

**Prerequisites**
none

**Recommendations**
The courses "Classical Methods for Partial Differential Equations" and "Functional Analysis" should be studied beforehand.

# T 3.107 Module component: Introduction to Python [T-MATH-106119]

**Coordinators:** Dr. Daniel Weiß
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102994 - Key Competences

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Coursework | 4 CP | pass/fail | Each summer term | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0169000 | Einführung in Python | 1 SWS | Lecture | Weiß |

**Workload**
120 hours

# T 3.108 Module component: Introduction to Scientific Computing [T-MATH-105837]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke
Prof. Dr. Andreas Rieder
Prof. Dr. Christian Wieners

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102889 - Introduction to Scientific Computing

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0165000 | Einführung in das Wissenschaftliche Rechnen | 3 SWS | Lecture | Jahnke |
| ST 2026 | 0165010 | Praktikum zu Einführung in das Wissenschaftliche Rechnen (0165000) | 3 SWS | Practical course | Jahnke, Kirn |

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-MATH-114059 - Project Lab Scientific Computing must have been passed.

# T 3.109 Module component: Introduction to Stochastic Differential Equations [T-MATH-112234]

**Coordinators:** Josef Janák
Prof. Dr. Mathias Trabs
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106045 - Introduction to Stochastic Differential Equations

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

**Assessment**
The module will be completed with an oral exam (approx. 30 min).

**Prerequisites**
none

**Recommendations**
The contents of the module "Probability Theory" are strongly recommended. The module "Continuous Time Finance" is recommended.

**Workload**
120 hours

# T 3.110 Module component: Inverse Problems [T-MATH-105835]

**Coordinators:** PD Dr. Tilo Arens
Prof. Dr. Roland Griesmaier
PD Dr. Frank Hettlich
Prof. Dr. Andreas Rieder

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102890 - Inverse Problems

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0105100 | Inverse Problems | 4 SWS | Lecture / 🗣 | Griesmaier |
| WT 25/26 | 0105110 | Tutorial for 0105100 (Inverse Problems) | 2 SWS | Practice / 🗣 | Griesmaier |
| **Exams** | | | | | |
| WT 25/26 | 7700143 | Inverse Problems | | | Griesmaier |
| ST 2026 | 7700099 | Inverse Problems | | | Griesmaier |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

*Below you will find excerpts from courses related to this module component:*

## V Inverse Problems

0105100, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture (V)**
**On-Site**

### Content

Following Hadamard, a problem whose solution does not depend continuously on the given data is called ill-posed. Prominent examples are the mathematical problems behind tomographic methods like X-ray tomography, ultrasound tomography or electrical impedance tomography as well as seismic imaging, radar imaging, or inverse scattering. The mathematical models used in this context are typically formulated in terms of integral transforms or differential equations. However the aim is not to evaluate the transform or to solve the differential equation but to invert the transform or to reconstruct parameters of this equation given (part of) its solution, respectively. Therefore these problems are called inverse problems.

Standard methods from numerical mathematics typically fail when they are directly applied to ill-posed problems -- the problem has to be regularized. The course gives an introduction to the functional analytic background of regularization methods for linear ill-posed problems. Results from functional analysis that are required in this context will be provided in the course of the lecture.

# T 3.111 Module component: IT Security [T-INFO-113960]

**Coordinators:** Prof. Dr. Jörn Müller-Quade
Prof. Dr. Christian Wressnegger
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-106998 - IT Security

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each winter term | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2400010 | IT Security | 4 SWS | Lecture / Practice / 🗣 | Müller-Quade, Wressnegger, Martin |
| **Exams** | | | | | |
| WT 25/26 | 7500038 | IT Security | | | Müller-Quade, Strufe, Wressnegger |

Legend: 🖥 Online, 🖥🗣 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) lasting 90 minutes.

**Prerequisites**
None.

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-INFO-112818 - IT Security must not have been started.

**Recommendations**
Students should be familiar with the content of the compulsory lecture "Informationssicherheit".

# T 3.112 Module component: Lecture Series Supplementary Studies on Science, Technology and Society - Self Registration [T-FORUM-113578]

**Coordinators:** Dr. Christine Mielke
Christine Myglas

**Organisation:** General Studies. Forum Science and Society (FORUM)

**Part of:** M-FORUM-106753 - Supplementary Studies on Science, Technology and Society

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Coursework | 2 CP | pass/fail | Each summer term | 1 semesters | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 1130716 | Lecture series Science in Society | 2 SWS | Lecture / 🗣 | Post, Mielke |

Legend: 💻 Online, Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Active participation, learning protocols, if applicable.

**Prerequisites**
None

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)
- FORUM (ehem. ZAK) Begleitstudium

**Recommendations**
It is recommended that you complete the lecture series "Science in Society" before attending events in the advanced module and in parallel with attending the basic seminar.
If it is not possible to attend the lecture series and the basic seminar in the same semester, the lecture series can also be attended after attending the basic seminar.
However, attending events in the advanced module before attending the lecture series should be avoided.

**Additional Information**
The basic module consists of the lecture series "Science in Society" and the basic seminar. The lecture series is only offered during the summer semester.
The basic seminar can be attended in the summer or winter semester.

*Below you will find excerpts from courses related to this module component:*

## V Lecture series Science in Society

1130716, SS 2026, 2 SWS, Language: German, Open in study portal

**Lecture (V)**
**On-Site**

**Content**
The lectures are also expected to be available in English via Lecture Translator.

**Organizational issues**
Anmeldung erforderlich unter: https://plus.campus.kit.edu/signmeup/procedures/6078

# T 3.113 Module component: Lie Groups and Lie Algebras [T-MATH-108799]

**Coordinators:** Prof. Dr. Tobias Hartnick
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-104261 - Lie Groups and Lie Algebras

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

**Prerequisites**
none

# T 3.114 Module component: Lie-Algebras [T-MATH-113907]

**Coordinators:** Prof. Dr. Tobias Hartnick
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106950 - Lie-Algebras

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
The module examination takes the form of an oral examination lasting 30 minutes.

**Prerequisites**
None.

**Workload**
240 hours

# T 3.115 Module component: Localization of Mobile Agents [T-INFO-115014]

**Coordinators:** Prof. Dr.-Ing. Uwe Hanebeck
**Organisation:** KIT Department of Humanities and Social Sciences
KIT Department of Informatics
**Part of:** M-INFO-107663 - Localization of Mobile Agents

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each summer term | 1 semesters | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 24613 | Localization of Mobile Agents | 3 SWS | Lecture / Practice / | Kim, Hanebeck |
| **Exams** | | | | | |
| ST 2026 | 7500482 | Localization of Mobile Agents | | | Hanebeck |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Assessment**
The assessment is carried out as an oral examination, lasting 15-30 minutes in accordance with Section 4 (2) No. 2 SPO. Participants can contact the chair at any time to arrange an appointment for the oral examination. (§ 4 Abs. 2 Nr. 2 SPO)

**Prerequisites**
T-INFO-115015 Digital exercise must be successfully completed before exam.

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-INFO-115015 - Localization of Mobile Agents - Pass must have been started.
2. The module component T-INFO-101377 - Localization of Mobile Agents must not have been started.

**Recommendations**
Knowledge of a higher-level programming language with mature libraries for scientific and numerical computing (e.g., Julia, Matlab, Python) is an advantage.

*Below you will find excerpts from courses related to this module component:*

## V Localization of Mobile Agents

24613, SS 2026, 3 SWS, Language: English, Open in study portal

**Lecture / Practice (VÜ)**
**Blended (On-Site/Online)**

**Content**
This module provides a systematic introduction to the field of localization methods. To facilitate entry, the module is divided into four central topics. Dead reckoning (1) deals with the step-by-step determination of a vehicle's position from dynamic parameters such as speed or steering angle, as well as intertial measurement unit (IMU) data. Localization with the aid of measurements to external, known landmarks is part of static localization (2). Specifically, signal times of arrival (multilateration and GPS), distance measurements, and angle measurements (bearings) are covered. In addition to closed-form solutions for special measurements, the method of least squares for fusing arbitrary measurements is introduced. This also includes nonlinear optimization methods and certifiable global optimization. Dynamic localization (3) deals with the combination of dead reckoning and static localization using the Kalman filter, which is used in virtually all object tracking scenarios and other state estimation problems. General estimator properties are also discussed. The course concludes with simultaneous localization and mapping (SLAM) (4), which allows localization even when the location of landmarks is partially unknown. Thereby the measurement association problem is also addressed.

The lecture is accompanied by a purely digital exercise. Here, numerical tasks are presented that can be solved, for example, with a small program, whereby the solution is automatically checked for correctness. The exercise certificate is a prerequisite for the oral exam. Both are offered throughout the year.

**Organizational issues**
In-person lecture and digital/online exercise with ILIAS tests.

Appointment scheduling for oral exam (available year-round): pruefung-isas@iar.kit.edu

**Literature**
Basic knowledge of linear algebra and stochastics is helpful.

# T 3.116 Module component: Localization of Mobile Agents - Pass [T-INFO-115015]

**Coordinators:** Prof. Dr.-Ing. Uwe Hanebeck
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-107663 - Localization of Mobile Agents

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Coursework | 0 CP | pass/fail | Each summer term | 1 semesters | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 24613 | Localization of Mobile Agents | 3 SWS | Lecture / Practice / | Kim, Hanebeck |
| **Exams** | | | | | |
| ST 2026 | 7500483 | Localization of Mobile Agents - Pass | | | Hanebeck |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

### Assessment
The assessment is carried out in form of course work (German Studienleistung, § 4 Abs. 3 SPO). Students must complete a digital exercise in Ilias which is ungraded. The digital exercise can be repeated as often as desired.

### Prerequisites
None.

### Modeled Prerequisites
The following conditions have to be fulfilled:

1. The module component T-INFO-114169 - Localization of Mobile Agents Pass must not have been started.

### Recommendations
Knowledge of a higher-level programming language with mature libraries for scientific and numerical computing (e.g., Julia, Matlab, Python) is an advantage.

*Below you will find excerpts from courses related to this module component:*

## V Localization of Mobile Agents
24613, SS 2026, 3 SWS, Language: English, Open in study portal

**Lecture / Practice (VÜ)**
**Blended (On-Site/Online)**

### Content
This module provides a systematic introduction to the field of localization methods. To facilitate entry, the module is divided into four central topics. Dead reckoning (1) deals with the step-by-step determination of a vehicle's position from dynamic parameters such as speed or steering angle, as well as intertial measurement unit (IMU) data. Localization with the aid of measurements to external, known landmarks is part of static localization (2). Specifically, signal times of arrival (multilateration and GPS), distance measurements, and angle measurements (bearings) are covered. In addition to closed-form solutions for special measurements, the method of least squares for fusing arbitrary measurements is introduced. This also includes nonlinear optimization methods and certifiable global optimization. Dynamic localization (3) deals with the combination of dead reckoning and static localization using the Kalman filter, which is used in virtually all object tracking scenarios and other state estimation problems. General estimator properties are also discussed. The course concludes with simultaneous localization and mapping (SLAM) (4), which allows localization even when the location of landmarks is partially unknown. Thereby the measurement association problem is also addressed.

The lecture is accompanied by a purely digital exercise. Here, numerical tasks are presented that can be solved, for example, with a small program, whereby the solution is automatically checked for correctness. The exercise certificate is a prerequisite for the oral exam. Both are offered throughout the year.

### Organizational issues
In-person lecture and digital/online exercise with ILIAS tests.

Appointment scheduling for oral exam (available year-round): pruefung-isas@iar.kit.edu

**Literature**
Basic knowledge of linear algebra and stochastics is helpful.

# T 3.117 Module component: Logical Foundations of Cyber-Physical Systems [T-INFO-112360]

**Coordinators:** Prof. Dr. André Platzer
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-106102 - Logical Foundations of Cyber-Physical Systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each winter term | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2400161 | Logical Foundations of Cyber-Physical Systems | 4 SWS | Lecture / 🗣 | Platzer |
| **Exams** | | | | | |
| WT 25/26 | 7500252 | Logical Foundations of Cyber-Physical Systems | | | Platzer |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Assessment
The assessment is usually carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) lasting 120 minutes.

Depending on the number of participants, it will be announced six weeks before the examination (Section 6 (3) SPO) whether the assessment will take the form of an oral examination of approx.
- in the form of an oral examination of approx. 30 minutes in accordance with § 4 Para. 2 No. 2 SPO or
- in the form of a written examination in accordance with § 4 Para. 2 No. 1 SPO
takes place.

*In order to receive a bonus, you must earn at least 50% of the points for solving the exercises. If the grade of the written examination is between 4.0 and 1.3, the bonus improves the grade by one grade level (0.3 or 0.4).*

### Prerequisites
None.

### Recommendations
The course assumes prior exposure to basic computer programming and mathematical reasoning. This course covers the basic required mathematical and logical background of cyber-physical systems. You will be expected to follow the textbook as needed: André Platzer. Logical Foundations of Cyber-Physical Systems. Springer 2018. DOI:10.1007/978-3-319-63588-0

### Additional Information
Course web page: https://lfcps.org/course/lfcps.html

# T 3.118 Module component: Markov Decision Processes [T-MATH-105921]

**Coordinators:** Prof. Dr. Nicole Bäuerle
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102907 - Markov Decision Processes

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 5 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700068 | Markov Decision Processes | Bäuerle |

**Prerequisites**
none

**Workload**
150 hours

# T 3.119 Module component: Master's Thesis [T-MATH-105878]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102917 - Master's Thesis

| Type | Credits | Grading | Version |
|---|---|---|---|
| Final Thesis | 30 CP | graded | 2 |

**Final Thesis**
This module component represents a final thesis. The following periods have been supplied:

| | |
|---|---|
| **Submission deadline** | 6 months |
| **Maximum extension period** | 3 months |
| **Correction period** | 8 weeks |

# T 3.120 Module component: Mathematical Methods in Signal and Image Processing [T-MATH-105862]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102897 - Mathematical Methods in Signal and Image Processing

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

**Prerequisites**
none

**Workload**
240 hours

# T 3.121 Module component: Mathematical Methods of Imaging [T-MATH-106488]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103260 - Mathematical Methods of Imaging

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 5 CP | graded | Irregular | 1 |

| **Courses** | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0100052 | Mathematische Methoden der Bildgebung | 2 SWS | Lecture | Rieder |
| WT 25/26 | 0100061 | Übungen zu 0102900 (mathematische Methoden der Bildgebung) | 2 SWS | Practice | Rieder |
| **Exams** | | | | | |
| WT 25/26 | 7700138 | Mathematical Methods of Imaging | | | Rieder |

**Prerequisites**
None

# T 3.122 Module component: Mathematical Modelling and Simulation in Practise [T-MATH-105889]

**Coordinators:** PD Dr. Gudrun Thäter
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102929 - Mathematical Modelling and Simulation in Practise

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 2 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0109400 | Mathematical Modelling and Simulation | 2 SWS | Lecture / 🗣 | Thäter |
| WT 25/26 | 0109410 | Tutorial for 0109400 (Mathematical modelling and simulation) | 1 SWS | Practice | Thäter |
| **Exams** | | | | | |
| WT 25/26 | 7500115 | Mathematical Modelling and Simulation in Practise | | | Thäter |

Legend: 💻 Online, 🔀 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

*Below you will find excerpts from courses related to this module component:*

## V Mathematical Modelling and Simulation

0109400, WS 25/26, 2 SWS, Language: English, Open in study portal

**Lecture (V)**
**On-Site**

**Content**

The general aim of this lecture course is threefold:

1) to interconnect different mathematical fields
2) to connect mathematics and real life problems
3) to learn to be critical and to ask relevant questions

We deal with topics such as

- Game theory
- Oscillation
- Population Models
- Simulation of traffic
- Chaotic behavior
- Heat conduction
- Fluids and Flow

There are no special prerequisites.

During the lecture course there will be one lecture of a person from industry (around the Christmas break) and one excursion (at the end of the lecture course).

To earn the credits you have to attend the lecture and finish the work on one project during the term in a group of 2-3 persons. The topic of the project is up to the choice of each group.

The exam is an oral exam.

Literature:
Hans-Joachim Bungartz e.a.: Modeling and Simulation: An Application-Oriented Introduction,
Springer, 2013 (English)

# T 3.123 Module component: Mathematical Statistics [T-MATH-105872]

**Coordinators:** Dr. rer. nat. Bruno Ebner
Prof. Dr. Vicky Fasen-Hartmann
PD Dr. Bernhard Klar
Prof. Dr. Mathias Trabs

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102909 - Mathematical Statistics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 2 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700086 | Mathematical Statistics | Fasen-Hartmann |
| WT 25/26 | 7700094 | Mathematical Statistics | Fasen-Hartmann |

**Prerequisites**
none

**Workload**
240 hours

# T 3.124 Module component: Mathematical Topics in Kinetic Theory [T-MATH-108403]

**Coordinators:** Prof. Dr. Dirk Hundertmark
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-104059 - Mathematical Topics in Kinetic Theory

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.125 Module component: Maxwell's Equations [T-MATH-105856]

**Coordinators:** PD Dr. Tilo Arens
Prof. Dr. Roland Griesmaier
PD Dr. Frank Hettlich

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102885 - Maxwell's Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700139 | Maxwell's Equations | Hettlich |

# T 3.126 Module component: Medical Imaging Technology [T-ETIT-113625]

**Coordinators:** Prof. Dr.-Ing. Maria Francesca Spadea
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** M-ETIT-106778 - Medical Imaging Technology

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2305263 | Medical Imaging Technology | 4 SWS | Lecture / Practice / 🗣 | Spadea, Arndt |
| **Exams** | | | | | |
| WT 25/26 | 7305260 | Medical Imaging Technology | | | Spadea |
| ST 2026 | 7305260 | Medical Imaging Technology | | | Spadea, Arndt |

Legend: 🖥 Online, 🖧 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The examination takes place in form of a written examination lasting 120 minutes. The course grade is the grade of the written exam.

**Prerequisites**
none

# T 3.127 Module component: Metric Geometry [T-MATH-111933]

**Coordinators:** Prof. Dr. Alexander Lytchak
Dr. Artem Nepechiy
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105931 - Metric Geometry

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700131 | Metric Geometry | Lytchak |

**Assessment**
Oral examination of circa 20 minutes.

**Prerequisites**
None.

**Recommendations**
Basic knowledge of set-theoretical topology, elementary geometry and fundamental groups, as taught in the module "M-MATH-103152 - Elementary Geometry", is recommended.

**Workload**
240 hours

# T 3.128 Module component: Minimal Surfaces [T-MATH-113417]

**Coordinators:** Dr. Peter Lewintan
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106666 - Minimal Surfaces

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 semesters | 1 |

**Prerequisites**
None

**Workload**
90 hours

# T 3.129 Module component: Modelling and Simulation of Lithium-Ion Batteries [T-MATH-113382]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106640 - Modelling and Simulation of Lithium-Ion Batteries

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 1 |

**Assessment**
oral exam (ca. 20 min)

**Prerequisites**
None

**Workload**
120 hours

# T 3.130 Module component: Models of Mathematical Physics [T-MATH-105846]

**Coordinators:** Prof. Dr. Dirk Hundertmark
Prof. Dr. Michael Plum
Prof. Dr. Wolfgang Reichel

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102875 - Models of Mathematical Physics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.131 Module component: Modern Experimental Physics I, Atoms, Nuclei and Molecules [T-PHYS-112846]

**Coordinators:** Studiendekan/in Physik
**Organisation:** KIT Department of Physics
**Part of:** M-PHYS-106331 - Modern Experimental Physics I, Atoms, Nuclei and Molecules

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 4010041 | Modern Experimental Physics I, Atoms, Nuclei and Molecules | 4 SWS | Lecture / 🗣 | Valerius, Lokhov |
| ST 2026 | 4010042 | Übungen zu Moderne Experimentalphysik I | 2 SWS | Practice / 🗣 | Valerius, Lokhov, Marsteller, Rodenbeck |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Oral exam, approx. 45 min

**Prerequisites**
successful completion of the exercises

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The following conditions have to be fulfilled:

# T 3.132 Module component: Modern Experimental Physics II, Structure of Matter [T-PHYS-112847]

**Coordinators:** Studiendekan/in Physik
**Organisation:** KIT Department of Physics
**Part of:** M-PHYS-106332 - Modern Experimental Physics II, Structure of Matter

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4010051 | Moderne Experimentalphysik II (Struktur der Materie) | 4 SWS | Lecture / 🗣 | Wegener, Rabbertz |
| WT 25/26 | 4010052 | Übungen zu Moderne Experimentalphysik II | 2 SWS | Practice / 🗣 | Ahäuser, Wegener, Rabbertz, Fischer |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Oral exam, approx. 45 min

**Prerequisites**
successful completion of the exercises

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The following conditions have to be fulfilled:

# T 3.133 Module component: Modern Methods in Combinatorics [T-MATH-113911]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106957 - Modern Methods in Combinatorics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Assessment**
Oral examination (approx. 30 min)

**Prerequisites**
None

**Workload**
180 hours

# T 3.134 Module component: Modular Forms [T-MATH-105843]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102868 - Modular Forms

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.135 Module component: Monotonicity Methods in Analysis [T-MATH-105877]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102887 - Monotonicity Methods in Analysis

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 3 CP | graded | 1 |

# T 3.136 Module component: Neural Networks [T-INFO-101383]

**Coordinators:** Prof. Dr. Alexander Waibel
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-100846 - Neural Networks

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2400024 | Deep Learning and Neural Networks | 4 SWS | Lecture / 🗣 | Niehues |
| **Exams** | | | | | |
| WT 25/26 | 7500400 | Deep Learning and Neural Networks (Nachklausur) | | | Niehues |
| ST 2026 | 7500044 | Deep Learning and Neural Networks | | | Niehues, Waibel |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-INFO-109124 - Deep Learning and Neural Networks must not have been started.

# T 3.137 Module component: Nonlinear Analysis [T-MATH-107065]

**Coordinators:** Prof. Dr. Tobias Lamm
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-103539 - Nonlinear Analysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.138 Module component: Nonlinear Control Systems [T-ETIT-114989]

**Coordinators:** Dr.-Ing. Mathias Kluwe
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** M-ETIT-107644 - Nonlinear Control Systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2303320 | Nonlinear Control Systems | 3 SWS | Lecture / 🗣 | Kluwe |
| ST 2026 | 2303321 | Exercises to 2303320 Nonlinear Control Systems | 1 SWS | Practice / 🗣 | Handwerker |
| **Exams** | | | | | |
| ST 2026 | 7303320 | Nonlinear Control Systems | | | Kluwe |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The examination takes place in form of a written examination lasting 120 minutes.

**Prerequisites**
none

# T 3.139 Module component: Nonlinear Evolution Equations [T-MATH-105848]

**Coordinators:** Prof. Dr. Dorothee Frey
Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102877 - Nonlinear Evolution Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.140 Module component: Nonlinear Functional Analysis [T-MATH-105876]

**Coordinators:** PD Dr. Gerd Herzog
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102886 - Nonlinear Functional Analysis

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 3 CP | graded | 1 |

# T 3.141 Module component: Nonlinear Maxwell Equations [T-MATH-110283]

**Coordinators:** Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105066 - Nonlinear Maxwell Equations

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.142 Module component: Nonlinear Wave Equations [T-MATH-110806]

**Coordinators:** Prof. Dr. Wolfgang Reichel
Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105326 - Nonlinear Wave Equations

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.143 Module component: Nonparametric Statistics [T-MATH-105873]

**Coordinators:** Dr. rer. nat. Bruno Ebner
Prof. Dr. Vicky Fasen-Hartmann
PD Dr. Bernhard Klar
Prof. Dr. Mathias Trabs

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102910 - Nonparametric Statistics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 2 |

**Assessment**
oral exam of ca. 20 minutes

**Workload**
120 hours

# T 3.144 Module component: Numerical Analysis of Neural Networks [T-MATH-113470]

**Coordinators:** TT-Prof. Dr. Roland Maier
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106695 - Numerical Analysis of Neural Networks

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700148 | Numerical Analysis of Neural Networks (examination on February 19 and 20) | Maier |
| WT 25/26 | 7700152 | Numerical Analysis of Neural Networks (examination on March 30 and 31) | Maier |

**Assessment**
oral exam of ca. 30 minutes

**Prerequisites**
none

**Workload**
180 hours

# T 3.145 Module component: Numerical Analysis on Quantum Computers [T-MATH-114990]

**Coordinators:** TT-Prof. Dr. Roland Maier
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-107646 - Numerical Analysis on Quantum Computers

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Assessment**
Oral examination lasting approx. 30 minutes.

**Prerequisites**
None.

**Workload**
180 hours

# T 3.146 Module component: Numerical Complex Analysis [T-MATH-112280]

**Coordinators:** Prof. Dr. Marlis Hochbruck
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106063 - Numerical Complex Analysis

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
oral exam of ca. 20 minutes

**Prerequisites**
none

**Recommendations**
Some basic knowledge of Complex Analysis is strongly recommended.

**Workload**
180 hours

# T 3.147 Module component: Numerical Linear Algebra in Image Processing [T-MATH-108402]

**Coordinators:** PD Dr. Volker Grimm
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-104058 - Numerical Linear Algebra in Image Processing

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700127 | Numerical Linear Algebra in Image Processing | Grimm |

**Prerequisites**
none

# T 3.148 Module component: Numerical Methods for Differential Equations [T-MATH-105836]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke
Prof. Dr. Andreas Rieder
Prof. Dr. Christian Wieners

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102888 - Numerical Methods for Differential Equations

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Each winter term | 4 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0110700 | Numerische Methoden für Differentialgleichungen | 4 SWS | Lecture / 🗣 | Jahnke |
| WT 25/26 | 0110800 | Übungen zu 0110700 (numerische Methoden für Differentialgleichungen) | 2 SWS | Practice / 🗣 | Jahnke |
| **Exams** | | | | | |
| WT 25/26 | 7700142 | Numerical Methods for Differential Equations | | | Jahnke |
| ST 2026 | 7700092 | Numerical Methods for Differential Equations | | | Jahnke |

Legend: 📱 Online, 🧩 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The module will be completed by an oral examination with a duration of approximately 30 minutes. If this would require an unreasonable amount of time, the oral examination may be replaced by a written exam with a duration of approximately 120 minutes. The decision will be announced at least six weeks before the examination.

**Prerequisites**
None.

**Workload**
240 hours

# T 3.149 Module component: Numerical Methods for Hyperbolic Equations [T-MATH-105900]

**Coordinators:** Prof. Dr. Willy Dörfler
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102915 - Numerical Methods for Hyperbolic Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

**Prerequisites**
none

**Workload**
180 hours

# T 3.150 Module component: Numerical Methods for Integral Equations [T-MATH-105901]

**Coordinators:** PD Dr. Tilo Arens
PD Dr. Frank Hettlich

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102930 - Numerical Methods for Integral Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0160500 | Integralgleichungen | 4 SWS | Lecture | Arens |

# T 3.151 Module component: Numerical Methods for Maxwell's Equations [T-MATH-105920]

**Coordinators:** Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102931 - Numerical Methods for Maxwell's Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

# T 3.152 Module component: Numerical Methods for Oscillatory Differential Equations [T-MATH-113437]

**Coordinators:** Prof. Dr. Tobias Jahnke
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106682 - Numerical Methods for Oscillatory Differential Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

**Assessment**
oral exam of ca. 30 minutes

**Prerequisites**
none

**Workload**
240 hours

# T 3.153 Module component: Numerical Methods for Time-Dependent Partial Differential Equations [T-MATH-105899]

**Coordinators:** Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102928 - Numerical Methods for Time-Dependent Partial Differential Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

**Assessment**
Success is assessed in form of an oral examination lasting approx. 25 minutes.

**Prerequisites**
None.

**Workload**
240 hours

# T 3.154 Module component: Numerical Methods in Computational Electrodynamics [T-MATH-105860]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke
Prof. Dr. Andreas Rieder
Prof. Dr. Christian Wieners

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102894 - Numerical Methods in Computational Electrodynamics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

**Prerequisites**
none

**Workload**
180 hours

# T 3.155 Module component: Numerical Methods in Fluid Mechanics [T-MATH-105902]

**Coordinators:** Prof. Dr. Willy Dörfler
PD Dr. Gudrun Thäter

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102932 - Numerical Methods in Fluid Mechanics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 1 |

| **Courses** | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0164200 | Numerische Methoden in der Strömungsmechanik | 2 SWS | Lecture | Thäter |
| ST 2026 | 0164210 | Übungen zu Numerische Methoden in der Strömungsmechanik (0164200) | 1 SWS | Practice | Thäter |
| **Exams** | | | | | |
| ST 2026 | 7700114 | Numerical Methods in Fluid Mechanics | | | Thäter |

# T 3.156 Module component: Numerical Methods in Mathematical Finance [T-MATH-105865]

**Coordinators:** Prof. Dr. Tobias Jahnke
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102901 - Numerical Methods in Mathematical Finance

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| ST 2026 | 7700055 | Numerical Methods in Mathematical Finance | Jahnke |

**Assessment**
oral exam of ca. 30 minutes

**Prerequisites**
none

**Workload**
240 hours

# T 3.157 Module component: Numerical Optimisation Methods [T-MATH-105858]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke
Prof. Dr. Andreas Rieder
TT-Prof. Dr. Benjamin Unger
Prof. Dr. Christian Wieners

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102892 - Numerical Optimisation Methods

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0124000 | Numerische Optimierungsmethoden | 4 SWS | Lecture | Wieners |
| WT 25/26 | 0124010 | Übungen zu 0124000 (numerische Optimierungsmethoden) | 2 SWS | Practice | Wieners, Schneiderhan |
| **Exams** | | | | | |
| WT 25/26 | 7700133 | Numerical Optimisation Methods | | | Wieners |

**Prerequisites**
None.

**Workload**
240 hours

# T 3.158 Module component: Numerical Simulation in Molecular Dynamics [T-MATH-110807]

**Coordinators:** PD Dr. Volker Grimm
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105327 - Numerical Simulation in Molecular Dynamics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.159 Module component: Optimal Control [T-ETIT-114701]

**Coordinators:** Prof. Dr.-Ing. Sören Hohmann
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** M-ETIT-107497 - Optimal Control

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2303183 | Optimal Control | 2 SWS | Lecture / | Hohmann |
| WT 25/26 | 2303185 | Tutorial to 2303183 Optimal Control | 2 SWS | Practice / | Riffel |
| WT 25/26 | 2303851 | Accompanying Group Tutorial to 2303183 Optimal Control | 1 SWS | Tutorial / | Riffel |
| **Exams** | | | | | |
| WT 25/26 | 7303183 | Optimization of Dynamic Systems | | | Hohmann |
| WT 25/26 | 7303183_2 | Optimal Control | | | Hohmann |
| ST 2026 | 7303183_2 | Optimal Control | | | Hohmann |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Assessment**
The assessment consists of a written exam (120 min) taking place in the recess period.

**Prerequisites**
none

# T 3.160 Module component: Optimisation and Optimal Control for Differential Equations [T-MATH-105864]

**Coordinators:** TT-Prof. Dr. Benjamin Unger
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102899 - Optimisation and Optimal Control for Differential Equations

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 2 |

**Assessment**
Oral examination lasting approx. 20 minutes.

**Prerequisites**
None.

**Workload**
180 hours

# T 3.161 Module component: Optimization in Banach Spaces [T-MATH-105893]

**Coordinators:** Prof. Dr. Roland Griesmaier
PD Dr. Frank Hettlich

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102924 - Optimization in Banach Spaces

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 5 CP | graded | 2 |

**Assessment**
oral examination of approximately 30 minutes

**Prerequisites**
none

**Recommendations**
Some basic knowledge of finite dimensional optimization theory and functional analysis is desirable.

**Workload**
150 hours

# T 3.162 Module component: Parallel Computing [T-MATH-102271]

**Coordinators:** PD Dr. Mathias Krause
Prof. Dr. Christian Wieners

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-101338 - Parallel Computing

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 5 CP | graded | 1 |

**Prerequisites**
none

**Workload**
150 hours

# T 3.163 Module component: Particle Physics I [T-PHYS-102369]

**Coordinators:** Prof. Dr. Torben Ferber
Prof. Dr. Ulrich Husemann
Prof. Dr. Markus Klute
Prof. Dr. Günter Quast
PD Dr. Klaus Rabbertz

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102114 - Particle Physics I

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 4022031 | Particle Physics I | 3 SWS | Lecture / 🗣 | Klute, Goldenzweig |
| WT 25/26 | 4022032 | Exercises to Particle Physics I | 2 SWS | / 🗣 | Klute, Goldenzweig |

Legend: 💻 Online, 🔀 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

# T 3.164 Module component: Pattern Recognition [T-INFO-101362]

**Coordinators:** Prof. Dr.-Ing. Jürgen Beyerer
Dr. Tim Zander
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-100825 - Pattern Recognition

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 2 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 24675 | Pattern Recognition | 4 SWS | Lecture / Practice / 🗣 | Beyerer |
| **Exams** | | | | | |
| WT 25/26 | 7500111 | Pattern Recognition | | | Beyerer |
| ST 2026 | 7500032 | Pattern Recognition | | | Beyerer |

Legend: 🖥 Online, 🌸 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The examination is conducted in the form of a written examination (usually lasting 60 minutes) in accordance with § 4 (2) No. 1 SPO.
Depending on the number of participants, it will be announced six weeks prior to the examination (§ 6 (3) SPO) whether the assessment will take place:

- in the form of an oral examination in accordance with § 4 (2) No. 2 SPO, or
- in the form of a written examination in accordance with § 4 (2) No. 1 SPO.

**Prerequisites**
None.

**Recommendations**
Basic knowledge of probability theory, signal processing, and image processing is helpful.

*Below you will find excerpts from courses related to this module component:*

## V Pattern Recognition

24675, SS 2026, 4 SWS, Language: German, Open in study portal

**Lecture / Practice (VÜ)**
**On-Site**

**Organizational issues**
Vorlesung: montags 15:45 bis 16:30 Uhr und mittwochs 14:00 bis 15:30 Uhr

Übung: montags 16:30 bis 17:15 Uhr

**Literature**
**Weiterführende Literatur**

- Richard O. Duda, Peter E. Hart, Stork G. David. Pattern Classification. Wiley-Interscience, second edition, 2001
- K. Fukunaga. Introduction to Statistical Pattern Recognition. Academic Press, second edition, 1997
- R. Hoffman. Signalanalyse und -erkennung. Springer, 1998
- H. Niemann. Pattern analysis and understanding. Springer, second edition, 1990
- J. Schürmann. Pattern classification. Wiley & Sons, 1996
- S. Theodoridis, K. Koutroumbas. Pattern recognition. London: Academic, 2003
- V. N. Vapnik. The nature of statistical learning theory. Springer, second edition, 2000

# T 3.165 Module component: Percolation [T-MATH-105869]

**Coordinators:** Prof. Dr. Daniel Hug
PD Dr. Steffen Winter
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102905 - Percolation

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 5 CP | graded | 2 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 770117000 | Percolation | Last |

**Prerequisites**
none

**Workload**
150 hours

# T 3.166 Module component: Physical Foundations of Cryogenics [T-CIWVT-106103]

**Coordinators:** Prof. Dr.-Ing. Steffen Grohmann
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103068 - Physical Foundations of Cryogenics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2250130 | Physical Foundations of Cryogenics | 2 SWS | Lecture / | Grohmann |
| ST 2026 | 2250131 | Exercises on 2250130 Physical Foundations of Cryogenics | 1 SWS | Practice / | Grohmann |
| **Exams** | | | | | |
| WT 25/26 | 7250130 | Physical Foundations of Cryogenics | | | Grohmann |
| ST 2026 | 7250130 | Physical Foundations of Cryogenics | | | Grohmann |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Assessment**
Learning control is an oral examination lasting approx. 30 minutes.

**Prerequisites**
None

# T 3.167 Module component: Poisson Processes [T-MATH-105922]

**Coordinators:** Prof. Dr. Vicky Fasen-Hartmann
Prof. Dr. Daniel Hug
Dr. Franz Nestmann
PD Dr. Steffen Winter

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102922 - Poisson Processes

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 5 CP | graded | 1 |

**Prerequisites**
none

**Workload**
150 hours

# T 3.168 Module component: Potential Theory [T-MATH-105850]

**Coordinators:** PD Dr. Tilo Arens
Prof. Dr. Roland Griesmaier
PD Dr. Frank Hettlich
Prof. Dr. Wolfgang Reichel

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102879 - Potential Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.169 Module component: Practical Course: Mathematical and Computational Methods in Robotics and AI [T-INFO-114911]

**Coordinators:** Prof. Dr. Katja Mombaur
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-107609 - Practical Course: Mathematical and Computational Methods in Robotics and AI

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Examination of another type | 6 CP | graded | Each term | 2 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2400181 | Practical Course: Mathematical and Computational Methods in Robotics & AI | 4 SWS | Practical course / 🗣 | Mombaur, Große Sundrup |
| ST 2026 | 2400202 | Practical Course: Mathematical and Computational Methods in Robotics & AI | 4 SWS | Practical course / 🗣 | Mombaur, Große Sundrup |
| **Exams** | | | | | |
| WT 25/26 | 7500388 | Practical Course: Mathematical and Computational Methods in Robotics and AI | | | Mombaur |
| ST 2026 | 7500306 | Practical Course: Mathematical and Computational Methods in Robotics and AI | | | Mombaur |

Legend: 🖥 Online, 🔀 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Assessment
The assessment is carried out as an examination of another type (§ 4 Abs. 2 No. 3 SPO).

This includes the preparation of a project report (ca. 10 pages and an oral presentation (30 Min + 15 min questions). Students may withdraw from the examination during the first two weeks after the topic has been communicated.

### Prerequisites
Programming skills

### Modeled Prerequisites
The following conditions have to be fulfilled:

1. The module component T-INFO-113898 - Practical Course: Mathematical and Computational Methods in Robotics and AI must not have been started.

### Recommendations
Basic mathematical knowledge will be helpful, depending on topic. For Projects in the context of robotics, knowledge of robotics is recommended, but not strictly necessary.

### Additional Information
Limited number of projects and participants. Specific project topics will be different each term and will be announced in a presentation during the first semester week or can be indivdually agreed upon with people supervising the practical. Students can propose topics on their own as well.

# T 3.170 Module component: Probability Theory and Combinatorial Optimization [T-MATH-105923]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102947 - Probability Theory and Combinatorial Optimization

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

**Prerequisites**
none

# T 3.171 Module component: Process Modeling in Downstream Processing [T-CIWVT-106101]

**Coordinators:** apl. Prof. Dr. Matthias Franzreb
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103066 - Process Modeling in Downstream Processing

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2214110 | Process Modeling in Downstream Processing | 2 SWS | Lecture / 🗣 | Franzreb |
| **Exams** | | | | | |
| WT 25/26 | 7214110 | Process Modeling in Downstream Processing | | | Franzreb |

Legend: 💻 Online, 🌸 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Learning control is an oral exam lasting approx. 20 minutes.

**Prerequisites**
None

# T 3.172 Module component: Processing of Nanostructured Particles [T-CIWVT-106107]

**Coordinators:** Prof. Dr.-Ing. Hermann Nirschl
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103073 - Processing of Nanostructured Particles

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2245030 | Processing of Nanostructured Particles | 2 SWS | Lecture / 🗣 | Nirschl |
| **Exams** | | | | | |
| WT 25/26 | 7245030 | Processing of Nanostructured Particles | | | Nirschl |
| ST 2026 | 7245030 | Processing of Nanostructured Particles | | | Nirschl |

Legend: 🖳 Online, 🖳🗣 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
None

# T 3.173 Module component: Project Lab Scientific Computing [T-MATH-114059]

**Coordinators:** Prof. Dr. Willy Dörfler
Prof. Dr. Marlis Hochbruck
Prof. Dr. Tobias Jahnke
Prof. Dr. Andreas Rieder
Prof. Dr. Christian Wieners

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102889 - Introduction to Scientific Computing

| Type | Credits | Grading | Version |
|---|---|---|---|
| Coursework | 0 CP | pass/fail | 1 |

# T 3.174 Module component: Random Graphs and Networks [T-MATH-112241]

**Coordinators:** Prof. Dr. Daniel Hug
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106052 - Random Graphs and Networks

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
none

**Recommendations**
The contents of the module 'Probability Theory' are strongly recommended.

**Workload**
240 hours

# T 3.175 Module component: Real-Time Systems [T-INFO-101340]

**Coordinators:** Prof. Dr.-Ing. Thomas Längle
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-100803 - Real-Time Systems

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 1 |

# T 3.176 Module component: Registration for Certificate Issuance - Supplementary Studies on Science, Technology and Society [T-FORUM-113587]

**Coordinators:** Dr. Christine Mielke
Christine Myglas

**Organisation:** General Studies. Forum Science and Society (FORUM)

**Part of:** M-FORUM-106753 - Supplementary Studies on Science, Technology and Society

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Coursework | 0 CP | pass/fail | Each term | 1 |

**Prerequisites**
In order to register, it is mandatory that the basic module and the advanced module have been completed and that the grades for the partial performances in the advanced module are available.

Registration as a partial achievement means the issue of a certificate.

# T 3.177 Module component: Regularity for Elliptic Operators [T-MATH-113472]

**Coordinators:** apl. Prof. Dr. Peer Kunstmann
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106696 - Regularity for Elliptic Operators

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

**Assessment**
oral exam of ca. 30 minutes

**Prerequisites**
none

**Workload**
180 hours

# T 3.178 Module component: Riemann Surfaces [T-MATH-113081]

**Coordinators:** Prof. Dr. Frank Herrlich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106466 - Riemann Surfaces

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
Oral examination of ca. 30 minutes.

**Prerequisites**
none

**Workload**
240 hours

# T 3.179 Module component: Robotics I - Introduction to Robotics [T-INFO-114190]

**Coordinators:** Prof. Dr.-Ing. Tamim Asfour
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-107162 - Robotics I - Introduction to Robotics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2424152 | Robotics I - Introduction to Robotics | 4 SWS | Lecture / 🗣 | Asfour, Mombaur |
| **Exams** | | | | | |
| WT 25/26 | 7500106 | Robotics I - Introduction to Robotics | | | Asfour |
| ST 2026 | 7500218 | Robotics I - Introduction to Robotics | | | Asfour |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Assessment
The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) lasting 120 minutes.

### Prerequisites
none.

### Modeled Prerequisites
The following conditions have to be fulfilled:

1. The module component T-INFO-108014 - Robotics I - Introduction to Robotics must not have been started.

*Below you will find excerpts from courses related to this module component:*

## V Robotics I - Introduction to Robotics
2424152, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture (V)**
**On-Site**

**Content**
The lecture provides an overview of the fundamentals of robotics using the examples of industrial robots, service robots and autonomous humanoid robots. An insight into all relevant topics is given. This includes methods and algorithms for robot modeling, control and motion planning, image processing and robot programming. First, mathematical basics and methods for kinematic and dynamic robot modeling, trajectory planning and control as well as algorithms for collision-free motion planning and grasp planning are covered. Subsequently, basics of image processing, intuitive robot programming especially by human demonstration and symbolic planning are presented.

In the exercise, the theoretical contents of the lecture are further illustrated with examples. Students deepen their knowledge of the methods and algorithms by independently working on problems and discussing them in the exercise. In particular, students can gain practical programming experience with tools and software libraries commonly used in robotics.

**Workload**:

Lecture with 3 SWS + 1 SWS Tutorial, 6 LP

6 LP corresponds to 180 hours, including

15 * 3= 45 hours attendance time (lecture)

15 * 1= 15 hours attendance time (tutorial)

15 * 6= 90 hours self-study and exercise sheets

30 hours preparation for the exam

**Competency Goals:**

The students are able to apply the presented concepts to simple and realistic tasks from robotics. This includes mastering and deriving the mathematical concepts relevant for robot modeling. Furthermore, the students master the kinematic and dynamic modeling of robot systems, as well as the modeling and design of simple controllers. The students know the algorithmic basics of motion and grasp planning and can apply these algorithms to problems in robotics. They know algorithms from the field of image processing and are able to apply them to problems in robotics. They are able to model and solve tasks as a symbolic planning problem. The students have knowledge about intuitive programming procedures for robots and know procedures for programming and learning by demonstration.

**Organizational issues**
The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) usually lasting 120 minutes.

**Module for the bachelor and master courses in Informatics,Mechanical Engineering, Mechatronics and Information Technology, Electrical Engineering and Information Technology**

**Literature**
**Additional literature:**

Fu, Gonzalez, Lee: Robotics - Control, Sensing, Vision, and Intelligence

Russel, Norvig: Artificial Intelligence - A Modern Approach, 2nd. Ed.

## T 3.180 Module component: Robotics II - Humanoid Robotics [T-INFO-105723]

**Coordinators:** Prof. Dr.-Ing. Tamim Asfour
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-102756 - Robotics II - Humanoid Robotics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 3 CP | graded | Each summer term | 4 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2400074 | Robotics II: Humanoid Robotics | 2 SWS | Lecture / 🗣 | Asfour |
| **Exams** | | | | | |
| WT 25/26 | 7500211 | Robotics II: Humanoid Robotics | | | Asfour |
| ST 2026 | 7500086 | Robotics II: Humanoid Robotics | | | Asfour |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Assessment
The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) lasting 60 minutes.

### Recommendations
Having visited the lectures on Robotics I - Introduction to Robotics and Mechano-Informatics and Robotics is recommended.

*Below you will find excerpts from courses related to this module component:*

### V Robotics II: Humanoid Robotics
2400074, SS 2026, 2 SWS, Language: English, Open in study portal

**Lecture (V)**
**On-Site**

**Content**
This lecture addresses the implementation of complex sensorimotor and cognitive abilities in humanoid robots, with humans serving as inspiration. The lecture begins by addressing the motivation for humanoid robotics.

The history of humanoid robotics and biomechanical models of the human body that inform robot design are covered, along with some mechatronic principles underlying humanoid robot systems.

The first main topic comprehensively addresses grasping and manipulation. After covering fundamentals, the lecture discusses neuroscientific insights and concepts like grasp phases and grasping synergies to reduce control complexity. Taxonomies are presented as structured frameworks for understanding the space of possible constraints in grasping and manipulation. The lecture addresses computational approaches for grasping known, familiar, and unknown objects, covering both classical methods and modern learning-based approaches using deep learning and vision-language-action models.

The second main topic covers learning from demonstration and imitation learning. After introducing the topic, fundamentals are presented including the learning from demonstration cycle. The lecture emphasizes learning task models on both symbolic/semantic and subsymbolic/sensorimotor levels. While methods for capturing human demonstrations are briefly covered, the focus is on semantic segmentation of human demonstrations and learning of task constraints that capture the task and allow generalization. Movement primitives are presented as efficient representations that allow robots to generalize learned behaviors to new situations.

The lecture concludes with cognitive and AI-based architectures for humanoid robots, discussing state-of-the-art approaches, methods to address the signal-to-symbol gap, and human-inspired memory architectures that enable intelligent robot behavior.

**Learning Objectives:**

Students can explain the challenges and goals of humanoid robotics research, particularly regarding the implementation of complex sensorimotor and cognitive abilities in humanoid robots. They are familiar with the history of the field and understand how biomechanical models of the human body inform humanoid robot design.

Students have comprehensive knowledge of human and robotic grasping and manipulation. They can analyze human grasping and manipulation strategies, understand taxonomies, and evaluate different computational approaches for grasping and manipulation. They understand the challenges in transferring concepts from human studies to humanoid robots.

Students understand fundamentals of learning from human demonstration and imitation learning. They can explain the learning from demonstration cycle and methods for learning generalized task representation, especially task constraints from demonstrations, and how learned behaviors are reproduced on robots.

Students can describe cognitive and AI-based architectures for humanoid robots, including approaches to address the signal-to-symbol gap and human-inspired memory architectures that enable intelligent robot behavior.

**Organizational issues**
Please note that this course starts in the **second week** of the semester, on 27.04.2026.

The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) of, in general, 60 minutes.

**Recommendations**
Having visited the lectures on *Robotics I – Introduction to Robotics* is recommended.

**Workload:**
90 h

- approx. 15 * 2 h = 30 h attendance time
- approx. 15 * 2 h = 30 h self-study prior/after the lecture
- approx. 30 h preparation for the exam and exam itself

**Literature**
**Additional literature**

Scientific publications on the topic are made available on the lecture website.

# T 3.181 Module component: Robotics III - Sensors and Perception in Robotics [T-INFO-109931]

**Coordinators:** Prof. Dr.-Ing. Tamim Asfour
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-104897 - Robotics III - Sensors and Perception in Robotics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 3 CP | graded | Each summer term | 2 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2400067 | Robotics III: Sensors and Perception in Robotics | 2 SWS | Lecture / 🗣 | Asfour, Triebel |
| **Exams** | | | | | |
| WT 25/26 | 7500207 | Robotics III - Sensors and Perception in Robotics | | | Asfour |
| ST 2026 | 7500242 | Robotics III - Sensors and Perception in Robotics | | | Asfour |

Legend: 🖥 Online, 🖧 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) lasting 60 minutes.

**Prerequisites**
none.

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-INFO-101352 - Robotics III - Sensors in Robotics must not have been started.

**Recommendations**
Attending the lecture Robotics I – Introduction to Robotics is recommended.

*Below you will find excerpts from courses related to this module component:*

## V Robotics III: Sensors and Perception in Robotics

2400067, SS 2026, 2 SWS, Language: English, Open in study portal

**Lecture (V)**
**On-Site**

**Content**
This lecture complements the lecture “Robotics I” and provides a comprehensive overview of sensors and perception methods in robotics. It is divided into two main parts.

The first part introduces fundamental concepts of perception in robotics, including the distinction between sensation and perception within the perception-cognition-action loop. It covers sensor fundamentals, such as sensor characteristics (resolution, range, accuracy, bandwidth), analog-to-digital conversion, and common sensor classification schemes. Proprioceptive sensors for measuring the robot’s internal state are discussed, including encoders (optical, magnetic, absolute, and incremental), force/torque sensors, and inertial measurement units (IMUs). The lecture then covers exteroceptive sensors, including proximity sensors, range sensors (LiDAR, time-of-flight cameras, ultrasonic sensors), visual sensors (monocular, stereo, RGB-D cameras), and tactile sensing technologies (capacitive, resistive, and optical).

The second part focuses on processing and interpreting sensor data. Topics in robot vision include image representation, feature detection and matching, object detection and recognition, semantic segmentation, and corresponding deep learning approaches. Point cloud processing is covered with emphasis on data structures, registration, surface reconstruction, and semantic segmentation. The lecture also addresses perception for manipulation, covering object pose estimation, grasp detection, visual servoing, active vision, and haptic exploration. It concludes with the simultaneous localization and mapping (SLAM) problem, including EKF SLAM, Graph SLAM, and FastSLAM.

**Learning Obejctives:**

Students can explain the main sensor principles used in robotics and distinguish between proprioceptive sensors (encoders, force/torque sensors, IMUs) and exteroceptive sensors (proximity, range, visual, and tactile sensors). They understand and can characterize sensor properties such as resolution, range, accuracy, and bandwidth, and can explain the principles of analog-to-digital conversion. Students are able to propose, analyze, and justify suitable sensor concepts for specific robotic tasks, taking into account trade-offs between different sensor modalities.

Students can apply fundamental perception methods for robotic applications. This includes robot vision techniques such as feature detection and matching, object detection and recognition, and semantic segmentation, including deep learning-based approaches. They can describe and analyze perception methods for manipulation tasks, including object pose estimation, grasp detection, active vision strategies, and haptic exploration. In addition, students can explain point cloud processing methods for registration and surface reconstruction, as well as principles of simultaneous localization and mapping (SLAM).

**Organizational issues**
Please note that this course starts in the **second week** of the semester, on 30.04.2026.

The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) of, in general, 60 minutes.

**Recommendations**
Having visited the lecture *Robotics I – Introduction to Robotics* is recommended.

**Workload:**
90 h

- approx. 15 * 2 h = 30 h attendance time
- approx. 15 * 2 h = 30 h self-study prior/after the lecture
- approx. 30 h preparation for the exam and exam itself

**Literature**
Lecture slides will be provided during the course.

Accompanying literature references regarding the individual topics of the lecture will be provided.

# T 3.182 Module component: Ruin Theory [T-MATH-108400]

**Coordinators:** Prof. Dr. Vicky Fasen-Hartmann
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-104055 - Ruin Theory

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.183 Module component: Sampling Methods for Machine Learning [T-INFO-114133]

**Coordinators:** Prof. Dr.-Ing. Uwe Hanebeck
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-107090 - Sampling Methods for Machine Learning

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2400194 | Sampling Methods for Machine Learning | 3 SWS | Lecture / Practice / | Hanebeck, Frisch |
| **Exams** | | | | | |
| WT 25/26 | 7500533 | Sampling Methods for Machine Learning | | | Hanebeck |
| ST 2026 | 7500391 | Sampling Methods for Machine Learning | | | Hanebeck |

Legend: Online, Blended (On-Site/Online), On-Site, × Cancelled

**Assessment**
The assessment is carried out as an oral examination, lasting 20 minutes in accordance with Section 4 (2) No. 2 SPO.

**Prerequisites**
Additional certificate for digital exercise (Übungsschein)

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. The module component T-INFO-114134 - Sampling Methods for Machine Learning - Pass must have been started.

**Recommendations**
Knowledge of a higher programming language with sophisticated libraries for scientific-numerical computing (e.g. Julia, Matlab, Python) is advantageous.

*Below you will find excerpts from courses related to this module component:*

## V Sampling Methods for Machine Learning

2400194, SS 2026, 3 SWS, Language: English, Open in study portal

**Lecture / Practice (VÜ)**
**Blended (On-Site/Online)**

**Content**
Sample-based inference is the de-facto standard for solving otherwise infeasible problems in machine learning, estimation, and control under (unavoidable) uncertainties. Thus, it is an important foundation for further studies. This lecture gives a thorough overview of state-of-the-art sampling methods and discusses current developments from the research frontier.

The first part shows how to efficiently sample large numbers of random samples from given densities starting with the special cases of uniform and Gaussian distributions. For sampling from arbitrary densities, important techniques such as inverse transform sampling, Knothe-Rosenblatt maps, Markov chain Monte Carlo, normalizing flows, and Langevin equations are introduced.

The second part is concerned with deterministic or low-discrepancy sampling, where the goal is to find a set of representative samples of a given density. These are usually obtained by optimization, which, in contrast to random samples, leads to good coverage, high homogeneity, and reproducible results. To analyze and synthesize such samples, various statistical tests and discrepancy measures are presented. This includes scalar tests such as the Cramér-von Mises test, Kolmogorov-Smirnov test, and multivariate generalizations based on Localized Cumulative Distributions and Stein discrepancy.

Finally, advanced topics such as importance sampling and sampling from the posterior density in a Bayesian update are discussed. Typical applications of sample-based inference include Bayesian neural networks, information fusion, and reinforcement learning.

**Organizational issues**
In-person lecture and digital/online exercise with ILIAS-Tests.

Appointsments for oral exams (available year-round): pruefung-isas@iar.kit.edu

# T 3.184 Module component: Sampling Methods for Machine Learning - Pass [T-INFO-114134]

**Coordinators:** Prof. Dr.-Ing. Uwe Hanebeck
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-107090 - Sampling Methods for Machine Learning

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Coursework | 0 CP | pass/fail | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2400194 | Sampling Methods for Machine Learning | 3 SWS | Lecture / Practice / | Hanebeck, Frisch |
| **Exams** | | | | | |
| WT 25/26 | 7500534 | Sampling Methods for Machine Learning - Pass | | | Hanebeck |
| ST 2026 | 7500392 | Sampling Methods for Machine Learning - Pass | | | Hanebeck |

Legend: Online, Blended (On-Site/Online), On-Site, Cancelled

**Assessment**
Digital exercise:

The assessment is carried out as an examination of another type (§ 4 Abs. 2 No. 3 SPO).

**Recommendations**
Knowledge of a higher programming language with sophisticated libraries for scientific-numerical computing (e.g. Julia, Matlab, Python) is advantageous

*Below you will find excerpts from courses related to this module component:*

## V Sampling Methods for Machine Learning

2400194, SS 2026, 3 SWS, Language: English, Open in study portal

**Lecture / Practice (VÜ)**
**Blended (On-Site/Online)**

**Content**
Sample-based inference is the de-facto standard for solving otherwise infeasible problems in machine learning, estimation, and control under (unavoidable) uncertainties. Thus, it is an important foundation for further studies. This lecture gives a thorough overview of state-of-the-art sampling methods and discusses current developments from the research frontier.

The first part shows how to efficiently sample large numbers of random samples from given densities starting with the special cases of uniform and Gaussian distributions. For sampling from arbitrary densities, important techniques such as inverse transform sampling, Knothe-Rosenblatt maps, Markov chain Monte Carlo, normalizing flows, and Langevin equations are introduced.

The second part is concerned with deterministic or low-discrepancy sampling, where the goal is to find a set of representative samples of a given density. These are usually obtained by optimization, which, in contrast to random samples, leads to good coverage, high homogeneity, and reproducible results. To analyze and synthesize such samples, various statistical tests and discrepancy measures are presented. This includes scalar tests such as the Cramér-von Mises test, Kolmogorov-Smirnov test, and multivariate generalizations based on Localized Cumulative Distributions and Stein discrepancy.

Finally, advanced topics such as importance sampling and sampling from the posterior density in a Bayesian update are discussed. Typical applications of sample-based inference include Bayesian neural networks, information fusion, and reinforcement learning.

**Organizational issues**
In-person lecture and digital/online exercise with ILIAS-Tests.

Appointsments for oral exams (available year-round): pruefung-isas@iar.kit.edu

# T 3.185 Module component: Scattering Theory [T-MATH-105855]

**Coordinators:** PD Dr. Tilo Arens
Prof. Dr. Roland Griesmaier
PD Dr. Frank Hettlich

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102884 - Scattering Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

# T 3.186 Module component: Scattering Theory for Time-dependent Waves [T-MATH-113416]

**Coordinators:** Prof. Dr. Roland Griesmaier
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106664 - Scattering Theory for Time-dependent Waves

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
none

**Workload**
180 hours

# T 3.187 Module component: Selected Methods in Fluids and Kinetic Equations [T-MATH-111853]

**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105897 - Selected Methods in Fluids and Kinetic Equations

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 semesters | 1 |

**Assessment**
oral examination of approx. 30 minutes

**Prerequisites**
none

**Recommendations**
The courses "Classical Methods for Partial Differential Equations" and "Functional Analysis" are recommended.

**Workload**
90 hours

# T 3.188 Module component: Selected Topics in Harmonic Analysis [T-MATH-109065]

**Coordinators:** Prof. Dr. Dirk Hundertmark
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-104435 - Selected Topics in Harmonic Analysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 3 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.189 Module component: Self-Booking-HOC-SPZ-FORUM-1-Graded [T-MATH-111515]

**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102994 - Key Competences

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Examination of another type | 2 CP | graded | Each term | 1 |

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- House of Competence
- Sprachenzentrum
- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)

**Additional Information**
Placeholder for self-booking of a graded interdisciplinary qualification, which was provided at the House of Competence, the "Sprachenzentrum" or the Forum Science and Society (FORUM).

# T 3.190 Module component: Self-Booking-HOC-SPZ-FORUM-2-Graded [T-MATH-111517]

**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102994 - Key Competences

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Examination of another type | 2 CP | graded | Each term | 1 |

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- House of Competence
- Sprachenzentrum
- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)

**Additional Information**
Placeholder for self-booking of a graded interdisciplinary qualification, which was provided at the House of Competence, the "Sprachenzentrum" or the Forum Science and Society (FORUM).

# T 3.191 Module component: Self-Booking-HOC-SPZ-FORUM-5-Ungraded [T-MATH-111516]

**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102994 - Key Competences

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Coursework | 2 CP | pass/fail | Each term | 1 |

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- House of Competence
- Sprachenzentrum
- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)

**Additional Information**
Placeholder for self-booking of a ungraded interdisciplinary qualification, which was provided at the House of Competence, the "Sprachenzentrum" or the Forum Science and Society (FORUM).

# T 3.192 Module component: Self-Booking-HOC-SPZ-FORUM-6-Ungraded [T-MATH-111520]

**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102994 - Key Competences

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Coursework | 2 CP | pass/fail | Each term | 1 |

**Self Service Assignment of Supplementary Studies**
This module component can be used for self service assignment of grades acquired from the following study providers:

- House of Competence
- Sprachenzentrum
- Studium Generale. Forum Wissenschaft und Gesellschaft (FORUM) (ehem. ZAK)

**Additional Information**
Placeholder for self-booking of an ungraded interdisciplinary qualification, which was provided at the House of Competence, the "Sprachenzentrum" or the Forum Science and Society (FORUM).

# T 3.193 Module component: Self-Booking-HOC-SPZ-FORUM-PEBA-10-Ungraded [T-MATH-112652]

**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102994 - Key Competences

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Coursework | 2 CP | pass/fail | Each term | 1 |

**Additional Information**
Placeholder for self-booking of a graded interdisciplinary qualification, which was provided at the House of Competence, the "Sprachenzentrum" or the Center for Applied Cultural Studies and Studium Generale.

# T 3.194 Module component: Self-Booking-HOC-SPZ-FORUM-PEBA-9-Graded [T-MATH-112651]

**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102994 - Key Competences

| Type | Credits | Grading | Version |
|---|---|---|---|
| Examination of another type | 2 CP | graded | 1 |

# T 3.195 Module component: Semigroup Theory for the Navier-Stokes Equations [T-MATH-113415]

**Coordinators:** Dr. rer. nat. Patrick Tolksdorf
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106663 - Semigroup Theory for the Navier-Stokes Equations

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
none

**Workload**
180 hours

# T 3.196 Module component: Seminar Advanced Topics in Parallel Programming [T-INFO-103584]

**Coordinators:** Prof. Dr. Achim Streit
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-101887 - Seminar Advanced Topics in Parallel Programming

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Examination of another type | 3 CP | graded | Each summer term | 1 |

# T 3.197 Module component: Seminar Mathematics [T-MATH-105686]

**Coordinators:** PD Dr. Stefan Kühnlein
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102730 - Seminar

| Type | Credits | Grading | Version |
|---|---|---|---|
| Coursework | 3 CP | pass/fail | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700048 | Seminar Mathematics | Kühnlein |
| ST 2026 | 7700025 | Seminar Mathematics | Kühnlein |

# T 3.198 Module component: Signal Processing Methods [T-ETIT-113837]

**Coordinators:** Prof. Dr.-Ing. Sander Wahls
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** M-ETIT-106899 - Signal Processing Methods

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2302113 | Signal Processing Methods | 2 SWS | Lecture / 🗣 | Wahls |
| WT 25/26 | 2302115 | Tutorial to 2302113 Signal Processing Methods | 2 SWS | Practice / 🗣 | Wahls, Al-Hammadi |
| **Exams** | | | | | |
| WT 25/26 | 7302113 | Signal Processing Methods | | | Wahls |
| ST 2026 | 7302113 | Signal Processing Methods | | | Wahls |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Written exam, approx. 120 minutes.
The module grade is the grade of the written exam.

**Prerequisites**
none

**Recommendations**
Familiarity with signals and systems (in particular, Fourier transforms) and probability theory at the Bachelor level is assumed.

# T 3.199 Module component: Signal Processing with Nonlinear Fourier Transforms and Koopman Operators [T-ETIT-113428]

**Coordinators:** Prof. Dr.-Ing. Sander Wahls
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** M-ETIT-106675 - Signal Processing with Nonlinear Fourier Transforms and Koopman Operators

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2302135 | Signal Processing with Nonlinear Fourier Transforms and Koopman Operators | 2 SWS | Lecture / 🗣 | Wahls |
| ST 2026 | 2302136 | Practice to 2302135 Signal Processing with Nonlinear Fourier Transforms and Koopman Operators | 2 SWS | Practice / 🗣 | Wahls, Liang |
| **Exams** | | | | | |
| WT 25/26 | 7302135 | Signal Processing with Nonlinear Fourier Transforms and Koopman Operators | | | Wahls |
| ST 2026 | 7302135 | Signal Processing with Nonlinear Fourier Transforms and Koopman Operators | | | Wahls |

Legend: 🖥 Online, 🖧 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The examination in this module consists of programming assessments and a graded written examination of 120 minutes.

The programming assignments are either pass or fail. They must be passed during the lecture period for admission to the written examination.

The module grade is the grade of the written exam.

**Prerequisites**
none

# T 3.200 Module component: Simulation and Optimization in Robotics and Biomechanics [T-INFO-113123]

**Coordinators:** Prof. Dr. Katja Mombaur
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-106504 - Simulation and Optimization in Robotics and Biomechanics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each winter term | 6 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2400160 | Simulation and Optimization in Robotics and Biomechanics | 4 SWS | Lecture / Practice / 🗣 | Mombaur, Ackermann |
| **Exams** | | | | | |
| WT 25/26 | 7500355 | Simulation and Optimization in Robotics and Biomechanics | | | Mombaur |

Legend: 💻 Online, 🌐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
The assessment is carried out as an oral examination (§ 4 Abs. 2 No. 1 SPO) lasting up to 30 minutes. It can be repeated once.

As a prerequisite for the participation in the oral exam, students must regularly and successfully participate in the exercises. Students must regularly submit exercise sheets. The number of exercise sheets and the scale for passing will be announced at the beginning of the course.

**Prerequisites**
T-INFO-114838 – Simulation and Optimization in Robotics and Biomechanics – Pass grade is required. Completion of module Robotics 1 or corresponding knowledge required
Programing skills in C/C++

**Modeled Prerequisites**
The following conditions have to be fulfilled:

1. You have to fulfill one of 2 conditions:
    1. The module component T-INFO-101465 - Robotics I - Introduction to Robotics must have been passed.
    2. The module component T-INFO-108014 - Robotics I - Introduction to Robotics must have been passed.
2. The following conditions have to be fulfilled:
    1. The module component T-INFO-114838 - Simulation and Optimization in Robotics and Biomechanics - Pass must have been passed.

**Additional Information**
Limitation to 30 participants

*Below you will find excerpts from courses related to this module component:*

## V Simulation and Optimization in Robotics and Biomechanics

2400160, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture / Practice (VÜ)**
**On-Site**

**Content**
The goal of this course is to give a practical introduction into simulation and optimization of motions in robotics and biomechanics. Simulation and optimization play an important role in generating and controlling motions in complex robotics systems and in predicting and analyzing motions of humans. Theory and methods will be covered, but the focus is on the use software tools for modeling, simulation, optimization and visualization of multibody systems. Topics covered include:

- Dynamic process modeling
- Transforming real world problems into mathematical models
- Modeling of complex robotics and biomechanics systems (e.g. humanoids), based on previous modeling knowledge
- Common template models for bipedal walking and running in robotics and biomechanics
- Simulation of mechanical / robotics systems (Integrators and Initial value problems)
- Boundary value problems
- Nonlinear optimization problems
- Optimal control problems
- Direct and indirect methods for optimal control problems, focus on direct methods, especially direct multiple shooting
- Stability of dynamical systems, stability in biomechanics and robotics

**Organizational issues**
Note that the class will start in the second week of the term - i.e. on Wednesday November 5!

# T 3.201 Module component: Simulation and Optimization in Robotics and Biomechanics - Pass [T-INFO-114838]

**Coordinators:** Prof. Dr. Katja Mombaur
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-106504 - Simulation and Optimization in Robotics and Biomechanics

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Coursework (oral) | 0 CP | pass/fail | Each winter term | 1 semesters | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7500313 | Simulation and Optimization in Robotics and Biomechanics - Pass | Mombaur |
| WT 25/26 | 7500355 | Simulation and Optimization in Robotics and Biomechanics | Mombaur |

**Assessment**
Success is assessed in the form of coursework in accordance with Section 4 (3) SPO (ungraded exercise certificate).
Exercise sheets must be handed in regularly to pass the course. The specific details will be announced in the lecture.

**Additional Information**
Participation in the exercise is compulsory and the contents of the exercise are relevant for the examination.

# T 3.202 Module component: Sobolev Spaces [T-MATH-105896]

**Coordinators:** Prof. Dr. Dorothee Frey
Prof. Dr. Roland Schnaubelt
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102926 - Sobolev Spaces

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 2 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0161150 | Sobolev Spaces | 4 SWS | Lecture | Frey |

**Recommendations**
Some basic knowledge of (elementary) linear functional analysis is strongly recommended.

*Below you will find excerpts from courses related to this module component:*

## V Sobolev Spaces

0161150 , SS 2026, 4 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**
The modern theory of partial differential equations works in L^p spaces to a large extent. One reason is that the energy of systems often involves L^2 norms, and also L^p norms in many nonlinear cases. However, the classical pointwise definition of derivatives does not fit well to L^p spaces. This problem has been solved by introducing weak derivatives and Sobolev spaces, which contain L^p-functions possessing weak derivatives in L^p. This theory has become one of the core parts of analysis and its applications.

In the lecture we discuss these objects in a systematic way, also giving complete proofs. Besides basic properties such as product estimates, we treat the main theorems on density, extension to R^n, embeddings, boundary traces, and duality. Moreover, we study the Helmholtz decomposition which expresses range and kernel of the curl and gradient operators. The theory will be applied to problems from partial differential equations at several points.

The lectures requires knowledge in functional analysis. If necessary, background material on partial differential equations will be briefly introduced.

# T 3.203 Module component: Software Engineering II [T-INFO-114259]

**Coordinators:** Prof. Dr.-Ing. Anne Koziolek
Prof. Dr. Raffaela Mirandola
Prof. Dr. Ralf Reussner

**Organisation:** KIT Department of Informatics

**Part of:** M-INFO-107235 - Software Engineering II

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 24076 | Software Engineering II | 4 SWS | Lecture / 🗣 | Reussner, Mirandola, Dehghani |
| **Exams** | | | | | |
| WT 25/26 | 7500054 | Software Engineering II | | | Reussner |
| ST 2026 | 7500207 | Software Engineering II | | | Reussner |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Assessment
The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) lasting 90 minutes.

### Prerequisites
None.

### Modeled Prerequisites
The following conditions have to be fulfilled:

1. The module component T-INFO-101370 - Software Engineering II must not have been started.

### Recommendations
The course *Software Engineering I* should already have been attended.

# T 3.204 Module component: Space and Time Discretization of Nonlinear Wave Equations [T-MATH-112120]

**Coordinators:** Prof. Dr. Marlis Hochbruck
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105966 - Space and Time Discretization of Nonlinear Wave Equations

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 semesters | 1 |

**Prerequisites**
none

**Workload**
180 hours

# T 3.205 Module component: Spatial Stochastics [T-MATH-105867]

**Coordinators:** Prof. Dr. Daniel Hug
Prof. Dr. Günter Last
PD Dr. Steffen Winter

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102903 - Spatial Stochastics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0105600 | Spatial Stochastics | 4 SWS | Lecture | Last |
| WT 25/26 | 0105610 | Tutorial for 0105600 (Spatial Stochastics) | 2 SWS | Practice | Last |
| **Exams** | | | | | |
| WT 25/26 | 7700052 | Spatial Stochastics | | | Last, Hug |
| ST 2026 | 7700090 | Spatial Stochastics | | | Last |

**Prerequisites**
none

**Workload**
240 hours

*Below you will find excerpts from courses related to this module component:*

## V Spatial Stochastics

0105600, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**
Competence Goal:
The students are familiar with some basic spatial stochastic processes. They do not only understand how to deal with general properties of distributions, but also know how to describe and apply specific models (Poisson process, Gaussian random fields). They know how to work self-organised and self-reflexive.

Content:
Random sets
Point processes
Random measures
Palm distributions
Random fields
Gaussian fields
Spectral theory of random fields
Spatial ergodic theorem

**Literature**
Skriptum/Lectures Notes

# T 3.206 Module component: Special Topics of Numerical Linear Algebra [T-MATH-105891]

**Coordinators:** PD Dr. Volker Grimm
Prof. Dr. Marlis Hochbruck
PD Dr. Markus Neher

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102920 - Special Topics of Numerical Linear Algebra

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700125 | Special Topics of Numerical Linear Algebra January 28, 2026 | Neher |

**Prerequisites**
none

**Workload**
240 hours

# T 3.207 Module component: Spectral Theory - Exam [T-MATH-103414]

**Coordinators:** Prof. Dr. Dorothee Frey
PD Dr. Gerd Herzog
Prof. Dr. Dirk Hundertmark
apl. Prof. Dr. Peer Kunstmann
Prof. Dr. Roland Schnaubelt
Dr. rer. nat. Patrick Tolksdorf

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-101768 - Spectral Theory

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0163700 | Spectral Theory | 4 SWS | Lecture | Hundertmark |
| ST 2026 | 0163710 | Tutorial for 0163700 (Spectral Theory) | 2 SWS | Practice | Hundertmark |
| **Exams** | | | | | |
| WT 25/26 | 0100017 | Spectral Theory - Exam | | | Schnaubelt |
| ST 2026 | 7700087 | Spectral Theory - Exam | | | Hundertmark |

**Assessment**
Oral examination of approx. 30 minutes.

**Prerequisites**
none

**Workload**
240 hours

*Below you will find excerpts from courses related to this module component:*

## V Spectral Theory

0163700, SS 2026, 4 SWS, Open in study portal — **Lecture (V)**

**Content**
After participation, students understand the concepts of spectrum and resolvent of closed operators on Banach spaces. They will know their basic properties and are able to explain them in simple examples. They can explain and justify the special features of compact operators and the Fredholm Alternative and deduce algebraic identities and norm bounds for operators by means of the Dunford functional calculus and the spectral calculus for self-adjoint operators. This in particular includes spectral projections and spectral mapping theorems. Students are able to apply this general theory to integral and differential equations, and recognize the importance of spectral theoretic methods in Analysis.

Content

- Closed operators on Banach spaces,
- Spectrum and resolvent,
- Compact operators and Fredholm alternative,
- Dunford functional calculus, spectral projections,
- Fourier transform,
- Unbounded self-adjoint operators on Hilbert spaces,
- Spectral theorem,
- Sesquilinear forms and sectorial operators,
- Applications to partial differential equation

**Literature**


- H.W. Alt: Lineare Funktionalanalysis.
- H. Brezis: Functional Analysis, Sobolev Spaces and Partial Differential Equations.
- J.B. Conway: A Course in Functional Analysis.
- N. Dunford, J.T. Schwartz: Linear Operators, Part I.
- T. Kato: Perturbation Theory of Linear Operators.
- B. Simon: Operator Theory. A Comprehensive Course in Analysis, Part 4.
- A.E. Taylor, D.C. Lay: Introduction to Functional Analysis.
- D. Werner: Funktionalanalysis.

# T 3.208 Module component: Spectral Theory of Differential Operators [T-MATH-105851]

**Coordinators:** Prof. Dr. Michael Plum
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102880 - Spectral Theory of Differential Operators

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700114 | Spectral Theory of Differential Operators | Plum |

**Prerequisites**
None.

**Workload**
240 hours

# T 3.209 Module component: Splitting Methods for Evolution Equations [T-MATH-110805]

**Coordinators:** Prof. Dr. Tobias Jahnke
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105325 - Splitting Methods for Evolution Equations

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Prerequisites**
none

**Workload**
180 hours

# T 3.210 Module component: Statistical Learning [T-MATH-111726]

**Coordinators:** Prof. Dr. Mathias Trabs
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105840 - Statistical Learning

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700151 | Statistical Learning - Exam 3 | Klar |

**Assessment**
The module will be completed with an oral exam (approx. 30 min).

**Prerequisites**
none

**Recommendations**
The module "Introduction to Stochastics" is recommended. The module "Probability theory" is preferable.

# T 3.211 Module component: Statistical Thermodynamics [T-CIWVT-106098]

**Coordinators:** Prof. Dr. Sabine Enders
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103059 - Statistical Thermodynamics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2250040 | Statistical Thermodynamics | 2 SWS | Lecture / 🗣 | Enders |
| ST 2026 | 2250041 | Statistical Thermodynamics - Exercises | 1 SWS | Practice / 🗣 | Enders |
| **Exams** | | | | | |
| WT 25/26 | 7250040 | Statistical Thermodynamics | | | Enders |
| ST 2026 | 7250040 | Statistical Thermodynamics | | | Enders |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Learning control is an oral examination lasting approx. 30 minutes.

**Prerequisites**
Thermodynamics III

# T 3.212 Module component: Steins Method with Applications in Statistics [T-MATH-111187]

**Coordinators:** Dr. rer. nat. Bruno Ebner
Prof. Dr. Daniel Hug

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-105579 - Steins Method with Applications in Statistics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.213 Module component: Stochastic Control [T-MATH-105871]

**Coordinators:** Prof. Dr. Nicole Bäuerle
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102908 - Stochastic Control

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 1 |

**Prerequisites**
none

**Workload**
120 hours

# T 3.214 Module component: Stochastic Geometry [T-MATH-105840]

**Coordinators:** Prof. Dr. Daniel Hug
PD Dr. Steffen Winter
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102865 - Stochastic Geometry

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0152600 | Stochastic Geometry | 4 SWS | Lecture | Winter |
| ST 2026 | 0152610 | Tutorial for 0152600 (Stochastic Geometry) | 2 SWS | Practice | Winter |

*Below you will find excerpts from courses related to this module component:*

## V Stochastic Geometry

0152600, SS 2026, 4 SWS, Open in study portal **Lecture (V)**

**Content**
For some idea what this course is about see

https://stoch.math.kit.edu/94.php

Competence Goals:

The students know the fundamental geometric models and characteristics in stochastic geometry, are familiar with properties of Poisson processes of geometric objects, know examples of applications of models of stochastic geometry, know how to work self-organised and self-reflexive.

Content:

- Random sets
- Geometric point processes
- Stationarity and isotropy
- Germ grain models
- Boolean models
- Foundations of integral geometry
- Geometric densities and characteristics
- Random tessellations

**Literature**
Lecture Notes will be provided.

# T 3.215 Module component: Stochastic Information Processing [T-INFO-101366]

**Coordinators:** Prof. Dr.-Ing. Uwe Hanebeck
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-100829 - Stochastic Information Processing

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2424113 | Stochastic Information Processing | 3 SWS | Lecture / Practice / 🗣 | Hanebeck, Frisch |
| **Exams** | | | | | |
| WT 25/26 | 7500031 | Stochastic Information Processing | | | Hanebeck |
| ST 2026 | 7500010 | Stochastic Information Processing | | | Hanebeck |

Legend: 🖥 Online, 🖥🗣 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Success is assessed in the form of an oral examination, usually lasting 15 - 25 minutes in accordance with Section 4 (2) No. 2 SPO.

**Prerequisites**
None.

**Recommendations**
Knowledge of the basics of probability theory is helpful.

**Additional Information**
As a theoretical foundation lecture, "Stochastic Information Systems" is an ideal introduction to the ISAS lectures. Conversely, prior knowledge of "Localization of Mobile Agents" (LMA) [course no. 24613] and "Information Processing in Sensor Networks" (IIS) [course no. 24102] may still be helpful, depending on the type of learner - more concrete applications are highlighted there. In all our lectures, all content is explained in detail from the very beginning; it is therefore possible to start with SI, LMA or IIS.

*Below you will find excerpts from courses related to this module component:*

## V Stochastic Information Processing

2424113, WS 25/26, 3 SWS, Language: German/English, Open in study portal

**Lecture / Practice (VÜ)**
**On-Site**

**Content**
To deal with complex dynamic systems, as they occur for example in robotics, one typically requires both system models and the temporal evolution of the system states. For both system identification and state reconstruction, however, usually only noisy data are available.

For continuous state spaces, an exact calculation of the probability densities is only possible in a few special cases. In practice, general nonlinear systems are often traced back to these special cases by simplifying assumptions. One extreme is linearization with subsequent application of linear estimation theory. However, this often leads to unsatisfactory results and requires additional heuristic measures. At the other extreme are numerical approximation methods, which only evaluate the desired probability densities at discrete points in the state space. Although the basic principle of these methods is usually quite simple, their practical implementation is often difficult and, in particular for higher-dimensional systems, computationally demanding.

As a middle ground, analytical nonlinear estimation methods would therefore often be desirable. In this lecture the main difficulties in the development of such estimation methods are outlined and corresponding solution modules are presented. Based on these building blocks, some analytical estimation methods are discussed in detail as examples, which are very suitable for practical implementation and offer a good compromise between computing effort and performance. Useful applications of these estimation methods are also discussed. Both known methods and the results of current research are presented.

**Organizational issues**
Der Prüfungstermin ist per E-Mail zu vereinbaren. Zusätzliche Anmeldung im CAS nicht vergessen.

**Literature**
**Weiterführende Literatur**
Skript zur Vorlesung

# T 3.216 Module component: Stochastic Simulation [T-MATH-112242]

**Coordinators:** Prof. Dr. Sebastian Krumscheid
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-106053 - Stochastic Simulation

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 5 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 0100027 | Stochastic Simulation | 2 SWS | Lecture | Krumscheid |
| **Exams** | | | | | |
| WT 25/26 | 7700109 | Stochastic Simulation | | | Krumscheid |

**Assessment**
oral exam of ca. 30 min

**Prerequisites**
none

**Workload**
150 hours

*Below you will find excerpts from courses related to this module component:*

## V Stochastic Simulation

0100027, WS 25/26, 2 SWS, Open in study portal **Lecture (V)**

**Content**
The course covers mathematical concepts and computational tools used to analyze systems with uncertainty arising across various application domains. First, we will address stochastic modelling strategies to represent uncertainty in such systems. Then we will discuss sampling-based methods to assess uncertain system outputs via stochastic simulation techniques. The focus of this course will be on the theoretical foundations of the discussed techniques, as well as their methodological realization as efficient computational tools.

Topics covered include:

- Random variable generation
- Simulation of random processes
- Simulation of Gaussian random fields
- Monte Carlo method; output analysis
- Variance reduction techniques
- Quasi Monte Carlo methods
- Markov Chain Monte Carlo methods (Metropolis-Hasting, Gibbs sampler)

Other topics that may be addressed if time allows, such as rare event simulations, and stochastic optimization using stochastic approximation or simulated annealing.

# T 3.217 Module component: Structural Graph Theory [T-MATH-111004]

**Coordinators:** Prof. Dr. Maria Aksenovich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105463 - Structural Graph Theory

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

**Prerequisites**
none

# T 3.218 Module component: Technical Optics [T-ETIT-100804]

**Coordinators:** Prof. Dr. Cornelius Neumann
**Organisation:** KIT Department of Electrical Engineering and Information Technology
**Part of:** M-ETIT-100538 - Technical Optics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 5 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2313720 | Technical Optics | 2 SWS | Lecture / 🗣 | Neumann |
| WT 25/26 | 2313722 | Technical Optics (Tutorial to 2313720) | 1 SWS | Practice / 🗣 | Neumann |
| **Exams** | | | | | |
| WT 25/26 | 7313720 | Technical Optics | | | Neumann |
| ST 2026 | 7313720 | Technical Optics | | | Neumann |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Success is assessed in the form of a written examination lasting 120 minutes. The module grade is the grade of the written examination.

**Prerequisites**
none

**Recommendations**
Previous attendance of the lecture on lighting technology.

# T 3.219 Module component: Technomathematical Seminar [T-MATH-105884]

**Coordinators:** Prof. Dr. Tobias Jahnke
PD Dr. Stefan Kühnlein

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102863 - Technomathematical Seminar

| Type | Credits | Grading | Version |
|---|---|---|---|
| Coursework | 3 CP | pass/fail | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700031 | Technomathematical Seminar | Kühnlein |
| ST 2026 | 7700056 | Technomathematical Seminar | Kühnlein |

# T 3.220 Module component: Telematics [T-INFO-114269]

**Coordinators:** Prof. Dr. Martina Zitterbart
**Organisation:** KIT Department of Informatics
**Part of:** M-INFO-107243 - Telematics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Written examination | 6 CP | graded | Each winter term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2400007 | Telematics | 4 SWS | Lecture / 🗣 | Zitterbart, Helmig, Mahrt, Seehofer |
| **Exams** | | | | | |
| WT 25/26 | 7500166 | Telematics | | | Zitterbart |
| ST 2026 | 7500098 | Telematics | | | Zitterbart |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Assessment
The assessment is carried out as a written examination (§ 4 Abs. 2 No. 1 SPO) lasting 90 minutes.

Depending on the number of participants, it will be announced six weeks before the examination (Section 6 (3) SPO) whether the assessment will take place

- in the form of an oral examination of approx. 30 minutes in accordance with § 4 Para. 2 No. 2 SPO
- or in the form of a written examination in accordance with § 4 Para. 2 No. 1 SPO

### Prerequisites
None.

### Modeled Prerequisites
The following conditions have to be fulfilled:

1. The module component T-INFO-101338 - Telematics must not have been started.

### Recommendations

- Contents of the lecture ***Introduction to computer networks***or comparable lectures are a prerequisite.
- Attendance of the module-accompanying ***basic practical course Protocol Engineering*** is recommended.

*Below you will find excerpts from courses related to this module component:*

## V Telematics
2400007, WS 25/26, 4 SWS, Language: English, Open in study portal

**Lecture (V)**
**On-Site**

**Content**
The lecture covers (i.a.) protocols, architectures, as well as methods and algorithms, for routing and establishing reliable end-to-end connections in the Internet. In addition to various methods for media access control in local area networks, the lecture also covers other communication systems, e.g. circuit-switched systems such as ISDN. Participants should also have understood the possibilities for managing and administering networks.

Familiary with the contents of the lecture *Einführung in Rechnernetze* or comparable lectures is assumed.

**Learning Objectives**

After attending this lecture, the students will

- have a profound understanding of protocols, architectures, as well as procedures and algorithms used for routing and for establishing reliable end-to-end connections in the Internet
- have a profound understanding of different media access control procedures in local networks and other communication systems like circuit-switched ISDN
- have a profound understanding of the problems that arise in large scale dynamic communication systems and are familiar with mechanism to deal with these problems
- be familiar with current developments such as SDN and data center networking
- be familiar with different aspects and possibilities for network management and administration

Students have a profound understanding of the basic protocol mechanisms that are necessary to establish reliable end-to-end communication. Students have detailed knowledge about the congestion and flow control mechanisms used in TCP and can discuss fairness issue in the context of multiple parallel transport streams. Students can analytically determine the performance of transport protocols and know techniques for dealing with specific constraints in the context of TCP, e.g., high data rates and low latencies. Students are familiar with current topics such as the problem of middle boxes on the Internet, the usage of TCP in data centers or multipath TCP. Students are also familiar with practical aspects of modern transport protocols and know practical ways to overcome heterogeneity in the development of distributed applications.

Students know the functions of (Internet) routing and routers and can explain and apply common routing algorithms. Students are familiar with routing architectures and different alternatives for buffer placement as well as their advantages and disadvantages. Students understand the classification into interior and exterior gateway protocols and have in-depth knowledge of the functionality and features of common protocols such as RIP, OSPF, and BGP. Students are also familiar with current topics such as label switching, IPv6 and SDN.

Students know the function of media access control and are able to classify and analytically evaluate different media access control mechanisms. Students have an in-depth knowledge of Ethernet and various Ethernet variants and characteristics, which especially includes current developments such as real-time Ethernet and data center Ethernet. Students can explain and apply the Spanning Tree Protocol.

Students know the architecture of ISDN and can reproduce the peculiarities of setting up the ISDN subscriber line. Students are familiar with the technical features of DSL.

**Literature**
S. Keshav. An Engineering Approach to Computer Networking. Addison-Wesley, 1997 J.F. Kurose, K.W. Ross. Computer Networking: A Top-Down Approach Featuring the Internet. 4rd Edition, Addison-Wesley, 2007 W. Stallings. Data and Computer Communications. 8th Edition, Prentice Hall, 2006 Weiterführende Literatur •D. Bertsekas, R. Gallager. Data Networks. 2nd Edition, Prentice-Hall, 1991 •F. Halsall. Data Communications, Computer Networks and Open Systems. 4th Edition, Addison-Wesley Publishing Company, 1996 •W. Haaß. Handbuch der Kommunikationsnetze. Springer, 1997 •A.S. Tanenbaum. Computer-Networks. 4th Edition, Prentice-Hall, 2004 •Internet-Standards •Artikel in Fachzeitschriften

# T 3.221 Module component: Theoretical Nanooptics [T-PHYS-104587]

**Coordinators:** Prof. Dr. Markus Garst
Prof. Dr. Carsten Rockstuhl
**Organisation:** KIT Department of Physics
**Part of:** M-PHYS-102295 - Theoretical Nanooptics

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 2 |

# T 3.222 Module component: Theoretical Optics [T-PHYS-104578]

**Coordinators:** PD Dr. Boris Narozhnyy
Prof. Dr. Carsten Rockstuhl

**Organisation:** KIT Department of Physics

**Part of:** M-PHYS-102277 - Theoretical Optics

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each summer term | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 4023111 | Theoretical Optics | 2 SWS | Lecture / 🗣 | Rockstuhl |
| ST 2026 | 4023112 | Exercises to Theoretical Optics | 1 SWS | Practice / 🗣 | Rockstuhl, NN |

Legend: 💻 Online, 🖧 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Prerequisites**
none

## T 3.223 Module component: Thermodynamics III [T-CIWVT-106033]

**Coordinators:** Prof. Dr. Sabine Enders
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103058 - Thermodynamics III

| Type | Credits | Grading | Version |
|---|---|---|---|
| Written examination | 6 CP | graded | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| WT 25/26 | 2250030 | Thermodynamics III | 2 SWS | Lecture / 🗣 | Enders |
| WT 25/26 | 2250031 | Thermodynamics III - Exercises | 1 SWS | Practice / 🗣 | Enders, und Mitarbeitende |
| **Exams** | | | | | |
| WT 25/26 | 7250030 | Thermodynamics III | | | Enders |

Legend: 🖥 Online, ⚙ Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

### Assessment
Learning control is a written examination lasting 90 minutes.

### Prerequisites
None

# T 3.224 Module component: Thermodynamics of Interfaces [T-CIWVT-106100]

**Coordinators:** Prof. Dr. Sabine Enders
**Organisation:** KIT Department of Chemical and Process Engineering
**Part of:** M-CIWVT-103063 - Thermodynamics of Interfaces

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Each summer term | 3 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 2250050 | Thermodynamics of Interfaces | 2 SWS | Lecture / 🗣 | Enders |
| ST 2026 | 2250051 | Exercises on 2250050 Thermodynamics of Interfaces | 1 SWS | Practice / 🗣 | Enders |
| **Exams** | | | | | |
| WT 25/26 | 7250050 | Thermodynamics of Interfaces | | | Enders |
| ST 2026 | 7250050 | Thermodynamics of Interfaces | | | Enders |

Legend: 💻 Online, 💐 Blended (On-Site/Online), 🗣 On-Site, ✕ Cancelled

**Assessment**
Erfolgskontrolle ist eine mündliche Prüfung im Umfang von 30 Minuten.

# T 3.225 Module component: Time Series Analysis [T-MATH-105874]

**Coordinators:** Dr. rer. nat. Bruno Ebner
Prof. Dr. Vicky Fasen-Hartmann
Prof. Dr. Tilmann Gneiting
PD Dr. Bernhard Klar
Prof. Dr. Mathias Trabs

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-102911 - Time Series Analysis

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 4 CP | graded | 4 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0161100 | Time Series Analysis | 2 SWS | Lecture | Gneiting |
| ST 2026 | 0161110 | Tutorial for 0161100 (Time Series Analysis) | 1 SWS | Practice | Gneiting |

**Workload**
120 hours

*Below you will find excerpts from courses related to this module component:*

## V Time Series Analysis

0161100, SS 2026, 2 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**
A time series is a sequence of data sequentially observed in time. This course provides an introduction to the theory and practice of statistical time series analysis. The content is as follows:

- Stationary time series
- Trends and seasonality
- Autocorrelation
- Autoregressive models
- ARMA models
- Parameter estimation
- Forecasting
- Spectral density and periodogram

# T 3.226 Module component: Topics in Algebraic Topology [T-MATH-114063]

**Coordinators:** TT-Prof. Dr. Manuel Krannich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-107017 - Topics in Algebraic Topology

| Type | Credits | Grading | Term offered | Expansion | Version |
|---|---|---|---|---|---|
| Written examination | 6 CP | graded | Irregular | 1 semesters | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700146 | Topics in Algebraic Topology | Krannich |

**Assessment**
written exam (120 min.)

**Prerequisites**
none

**Workload**
180 hours

# T 3.227 Module component: Topics in Homotopy Theory [T-MATH-114682]

**Coordinators:** TT-Prof. Dr. Manuel Krannich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-107484 - Topics in Homotopy Theory

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700145 | Topics in Homotopy Theory | Krannich |

**Prerequisites**
none

**Workload**
180 hours

# T 3.228 Module component: Topological Data Analysis [T-MATH-111031]

**Coordinators:** Prof. Dr. Tobias Hartnick
Prof. Dr. Roman Sauer

**Organisation:** KIT Department of Mathematics

**Part of:** M-MATH-105487 - Topological Data Analysis

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 6 CP | graded | Irregular | 1 |

**Prerequisites**
None.

**Workload**
180 hours

# T 3.229 Module component: Translation Surfaces [T-MATH-112128]

**Coordinators:** Prof. Dr. Frank Herrlich
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105973 - Translation Surfaces

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

**Prerequisites**
none

**Workload**
240 hours

# T 3.230 Module component: Traveling Waves [T-MATH-105897]

**Coordinators:** Dr. Björn de Rijk
Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102927 - Traveling Waves

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 6 CP | graded | 2 |

**Assessment**
The module examination takes place in form of an oral exam of about 30 minutes. Please see under "Modulnote" for more information about the bonus regulation.

**Prerequisites**
none

**Recommendations**
The following background is strongly recommended: Analysis 1-4.

**Workload**
180 hours

# T 3.231 Module component: Uncertainty Quantification [T-MATH-108399]

**Coordinators:** Prof. Dr. Martin Frank
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-104054 - Uncertainty Quantification

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 4 CP | graded | Irregular | 1 |

| Courses | | | | | |
|---|---|---|---|---|---|
| ST 2026 | 0164400 | Uncertainty Quantification | 2 SWS | Lecture | Frank |
| ST 2026 | 0164410 | Tutorial for 0164400 (Uncertainty quantification) | 1 SWS | Practice | Frank |
| **Exams** | | | | | |
| ST 2026 | 7700045 | Uncertainty Quantification | | | Frank |

**Prerequisites**
none

*Below you will find excerpts from courses related to this module component:*

## V Uncertainty Quantification

0164400, SS 2026, 2 SWS, Language: English, Open in study portal

**Lecture (V)**

**Content**
"There are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – there are things we do not know we don't know." (Donald Rumsfeld)

In this class, we learn to deal with the known unknowns, a field called Un- certainty Quantification (UQ). We particularly focus on the propagation of uncertainties (e.g. unknown data, unknown initial or boundary conditions) through models (mostly differential equations) and leave other important questions of UQ (especially inference) aside. Given uncertain input, how un- certain is the output? The uncertainties are modeled as random variables, and thus the solutions of the equations become random variables themselves.

Thus we summarize the necessary foundations of probability theory, with a focus on modeling correlated and uncorrelated random vectors. Further- more, we will see that every uncertain parameter becomes a dimension in the problem. We are thus quickly led to high-dimensional problems. Standard numerical methods suffer from the so-called curse of dimensionality, i.e. to reach a certain accuracy one needs excessively many model evaluations. Thus we study the fundamentals of approximation theory.

The first part of the course ("how to do it") gives an overview on techniques that are used. Among these are:

- Sensitivity analysis
- Monte-Carlo methods
- Spectral expansions
- Stochastic Galerkin method
- Collocation methods, sparse grids

The second part of the course ("why to do it like this") deals with the theoretical foundations of these methods. The so-called "curse of dimensionality" leads us to questions from approximation theory. We look back at the very standard numerical algorithms of interpolation and quadrature, and ask how they perform in many dimensions.

**Organizational issues**
The course will be offered in flipped classroom format. This means that the lectures will be made available as videos; students will also have lecture notes. We meet in presence for the tutorials, and there will also be office hours.

**Literature**


- R.C. Smith: Uncertainty Quantification: Theory, Implementation, and Applications, SIAM, 2014.
- T.J. Sullivan: Introduction to Uncertainty Quantification, Springer-Verlag, 2015.
- D. Xiu: Numerical Methods for Stochastic Computations, Princeton University Press, 2010.
- O.P. Le Maître, O.M. Knio: Spectral Methods for Uncertainty Quantification, Springer-Verlag, 2010.
- R. Ghanem, D. Higdon, H. Owhadi:Handbook of Uncertainty Quantification, Springer-Verlag, 2017.

# T 3.232 Module component: Variational Methods [T-MATH-110302]

**Coordinators:** Prof. Dr. Wolfgang Reichel
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-105093 - Variational Methods

| Type | Credits | Grading | Version |
|---|---|---|---|
| Oral examination | 8 CP | graded | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700104 | Variational Methods | Reichel, Lamm |

# T 3.233 Module component: Wavelets [T-MATH-105838]

**Coordinators:** Prof. Dr. Andreas Rieder
**Organisation:** KIT Department of Mathematics
**Part of:** M-MATH-102895 - Wavelets

| Type | Credits | Grading | Term offered | Version |
|---|---|---|---|---|
| Oral examination | 8 CP | graded | Irregular | 1 |

| Exams | | | |
|---|---|---|---|
| WT 25/26 | 7700137 | Wavelets | Rieder |

**Assessment**
Mündliche Prüfung im Umfang von ca. 30 Minuten.

**Prerequisites**
none

**Workload**
240 hours