Computational modeling and visualization of physical systems with Python

Digital Online Companion

J Wang
Digital Online Companion

The Digital Online Companion contains advanced and in-depth topics arranged in parallel chapters to the print edition. It is intended to provide closely-related but optional material at upper undergraduate or graduate levels.

Throughout, references to the print edition are indicated by the “A:” prefix, including the completely merged index.
# Contents

1 Introduction ................................. 1

2 Free fall and solutions of ODEs .................. 3

3 Realistic projectile motion with air resistance .... 5
   3.1 Exercises and Projects ........................ 5
   3.A Approximate formulas for the Lambert \( W \) function ... 7

4 Planetary motion and few-body problems ............ 11
   4.1 Exercises and Projects ........................ 11

5 Nonlinear dynamics and chaos ..................... 19
   5.1 The kicked rotor and the stadium billiard ........ 19
   5.2 Exercises and Projects ........................ 25
   5.A Renormalization and self-similarity ............ 28
   5.B Fast Fourier transform (FFT) .................. 30
   5.C Program listings and descriptions .............. 44

6 Oscillations and waves .......................... 47
   6.1 The hanging chain and the catenary ............. 47
   6.2 Exercises and Projects ........................ 53
   6.A Gauss elimination and related methods .......... 55
   6.B Program listings and descriptions .............. 57
CONTENTS

7 Electromagnetic fields 65
  7.1 Equilibrium of charges on a sphere ..................... 65
  7.2 Exercises and Projects .................................. 69

8 Time-dependent quantum mechanics 75
  8.1 Scattering and split evolution operator .................... 75
  8.2 Quantum transitions and coupled channels ................... 86
  8.3 Exercises and Projects .................................. 100
  8.A Theory of Gaussian integration ............................ 107
  8.B Profiling code execution ................................ 109
  8.C Coupled channels in real arithmetic ....................... 110
  8.D Program listings and descriptions ......................... 112

9 Time-independent quantum mechanics 115
  9.1 Energy level statistics ................................... 115
  9.2 Quantum chaos ............................................ 117
  9.3 Exercises and Projects .................................. 126
  9.A Program listings and descriptions ......................... 135

10 Simple random problems 137
  10.1 Game of life ............................................. 137
  10.2 Traffic flow .............................................. 139
  10.3 Ants raiding patterns .................................... 142
  10.4 Exercises and Projects .................................. 145
  10.A Program listings and descriptions ......................... 149

11 Thermal systems 153
  11.1 Thermal relaxation of a suspended chain ................... 153
  11.2 Particle transport ....................................... 160
  11.3 Bose-Einstein condensation ............................... 170
  11.4 Exercises and Projects .................................. 177
  11.A Mean field approximation of 2D Ising model ............... 184
  11.B Program listings and descriptions ......................... 187

12 Classical and quantum scattering 195
  12.1 Orbiting ............................................... 195
  12.2 Green’s function method .................................. 198
  12.3 Scattering at low and high energies ...................... 202
12.4 Inelastic scattering and atomic reactions ........... 211
12.5 Classical dynamics of atomic reactions ............ 221
12.6 Exercises and Projects .............................. 237
12.A The phase shift integral ............................. 251
12.B Direct determination of cross sections .............. 253
12.C WKB scattering wave functions ...................... 254
12.D The Born T-Matrix ................................ 255
12.E The microcanonical ensemble ......................... 260
12.F Time-dependent leapfrog method ...................... 261
12.G Program listings and descriptions .................... 262

Bibliography ............................................. 267

Index ..................................................... 271