

BRIEF CONTENTS

Acknowledgments	xxiii
Introduction	xxv

PART I: A HASKELL PRIMER FOR PHYSICISTS

Chapter 1: Calculating with Haskell	3
Chapter 2: Writing Basic Functions	15
Chapter 3: Types and Entities	25
Chapter 4: Describing Motion	35
Chapter 5: Working with Lists	51
Chapter 6: Higher-Order Functions	69
Chapter 7: Graphing Functions	91
Chapter 8: Type Classes	97
Chapter 9: Tuples and Type Constructors	113
Chapter 10: Describing Motion in Three Dimensions	129
Chapter 11: Creating Graphs	165
Chapter 12: Creating Stand-Alone Programs	175
Chapter 13: Creating 2D and 3D Animations	187

PART II: EXPRESSING NEWTONIAN MECHANICS AND SOLVING PROBLEMS

Chapter 14: Newton's Second Law and Differential Equations	205
Chapter 15: Mechanics in One Dimension	243
Chapter 16: Mechanics in Three Dimensions	279
Chapter 17: Satellite, Projectile, and Proton Motion	307
Chapter 18: A Very Short Primer on Relativity	329
Chapter 19: Interacting Particles	339
Chapter 20: Springs, Billiard Balls, and a Guitar String	363

PART III: EXPRESSING ELECTROMAGNETIC THEORY AND SOLVING PROBLEMS

Chapter 21: Electricity	409
Chapter 22: Coordinate Systems and Fields	421
Chapter 23: Curves, Surfaces, and Volumes	449
Chapter 24: Electric Charge	461
Chapter 25: Electric Field	473
Chapter 26: Electric Current	507
Chapter 27: Magnetic Field	519
Chapter 28: The Lorentz Force Law	535
Chapter 29: The Maxwell Equations	551
Appendix: Installing Haskell	581
Bibliography	595
Index	597

CONTENTS IN DETAIL

ACKNOWLEDGMENTS

xxiii

INTRODUCTION

xxv

Who This Book Is For	xxvi
Why Functional Programming, and Why Haskell?	xxvi
About This Book	xxvii

PART I A HASKELL PRIMER FOR PHYSICISTS

1 CALCULATING WITH HASKELL

3

A Kinematics Problem	3
The Interactive Compiler	4
Numeric Functions	4
Operators	6
Precedence and Associativity	7
The Application Operator	9
Functions with Two Arguments	9
Numbers in Haskell	10
Negative Numbers in Haskell	10
Decimal Numbers in Haskell	11
Exponential Notation	11
Approximate Calculation	11
Errors	12
Getting Help and Quitting	13
More Information	13
Summary	13
Exercises	14

2 WRITING BASIC FUNCTIONS

15

Constants, Functions, and Types	16
How We Talk About Functions	19
Anonymous Functions	20
Composing Functions	21

Variable Not in Scope Error	22
Summary	23
Exercises	23
3	
TYPES AND ENTITIES	25
Basic Types	25
The Boolean Type	26
The Character Type	28
The String Type	28
Numeric Types	29
Function Types	30
Summary	32
Exercises	32
4	
DESCRIBING MOTION	35
Position and Velocity on an Air Track	35
Types for Physical Quantities	37
Introducing Derivatives	38
Derivatives in Haskell	40
Modeling the Car's Position and Velocity	41
Modeling Acceleration	44
Approximate Algorithms and Finite Precision	45
Summary	47
Exercises	47
5	
WORKING WITH LISTS	51
List Basics	52
Selecting an Element from a List	52
Concatenating Lists	53
Arithmetic Sequences	54
List Types	55
Functions for Lists of Numbers	55
When Not to Use a List	56
Type Variables	56
Type Conversion	57
The Length of Lists	58
A String Is a List of Characters	59
List Comprehensions	60
Infinite Lists	61
List Constructors and Pattern Matching	62

Summary	64
Exercises	64

6 HIGHER-ORDER FUNCTIONS **69**

How to Think About Functions with Parameters	70
Mapping a Function Over a List	73
Iteration and Recursion	74
Anonymous Higher-Order Functions	76
Operators as Higher-Order Functions	77
Combinators	78
Predicate-Based Higher-Order Functions	79
Numerical Integration	81
Introducing Integrators	81
Digital Integration	82
Implementing Antiderivatives	85
Summary	87
Exercises	88

7 GRAPHING FUNCTIONS **91**

Using Library Modules	91
Standard Library Modules	91
Other Library Modules	92
Plotting	93
Function Only	93
Function and Module	94
Function, Module, and Plot Definition	94
Summary	95
Exercises	95

8 TYPE CLASSES **97**

Type Classes and Numbers	98
Type Classes from the Prelude	99
The Eq Type Class	99
The Show Type Class	100
The Num Type Class	101
The Integral Type Class	102
The Ord Type Class	102
The Fractional Type Class	103
The Floating Type Class	104
Exponentiation and Type Classes	104

Sections	105
Example of Type Classes and Plotting	106
Summary	109
Exercises	109

9 TUPLES AND TYPE CONSTRUCTORS 113

Pairs	113
Currying a Function of Two Variables	115
Triples	116
Comparing Lists and Tuples	117
Maybe Types	117
Lists of Pairs	119
Tuples and List Comprehensions	120
Type Constructors and Kinds	121
Numerical Integration Redux	124
Summary	125
Exercises	125

10 DESCRIBING MOTION IN THREE DIMENSIONS 129

Three-Dimensional Vectors	129
Coordinate-Free Vectors	131
Geometric Definition of Vector Addition	131
Geometric Definition of Scaling a Vector	132
Geometric Definition of Vector Subtraction	133
Geometric Definition of Dot Product	134
Geometric Definition of Cross Product	134
Derivative of a Vector-Valued Function	135
Coordinate Systems	136
Vector Addition with Coordinate Components	138
Vector Scaling with Coordinate Components	139
Vector Subtraction with Coordinate Components	139
Dot Product with Coordinate Components	140
Cross Product with Coordinate Components	140
Derivative with Coordinate Components	140
Kinematics in 3D	142
Defining Position, Velocity, and Acceleration	143
Two Components of Acceleration	145
Projectile Motion	148
Making Your Own Data Type	150
Single Data Constructor	150
Multiple Data Constructors	153

Defining a New Data Type for 3D Vectors	154
Possible Implementations	154
Data Type Definition for Vec	155
Vec Functions	157
Summary	159
Exercises	159

11 CREATING GRAPHS **165**

Title and Axis Labels	166
Other Labels	168
Plotting Data	169
Multiple Curves on One Set of Axes	170
Controlling the Plot Ranges	171
Making a Key	171
Summary	172
Exercises	172

12 CREATING STAND-ALONE PROGRAMS **175**

Using GHC to Make a Stand-Alone Program	176
Hello, World!	176
A Program That Imports Modules	177
Using Cabal to Make a Stand-Alone Program	179
Using Stack to Make a Stand-Alone Program	182
Summary	185
Exercises	186

13 CREATING 2D AND 3D ANIMATIONS **187**

2D Animation	187
Displaying a 2D Picture	188
Making a 2D Animation	190
Making a 2D Simulation	191
3D Animation	195
Displaying a 3D Picture	195
Making a 3D Animation	198
Making a 3D Simulation	198
Summary	200
Exercises	201

PART II EXPRESSING NEWTONIAN MECHANICS AND SOLVING PROBLEMS

14		
NEWTON'S SECOND LAW AND DIFFERENTIAL EQUATIONS		205
Newton's First Law		206
Newton's Second Law in One Dimension		207
Second Law with Constant Forces		209
Second Law with Forces That Depend Only on Time		214
Air Resistance		219
Second Law with Forces That Depend Only on Velocity		220
Euler Method by Hand		225
Euler Method in Haskell		227
The State of a Physical System		228
Second Law with Forces That Depend on Time and Velocity		229
Method 1: Produce a List of States		234
Method 2: Produce a Velocity Function		234
Example: Pedaling and Coasting with Air Resistance		235
Euler Method by Hand		235
Method 1: Produce a List of States		236
Method 2: Produce a Velocity Function		237
Summary		238
Exercises		238
15		
MECHANICS IN ONE DIMENSION		243
Introductory Code		244
Forces That Depend on Time, Position, and Velocity		245
A General Strategy for Solving Mechanics Problems		247
Solving with Euler's Method		249
Producing a List of States		251
Position and Velocity Functions		252
A Damped Harmonic Oscillator		253
Euler Method by Hand		254
Method 1: Producing a List of States		256
Method 2: Producing Position and Velocity Functions		258
Euler-Cromer Method		260
Solving Differential Equations		262
Generalizing the State Space		263
Type Classes for State Spaces		266

One More Numerical Method	268
Comparison of Numerical Methods	269
Summary	270
Exercises	270

16 MECHANICS IN THREE DIMENSIONS 279

Introductory Code	280
Newton's Second Law in Three Dimensions	281
The State of One Particle	283
Solving Newton's Second Law	286
One-Body Forces	288
Earth Surface Gravity	288
Gravity Produced by the Sun	288
Air Resistance	290
Wind Force	291
Force from Uniform Electric and Magnetic Fields	291
State Update for One Particle	292
Preparing for Animation	296
Two Helpful Animation Functions	296
How the Functions Work	299
Summary	301
Exercises	302

17 SATELLITE, PROJECTILE, AND PROTON MOTION 307

Satellite Motion	307
State-Update Function	308
Initial State	309
Time-Scale Factor	309
Animation Rate	310
Display Function	311
Projectile Motion with Air Resistance	312
Calculating a Trajectory	313
Finding the Angle for Maximum Range	314
2D Animation	316
3D Animation	320
Proton in a Magnetic Field	321
Summary	323
Exercises	323

18
A VERY SHORT PRIMER ON RELATIVITY **329**

A Little Theory	330
A Replacement for Newton's Second Law	331
Response to a Constant Force	332
Proton in a Magnetic Field	334
Summary	337
Exercises	338

19
INTERACTING PARTICLES **339**

Newton's Third Law	340
Two-Body Forces	341
Universal Gravity	343
Constant Repulsive Force	344
Linear Spring	345
Central Force	347
Elastic Billiard Interaction	348
Internal and External Forces	348
The State of a Multi-Particle System	350
State Update for Multiple Particles	352
Implementing Newton's Second Law	352
Numerical Methods for Multiple Particles	358
Composite Functions	359
Summary	359
Exercises	361

20
SPRINGS, BILLIARD BALLS, AND A GUITAR STRING **363**

Introductory Code	364
Two Masses and Two Springs	364
Forces	365
Animation Functions	366
Stand-Alone Animation Program	367
Using Mechanical Energy as a Guide to Numerical Accuracy	369
A Collision	373
Data Representations	373
Spring Constant and Time Step	376
Momentum and Energy Conservation	377
Numerical Issues	385
Animated Results	388
Wave on a Guitar String	390
Forces	391
State-Update Function	392

Initial State	392
Stand-Alone Program	394
Asynchronous Animation	397
Summary	399
Exercises	400

PART III EXPRESSING ELECTROMAGNETIC THEORY AND SOLVING PROBLEMS

21 ELECTRICITY **409**

Electric Charge	409
Coulomb's Law	411
Two Charges Interacting	412
Looking at Extremes	413
Modeling the Situation in Haskell	414
Summary	418
Exercises	418

22 COORDINATE SYSTEMS AND FIELDS **421**

Polar Coordinates	422
Cylindrical Coordinates	424
Spherical Coordinates	425
Introductory Code	426
A Type for Position	427
Defining the New Type	427
Making a Position	428
Using a Position	430
Displacement	431
The Scalar Field	431
The Vector Field	433
Functions for Visualizing Scalar Fields	437
3D Visualization	437
2D Visualization	438
Functions for Visualizing Vector Fields	439
3D Visualization	439
2D Visualization	441
Gradient Visualization	443
Summary	445
Exercises	446

23		
CURVES, SURFACES, AND VOLUMES		449
Introductory Code		450
Curves		450
Parameterizing Curves.....		450
Examples of Curves		451
Surfaces		452
Parameterizing Surfaces		452
Examples of Surfaces		454
Orientation		455
Volumes		456
Summary		457
Exercises		458

24		
ELECTRIC CHARGE		461
Charge Distributions		461
Introductory Code		463
A Type for Charge Distribution.....		464
Examples of Charge Distributions		465
Total Charge.....		466
Total Charge of a Line Charge		466
Total Charge of a Surface Charge		466
Total Charge of a Volume Charge		467
Calculating Total Charge in Haskell.....		467
Electric Dipole Moment		469
Summary		471
Exercises		471

25		
ELECTRIC FIELD		473
What Is an Electric Field?		474
Introductory Code		475
Charge Creates an Electric Field		475
Electric Field Created by a Point Charge		476
Electric Field Created by Multiple Charges.....		479
Electric Field Created by a Line Charge		483
Electric Field Created by a Surface Charge		486
Electric Field Created by a Volume Charge		491
Scalar Integrals		494
Scalar Line Integral.....		494
Scalar Surface Integral		494
Scalar Volume Integral		495

Approximating Curves, Surfaces, and Volumes	495
Approximating a Curve	496
Approximating a Surface	498
Approximating a Volume	499
Summary	502
Exercises	502

26 ELECTRIC CURRENT 507

Current Distributions	508
Introductory Code	508
A Type for Current Distribution	509
Examples of Current Distributions	510
Conservation of Charge and Constraints on Steady Current Distributions	512
Magnetic Dipole Moment	514
Summary	516
Exercises	516

27 MAGNETIC FIELD 519

A Simple Magnetic Effect	519
Introductory Code	520
Current Creates Magnetic Field	521
Magnetic Field Created by a Line Current	521
Magnetic Field Created by a Surface Current	529
Magnetic Field Created by a Volume Current	530
Summary	530
Exercises	531

28 THE LORENTZ FORCE LAW 535

Introductory Code	536
Statics and Dynamics	536
State of One Particle and Fields	538
Lorentz Force Law	541
Do We Really Need an Electric Field?	541
State Update	543
Animating a Particle in Electric and Magnetic Fields	544
Uniform Fields	546
Classical Hydrogen	547
Summary	548
Exercises	549

THE MAXWELL EQUATIONS**551**

Introductory Code	552
The Maxwell Equations	552
Relationships Between Electricity and Magnetism	554
Connection to Coulomb's Law and Biot-Savart Law	554
State Update	555
Spatial Derivatives and the Curl	557
A Naive Method	558
The FDTD Method	560
The Yee Cell	562
A Type for State	564
FDTD and the Curl	566
State Update	568
Animation	571
Current Density	571
Grid Boundary	572
Display Function	573
Two Helping Functions	574
Main Program	576
Summary	577
Exercises	579

APPENDIX: INSTALLING HASKELL**581**

Installing GHC	581
Installing a Text Editor	582
Installing Gnuplot	582
Installing Haskell Library Packages	583
Using Cabal	584
Using Stack	586
Installing Gloss	586
Installing Diagrams	587
Setting Up Your Coding Environment	587
What We Want in a Coding Environment	588
All Code in One Directory	589
One Way to Use Stack	590
Summary	593

BIBLIOGRAPHY**595****INDEX****597**