


INVITATION TO PHYSICS

Four horizontal stripes of equal width in maroon, red, green, and blue colors, spanning the width of the cover.

Ken Greider

Ken Greider
University of California, Davis

INVITATION TO PHYSICS

Harcourt Brace Jovanovich, Inc. 
New York Chicago San Francisco Atlanta

Drawings by Ed Malsberg

Figures 1-1, 2-1, 4-8, 5-7, 6-6, 6-7, 6-9, 7-3, 7-4, 7-6, 14-1, 14-2, 14-3, 14-4, 15-1, 15-2, 15-3, 15-5, 15-6, 15-7, 15-8, 15-9, 15-10, 16-3, 16-4, 16-6.

© 1973 by Harcourt Brace Jovanovich, Inc.

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

ISBN: 0-15-546907-X

Library of Congress Catalog Card Number: 72-917-46

Printed in the United States of America

To my Mother and my Father

Preface

Invitation to Physics is intended for a one-semester or one-quarter course in elementary physics for humanities students, or for the physics segment of a general introduction to physical science. It is the final product of a series of lecture notes that I developed and class tested for several years at the University of California at Davis.

I had two objectives in writing this book: (1) to expose the reader to the changing nature of science in general through a study of the evolution of physics in particular and (2) to recreate the changing ideas of physics as real revolutions in man's perception of the universe—revolutions that were (and still are) being made by real men.

Although it has been my experience in teaching this course that some degree of problem solving is beneficial, I have avoided any temptation to emphasize mathematical manipulations. A blend of mathematical problems and/or questions requiring nonmathematical answers appears at the end of each chapter for use at the instructor's discretion. The few mathematical exercises that have been included are designed to enhance the student's understanding of the subject and allow the reader to recreate a degree of the emotional satisfaction that a physicist feels when he successfully brings theory to bear on solving a practical problem. If I have succeeded in communicating any of the excitement, the creativity, and the fun of stretching one's mind with

new ideas, the humanities student may come to appreciate physics as a science that is both comprehensible and enlightening.

In addition to mathematical and verbal problems, the end-of-chapter material includes a few questions requiring outside reading. The instructor can use these questions as he wishes for term-paper subjects or as topics for small-group discussions.

I have tried to free the main body of the book from lengthy mathematical derivations that would detract from its readability. Several appendixes contain these derivations for the mathematically curious student.

I have included a number of references to and diagrams of lecture demonstrations that are common in any beginning physics course. Most of these are available commercially or are easy to build, and I strongly recommend their use as supplementary visual aids. The first appearance of new units, technical definitions, and terms is rendered in color merely to emphasize the fact that they are likely to be new to the reader. Brief biographical portraits of 25 key physicists are included.

In developing this book, I was indebted to the work of many hands and the inspiration of many minds. I would especially like to express my appreciation and gratitude to: Dave Faulkner for his suggestions and for the countless, tedious hours he spent helping to prepare questions and problems. Frank Serduke for his assistance on earlier versions of the manuscript. Virginia Rosato and Rory Tafoya, who typed the notes and the manuscript, for their patience in decoding my scribbling. My reviewers who read the manuscript in its earlier stages—William J. Bruff, Foot-hill College, Los Altos Hills, California; John D. McCullen, The University of Arizona; and Paul W. Wagner, Los Angeles City College—for contributing helpful comments and suggestions that have improved the book immensely. Hans Weidenmüller for the kind hospitality of the Max Planck Institut für Kernphysik in Heidelberg, West Germany, where the last stages of the book were completed. Roger Dunn for his prodding and patience. Marian Flanders for her warm support and understanding throughout all my writing agonies. And, last, my many, many friends who, over the years as my students, contributed immeasurably to the development of this book.

Ken Greider

Contents

Early Greek Physics 1

1

- 1-1 **Introduction** 1
- 1-2 **The Early Greek Period: Sixth and Fifth Centuries B.C.** 1
- 1-3 **The Pythagoreans** 3
 - **PYTHAGORAS** 4
- 1-4 **Plato** 6

Aristotle's Physics 9

2

- 2-1 **Introduction** 9
- 2-2 **Aristotle's Cosmology** 9
 - **ARISTOTLE** 12
- 2-3 **Natural Motion** 13
- 2-4 **Projectile Motion** 14
- 2-5 **The Late Greek Period** 16

2-6	From Aristotle to Copernicus: Ptolemy and Astronomy	18
	□ CLAUDIUS PTOLEMY	20

2-7	Terrestrial Motion	21
-----	---------------------------	----

3

Copernicus: The Beginning of the Mechanical Revolution 23

3-1	Introduction	23
	□ NICOLAS COPERNICUS	24
3-2	Retrograde Motion	24
3-3	Copernicus versus Ptolemy	26
3-4	The Need for a New Physics	27
	□ GIORDANO BRUNO	33

4

Galileo and the Problem of Terrestrial Motion 36

4-1	Introduction	36
4-2	Galileo Sees Motion in a New Way	36
	□ GALILEO GALILEI	39
	□ RENÉ DESCARTES	41
4-3	Motion with Constant Speed	41
4-4	Motion with Constant Acceleration	44
4-5	Galileo's Inclined Plane	46
4-6	Compound Motion	50

4-7 **Galileo and the Inertia Principle** 52

4-8 **Galileo's Difficulties** 54

Kepler and the Discovery of Planetary Orbits 59

5-1 **Introduction** 59

5-2 **Kepler and Tycho Brahe** 59

□ **TYCHO BRAHE** 61

5-3 **The Three Laws** 63

□ **JOHANNES KEPLER** 65

5-4 **The Harmony of the Worlds** 65

5-5 **Centripetal Motion** 67

Newton and the Synthesis of the Mechanical Revolution 71

6-1 **Introduction** 71

6-2 **Newton's Contributions to Physics** 71

□ **ISAAC NEWTON** 73

6-3 **Newton's Four "Laws"** 77

6-4 **Derivation of Kepler's Laws from Newton's Laws** 80

6-5 **Examples of Newtonian Mechanics** 82

6-6 **The Influence of Newtonian Mechanics** 88

5

6

7

Energy and Momentum 92

- 7-1 **Introduction** 92
- 7-2 **The Conservation of Momentum** 93
- 7-3 **The Conservation of Energy** 96
- 7-4 **Kinetic Energy** 97
- 7-5 **Potential Energy** 98
- 7-6 **Angular Momentum** 100

8

The Electromagnetic Revolution 104

- 8-1 **Introduction** 104
- 8-2 **Static Electricity** 105
- 8-3 **Electricity: An Inverse Square Force** 106
- 8-4 **Lines of Force for Two Charges** 108
- 8-5 **Lines of Force for More Than Two Charges** 110
- 8-6 **Lines of Force from a Uniformly Charged Sphere** 112
- 8-7 **Charged Conductors** 113
- 8-8 **The Electric Field** 115

9

Electric Currents 120

- 9-1 **Introduction** 120

- 9-2 **Electric Current** 121
- 9-3 **Magnetism and Currents** 121
 - HANS CHRISTIAN OERSTED 123
- 9-4 **Electric Currents as Moving Charges** 126
- 9-5 **More about Forces on Moving Charges** 128

Magnetism and Electromagnetic Induction 132

10

- 10-1 **Introduction** 132
- 10-2 **Electric Current Forces via the Magnetic Field** 132
- 10-3 **Magnets** 133
- 10-4 **Magnet-Magnet and Current-Magnet Forces** 134
- 10-5 **Michael Faraday and Electromagnetic Induction** 136
 - MICHAEL FARADAY 139

Light 144

11

- 11-1 **Introduction** 144
- 11-2 **Is Light a Particle or a Wave?** 144
- 11-3 **Waves** 146
- 11-4 **Interference of Two Waves and Young's Experiment** 150
- 11-5 **Polarization of Light** 151
- 11-6 **Electric Units and the Velocity of Light** 153

12

Maxwell and the Electromagnetic Synthesis 156

- 12-1 **Introduction** 156
- 12-2 **Maxwell's Synthesis** 157
 - JAMES CLERK MAXWELL 158
- 12-3 **Maxwell and Newton** 159
- 12-4 **Maxwell's Equations in Terms of Magnetic Fields** 159
- 12-5 **Maxwell Adds Something New** 161
- 12-6 **Maxwell's Equations without Magnetic Fields** 162
- 12-7 **The Implications of Maxwell's Revolution** 164

13

The End of the Electromagnetic Revolution 166

- 13-1 **Introduction** 166
- 13-2 **The Motion of the Earth through the Ether** 167
- 13-3 **The Michelson-Morley Experiment** 168
 - ALBERT MICHELSON 169
- 13-4 **The Results of the Michelson-Morley Experiment** 173
- 13-5 **The Philosophical Consequences of the Electromagnetic Revolution** 173

The Beginning of the Particle Revolution: Einstein and Relativity 176

14

- 14-1 **Introduction** 176
- 14-2 **The Bases for Einstein's Relativity** 176
 - ALBERT EINSTEIN 178
- 14-3 **Galilean Relativity** 180
- 14-4 **Simultaneity** 183
- 14-5 **The Basic Equation** 184
- 14-6 **The Failure of Galilean Relativity** 185
- 14-7 **The Lorentz Transformations** 186
- 14-8 **The Constancy of the Speed of Light** 187

The Consequences of Relativity 190

15

- 15-1 **Introduction** 190
- 15-2 **Time Dilation** 191
- 15-3 **Length Contraction** 193
- 15-4 **Velocity Addition** 195
- 15-5 **Momentum and Mass Increase** 196
- 15-6 **Energy and Mass** 199

16

Other Effects of Relativity 203

- 16-1 **Introduction** 203
- 16-2 **Relativistic Energy-Momentum Relation** 204
- 16-3 **Four-Dimensional Space-Time** 205
- 16-4 **Ampère's Law for Current-Current Forces** 206
- 16-5 **The Role of the Observer** 207
- 16-6 **General Relativity** 208

17

The Beginning of Quantum Mechanics 214

- 17-1 **Introduction** 214
- 17-2 **Photons—The First Basis of Quantum Mechanics** 214
- 17-3 **Einstein and the Photoelectric Effect** 216
 - MAX PLANCK 217
- 17-4 **Atoms—The Second Basis of Quantum Mechanics** 220
- 17-5 **The Hydrogen Atom and Niels Bohr** 223
 - NIELS BOHR 225
 - LOUIS DE BROGLIE 226
- 17-6 **de Broglie and Electron Waves** 226
- 17-7 **de Broglie Explains Bohr** 228
- 17-8 **Energy-Level Diagrams** 231

Quantum Mechanics: A New Picture of the Universe 235

18

- 18-1 **Introduction** 235
- 18-2 **The Schrödinger Equation** 235
 - ERWIN SCHRÖDINGER 237
- 18-3 **Quantum Mechanical Collisions** 237
 - WERNER HEISENBERG 240
- 18-4 **The Uncertainty Principle** 241
- 18-5 **Bound States and Energy Levels in Real Atoms** 245
- 18-6 **Multielectron Atoms** 247
- 18-7 **The Pauli Exclusion Principle and Electron Spin** 248
 - WOLFGANG PAULI 249
- 18-8 **Heavier Atoms** 251
- 18-9 **More Philosophy** 252

Nuclear Physics — An Application of Quantum Mechanics 256

19

- 19-1 **Introduction** 256
- 19-2 **What Is in the Nucleus?** 257
- 19-3 **Binding Energy** 258
- 19-4 **Nuclear Fission** 259
 - ENRICO FERMI 261

19-5	The Nuclear Force	263
19-6	Models of the Nucleus	263

20

Elementary Particles 268

20-1	Introduction	268
20-2	When Physics Was Simple—Only Three Elementary Particles	269
20-3	Dirac and Antiparticles	269
	□ P. A. M. DIRAC	271
20-4	The Modern Theory—Quantum Electrodynamics	273
20-5	More Elementary Particles	274
	□ RICHARD FEYNMAN	275
20-6	Strangeness	277
	□ MURRAY GELL-MANN	279
20-7	Still More Particles and the “Eight-Fold Way”	281
20-8	The Quark	283
20-9	Symmetry	284

21

Epilogue 290

21-1	Introduction	290
21-2	Relativity, Quantum Mechanics, and the Elementary Particle Concept	290

21-3 **Other Problems** 293

21-4 **Conclusion** 295

Appendixes 297

4A **Mathematical Addendum on Vectors** 297

4B **Graphic Representation of Velocity and
Acceleration Formulas** 299

4C **Table of Units and Conversions** 301

4D **Derivation of Equation (4-7)** 301

5 **Derivation of Centripetal Force, Equation (5-1)** 302

6 **Derivation of Kepler's Third Law** 303

7 **Derivation of Kinetic Energy, Equation (7-2)** 303

14 **Proof that the Lorentz Transformations Satisfy
the Relativity Equation** 304

15 **Derivation of the Velocity Addition Formula
(Section 15-4)** 305

16 **Derivation of Equation (16-3)** 306

Index 307