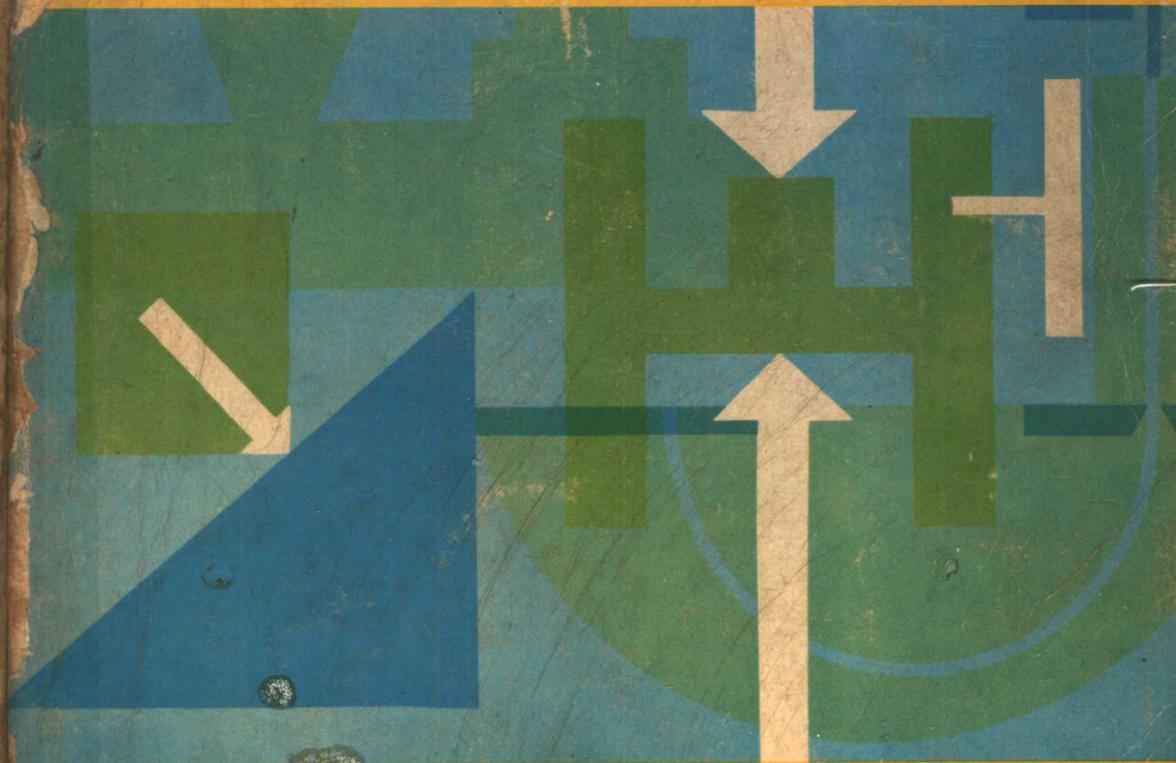


MODERN COLLEGE PHYSICS

COMPLETE



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MODERN COLLEGE PHYSICS

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PREFACE

This text is both new and old. It is new in that it presents in one volume a course of study which assumes no background in physics but which provides a meaningful introduction to classical, relativistic, and quantum physics. In an ambitious course it can be covered in one year. A background in chemistry is desirable, and a concurrent course in calculus is recommended but not required. Vectors are expressed in boldface type wherever magnitude *and* direction are meant, and both the scalar and vector multiplication operations are introduced. These techniques emphasize vector quantities and permit many physical laws to be presented more concisely.

This text is old in that it is almost entirely taken from two other texts: *College Physics* by Sears and Zemansky and *Introductory Atomic Physics* by Wehr and Richards. Some parts have been rewritten, particularly the discussions of work, energy, and momentum. Considerable material in the source books has been omitted. This shortening has been accomplished for the following reasons. First, there was some material common to both books. Second, most students who use this book will take additional courses which will include topics we have deleted. Third, some topics are applications which will be covered in the laboratory. Fourth, some traditional topics, such as color and musical scales, are of secondary importance to physics, inasmuch as they involve psychology as much as they involve physics. We have retained those topics which provide a foundation in physics and which are essential to a unified development of the subject. Anyone familiar with the source texts will note that those topics we have included here are treated about as extensively as they were in the sources. Although we have shifted the emphasis, we have retained or increased depth of content.

Both the English and metric systems of units have been introduced and used. The meter-kilogram-second system is used throughout, and the English engineering system is used for topics where engineers use them. We have introduced special units like the electron volt and the angstrom where these units are essential to the subject matter.

We gratefully reaffirm our thanks to the many students, colleagues, and friends whose comments and suggestions concerning the source books are reflected in *Modern College Physics*. Particular thanks are extended to R. A. Boyer, L. C. Heckert, R. A. Kane, P. Kirkpatrick, and M. C. Schwartz.

Philadelphia, Hanover, and New York
January, 1962

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CONTENTS

CHAPTER 1. COMPOSITION AND RESOLUTION OF VECTORS	1
1-1 Introduction	1
1-2 The fundamental indefinables of mechanics	2
1-3 Standards and units	3
1-4 Symbols for physical quantities	7
1-5 Force	7
1-6 Graphical representation of forces. Vectors	8
1-7 Components of a vector	10
1-8 Resultant of forces and vector sum	12
1-9 Resultant by rectangular resolution	15
1-10 Vector difference	17
 CHAPTER 2. EQUILIBRIUM	 20
2-1 Introduction	20
2-2 Equilibrium. Newton's first law	20
2-3 Newton's third law of motion	23
2-4 Examples of equilibrium	25
2-5 Friction	30
 CHAPTER 3. EQUILIBRIUM. MOMENT OF A FORCE	 40
3-1 Moment of a force	40
3-2 The second condition of equilibrium	41
3-3 Resultant of parallel forces	45
3-4 Center of gravity	47
3-5 Couples	50
 CHAPTER 4. RECTILINEAR MOTION	 56
4-1 Motion	56
4-2 Average velocity	56
4-3 Instantaneous velocity	57
4-4 Average and instantaneous acceleration	59
4-5 Rectilinear motion; constant acceleration	62
4-6 Freely falling bodies	64
4-7 Graphical method for finding displacement and velocity	68
4-8 Velocity components. Relative velocity	70
 CHAPTER 5. NEWTON'S SECOND LAW. GRAVITATION	 81
5-1 Introduction	81
5-2 Newton's second law. Mass	81
5-3 Systems of units	85
5-4 Mass and weight	86
5-5 Newton's law of universal gravitation	88
5-6 The mass of the earth	89
5-7 Variations in "g"	90
5-8 Applications of Newton's second law	91
5-9 The equal-arm analytical balance	96

CHAPTER 6. MOTION IN A PLANE	104
6-1 Motion of a projectile	104
6-2 Circular motion	109
6-3 Centripetal force	113
6-4 Motion of a satellite	118
6-5 Tangential acceleration	119
CHAPTER 7. WORK AND ENERGY	128
7-1 Work	128
7-2 Work of a varying force	131
7-3 Work and kinetic energy	134
7-4 Gravitational potential energy near the earth	136
7-5 Gravitational potential energy at any distance from the earth	141
7-6 Elastic potential energy	144
7-7 Conservative and dissipative forces	146
7-8 Internal work and internal potential energy	147
7-9 Power	150
CHAPTER 8. IMPULSE AND MOMENTUM	158
8-1 Impulse and momentum	158
8-2 Conservation of linear momentum	163
8-3 Elastic and inelastic collisions	164
8-4 Recoil	169
8-5 Newton's second law	170
8-6 The rocket	171
CHAPTER 9. ROTATION	177
9-1 Introduction	177
9-2 Angular velocity	177
9-3 Angular acceleration	179
9-4 Rotation with constant angular acceleration	180
9-5 Relation between angular and linear velocity and acceleration	181
9-6 Kinetic energy of rotation. Moment of inertia	183
9-7 Work and power in rotational motion	186
9-8 Torque and angular acceleration	187
9-9 Angular momentum	189
9-10 Rotation about a moving axis. The top and the gyroscope	195
CHAPTER 10. ELASTICITY	205
10-1 Stress	205
10-2 Strain	208
10-3 Elastic modulus	209
10-4 The force constant	214
CHAPTER 11. HARMONIC MOTION	217
11-1 Introduction	217
11-2 Elastic restoring forces	217
11-3 Definitions	218
11-4 Equations of simple harmonic motion	219
11-5 Energy of a body oscillating with SHM	227
11-6 Motion of a body suspended from a coil spring	228
11-7 The simple pendulum	229

CHAPTER 12. WAVE MOTION	234
12-1 Propagation of a disturbance in a medium	234
12-2 Calculation of the speed of a transverse pulse	235
12-3 Calculation of the speed of a longitudinal pulse	237
12-4 The motion of a wave	238
12-5 Mathematical representation of a traveling wave	241
CHAPTER 13. VIBRATING BODIES—SOUND	246
13-1 Boundary conditions for a string	246
13-2 Stationary waves in a string	247
13-3 Vibration of a string fixed at both ends	251
13-4 Resonance	252
13-5 Interference of longitudinal waves	253
13-6 Stationary longitudinal waves	254
13-7 Vibrations in organ pipes	256
13-8 Vibrations of rods and plates	257
13-9 Pressure variations in a sound wave	259
13-10 Quality and pitch	260
13-11 Beats	261
13-12 The Doppler effect	263
CHAPTER 14. HYDROSTATICS	269
14-1 Introduction	269
14-2 Pressure in a fluid	270
14-3 The hydrostatic paradox	272
14-4 Pressure gauges	273
14-5 Archimedes' principle	275
CHAPTER 15. TEMPERATURE—EXPANSION	283
15-1 Concept of temperature	283
15-2 Thermometers	284
15-3 The establishment of a temperature scale	286
15-4 The celsius, rankine, and fahrenheit scales	290
15-5 Linear expansion	293
15-6 Surface and volume expansion	295
CHAPTER 16. WORK AND HEAT	300
16-1 External work	300
16-2 Work in changing the volume	300
16-3 Work depends on the path	303
16-4 Work and heat	303
16-5 Quantity of heat	305
16-6 The mechanical equivalent of heat	306
16-7 Heat capacity. Specific heat	307
16-8 Change of phase	308
16-9 Calorimetry	312
16-10 Thermal properties of matter	313
16-11 Conduction of heat through a slab	320
16-12 Convection	322
16-13 Radiation	324

CHAPTER 17. THE LAWS OF THERMODYNAMICS	329
17-1 Internal energy	329
17-2 The first law of thermodynamics	329
17-3 Adiabatic process	330
17-4 Isochoric process	330
17-5 Isobaric process	331
17-6 Free expansion	332
17-7 Throttling process	332
17-8 The conversion of heat into work	334
17-9 The gasoline engine	337
17-10 The diesel engine	339
17-11 The steam engine	339
17-12 The second law of thermodynamics	340
17-13 The refrigerator	341
17-14 The Carnot cycle	343
17-15 The kelvin temperature scale	344
17-16 Absolute zero	346
CHAPTER 18. THE IDEAL GAS AND THE ATOMIC VIEW OF MATTER	350
18-1 The ideal gas law	350
18-2 Properties of an ideal gas	353
18-3 Chemical evidence for the atomic view of matter	356
18-4 Physical evidence for the atomic view of matter	357
18-5 Kinetic theory of gases. Molar heat capacity	358
18-6 Equipartition of energy	362
18-7 Maxwell's speed distribution law	363
18-8 Collision cross section. Mean free path	366
18-9 Faraday's law of electrolysis—skepticism	369
18-10 Perrin's verification of the atomic view of matter	370
18-11 Boltzmann's constant	373
CHAPTER 19. COULOMB'S LAW	377
19-1 Electric charges	377
19-2 Charging by contact	378
19-3 Conductors and insulators	379
19-4 Charging a metal by induction	380
19-5 Coulomb's law	381
19-6 Quantity of charge	383
CHAPTER 20. THE ELECTRIC FIELD	387
20-1 The electric field	387
20-2 Calculation of electric intensity	388
20-3 Lines of force	390
20-4 Gauss' law	393
20-5 Conclusions from Gauss' law concerning the charge within a conductor	396
20-6 Conclusions from Gauss' law concerning the field outside a charged conductor	399
20-7 The ultimate unit of charge. The Millikan oil-drop experiment	405
20-8 Electrical discharges. Cathode rays	409

CHAPTER 21. POTENTIAL	418
21-1 Electrical potential energy	418
21-2 The electric field near a charged conductor	421
21-3 Potential	422
21-4 Potential difference	425
21-5 Potential of a charged spherical conductor	427
21-6 The energy principle	428
21-7 Equipotential surfaces	429
21-8 Potential gradient	431
21-9 Sharing of charge by conductors	433
21-10 The Van de Graaff generator	435
CHAPTER 22. CURRENT AND RESISTANCE	440
22-1 Current	440
22-2 The complete circuit	444
22-3 Resistivity, resistance, and Ohm's law	445
22-4 Calculation of resistance	448
22-5 Measurement of current, potential difference, and resistance	450
22-6 The Wheatstone bridge	452
22-7 Joule's law	453
CHAPTER 23. DIRECT-CURRENT CIRCUITS	458
23-1 Electromotive force	458
23-2 The circuit equation	460
23-3 Potential difference between points in a circuit	462
23-4 Terminal voltage of a seat of emf	466
23-5 The potentiometer	467
23-6 Series and parallel connection of resistors	468
23-7 Power	472
CHAPTER 24. THE MAGNETIC FIELD	480
24-1 Magnetism	480
24-2 The magnetic field	481
24-3 Lines of induction. Magnetic flux	485
24-4 Orbits of charged particles in magnetic fields	486
24-5 Thomson's measurement of q/m	486
24-6 Mass of the electron. Avogadro's number	491
24-7 Positive rays	492
24-8 Isotopes	495
24-9 Mass spectrometry	496
24-10 Physical scale of atomic weights; atomic mass unit	498
24-11 The cyclotron	498
CHAPTER 25. MAGNETIC FORCES ON CURRENT-CARRYING CONDUCTORS	505
25-1 Force on a current-carrying conductor	505
25-2 Force and torque on a complete circuit	506
25-3 The galvanometer	508
25-4 The pivoted-coil galvanometer	510
25-5 Ammeters and voltmeters	510
25-6 The ballistic galvanometer	512
25-7 The direct-current motor	513

CHAPTER 26. MAGNETIC FIELD OF A CURRENT. MAGNETIC PROPERTIES OF MATTER	520
26-1 Magnetic field of a current element	520
26-2 Magnetic field of a long straight conductor	523
26-3 Force between parallel conductors. The ampere	525
26-4 Field at the center of a circular turn	526
26-5 Ampere's law	529
26-6 Field of a solenoid and of a toroid	530
26-7 Magnetic properties of matter	533
26-8 Magnetic permeability	534
26-9 Magnetic intensity	536
26-10 Ferromagnetism	537
26-11 Hysteresis	538
26-12 Ampere's theory of magnetism	540
26-13 Magnetic poles	541
26-14 Magnetic field of the earth	543
CHAPTER 27. INDUCED ELECTROMOTIVE FORCE	548
27-1 Motional electromotive force	548
27-2 The Faraday law	550
27-3 Lenz's law	553
27-4 The betatron	554
27-5 Induced emf in a rotating coil	557
27-6 The direct-current generator	559
27-7 Search-coil method of measuring magnetic flux	560
CHAPTER 28. CAPACITANCE. PROPERTIES OF DIELECTRICS	565
28-1 Capacitors	565
28-2 The parallel-plate capacitor	566
28-3 Capacitors in series and in parallel	569
28-4 Energy of a charged capacitor	571
28-5 Dielectric coefficient. Permittivity	573
CHAPTER 29. INDUCTANCE AND TRANSIENT CURRENTS	582
29-1 Self-inductance	582
29-2 Circuit containing inductance and resistance	584
29-3 Energy associated with an inductor	588
29-4 Circuit containing resistance and capacitance	589
29-5 Electrical oscillations	590
CHAPTER 30. ALTERNATING CURRENTS AND ELECTROMAGNETIC WAVES	595
30-1 The alternating-current series circuit	595
30-2 Effective values	599
30-3 Resonance	600
30-4 The transformer	600
30-5 Electromagnetic waves	602
30-6 Electrodynamics	603
30-7 The unity of radiation	604
CHAPTER 31. THE NATURE AND PROPAGATION OF LIGHT	607
31-1 The nature of light	607
31-2 Waves and rays	608
31-3 Sources of light	609

31-4	Shadows	610
31-5	The speed of light	611
31-6	Index of refraction	614
31-7	Huygens' principle	614
31-8	Atmospheric refraction	616
CHAPTER 32. REFLECTION AND REFRACTION AT PLANE SURFACES		619
32-1	Reflection of light	619
32-2	Reflection of a plane wave at a plane surface	619
32-3	Refraction of a plane wave at a plane surface	620
32-4	Ray treatment of reflection and refraction	623
32-5	Total internal reflection	624
32-6	Refraction by a plane parallel plate	625
32-7	Refraction by a prism	626
32-8	Dispersion	628
CHAPTER 33. REFLECTION AND REFRACTION AT A SINGLE SURFACE		632
33-1	Introduction	632
33-2	Reflection at a plane mirror	632
33-3	Reflection at a spherical mirror	635
33-4	Sign conventions	638
33-5	Focal point and focal length	641
33-6	Graphical methods	643
33-7	Refraction at a plane surface	645
33-8	Refraction at a spherical surface	648
33-9	Summary	651
CHAPTER 34. LENSES		655
34-1	Images as objects	655
34-2	The thin lens	656
34-3	Diverging lenses	661
34-4	Graphical methods	663
34-5	Images as objects for lenses	665
34-6	Lens aberrations	665
34-7	The telescope	666
34-8	The prism spectrometer	668
CHAPTER 35. INTERFERENCE AND DIFFRACTION		672
35-1	Principles of interference. Coherent sources	672
35-2	Young's experiment and Pohl's experiment	674
35-3	Phase changes in reflection	679
35-4	Interference in thin films	679
35-5	Newton's rings	682
35-6	Diffraction	683
35-7	Fraunhofer diffraction by a single slit	687
35-8	The plane diffraction grating	690
35-9	Fresnel diffraction due to a circular obstacle	694
35-10	The resolving power of optical instruments	694
CHAPTER 36. POLARIZATION		700
36-1	Polarization	700
36-2	Polarization by reflection	701
36-3	Double refraction	703

36-4	Polarization by double refraction	706
36-5	The scattering of light	707
36-6	Circular and elliptic polarization	709
36-7	Optical activity	711
CHAPTER 37. QUANTUM THEORY OF RADIATION		714
37-1	Introduction	714
37-2	Thermal radiation	714
37-3	Emission and absorption of radiation	715
37-4	Blackbody radiation	716
37-5	The Wien and Rayleigh-Jeans laws	718
37-6	Planck's law; emission quantized	720
37-7	Photoelectric effect	724
37-8	Summary of the atomic view of radiation	729
37-9	The electron volt	729
37-10	Thermionic emission	731
CHAPTER 38. THE ATOMIC MODELS OF RUTHERFORD AND BOHR		734
38-1	Introduction	734
38-2	The Rutherford nuclear atom	734
38-3	Spectra	739
38-4	The hydrogen spectrum	739
38-5	The Bohr model and theory of the atom	741
38-6	Evaluation of the Bohr theory of the atom	746
38-7	Energy levels	747
38-8	Ionization potentials	749
38-9	Resonance potentials	750
38-10	Photon absorption	754
38-11	Fluorescence and phosphorescence	756
38-12	Many-electron atoms	756
38-13	The status of Bohr's model and theory of the atom	758
CHAPTER 39. RELATIVITY		761
39-1	Importance of viewpoint	761
39-2	The search for a frame of reference—the ether	762
39-3	The Michelson interferometer	763
39-4	The Michelson-Morley experiment	767
39-5	The constant velocity of light	768
39-6	General and special theories of relativity	769
39-7	Classical relativity	770
39-8	Einsteinian relativity	772
39-9	Relativistic space-time transformation equations	773
39-10	The relativistic velocity transformation	777
39-11	Relativistic mass transformation	779
39-12	Relativistic mass-energy equivalence	782
39-13	The upper limit of velocity	784
39-14	Examples of relativistic calculations	786
39-15	Pair production	788
39-16	Summary	792

CHAPTER 40. X-RAYS	796
40-1 Discovery	796
40-2 Production of x-rays	797
40-3 The nature of x-rays. X-ray diffraction	798
40-4 Mechanism of x-ray production	808
40-5 X-ray energy levels	810
40-6 X-ray spectra of the elements. Atomic number	813
40-7 X-ray absorption	814
40-8 Intensity measurements	815
40-9 Absorption coefficients	816
40-10 Compton scattering	822
40-11 Absorption by pair production	827
40-12 Diffraction with ruled gratings	828
40-13 Radiation units	829
CHAPTER 41. WAVES AND CORPUSCLES	835
41-1 The de Broglie hypothesis	835
41-2 Bohr's first postulate	835
41-3 Matter waves	836
41-4 The Davisson and Germer experiment	840
41-5 Electron optics	842
41-6 Waves and particles	843
41-7 Wave mechanics	844
41-8 The Heisenberg uncertainty principle	848
41-9 Phase and group waves	851
41-10 Matrix mechanics	852
41-11 Summary	853
CHAPTER 42. NATURAL RADIOACTIVITY	856
42-1 Discovery of radioactivity	856
42-2 The seat of radioactivity	856
42-3 Radium	856
42-4 The radiations	857
42-5 Radiation detectors	859
42-6 Geiger-Mueller counters	861
42-7 Cloud and bubble chambers	862
42-8 Energies of the radiations. Nuclear spectra	867
42-9 Law of radioactive disintegration	868
42-10 Radioactive series	872
42-11 Radioactive growth and decay	879
42-12 The age of the earth	881
42-13 Radioactive equilibrium	882
42-14 Secondary radiations	884
42-15 Radiation hazards	885
42-16 The "radium radiations" in medicine	887
42-17 Units of radioactivity and dose	887
42-18 Conclusion	888
CHAPTER 43. NUCLEAR REACTIONS AND ARTIFICIAL RADIOACTIVITY	892
43-1 Protons from nitrogen	892
43-2 Penetrating radiation puzzle	896

43-3	Discovery of the neutron	897
43-4	Accelerators	900
43-5	The Cockcroft-Walton experiment	902
43-6	Nuclear mass-energy equations. <i>Q</i> -value	905
43-7	Artificial (induced) radioactivity	908
43-8	Carbon dating	909
43-9	Nuclear binding energy	910
43-10	Radioactivity and wave mechanics	913
43-11	The bombarding particles	916
43-12	Neutron reactions. Modes of nuclide decay	917
43-13	The discovery of fission	919
CHAPTER 44. NUCLEAR ENERGY		924
44-1	Nuclear energy	924
44-2	Chain reaction	925
44-3	Neutron cross sections	928
44-4	Reactor criticality	933
44-5	Moderators	936
44-6	The first reactor	939
44-7	The conversion process	942
44-8	Converter reactors	943
44-9	Research reactors	944
44-10	Cherenkov radiation	945
44-11	Power reactors	946
44-12	The boiling-water reactor	948
44-13	Natural fusion	949
44-14	Man-made fusion	951
CHAPTER 45. COSMIC RAYS AND THE FUNDAMENTAL PARTICLES		957
45-1	Introduction	957
45-2	Cosmic rays	957
45-3	Cosmic-ray showers	958
45-4	Discovery of mu-mesons	959
45-5	Nuclear emulsion technique	960
45-6	Discovery of pi-mesons	961
45-7	Superaccelerators	962
45-8	The strange particles	963
45-9	The symmetry of matter	963
45-10	Conclusion	965
APPENDIX 1. COMMON LOGARITHMS		968
APPENDIX 2. NATURAL TRIGONOMETRIC FUNCTIONS		970
APPENDIX 3. THE EXPONENTIAL FUNCTION		971
APPENDIX 4. PERIODIC TABLE OF THE ELEMENTS		977
APPENDIX 5. PARTIAL LIST OF ISOTOPES		978
APPENDIX 6. PARTIAL LIST OF RADIOISOTOPES		986
APPENDIX 7. THE MKS SYSTEM		989
APPENDIX 8. ATOMIC CONSTANTS		992
ANSWERS TO ODD-NUMBERED PROBLEMS		993
INDEX		1006

CHAPTER 1

COMPOSITION AND RESOLUTION OF VECTORS

1-1 Introduction. A good mystery story is a kind of game. The author describes a situation—usually violent. The detective inquires into the activities of the principal characters and conducts an investigation, during which various facts are brought out. You, as the reader, try to organize these clues by framing hypotheses which will “explain” the facts. When more information becomes available you may have to revise your hypotheses as they become inconsistent with new facts. A clever author of a good mystery may fool you into several blind alleys before the detective finally resolves the whole matter in an intellectually satisfying way. You remember the clues which set him on the right track and you realize that if you had been as observant as he you would have come to the heart of the matter as quickly as he did.

Scientific investigation is very much like a good mystery story which has no apparent end. Some hypotheses about the universe seem ridiculous today. Ptolemy taught that the earth was the center of the solar system, with the sun and all the planets moving about it in complicated paths. Copernicus, on the other hand, adopted the view that the earth and the other planets revolve about the sun. Only about a hundred years ago there was supposed to be a substance called *caloric* which accounted for an astonishing number of phenomena but which was specifically designed to account for the changed properties of bodies as they are heated and cooled. Heat was considered to be caloric, and when a body was heated the caloric entered the body and caused it to expand. Although we now have no need whatsoever for this concept, it still lingers on. We still speak of heat “flow” as though heat were a fluid. We could enumerate similar abandoned hypotheses almost without limit.

Some of the blind alleys into which science has turned have seriously delayed progress. On the other hand, some alleys which seemed to be “dead end” have been far from blind. The alchemists tried to change lead into gold. Their efforts were frustrated, but they discovered many less profound changes which were nevertheless important. They were the first chemists. At the beginning of this century it was thought that light was a wave motion of a substance called the ether. This theory has been abandoned in the sense that we know that we have a better one (which we will discuss later in this book). But the wave theory of light has by no means been abandoned as a means for understanding many phenomena. The wave theory has so much “truth” about it that it is still exceedingly

useful. It approximates the truth very, very closely in many situations. It was a fruitful theory because it correlated a tremendous range of observations and suggested possibilities previously unanticipated, and even though it has been modified, it is still useful and worthy of detailed study.

One might suppose that we could convey the latest ideas about physical reality with a minimum of wasted effort by skipping theories which have been discarded or modified, and instead beginning with the most modern interpretation of physical events. There are several reasons why we must begin with the older classical physics. The familiar languages of words and pictures are sufficient for introducing classical physics but they cannot adequately portray modern theories. The elegant language of modern physics is higher mathematics, since the modern concepts are impossible to visualize. One might begin with modern physics for a group of trained mathematicians, although it would be hard to find such a group which did not include many who had studied classical physics as part of their training. Fortunately, it is possible to convey much of the new physics if, in addition to words and pictures, there are classical concepts to enlarge and modify. A more practical reason for starting with classical physics is that despite its having been replaced theoretically, it is still an extremely useful approximation. It is relatively simple and it is precise enough for the solution of many problems in science and engineering. A third reason is that classical physics came before modern physics. Our treatment is hardly chronological, but we do trace, however loosely, the development of ideas. It spoils a mystery story to read the last page first.

Thus our telling of the "mystery story" of physics will include some ideas which we will later replace with new ideas that are more inclusive or more exact. Since the mystery of physics has no apparent end, the best modern ideas may become old in their turn. One thing, however, is certain. The scientists who devise the theories of tomorrow will be thoroughly familiar with the theories of today.

In order that the "clues" we present may be quantitative, we begin by discussing measurements.

1-2 The fundamental indefinables of mechanics. Physics has been called the science of measurement. To quote from Lord Kelvin (1824-1907), "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *Science*, whatever the matter may be."

A definition of a quantity in physics must provide a set of rules for calculating it in terms of other quantities that can be measured. Thus, when momen-

tum is defined as the product of "mass" and "velocity," the rule for calculating momentum is contained within the definition, and all that is necessary is to know how to measure mass and velocity. The definition of velocity is given in terms of length and time, but there are no simpler or more fundamental quantities in terms of which length and time may be expressed. *Length and time are two of the indefinables of mechanics.* It has been found possible to express all the quantities of mechanics in terms of only three indefinables. The third may be taken to be "mass" or "force" with equal justification. *We shall choose mass as the third indefinable of mechanics.*

In geometry, the fundamental indefinable is the "point." The geometer asks his disciple to build any picture of a point in his mind, provided the picture is consistent with what the geometer *says* about the point. In physics, the situation is not so subtle. Physicists from all over the world have international committees at whose meetings the rules of measurement of the indefinables are adopted. The rule for measuring an indefinable takes the place of a definition.

1-3 Standards and units. The set of rules for measuring the indefinables of mechanics is determined by an international committee called the *General Conference on Weights and Measures*, to which all the major countries send delegates. One of the chief functions of the Conference is to decide on a standard for each indefinable. A standard may be an actual object, in which case its main characteristic must be *durability*. Thus in 1889 when the meter bar of platinum-iridium alloy was chosen as the standard of length, it was felt that this alloy was particularly stable in its chemical structure. If, instead of platinum-iridium, a glass bar had been chosen, its length would have changed throughout the years because of the unavoidable crystallization that glass undergoes as it ages. Although platinum-iridium is an unusually stable alloy, the preservation of a bar of this material as a world standard entails a number of cumbersome provisions, such as making a large number of replicas for all the major countries and comparing these replicas with the world standard at periodic intervals.

On October 14, 1960, the General Conference changed the standard of length to an *atomic constant*, namely, the *wavelength of the orange-red light emitted by the individual atoms of krypton-86* in a tube filled with krypton gas in which an electrical discharge is maintained. The standard of mass is the mass of a *cylinder of platinum-iridium*, designated as *one kilogram*, and kept at the International Bureau of Weights and Measures at Sèvres, near Paris. Before 1960, the standard of time was the time between successive appearances of the sun overhead, averaged over a year, known as a mean solar day. This has now been changed to what is