

Feynman's Preface



These are the lectures in physics that I gave last year and the year before to the freshman and sophomore classes at Caltech. The lectures are, of course, not verbatim—they have been edited, sometimes extensively and sometimes less so. The lectures form only part of the complete course. The whole group of 180 students gathered in a big lecture room twice a week to hear these lectures and then they broke up into small groups of 15 to 20 students in recitation sections under the guidance of a teaching assistant. In addition, there was a laboratory session once a week.

The special problem we tried to get at with these lectures was to maintain the interest of the very enthusiastic and rather smart students coming out of the high schools and into Caltech. They have heard a lot about how interesting and exciting physics is—the theory of relativity, quantum mechanics, and other modern ideas. By the end of two years of our previous course, many would be very discouraged because there were really very few grand, new, modern ideas presented to them. They were made to study inclined planes, electrostatics, and so forth, and after two years it was quite stultifying. The problem was whether or not we could make a course which would save the more advanced and excited student by maintaining his enthusiasm.

The lectures here are not in any way meant to be a survey course, but are very serious. I thought to address them to the most intelligent in the class and to make sure, if possible, that even the most intelligent student was unable to completely encompass everything that was in the lectures—by putting in suggestions of applications of the ideas and concepts in various directions outside the main line of attack. For this reason, though, I tried very hard to make all the statements as accurate as possible, to point out in every case where the equations and ideas fitted into the body of physics, and how—when they learned more—things would be modified. I also felt that for such students it is important to indicate what it is that they should—if they are sufficiently clever—be able to understand by deduction from what has been said before, and what is being put in as something new. When new ideas came in, I would try either to deduce them if they were deducible, or to explain that it *was* a new idea which hadn't any basis in terms of things they had already learned and which was not supposed to be provable—but was just added in.

At the start of these lectures, I assumed that the students knew something when they came out of high school—such things as geometrical optics, simple chemistry ideas, and so on. I also didn't see that there was any reason to make the lectures

in a definite order, in the sense that I would not be allowed to mention something until I was ready to discuss it in detail. There was a great deal of mention of things **to** come, without complete discussions. These more complete discussions would come later when the preparation became more advanced. Examples are the discussions of inductance, and of energy levels, which are at first brought in in a very qualitative way and are later developed more completely.

At the same time that I was aiming at the more active student, I also wanted to take care of the fellow for whom the extra fireworks and side applications are merely disquieting and who cannot be expected to learn most of the material in the lecture at all. For such students I wanted there to be at least a central core or backbone of material which he *could* get. Even if he didn't understand everything in a lecture, I hoped he wouldn't get nervous. I didn't expect him to understand everything, but only the central and most direct features. It takes, of course, a certain intelligence on his part to see which are the central theorems and central ideas, and which are the more advanced side issues and applications which he may understand only in later years.

In giving these lectures there was one serious difficulty: in the way the course was given, there wasn't any feedback from the students to the lecturer to indicate how well the lectures were going over. This is indeed a very serious difficulty, and I don't know how good the lectures really are. The whole thing was essentially an experiment. And if I did it again I wouldn't do it the same way—I hope I *don't* have to do it again! I think, though, that things worked out—so far as the physics is concerned—quite satisfactorily in the first year.

In the second year I was not so satisfied. In the first part of the course, dealing with electricity and magnetism, I couldn't think of any really unique or different way of doing it—of any way that would be particularly more exciting than the usual way of presenting it. So I don't think I did very much in the lectures on electricity and magnetism. At the end of the second year I had originally intended to go on, after the electricity and magnetism, by giving some more lectures on the properties of materials, but mainly to take up things like fundamental modes, solutions of the diffusion equation, vibrating systems, orthogonal functions,... developing the first stages of what are usually called "the mathematical methods of physics." In retrospect, I think that if I were doing it again I would go back to that original idea. But since it was not planned that I would be giving these lectures again, it was suggested that it might be a good idea to try to give an introduction to the quantum mechanics—what you will find in Volume III.

It is perfectly clear that students who will major in physics can wait until their third year for quantum mechanics. On the other hand, the argument was made that many of the students in our course study physics as a background for their primary interest in other fields. And the usual way of dealing with quantum mechanics makes that subject almost unavailable for the great majority of students because they have to take so long to learn it. Yet, in its real applications—especially in its more complex applications, such as in electrical engineering and chemistry—the full machinery of the differential equation approach is not actually used. So I tried to describe the principles of quantum mechanics in a way which wouldn't require that one first know the mathematics of partial differential equations. Even for a physicist I think that is an interesting thing to try to do—to present quantum mechanics in this reverse fashion—for several reasons which may be apparent in the lectures themselves. However, I think that the experiment in the quantum mechanics part was not completely successful—in large part because I really did not have enough time at the end (I should, for instance, have had three or four more lectures in order to deal more completely with such matters as energy bands and the spatial dependence of amplitudes). Also, I had never presented the subject this way before, so the lack of feedback was particularly serious. I now believe the quantum mechanics should be given at a later time. Maybe I'll have a chance to do it again someday. Then I'll do it right.

The reason there are no lectures on how to solve problems is because there **were** recitation sections. Although I did put in three lectures in the first year on how to solve problems, they are not included here. Also there was a lecture on inertial

guidance which certainly belongs after the lecture on rotating systems, but which was, unfortunately, omitted. The fifth and sixth lectures are actually due to Matthew Sands, as I was out of town.

The question, of course, is how well this experiment has succeeded. My own point of view—which, however, does not seem to be shared by most of the people who worked with the students—is pessimistic. I don't think I did very well by the students. When I look at the way the majority of the students handled the problems on the examinations, I think that the system is a failure. Of course, my friends point out to me that there were one or two dozen students who—very surprisingly—understood almost everything in all of the lectures, and who were quite active in working with the material and worrying about the many points in an excited and interested way. These people have now, I believe, a first-rate background in physics—and they are, after all, the ones I was trying to get at. But then, "The power of instruction is seldom of much efficacy except in those happy dispositions where it is almost superfluous." (Gibbon)

Still, I didn't want to leave any student completely behind, as perhaps I did. I think one way we could help the students more would be by putting more hard work into developing a set of problems which would elucidate some of the ideas in the lectures. Problems give a good opportunity to fill out the material of the lectures and make more realistic, more complete, and more settled in the mind the ideas that have been exposed.

I think, however, that there isn't any solution to this problem of education other than to realize that the best teaching can be done only when there is a direct individual relationship between a student and a good teacher—a situation in which the student discusses the ideas, thinks about the things, and talks about the things. It's impossible to learn very much by simply sitting in a lecture, or even by simply doing problems that are assigned. But in our modern times we have so many students to teach that we have to try to find some substitute for the ideal. Perhaps my lectures can make some contribution. Perhaps in some small place where there are individual teachers and students, they may get some inspiration or some ideas from the lectures. Perhaps they will have fun thinking them through—or going on to develop some of the ideas further.

RICHARD P. FEYNMAN

June, 1963

Foreword

This book is based upon a course of lectures in introductory physics given by Prof. R. P. Feynman at the California Institute of Technology during the academic year 1961-62; it covers the first year of the two-year introductory course taken by all Caltech freshmen and sophomores, and was followed in 1962-63 by a similar series covering the second year. The lectures constitute a major part of a fundamental revision of the introductory course, carried out over a four-year period.

The need for a basic revision arose both from the rapid development of physics in recent decades and from the fact that entering freshmen have shown a steady increase in mathematical ability as a result of improvements in high school mathematics course content. We hoped to take advantage of this improved mathematical background, and also to introduce enough modern subject matter to make the course challenging, interesting, and more representative of present-day physics.

In order to generate a variety of ideas on what material to include and how to present it, a substantial number of the physics faculty were encouraged to offer their ideas in the form of topical outlines for a revised course. Several of these were presented and were thoroughly and critically discussed. It was agreed almost at once that a basic revision of the course could not be accomplished either by merely adopting a different textbook, or even by writing one *ab initio*, but that the new course should be centered about a set of lectures, to be presented at the rate of two or three per week; the appropriate text material would then be produced as a secondary operation as the course developed, and suitable laboratory experiments would also be arranged to fit the lecture material. Accordingly, a rough outline of the course was established, but this was recognized as being incomplete, tentative, and subject to considerable modification by whoever was to bear the responsibility for actually preparing the lectures.

Concerning the mechanism by which the course would finally be brought to life, several plans were considered. These plans were mostly rather similar, involving a cooperative effort by N staff members who would share the total burden symmetrically and equally: each man would take responsibility for $1/N$ of the material, deliver the lectures, and write text material for his part. However, the unavailability of sufficient staff, and the difficulty of maintaining a uniform point of view because of differences in personality and philosophy of individual participants, made such plans seem unworkable.

The realization that we actually possessed the means to create not just a new and different physics course, but possibly a unique one, came as a happy inspiration to Professor Sands. He suggested that Professor R. P. Feynman prepare and deliver the lectures, and that these be tape-recorded. When transcribed and edited, they would then become the textbook for the new course. This is essentially the plan that was adopted.

It was expected that the necessary editing would be minor, mainly consisting of supplying figures, and checking punctuation and grammar; it was to be done by one or two graduate students on a part-time basis. Unfortunately, this expectation was short-lived. It was, in fact, a major editorial operation to transform the verbatim transcript into readable form, even without the reorganization or revision of the subject matter that was sometimes required. Furthermore, it was not a job for a technical editor or for a graduate student, but one that required the close attention of a professional physicist for from ten to twenty hours per lecture!

The difficulty of the editorial task, together with the need to place the material in the hands of the students as soon as possible, set a strict limit upon the amount of "polishing" of the material that could be accomplished, and thus we were forced to aim toward a preliminary but technically correct product that could be used immediately, rather than one that might be considered final or finished. Because of an urgent need for more copies for our students, and a heartening interest on the part of instructors and students at several other institutions, we decided to publish the material in its preliminary form rather than wait for a further major revision which might never occur. We have no illusions as to the completeness, smoothness, or logical organization of the material; in fact, we plan several minor modifications in the course in the immediate future, and we hope that it will not become static in form or content.

In addition to the lectures, which constitute a centrally important part of the course, it was necessary also to provide suitable exercises to develop the students' experience and ability, and suitable experiments to provide first-hand contact with the lecture material in the laboratory. Neither of these aspects is in as advanced a state as the lecture material, but considerable progress has been made. Some exercises were made up as the lectures progressed, and these were expanded and amplified for use in the following year. However, because we are not yet satisfied that the exercises provide sufficient variety and depth of application of the lecture material to make the student fully aware of the tremendous power being placed at his disposal, the exercises are published separately in a less permanent form in order to encourage frequent revision.

A number of new experiments for the new course have been devised by Professor H. V. Neher. Among these are several which utilize the extremely low friction exhibited by a gas bearing: a novel linear air trough, with which quantitative measurements of one-dimensional motion, impacts, and harmonic motion can be made, and an air-supported, air-driven Maxwell top, with which accelerated rotational motion and gyroscopic precession and nutation can be studied. The development of new laboratory experiments is expected to continue **for a** considerable period of time.

The revision program was under the direction of Professors R. B. Leighton, H. V. Neher, and M. Sands. Officially participating in the program were Professors R. P. Feynman, G. Neugebauer, R. M. Sutton, H. P. Stabler,* F. Strong, and R. Vogt, from the division of Physics, Mathematics and Astronomy, and Professors T. Caughey, M. Plesset, and C. H. Wilts from the division of Engineering Science. The valuable assistance of all those contributing to the revision program is gratefully acknowledged. We are particularly indebted to the Ford Foundation, without whose financial assistance this program could not have been carried out.

ROBERT B. LEIGHTON

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* 1961-62, while on leave from Williams College, Williamstown, Mass.

Contents

CHAPTER 1. ATOMS IN MOTION

- 1-1 Introduction 1-1
- 1-2 Matter is made of atoms 1-2
- 1-3 Atomic processes 1-5
- 1-4 Chemical reactions 1-6

CHAPTER 2. BASIC PHYSICS

- 2-1 Introduction 2-1
- 2-2 Physics before 1920 2-3
- 2-3 Quantum physics 2-6
- 2-4 Nuclei and particles 2-8

CHAPTER 3. THE RELATION OF PHYSICS TO OTHER SCIENCES

- 3-1 Introduction 3-1
- 3-2 Chemistry 3-1
- 3-3 Biology 3-2
- 3-4 Astronomy 3-6
- 3-5 Geology 3-7
- 3-6 Psychology 3-8
- 3-7 How did it get that way? 3-9

CHAPTER 4. CONSERVATION OF ENERGY

- 4-1 What is energy? 4-1
- 4-2 Gravitational potential energy 4-2
- 4-3 Kinetic energy 4-5
- 4-4** Other forms of energy 4-6

CHAPTER 5. TIME AND DISTANCE

- 5-1 Motion 5-1
- 5-2 Time 5-1
- 5-3 Short times 5-2
- 5-4 Long times 5-3
- 5-5 Units and standards of time 5-5
- 5-6 Large distances 5-5
- 5-7 Short distances 5-8

CHAPTER 6. PROBABILITY

- 6-1 Chance and likelihood 6-1
- 6-2 Fluctuations 6-3
- 6-3 The random walk 6-5
- 6-4 A probability distribution 6-7
- 6-5 The uncertainty principle 6-10

CHAPTER 7. THE THEORY OF GRAVITATION

- 7-1 Planetary motions 7-1
- 7-2 Kepler's laws 7-1
- 7-3 Development of dynamics 7-2
- 7-4** Newton's law of gravitation 7-3
- 7-5 Universal gravitation 7-5
- 7-6 Cavendish's experiment 7-9
- 7-7 What is gravity? 7-9
- 7-8 Gravity and relativity 7-11

CHAPTER 8. MOTION

- 8-1 Description of motion 8-1
- 8-2 Speed 8-2
- 8-3 Speed as a derivative 8-5
- 8-4 Distance as an integral 8-7
- 8-5 Acceleration 8-8

CHAPTER 9. NEWTON'S LAWS OF DYNAMICS

- 9-1 Momentum and force 9-1
- 9-2 Speed and velocity 9-2
- 9-3** Components of velocity, **acceleration, and force 9-3**
- 9-4** What is the force? 9-3
- 9-5 Meaning of the dynamical equations 9-4
- 9-6 Numerical solution of the equations 9-5
- 9-7 Planetary motions 9-6

CHAPTER 10. CONSERVATION OF MOMENTUM

- 10-1 Newton's Third Law 10-1
- 10-2 Conservation of momentum 10-2
- 10-3 Momentum *is* conserved! 10-5
- 10-4 Momentum and energy 10-7
- 10-5 Relativistic momentum 10-8

CHAPTER 11. VECTORS

- 11-1 Symmetry in physics **11-1**
- 11-2 Translations 11-1
- 11-3 Rotations 11-3
- 11-4 Vectors 11-5
- 11-5** Vector algebra **11-6**
- 11-6 Newton's laws in vector notation **11-7**
- 11-7 Scalar product of vectors 11-8

CHAPTER 12. CHARACTERISTICS OF FORCE

- 12-1 What is a force? 12-1
- 12-2 Friction 12-3
- 12-3 Molecular forces 12-6
- 12-4 Fundamental forces. Fields 12-7
- 12-5 Pseudo forces 12-10
- 12-6 Nuclear forces 12-12

CHAPTER 13. WORK AND POTENTIAL ENERGY (A)

- 13-1 Energy of a falling body 13-1
- 13-2 Work done by gravity 13-3
- 13-3 Summation of energy 13-6
- 13-4 Gravitational field of large objects 13-8

CHAPTER 14. WORK AND POTENTIAL ENERGY (conclusion)

- 14-1 Work 14-1
- 14-2 Constrained motion 14-3
- 14-3 Conservative forces 14-3
- 14-4 Nonconservative forces 14-6
- 14-5 Potentials and fields 14-7

CHAPTER 15. THE SPECIAL THEORY OF RELATIVITY

- 15-1 The principle of relativity 15-1
- 15-2 The Lorentz transformation 15-3
- 15-3 The Michelson-Morley experiment 15-3
- 15-4 Transformation of time 15-5
- 15-5 The Lorentz contraction 15-7
- 15-6 Simultaneity 15-7
- 15-7 Four-vectors 15-8
- 15-8 Relativistic dynamics 15-9
- 15-9 Equivalence of mass and energy 15-10

CHAPTER 16. RELATIVISTIC ENERGY AND MOMENTUM

- 16-1 Relativity and the philosophers 16-1
- 16-2 The twin paradox 16-3
- 16-3 Transformation of velocities 16-4
- 16-4 Relativistic mass 16-6
- 16-5 Relativistic energy 16-8

CHAPTER 17. SPACE-TIME

- 17-1 The geometry of space-time 17-1
- 17-2 Space-time intervals 17-2
- 17-3 Past, present, and future 17-4
- 17-4 More about four-vectors 17-5
- 17-5 Four-vector algebra 17-7.

CHAPTER 18. ROTATION IN Two DIMENSIONS

- 18-1 The center of mass 18-1
- 18-2 Rotation of a rigid body 18-2
- 18-3 Angular momentum 18-5
- 18-4 Conservation of angular momentum 18-6

CHAPTER 19. CENTER OF MASS; MOMENT OF INERTIA

- 19-1 Properties of the center of mass 19-1
- 19-2 Locating the center of mass 19-4
- 19-3 Finding the moment of inertia 19-5
- 19-4 Rotational kinetic energy 19-7

CHAPTER 20. ROTATION IN SPACE

- 20-1 Torques in three dimensions 20-1
- 20-2 The rotation equations using cross products 20-4
- 20-3 The gyroscope 20-5
- 20-4 Angular momentum of a solid body 20-8

CHAPTER 21. THE HARMONIC OSCILLATOR

- 21-1 Linear differential equations 21-1
- 21-2 The harmonic oscillator 21-1
- 21-3 Harmonic motion and circular motion 21-4
- 21-4 Initial conditions 21-4
- 21-5 Forced oscillations 21-5

CHAPTER 22. ALGEBRA

- 22-1 Addition and multiplication 22-1
- 22-2 The inverse operations 22-2
- 22-3 Abstraction and generalization 22-3
- 22-4 Approximating irrational numbers 22-4
- 22-5 Complex numbers 22-7
- 22-6 Imaginary exponents 22-9

CHAPTER 23. RESONANCE

- 23-1 Complex numbers and harmonic motion 23-1
- 23-2 The forced oscillator with damping 23-3

- 23-3 Electrical resonance 23-5
- 23-4 Resonance in nature 23-7

CHAPTER 24. TRANSIENTS

- 24-1 The energy of an oscillator 24-1
- 24-2 Damped oscillations 24-2
- 24-3 Electrical transients 24-5

CHAPTER 25. LINEAR SYSTEMS AND REVIEW

- 25-1 Linear differential equations 25-1
- 25-2 Superposition of solutions 25-2
- 25-3 Oscillations in linear systems 25-5
- 25-4 Analogs in physics 25-6
- 25-5 Series and parallel impedances 25-8

CHAPTER 26. OPTICS: THE PRINCIPLE OF LEAST TIME

- 26-1 Light 26-1
- 26-2 Reflection and refraction 26-2
- 26-3 Fermat's principle of least time 26-3
- 26-4 Applications of Fermat's principle 26-5
- 26-5 A more precise statement of Fermat's principle 26-7
- 26-6 How it works 26-8

CHAPTER 27. GEOMETRICAL OPTICS

- 27-1 Introduction 27-1
- 27-2 The focal length of a spherical surface 27-1
- 27-3 The focal length of a lens 27-4
- 27-4 Magnification 27-5
- 27-5 Compound lenses 27-6
- 27-6 Aberrations 27-7
- 27-7 Resolving power 27-7

CHAPTER 28. ELECTROMAGNETIC RADIATION

- 28-1 Electromagnetism 28-1
- 28-2 Radiation 28-3
- 28-3 The dipole radiator 28-5
- 28-4 Interference 28-6

CHAPTER 29. INTERFERENCE

- 29-1 Electromagnetic waves 29-1
- 29-2 Energy of radiation 29-2
- 29-3 Sinusoidal waves 29-2
- 29-4 Two dipole radiators 29-3
- 29-5 The mathematics of interference 29-5

CHAPTER 30. DIFFRACTION

- 30-1 The resultant amplitude due to n equal oscillators 30-1
- 30-2 The diffraction grating 30-3
- 30-3 Resolving power of a grating 30-5
- 30-4 The parabolic antenna 30-6
- 30-5 Colored films; crystals 30-7
- 30-6 Diffraction by opaque screens 30-8
- 30-7 The field of a plane of oscillating charges 30-10

CHAPTER 31. THE ORIGIN OF THE REFRACTIVE INDEX

- 31-1 The index of refraction 31-1
- 31-2 The field due to the material 31-4
- 31-3 Dispersion 31-6
- 31-4 Absorption 31-8
- 31-5 The energy carried by an electric wave 31-9
- 31-6 Diffraction of light by a screen 31-10

CHAPTER 32. RADIATION DAMPING. LIGHT SCATTERING

- 32-1 Radiation resistance 32-1
- 32-2 The rate of radiation of energy 32-2
- 32-3 Radiation damping 32-3
- 32-4 Independent sources 32-5
- 32-5 Scattering of light 32-6

CHAPTER 33. POLARIZATION

- 33-1 The electric vector of light 33-1
- 33-2 Polarization of scattered light 33-3
- 33-3 Birefringence 33-3
- 33-4 Polarizers 33-5
- 33-5 Optical activity 33-6
- 33-6 The intensity of reflected light 33-7
- 33-7 Anomalous refraction 33-9

CHAPTER 34. RELATIVISTIC EFFECTS IN RADIATION

- 34-1 Moving sources 34-1
- 34-2 Finding the "apparent" motion 34-2
- 34-3 Synchrotron radiation 34-3
- 34-4 Cosmic synchrotron radiation 34-6
- 34-5 Bremsstrahlung 34-6
- 34-6 The Doppler effect 34-7
- 34-7 The ω , k four-vector 34-9
- 34-8 Aberration 34-10
- 34-9 The momentum of light 34-10

CHAPTER 35. COLOR VISION

- 35-1 The human eye 35-1
- 35-2 Color depends on intensity 35-2
- 35-3 Measuring the color sensation 35-3
- 35-4 The chromaticity diagram 35-6
- 35-5 The mechanism of color vision 35-7
- 35-6 Physiochemistry of color vision 35-9

CHAPTER 36. MECHANISMS OF SEEING

- 36-1 The sensation of color 36-1
- 36-2 The physiology of the eye 36-3
- 36-3 The rod cells 36-6
- 36-4 The compound (insect) eye 36-6
- 36-5 Other eyes 36-9
- 36-6 Neurology of vision 36-9

CHAPTER 37. QUANTUM BEHAVIOR

- 37-1 Atomic mechanics 37-1
- 37-2 An experiment with bullets 37-2
- 37-3 An experiment with waves 37-3
- 37-4 An experiment with electrons 37-4
- 37-5 The interference of electron waves 37-5
- 37-6 Watching the electrons 37-7
- 37-7 First principles of quantum mechanics 37-10
- 37-8 The uncertainty principle 37-11

CHAPTER 38. THE RELATION OF WAVE AND PARTICLE VIEWPOINTS

- 38-1 Probability wave amplitudes 38-1
- 38-2 Measurement of position and momentum 38-2
- 38-3 Crystal diffraction 38-4
- 38-4 The size of an atom 38-5

- 38-5 Energy levels 38-7
- 38-6 Philosophical implications 38-8

CHAPTER 39. THE KINETIC THEORY OF GASES

- 39-1 Properties of matter 39-1
- 39-2 The pressure of a gas 39-2
- 39-3 Compressibility of radiation 39-6
- 39-4 Temperature and kinetic energy 39-6
- 39-5 The ideal gas law 39-10

CHAPTER 40. THE PRINCIPLES OF STATISTICAL MECHANICS

- 40-1 The exponential atmosphere 40-1
- 40-2 The Boltzmann law 40-2
- 40-3 Evaporation of a liquid 40-3
- 40-4 The distribution of molecular speeds 40-4
- 40-5 The specific heats of gases 40-7
- 40-6 The failure of classical physics 40-8

CHAPTER 41. THE BROWNIAN MOVEMENT

- 41-1 Equipartition of energy 41-1
- 41-2 Thermal equilibrium of radiation 41-3
- 41-3 Equipartition and the quantum oscillator 41-6
- 41-4** The random walk 41-8

CHAPTER 42. APPLICATIONS OF KINETIC THEORY

- 42-1 Evaporation 42-1
- 42-2 Thermionic emission 42-4
- 42-3 Thermal ionization 42-5
- 42-4** Chemical kinetics 42-7
- 42-5 Einstein's laws of radiation 42-8

CHAPTER 43. DIFFUSION

- 43-1 Collisions between molecules 43-1
- 43-2 The mean free path 43-3
- 43-3 The drift speed 43-4
- 43-4 Ionic conductivity 43-6
- 43-5 Molecular diffusion 43-7
- 43-6 Thermal conductivity 43-9

CHAPTER 44. THE LAWS OF THERMODYNAMICS

- 44-1 Heat engines; the first law 44-1
- 44-2 The second law 44-3
- 44-3 Reversible engines 44-4
- 44-4 The efficiency of an ideal engine 44-7
- 44-5 The thermodynamic temperature 44-9
- 44-6 Entropy 44-10

CHAPTER 45. ILLUSTRATIONS OF THERMODYNAMICS

- 45-1 Internal energy 45-1
- 45-2 Applications 45-4
- 45-3 The Clausius-Clapeyron equation 45-6

CHAPTER 46. RATCHET AND PAWL

- 46-1 How a ratchet works 46-1
- 46-2 The ratchet as an engine 46-2
- 46-3 Reversibility in mechanics 46-4
- 46-4 Irreversibility 46-5
- 46-5 Order and entropy 46-7

CHAPTER 47. SOUND. THE WAVE EQUATION

- 47-1 Waves 47-1
- 47-2 The propagation of sound 47-3
- 47-3 The wave equation 47-4
- 47-4 Solutions of the wave equation 47-6
- 47-5 **The speed of sound** 47-7

CHAPTER 48. BEATS

- 48-1 Adding two waves 48-1
- 48-2 Beat notes and modulation 48-3
- 48-3 Side bands 48-4
- 48-4 Localized wave trains 48-5
- 48-5 Probability amplitudes for particles 48-7
- 48-6 Waves in three dimensions 48-9
- 48-7 Normal modes 48-10

CHAPTER 49. MODES

- 49-1 The reflection of waves 49-1
- 49-2 Confined waves, with natural frequencies 49-2
- 49-3 Modes in two dimensions 49-3
- 49-4 Coupled pendulums 49-6
- 49-5 Linear systems 49-7

INDEX

CHAPTER 50. HARMONICS

- 50-1 Musical tones 50-1
- 50-2 The Fourier series 50-2
- 50-3 Quality and consonance 50-3
- 50-4 The Fourier coefficients 50-5
- 50-5 The energy theorem 50-7
- 50-6 Nonlinear responses 50-8

CHAPTER 51. WAVES

- 51-1 Bow waves **51-1**
- 51-2 Shock waves 51-2
- 51-3 Waves in solids 51-4
- 51-4 Surface waves 51-7

CHAPTER 52. SYMMETRY IN PHYSICAL LAWS

- 52-1 Symmetry operations 52-1
- 52-2 Symmetry **in space and time** **52-1**
- 52-3 Symmetry and conservation laws 52-3
- 52-4 Mirror reflections 52-4
- 52-5 Polar and axial vectors 52-6
- 52-6 Which hand is right? 52-8
- 52-7 Parity is not conserved! 52-8
- 52-8 Antimatter 52-10
- 52-9 Broken symmetries 52-11