

# *The Feynman* LECTURES ON PHYSICS

MAINLY MECHANICS, RADIATION, AND HEAT

---

RICHARD P. FEYNMAN

*Ronald Clark Tolman Professor of Theoretical Physics  
California Institute of Technology*

ROBERT B. LEIGHTON

*Professor of Physics  
California Institute of Technology*

MATTHEW SANDS

*Professor  
Stanford University*

ADDISON-WESLEY PUBLISHING COMPANY

Reading, Massachusetts  
Menlo Park, California • London • Amsterdam • Don Mills, Ontario • Sydney

\* of the

## 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 13-5
- 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 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 47-5
- 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