

17 ■ Visualization and Rigid Body Dynamics	722
17.1 Two-Dimensional Transformations	722
17.2 Three-Dimensional Transformations	726
17.3 The Three-Dimensional Open Source Physics Library	732
17.4 Dynamics of a Rigid Body	735
17.5 Quaternion Arithmetic	740
17.6 Quaternion Equations of Motion	742
17.7 Rigid Body Model	748
17.8 Motion of a Spinning Top	753
17.9 Projects	756
Appendix 17A: Matrix Transformations	756
Appendix 17B: Conversions	759
18 ■ Seeing in Special and General Relativity	763
18.1 Special Relativity	763
18.2 General Relativity	767
18.3 Dynamics in Polar Coordinates	768
18.4 Black Holes and Schwarzschild Coordinates	770
18.5 Particle and Light Trajectories	772
18.6 Seeing	774
18.7 General Relativistic Dynamics	775
*18.8 The Kerr Metric	776
18.9 Projects	778
19 ■ Epilogue: The Unity of Physics	780
19.1 The Unity of Physics	780
19.2 Spiral Galaxies	781
19.3 Numbers, Pretty Pictures, and Insight	782
19.4 Constrained Dynamics	784
19.5 What are Computers Doing to Physics?	788
Index	791

CHAPTER

1

Introduction

The importance of computers in physics and the nature of computer simulation is discussed. The nature of object-oriented programming and various computer languages is also considered.

1.1 ■ IMPORTANCE OF COMPUTERS IN PHYSICS

Computation is now an integral part of contemporary science and is having a profound effect on the way we do physics, on the nature of the important questions, and on the physical systems we choose to study. Developments in computer technology are leading to new ways of thinking about physical systems. Asking “How can I formulate this problem on a computer?” has led to the understanding that it is practical and natural to formulate physical laws as rules for a computer rather than only in terms of differential equations.

For the purposes of discussion, we will divide the use of computers in physics into the following categories: numerical analysis, symbolic manipulation, visualization, simulation, and the collection and analysis of data. *Numerical analysis* refers to the solution of well-defined mathematical problems to produce numerical (in contrast to symbolic) solutions. For example, we know that the solution of many problems in physics can be reduced to the solution of a set of simultaneous linear equations. Consider the equations

$$2x + 3y = 18$$

$$x - y = 4.$$

It is easy to find the analytical solution $x = 6$, $y = 2$ using the method of substitution. Suppose we wish to solve a set of four simultaneous equations. We again can find an analytical solution, perhaps using a more sophisticated method. However, if the number of simultaneous equations becomes much larger, we would need to use a computer to find a solution. In this mode the computer is a tool of numerical analysis. Because it is often necessary to compute multidimensional integrals, manipulate large matrices, or solve nonlinear differential equations, this use of the computer is important in physics.

One of the strengths of mathematics is its ability to use the power of abstraction, which allows us to solve many similar problems simultaneously by using symbols. Computers can be used to do much of the *symbolic manipulation*. As an example, suppose we want to know the solution of the quadratic equation, $ax^2 + bx + c = 0$. A symbolic manipulation program can give the solution as $x = [-b \pm \sqrt{b^2 - 4ac}]/2a$. In addition, such a program can give the usual numerical solutions for specific values of a , b , and c . Mathematical operations such as differentiation, integration, matrix inversion, and power series expansion can be