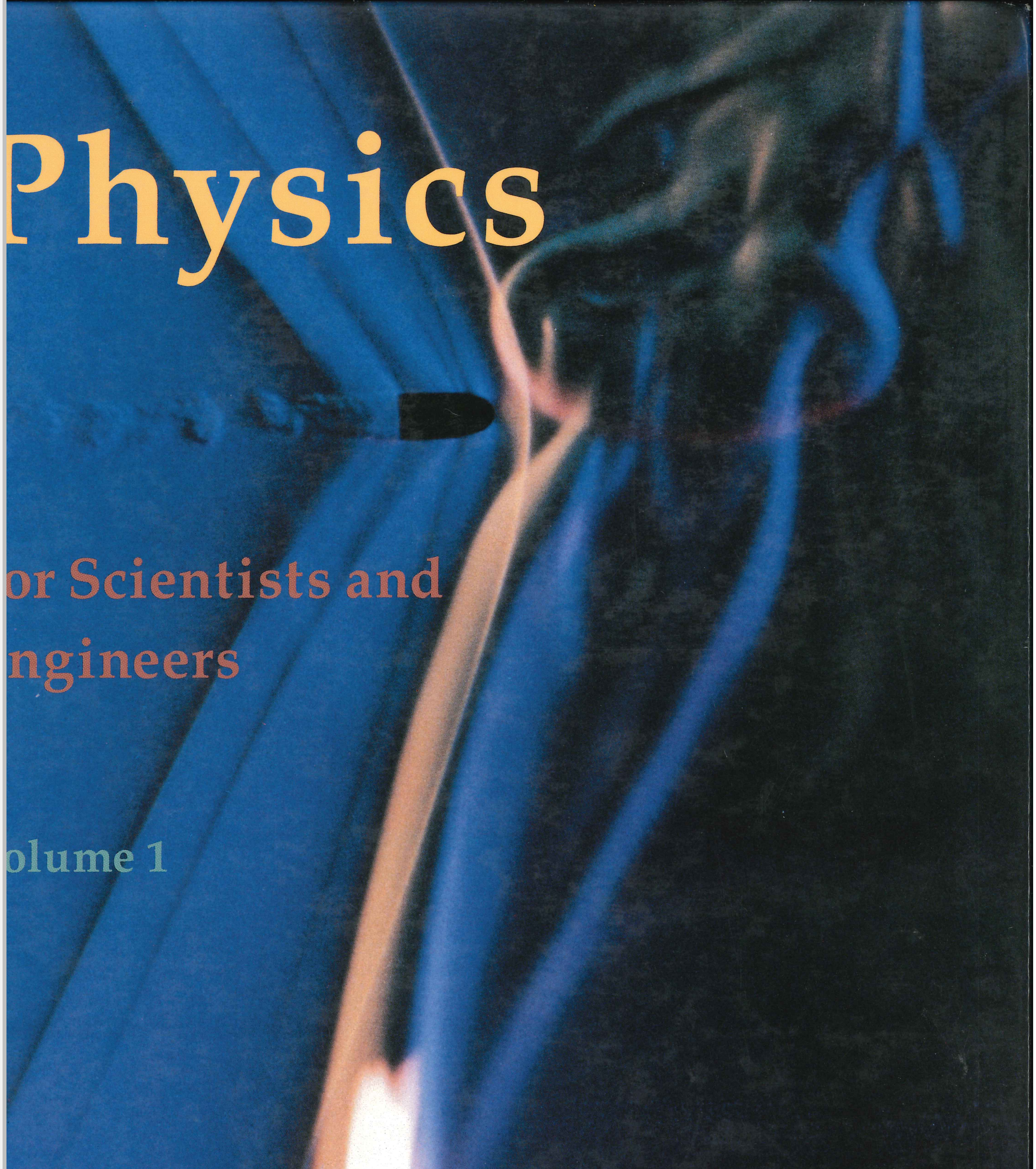
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Third Edition

Volume 1

# Physics

## For Scientists and Engineers

Paul A. Tipler

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Paul A. Tipler



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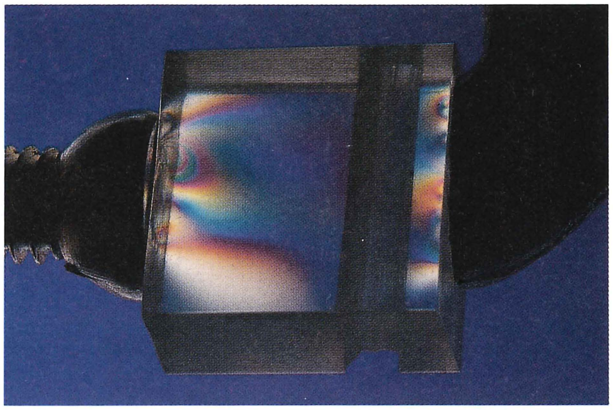


Contact forces exerted by one object on another produce deformations in the objects that are often not visible. Here, the forces exerted by the C-clamp on the plastic block produce stress patterns in the block that are made visible by polarized light.

## Contact Forces

Most of the everyday forces we observe on macroscopic objects are contact forces exerted by springs, strings, and surfaces in direct contact with the object. The forces are the result of molecular forces exerted by the molecules of one object on those of another. These molecular forces are themselves complicated manifestations of the basic electromagnetic force.

A spring made by winding a stiff wire into a helix is a familiar device. The force exerted by the spring when it is compressed or extended is the result of complicated intermolecular forces in the spring, but an empirical description of the macroscopic behavior of the spring is sufficient for most applications. If the spring is compressed or extended and released, it returns to its original, or natural, length, provided the displacement is not too great. There is a limit to such displacements beyond which the spring does not return to its original length but remains permanently deformed. If we allow only displacements below this limit, we can calibrate the extension or compression $\Delta x$ in terms of the force needed to produce the extension or compression. It has been found experimentally that, for small $\Delta x$, the force exerted by the spring is approximately proportional to $\Delta x$ and in the opposite direction. This relationship, known as **Hooke's law,** can be written

$$F_x = -k(x - x_0) = -k\,\Delta x \qquad 4\text{-}5$$

where the constant $k$ is called the **force constant** of the spring. The distance $x$ is the coordinate of the free end of the spring or of any object attached to that end of the spring. The constant $x_0$ is the value of this coordinate when the spring is unstretched from its equilibrium position. There is a negative sign in Equation 4-5 because, if the spring is stretched ($\Delta x$ is positive), the force $F_x$ is negative, whereas if the spring is compressed ($\Delta x$ is negative), $F_x$ is positive (Figure 4-6). Such a force is called a **restoring force** because it tends to restore the spring to its initial configuration.

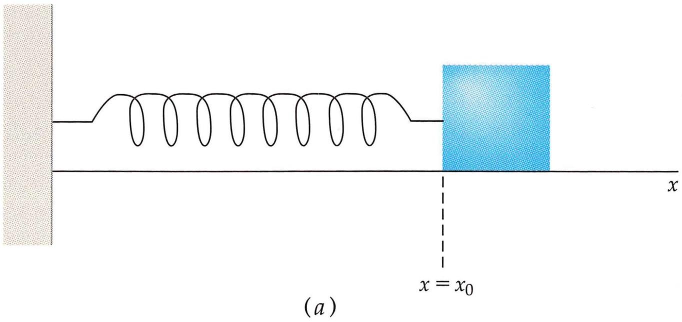
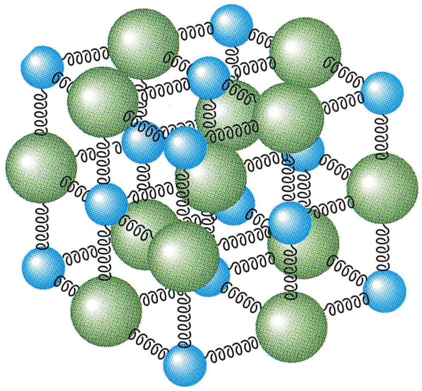
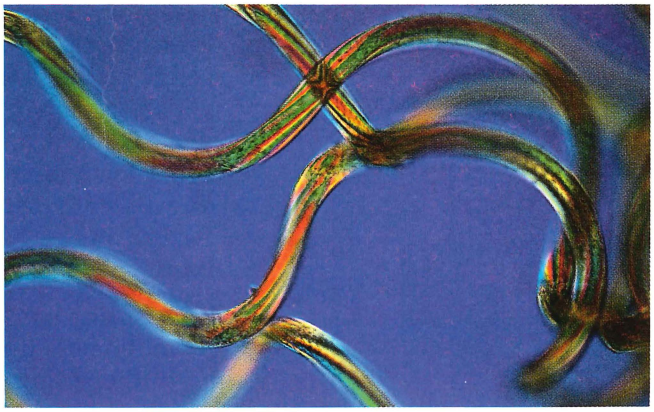



**Figure 4-6** A horizontal spring attached to a block. (*a*) When the spring is unstretched, it exerts no force on the block. (*b*) When the spring is stretched such that $\Delta x$ is positive, it exerts a force on the block of magnitude $k\,\Delta x$ in the negative $x$ direction. (*c*) When the spring is compressed such that $\Delta x$ is negative, the spring exerts a force on the block of magnitude $k\,\Delta x$ in the positive $x$ direction.



(*a*)



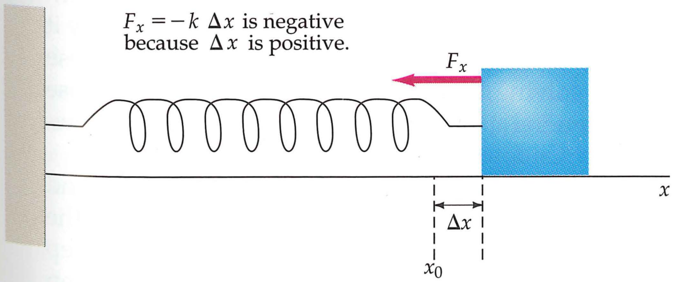
(*b*)

**Figure 4-7** (*a*) Model of a solid as consisting of atoms connected to each other by springs. (*b*) The elasticity of nylon arises from the shape and cross linking of its fibers shown here under polarized light.

The force exerted by a spring is similar to that exerted by one atom on another in a molecule or in a solid in the sense that, for small displacements from equilibrium, the restoring force is proportional to the displacement. It is often useful to visualize the atoms in a molecule or solid as being connected by springs (Figure 4-7). For example, if we slightly increase the separation of the atoms in a molecule and release them, we would expect the atoms to oscillate back and forth as if they were two masses connected by a spring.

If we pull on a flexible string, the string stretches slightly and pulls back with an equal but opposite force (unless the string breaks). We can think of a string as a spring with such a large force constant that the extension of the string is negligible. Because the string is flexible, however, we cannot exert a force of compression on it. When we push on a string, it merely flexes or bends.

When two bodies are in contact with each other, they exert forces on each other due to the interaction of the molecules of one object with those of the other. Consider a block resting on a horizontal table. The weight of the block pulls the block downward, pressing it against the table. Because the molecules in the table have a great resistance to compression, the table exerts a force upward on the block perpendicular, or normal, to the surface. Such a force is called a **normal force.** (The word *normal* means perpendicular.) Careful measurement would show that a supporting surface always bends slightly in response to a load, but this compression is not noticeable to the naked eye. Since the table exerts an upward force on the block, the block must exert an equal force downward on the table. Note that the normal force exerted by one surface on another can vary over a wide range of values. For example, unless the block is so heavy that the table breaks, the table will exert an upward support force on the block exactly equal to the weight of the

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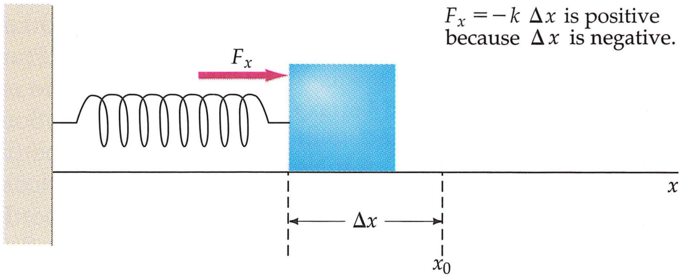


(*c*)