We begin the study of fluid mechanics by pointing out the differences between fluids and solids and by describing a fluid flow in terms of the motion of elementary fluid parcels. As the volume of a parcel becomes infinitesimal, the parcel reduces to a point particle and the average velocity of the parcel reduces to the local fluid velocity computed just before the molecular nature of the fluid becomes apparent. The study of the motion and deformation of material lines and surfaces consisting of collections of point particles reveals the nature and illustrates the diversity of motion in fluid mechanics.

1.1 Fluids and solids

Casual observation of the world around us reveals materials that are classified as solids and fluids; the second category includes gases and liquids. What are the distinguishing features of these two groups? The answer can be given on a wide variety of levels: from the molecular level of the physicist, to the macroscopic level of the engineer or oceanographer, to the cosmic level of the astronomer.

From the perspective of mainstream fluid mechanics underlying this book, the single most important difference between fluids and solids is that a fluid must assume the shape of the container in which it is placed, whereas a solid is able to stand alone, sustaining its own shape. As a consequence, a body of fluid is not able to resist a shearing force exerted on its surface parallel to the surface, but must keep deforming in perpetuity when subjected to it. An example is the motion of water in a lake due to an overpassing wind. In contrast, a solid is able to deform and assume a new stationary shape. An example is the deformation of a squeezed sponge.
Certain materials, such as polymeric melts and solutions, exhibit properties that are intermediate between those of fluids and solids in that they exhibit viscous and elastic response. These materials are classified as viscoelastic.

**Intermolecular forces**

The differences between fluids and solids can be attributed to the intensity of the forces holding the molecules together to form a coherent piece of material. The inability of a fluid to assume its own shape is due to the weakness of the potential energy associated with intermolecular forces relative to the kinetic energy associated with the vibrations of the individual molecules. The molecules of a fluid are too busy vibrating to hang onto one another and thus form a long-lived crystalline material.

Fluids can be transformed into solids, and *vice versa*, by manipulating the relative magnitude of the potential energy due to intermolecular forces and the kinetic energy due to thermal motion. In practice, this is done by heating or by changing the pressure of the ambient environment.

**Problems**

1.1.1 *Nature of a liquid/solid suspension*

Fluids containing particles, called suspensions, abound in nature, physiology, and technology. Examples include (a) blood consisting of a dense suspension of red, white, and other blood cells, (b) slurry used in the petroleum industry for the hydrodynamic transport of particulates, (c) toothpaste and dough. Discuss whether a suspension should be classified as a fluid or solid with reference to the volume fraction of the suspended solid phase.

1.1.2 *Water and milk*

A glass is filled half way with water, and another glass is filled half way with milk. Half the water is transfer into the milk glass and the contents of the milk glass are thoroughly mixed. One third of the diluted milk is then transferred back into the water glass and the contents of the water glass are thoroughly mixed. What is the volume and constitution of the liquid in each glass at the end?

1.2 *Fluid parcels and flow kinematics*

The motion of a non-deformable solid body, called a rigid body, can be described in terms of the velocity of translation vector, \( \mathbf{V} \), and the angular velocity of rotation vector, \( \mathbf{\Omega} \), where rotation occurs around a specified center of rotation, as shown in Figure 1.2.1. A rigid body moves as a whole in the direction of the velocity vector, while rotating as a whole around the angular velocity vector that is pinned at the designated center of rotation. For example, a rigid sphere translates with the velocity of its center, while rotating about the center.

In contrast, the motion of a deformable body, such as an elastic solid or a fluid, cannot generally be described in terms of two vectors alone. A more advanced framework that