

CHAPTER 11

Fluid Statics



FIGURE 11.1 The fluid essential to all life has a beauty of its own. It also helps support the weight of this swimmer. (credit: Terren, Wikimedia Commons)

CHAPTER OUTLINE

11.1 What Is a Fluid?

11.2 Density

11.3 Pressure

11.4 Variation of Pressure with Depth in a Fluid

11.5 Pascal's Principle

11.6 Gauge Pressure, Absolute Pressure, and Pressure Measurement

11.7 Archimedes' Principle

11.8 Cohesion and Adhesion in Liquids: Surface Tension and Capillary Action

11.9 Pressures in the Body

INTRODUCTION TO FLUID STATICS Much of what we value in life is fluid: a breath of fresh winter air; the hot blue flame in our gas cooker; the water we drink, swim in, and bathe in; the blood in our veins. What exactly is a fluid? Can we understand fluids with the laws already presented, or will new laws emerge from their study? The physical characteristics of static or stationary fluids and some of the laws that govern their behavior are the topics of this chapter. [Fluid Dynamics and Its Biological and Medical Applications](https://openstax.org/books/college-physics-2e/pages/11-introduction-to-fluid-statics) explores aspects of fluid flow.

[Click to view content \(https://openstax.org/books/college-physics-2e/pages/11-introduction-to-fluid-statics\)](https://openstax.org/books/college-physics-2e/pages/11-introduction-to-fluid-statics)

11.1 What Is a Fluid?

LEARNING OBJECTIVES

By the end of this section, you will be able to:

- State the common phases of matter.
- Explain the physical characteristics of solids, liquids, and gases.
- Describe the arrangement of atoms in solids, liquids, and gases.

Matter most commonly exists as a solid, liquid, gas, or plasma; these states are known as the common *phases of*

matter. Solids have a definite shape and a specific volume, liquids have a definite volume but their shape changes depending on the container in which they are held, gases have neither a definite shape nor a specific volume as their molecules move to fill the container in which they are held, and plasmas also have neither definite shape nor volume. (See [Figure 11.2](#).) Liquids, gases, and plasmas are considered to be fluids because they yield to shearing forces, whereas solids resist them. Note that the extent to which fluids yield to shearing forces (and hence flow easily and quickly) depends on a quantity called the viscosity which is discussed in detail in [Viscosity and Laminar Flow; Poiseuille's Law](#). We can understand the phases of matter and what constitutes a fluid by considering the forces between atoms that make up matter in the three phases.

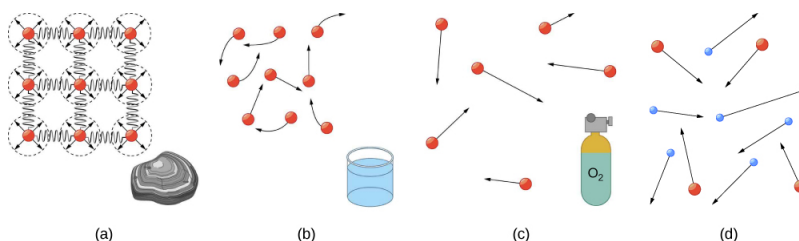


FIGURE 11.2 (a) Atoms in a solid always have the same neighbors, held near home by forces represented here by springs. These atoms are essentially in contact with one another. A rock is an example of a solid. This rock retains its shape because of the forces holding its atoms together. (b) Atoms in a liquid are also in close contact but can slide over one another. Forces between them strongly resist attempts to push them closer together and also hold them in close contact. Water is an example of a liquid. Water can flow, but it also remains in an open container because of the forces between its atoms. (c) Atoms in a gas are separated by distances that are considerably larger than the size of the atoms themselves, and they move about freely. A gas must be held in a closed container to prevent it from moving out freely. (d) A plasma is composed of electrons, protons, and ions that, like gases, are spaced far apart and move about freely.

Atoms in *solids* are in close contact, with forces between them that allow the atoms to vibrate but not to change positions with neighboring atoms. (These forces can be thought of as springs that can be stretched or compressed, but not easily broken.) Thus a solid *resists* all types of stress. A solid cannot be easily deformed because the atoms that make up the solid are not able to move about freely. Solids also resist compression, because their atoms form part of a lattice structure in which the atoms are a relatively fixed distance apart. Under compression, the atoms would be forced into one another. Most of the examples we have studied so far have involved solid objects which deform very little when stressed.

Connections: Submicroscopic Explanation of Solids and Liquids

Atomic and molecular characteristics explain and underlie the macroscopic characteristics of solids and fluids. This submicroscopic explanation is one theme of this text and is highlighted in the Things Great and Small features in [Conservation of Momentum](#). See, for example, microscopic description of collisions and momentum or microscopic description of pressure in a gas. This present section is devoted entirely to the submicroscopic explanation of solids and liquids.

In contrast, *liquids* deform easily when stressed and do not spring back to their original shape once the force is removed because the atoms are free to slide about and change neighbors—that is, they *flow* (so they are a type of fluid), with the molecules held together by their mutual attraction. When a liquid is placed in a container with no lid on, it remains in the container (providing the container has no holes below the surface of the liquid!). Because the atoms are closely packed, liquids, like solids, resist compression.

Atoms in *gases* and charged particles in *plasmas* are separated by distances that are large compared with the size of the particles. The forces between the particles are therefore very weak, except when they collide with one another. Gases and plasmas thus not only flow (and are therefore considered to be fluids) but they are relatively easy to compress because there is much space and little force between the particles. When placed in an open container gases, unlike liquids, will escape. The major distinction is that gases are easily compressed, whereas liquids are not. Plasmas are difficult to contain because they have so much energy. When discussing how substances flow, we shall generally refer to both gases and liquids simply as **fluids**, and make a distinction between them only when they behave differently.



PHET EXPLORATIONS

States of Matter—Basics

Heat, cool, and compress atoms and molecules and watch as they change between solid, liquid, and gas phases.

[Click to view content \(https://openstax.org/books/college-physics-2e/pages/11-1-what-is-a-fluid\)](https://openstax.org/books/college-physics-2e/pages/11-1-what-is-a-fluid)



11.2 Density

LEARNING OBJECTIVES

By the end of this section, you will be able to:

- Define density.
- Calculate the mass of a reservoir from its density.
- Compare and contrast the densities of various substances.

Which weighs more, a ton of feathers or a ton of bricks? This old riddle plays with the distinction between mass and density. A ton is a ton, of course; but bricks have much greater density than feathers, and so we are tempted to think of them as heavier. (See [Figure 11.3](#).)

Density, as you will see, is an important characteristic of substances. It is crucial, for example, in determining whether an object sinks or floats in a fluid. Density is the mass per unit volume of a substance or object. In equation form, density is defined as

$$\rho = \frac{m}{V}, \quad 11.1$$

where the Greek letter ρ (rho) is the symbol for density, m is the mass, and V is the volume occupied by the substance.

Density

Density is mass per unit volume.

$$\rho = \frac{m}{V}, \quad 11.2$$

where ρ is the symbol for density, m is the mass, and V is the volume occupied by the substance.

In the riddle regarding the feathers and bricks, the masses are the same, but the volume occupied by the feathers is much greater, since their density is much lower. The SI unit of density is kg/m^3 , representative values are given in [Table 11.1](#). The metric system was originally devised so that water would have a density of 1 g/cm^3 , equivalent to 10^3 kg/m^3 . Thus the basic mass unit, the kilogram, was first devised to be the mass of 1000 mL of water, which has a volume of 1000 cm^3 .

Substance	$\rho(\times 10^3 \text{ kg/m}^3 \text{ or g/mL})$	Substance	$\rho(10^3 \text{ kg/m}^3 \text{ or g/mL})$	Substance	$\rho(10^3 \text{ kg/m}^3 \text{ or g/mL})$
Solids		Liquids		Gases	
Aluminum	2.7	Water (4°C)	1.000	Air	1.29×10^{-3}

TABLE 11.1 Densities of Various Substances