# Solids, Liquids, and Gases

        Matter can be described in terms of its physical state, that is, its physical condition at any one moment. The possible states are known as solid, liquid, and gas. When in its solid state, matter has a fixed volume and a fixed shape. An example would be an ice cube. The ice cube will occupy the same
volume of space no matter how much larger than the ice cube the container may be. Furthermore, the ice will maintain its shape (a cube) regardless of the shape of the container, provided the container is larger than the cube and no other changes are made, such as temperature.

        When in a liquid state, matter has a fixed volume but not a fixed shape. Water is an obvious example of a liquid. When placed in a container, such as a cup, the water will flow to take the shape of the container. If poured from a cup into a bowl, the water will change its shape accordingly. The water will, however, maintain its volume, even though it might be placed in a much larger container.

        When in a gaseous state, matter has neither a fixed volume nor a fixed shape. Steam or water vapor is the corresponding gas to ice and water. When placed in a container, the gas will take the shape of the container and will occupy the entire space available within the container. If the size or shape of the container is changed, the gas will change accordingly.

        Most types of matter can be converted from one state to another by changing the temperature or, less commonly, changing the pressure. For instance, ice will change into a liquid at the melting point. Water will, in turn, change into steam at the boiling point. The single most important property that controls the state of a material is the freedom of movement of its particles (atoms or molecules). If the particles are highly restricted in their movements, the material is likely to be a solid. If the particles can move independently in all directions, the material is likely to be a gas. A liquid is between the two in ease of particle movement.

        For instance, in ice, the molecules are locked in a three-dimensional crystal structure with relatively strong bonds holding each water molecule in place relative to its neighbors. As heat is added to the ice crystal, the atoms gain more energy and begin to vibrate and move slightly. More heat will result in more vibrations, rotations and other localized movement until, eventually, the molecules have more energy than the energy associated with the crystal structure bonds that hold the molecules in place. (These are secondary bonds acting in three dimensions.) When this energy point is reached, the ice melts. However, even after melting there are still some secondary bonds acting between the now liquid water molecules. These secondary bonds are generally not three dimensional and are, besides, weaker than in the solid case because the molecules are farther apart and secondary bonds are very distance dependent. Hence, the molecules in the liquid state are "semirestricted." With added energy, the molecules continue to gain greater energy, which imparts further increases in vibrations, rotations, and other movements, until eventually the energy of the remaining secondary bonds is exceeded and the molecules begin to act completely independently. This is the boiling point. The molecules with energies above this boiling point energy are no longer associated with the rest of the molecules and are free to move about within the container. They will, therefore, fill the container in a random fashion, characteristic of a gas. Additional energy input will cause all of the liquid to boil, with no increase in temperature, and become a gas.

        Additional energy could still be added to the gaseous system. This will continue to cause the molecules to vibrate, rotate, and move until eventually sufficient energy is present in the system that the bond energy is reached. When that occurs, the atoms in the molecule will separate and the material will no longer be water but will revert to
hydrogen and oxygen atoms. The point where the covalent bonds are broken is called the decomposition point. (Further energy addition could conceivably break the atoms apart but these energies are associated with nuclear reactions, such as occur in atom bombs, and are beyond the scope of this text.) As the number of atoms in a molecule increases, the number of sites for secondary bonding also increases. Hence, the amount of energy required to break these bonds and convert the material from a solid to a liquid also increases. Polymers, which have very long chains of atoms, will generally require much more energy for each thermal change than smaller, non-polymeric covalent materials. Hence, thermal transitions in polymers occur at higher temperatures than in small, nonpolymeric molecules. Other characteristics within the molecules that could increase secondary bonding (such as having polar sites that can form strong hydrogen bonds) will also increase the thermal transitions of small covalent materials.

        Ionic solids (ceramics) and metallic solids (metals) can also be melted if sufficient energy is added to the system to cause the bonds between the particles in the solid structure to separate. In these cases, the particles are atoms (or ions), and the bonds that hold the materials together are the ionic or metallic bonds discussed in Chapter 2. These bonds are much stronger than the secondary bonds that hold covalent solid structures together. Hence, the energies required to melt ceramics and metals are generally much higher than the energies required to melt small covalent solids, and the melting points of ceramics and metals are also higher than covalent solids. (The energies to break the primary covalent bonds in covalent molecules are roughly the same as the energies to break apart the atoms in ceramics and metals. But, in the case of covalent molecules, these energies are associated with the decomposition point rather than the melting point.)

        All the changes in state (solid to liquid to gas) are reversible with the subtraction of energy from the system. Gases can be condensed to liquids and liquids frozen to solids by cooling. Most materials can be changed from one state to another and back repeatedly, with some important exceptions, which will be discussed later.

        The changes between the solid and liquid states with the addition of energy are important in the understanding of plastics. As discussed in Chapter 1, the definition of a plastic material implies that it is used as a solid but at some time has been shaped or molded into a useful shape. The shaping or molding is usually done when it is in liquid form. Hence, almost all plastics have made a transition from the liquid to the solid state. Many of the processes discussed in the later chapters in this text will discuss different methods of making these transitions.

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