Section 2

States of Matter

SECTION II INTRODUCTION

Humans live their lives amidst a sea of chemical substances that are in different physical states, either gas, liquid, or solid. Most are not single substances but rather are **mixtures** of substances. If a mixture looks as if it is a single substance, it is called a **solution**. There are several different kinds of solutions, although most people think of solutions as liquids dissolved in liquids, or solids dissolved in liquids. Examples of these types of solutions include lemon juice in water and sugar in water, which make a solution called lemonade. Chemists also recognize gas in gas solutions and solid in solid solutions. For example, you breathe the gases that are found in the gas solution called air; you drink solutions in which gas, liquid, or solid is dissolved in liquid water when you enjoy beverages such as soda-pop, lemonade, tea, or coffee; and you may ride a bicycle made of high-strength solid solutions called steels. Only gas in gas solutions and solid in liquid solutions will be reviewed in this section of the resource guide.

This section of the guide will explore the properties of each state of matter and how they vary with composition, temperature, and pressure. We will begin our discussion with pure gases and then proceed to pure liquids. You will learn that chemists discovered that all substances (except at **absolute zero temperature**) can be considered as an ensemble of rapidly moving particles. The dynamic motion and energy of these particles form the basis of the **kinetic-molecular theory** of matter. This particulate model can be used with appropriate mathematics to explain the laws that govern the behavior of gases, which were discovered much earlier by experiment.

You will also learn about the major differences between gases, liquids, and solids and about "**phase diagrams**," which show how all three states for a pure substance can exist under different conditions and how they can interchange in a process of molecular dynamic equilibrium. Then we will examine the properties of solutions in water and in **organic** solvents. You will learn that these properties can be predicted if the molecular properties and the relative concentrations of the components of the solutions are known.

GASES

Laws of Ideal Gases

In the seventeenth and eighteenth centuries, scientists were fascinated by the behavior of gases, which they had learned to isolate from one another or from air. These scientists observed that gases exhibited a high degree of regularity of behavior. If a certain mass of gas was trapped in a flexible container, such as a balloon, and then extra pressure (P) was applied, the **volume** (V) of the balloon always *decreased* in a direct proportion to the applied pressure. This behavior pattern became known as **Boyle's law**, which can be stated in a simple algebraic equation: P x V = a constant, or PV = C. Pressure is usually measured in atmosphere units and volume in liters, so C is measured in units of liter-atmospheres (L-atm).

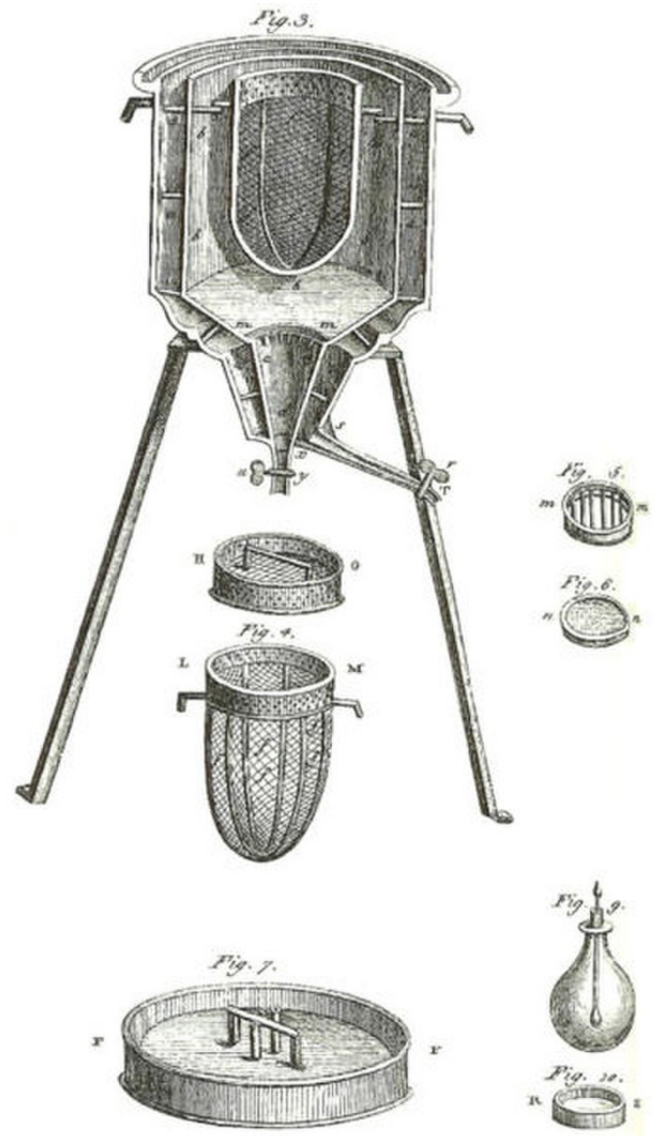
Similarly, **Charles's law** states that if you heat the trapped gas, the volume *increases* in direct proportion to the temperature change, so that V/T = a constant, or V/T = D. With volume in liters and temperature in degree units, the constant is measured in units of liters per degree.

In experimenting with gases, scientists made an interesting discovery. They found that when a gas was trapped in a cylinder with a movable piston and the weight of the piston applied a constant pressure to the gas, as the temperature was lowered from about 70 °C to –100 °C, the volume of the trapped gas decreased from 60 mL to 30 mL. Other measurements would show that a straight line could be drawn through all the observed volumes. However, this straight line extrapolates to

JOSEPH BLACK AND LATENT HEAT

The Scottish chemist Joseph Black, whom we discussed earlier with regard to his discovery of carbon dioxide, also made foundational contributions to the field of thermochemistry, the branch of chemistry that focuses on the quantities of heat evolved or absorbed during chemical reactions. As early as the 1750s, Black began to focus his research on the topic of heat. Like anyone who has observed melting snow, Black understood that even after the air temperature has risen above the freezing point, a quantity of snow will not immediately melt but rather will melt quite slowly.

To investigate why this is so, Black conducted an experiment in which he observed one container filled with five ounces of water at 33 °F in a room whose temperature was 47 °F and a second container with five ounces of ice at 32 °F. Black observed that in thirty minutes time, the water had warmed to a temperature of 40 °F. The ice, meanwhile, took ten and a half hours to warm to a temperature of 40 °F. In other words, the ice took twenty-one times the amount of time to arrive at the same temperature as the water. Therefore, Black concluded that the ice absorbed 147 units of heat (40 – 33) x 21 = 147. The water, by comparison, had absorbed 8 units of heat. Black thus proposed that 139 units of heat (147–8) had been absorbed by the melting ice and were in the water that had melted from the ice.[20]



The world's first ice-calorimeter, which was used in 1782–83 by Antoine Lavoisier and Pierre-Simon Laplace to determine the heat evolved in various chemical changes. Their calculations were based on Joseph Black's prior discovery of latent heat.

Black conducted additional experiments in which he came to better understand the concept of **latent heat**. Although he never formally published his findings, Black lectured on his discoveries, and he is credited with being the first to describe latent heat—the heat that is added or lost when a substance changes its state, such as when water freezes and becomes solid ice or evaporates and becomes steam. The latent heat involved in the melting of a solid or the freezing of a liquid is referred to as the **heat of fusion**. The latent heat involved in vaporizing a liquid or solid or condensing a gas is called the **heat of vaporization**. Black's findings not only revolutionized our understanding of thermochemistry, but they also led to major changes in the world at large. James Watt, the Scottish inventor of the steam engine—the advancement that drove much of the Industrial Revolution—was a student and friend of Black's who utilized the concept of latent heat to develop his invention.