9.6: Avogadro's Law

For most solids and liquids it is convenient to obtain the amount of substance (and the number of particles, if we want it) from the mass. In the section on The Molar Mass numerous such calculations using molar mass were done. In the case of gases, however, accurate measurement of mass is not so simple. Think about how you would weigh a balloon filled with helium, for example. Because it is buoyed up by the air it displaces, such a balloon would force a balance pan *up* instead of down, and a negative weight would be obtained.

The mass of a gas can be obtained by weighing a truly empty container (with a perfect vacuum), and then filling and re-weighing the container. But this is a time-consuming, inconvenient, and sometimes dangerous procedure. (Such a container might **implode**—explode inward—due to the difference between atmospheric pressure outside and zero pressure within.)

A more convenient way of obtaining the amount of substance in a gaseous sample is suggested by the data on molar volumes in Table $9.6.1$. Remember that a molar quantity (a quantity divided by the amount of substance) refers to the same number of particles.

TABLE* $9.6.1$*: Molar Volumes of Several Gases at 0°C and 1 atm Pressure.

Substance	Formula	Molar Volume/liter mol^{-1}
Hydrogen	$H_2(g)$	22.43
Neon	$Ne(g)$	22.44
Oxygen	$O_2(g)$	22.39
Nitrogen	$N_2(g)$	22.40
Carbon dioxide	$CO_2(g)$	22.26
Ammonia	$NH_2(g)$	22.09

The data in Table $9.6.1$, then, indicate that for a variety of gases, 6.022×10^{23} molecules occupy almost exactly the same volume (the ***molar volume***) if the temperature and pressure are held constant. We define ***Standard Temperature and Pressure (STP)*** for gases as 0°C and 1.00 atm (101.3 kPa) to establish convenient conditions for comparing the molar volumes of gases.

The molar volume is close to 22.4 liters (22.4 dm^3) for virtually all gases. That *equal volumes of gases at the same temperature and pressure contain equal numbers of molecules* was first suggested in 1811 by the Italian chemist Amadeo Avogadro (1776 to 1856). Consequently it is called **Avogadro's law** or **Avogadro's hypothesis**.

Avogadro's law has two important messages. First, it says that molar volumes of *all* gases are the same at a given temperature and pressure. Therefore, even if we do not know what gas we are dealing with, we can still find the amount of substance. The image below demonstrates this concept. All 3 balloons are full of different gases, yet have the same number of moles and therefore the same volume (22.4 Liters).

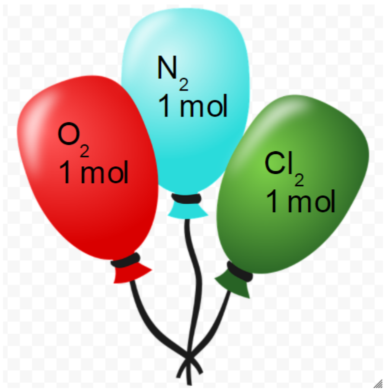


Illustration of three different colored balloons with 1 mol of oxygen gas, 1 mol of nitrogen gas, and 1 mol of chlorine gas respectively. The size of all the balloons are identical.

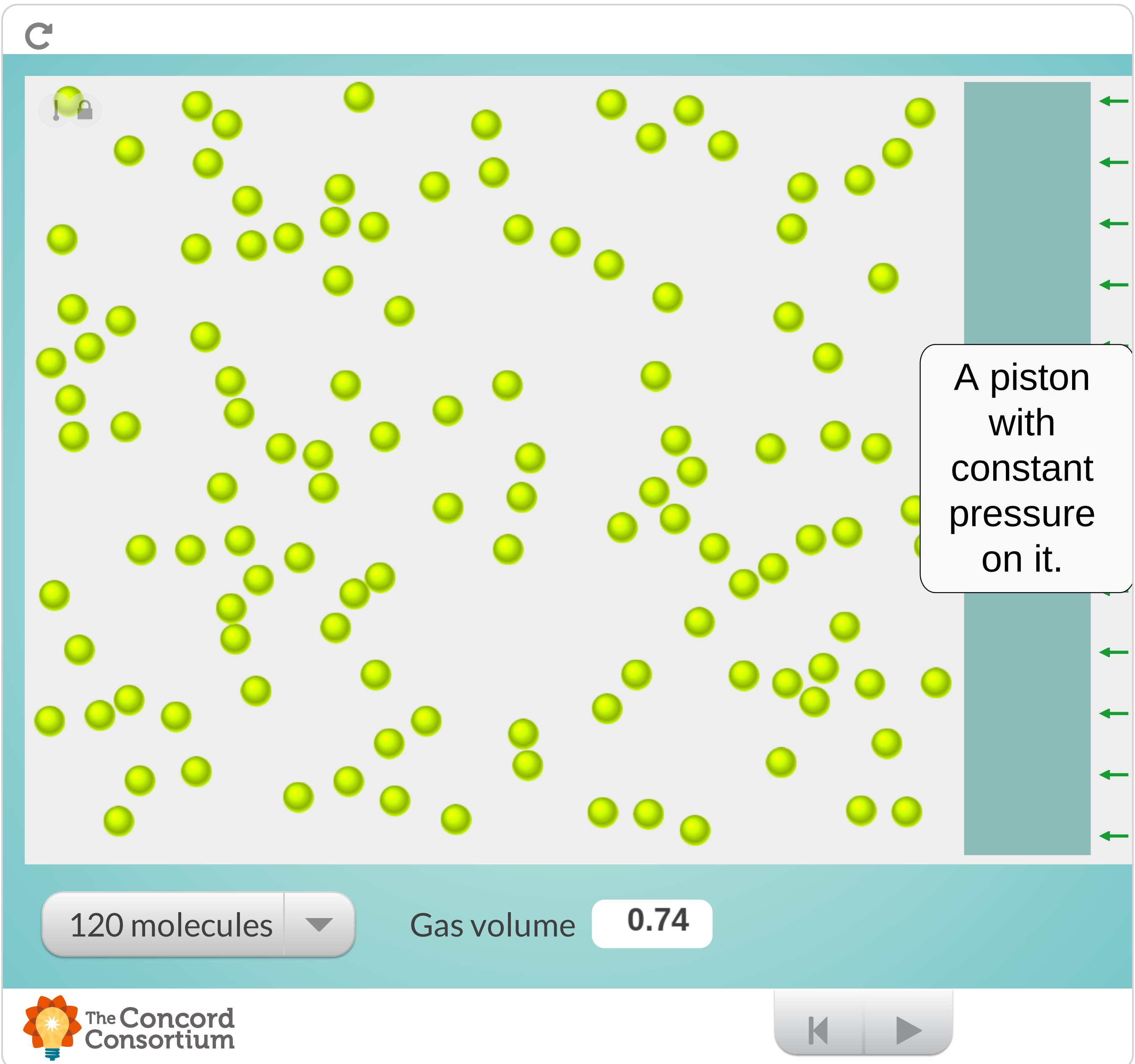
Second, we expect that if a particular volume corresponds to a certain number of molecules, twice that volume would contain twice as many molecules. In other words, *doubling* the volume corresponds to *doubling* the amount of substance, *halving* the volume corresponds to *halving* the amount, and so on.

In general, if we *multiply* the volume by some factor, say *x*, then we also *multiply* the amount of substance by that same factor *x*. Such a relationship is called direct proportionality and may be expressed mathematically as

$$V \propto n \tag{9.6.1}$$

where the symbol $\propto$ means "is proportional to."

For a simple demonstration of this concept, play with Concord Consortium's tool shown below, which allows you to manipulate the number of gas molecules in an a certain area and observe the effects on the volume. Try beginning with the default 120 molecules and observing the volume. Then cut the number of molecules in half to 60 and see what affect that has on the volume...*To begin the animation, press the play at the bottom of the screen.*



Any proportion, such as Equation 9.6.1 can be changed to an equivalent equation if one side is multiplied by a proportionality constant, such a k_A in Equation 9.6.2:

$$\mathrm{V} = \mathrm{k}_A \mathrm{n} \tag{9.6.2}$$

If we know k_A for a gas, we can determine the amount of substance from Equation 9.6.2.

The situation is complicated by the fact that the volume of a gas depends on pressure and temperature, as well as on the amount of substance. That is, k_A will vary as temperature and pressure change. Therefore we need quantitative information about the effects of pressure and temperature on the volume of a gas before we can explore the relationship between amount of substance and volume.