Physical Properties of Gases and the Gas Laws

Gases have five physical properties, listed in the previous section that set them apart from solids and liquids. The four measurable physical properties described below are needed to describe the amount, state, or condition of a gas. An understanding of these properties if fundamental to understanding the physical and chemical behaviors of a gas.

The following four properties of gases and their relationships to one another are further described by the Gas Laws, to be investigated in a future section. The Gas Laws started to evolve in 1643 with the invention of the barometer by Torricelli and continued until 1873 with the van der Waals equation. These laws were formulated well before the Atomic Theory was accepted in the early 1800's. The gas laws led to numerous concepts including the mole, temperature, formula weight, absolute zero, kinetic energy, and stoichiometric coefficients.

What is a Law?

The term *law* as used in science is a generalization that describes one or more behaviors observed in nature.

Laws do not attempt to explain the phenomena they describe.

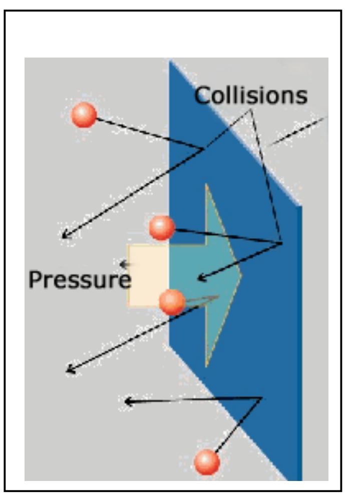
Laws may be expressed as mathematical equations.

Laws are never proven true; rather they are taken as true until they are found to be violated. The law must then be rewritten to be true with respect to this new evidence.

The Properties of Gases

1) Pressure

Gas particles collide with themselves as stated by the Kinetic-Molecular Theory. They also collide with the walls of their container.



Each collision exerts a force on the container wall. The force and number of these collisions that cause the phenomenon we have labeled *pressure*. These collisions are measured as pounds per unit area, for example, pounds per square inch (PSI.) Remembering this mental image will be very helpful in understanding the role of gas pressure.

The symbol P is used to refer to the pressure of a system in general.

The units used to measure pressure are as follows:
Atmospheric pressure at sea level is used as a standard around the world to facilitate communication among scientists. This value has been set at 1 atmosphere (1 atm) and is approximately equal to the force exerted:

3 descriptions of pressure

- by a 1" square column of air reaching into outer space (14.7 lbs or 1 PSI)
- by 1.01325 kg mass per square cm of surface (101.325 KPa)
- to push a column of Hg 760 mm into the air (760 mm Hg or 1 Torr)

sq. in on top of your head — 35 in² x 14.7 psi (weight of air on each sq in) = 514 lbs → no wonder we are tired at night!

Pressure Units and Conversions

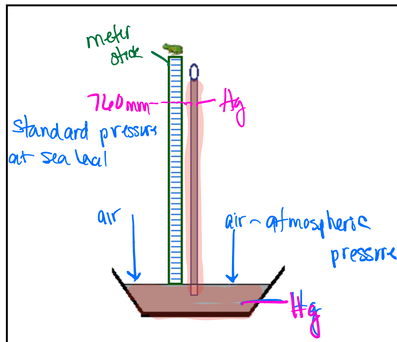


Figure 1:
A Simple Barometer: the air is pressing down on the flat surface of the mercury in the dish with a force great enough to cause the mercury in the tube to rise to a height of 760 mm.

The atmospheric pressure per square inch at sea level is
14.7 pounds of air per square inch of surface
14.7 pounds per square inch (PSI) is also equal to:
14.7 PSI = 1 atmosphere
14.7 PSI = 760 mm Hg (also known as 1 Torr)
14.7 PSI = 101.325 KPa

so:
1 atm = 760 mm Hg = 101.325 KPa
atmospheres (atm)
millimeters of mercury (mm Hg)
Pascals (Pa) or, more commonly, kiloPascals (KPa)

Standard pressure is defined as one atm. or 760.0 mm Hg or 101.325 KPa. Standard temperature, explained later, is taken at 0°C. Standard temperature and pressure are used commonly in chemistry. The abbreviation is STP.

There is no actual standard volume for gases. Gas volume varies greatly with temperature and pressure. Volumes are sometimes described as Standard Molar Volume. Standard Molar Volume will be defined in the next section as the volume occupied by one mole of any gas at the standard pressure of 1 atm and the standard temperature of 0°Celsius.

2) Volume

The three-dimensional space enclosed by the container walls is called volume. The volume of a gas is measured by placing it in a sealed container of known volume. The constant motion of the particles of a gas as described earlier is responsible for the gas completely filling the container, so the gas volume can be accurately taken as the volume of the container. When the generalized variable of volume is discussed or used in an equation, the symbol V is used. The pressure and temperature of the gas are needed to give meaning to the volume measurement as well.

Due to this movement of particles, the same number of particles in a sample of gas will fit any container they are placed in. If the gas is allowed to flow into a larger container, the particles will simply have more space to move and the space between the particles increases. If the particles are forced into a smaller container, the particles will have less space to move and the space between them will decrease.

Volume is measured in:

Liters, represented by the unit L
1 cubic decimeter (1 dm^3) = 1 Liter.
milliliters , mL
cubic feet, cu. ft. or ft^3
cubic centimeters, cc or cm

Constant volume can be maintained if the container has thick, rigid walls as in a cylinder to hold a compressed gas; for example a welder's tank or SCUBA cylinder.

The units used must be consistent throughout the problem. Use the following common conversions:

1 L = 1000 mL
1 mL = 1 cm^3

Volume changes greatly in response to temperature and pressure changes. Boyle's Law and Charles' Law illustrate these changes. Volume change means the container involved in the experiment has a movable wall. The walls of the container move farther apart as the volume increases. When the volume goes down, the walls move closer together again. There is no movement of gas particles in or out of the container.

If the volume is constant, then the container is made with thick, rigid walls that cannot move. If the pressure increases too much, the walls would break, destroying the experiment.

3. Temperature

Gas temperature is measured in degrees Celsius (°C). The word Celsius is capitalized, as it is the surname of Anders Celsius. The symbol T is used to represent temperature in mathematical equations.

The temperature scale important in describing gas behavior is called the Kelvin scale (K, with no degree sign). Kelvin is capitalized because this was a person's title (Lord Kelvin, his given name was William Thomson).
When collecting data on gases, temperatures are measured with a Celsius thermometer and converted mathematically to Kelvin. Reasons why gas calculations must be done in Kelvins are twofold:

1. The Kelvin temperature scale does not use negative numbers. 0 K is the lowest temperature possible, Absolute Zero.
2. Charles' Law shows the relationship between the changes in volume of a gas per degree Celsius of temperature change to be 1/273 the volume of the gas per degree Celsius temperature change. The Kelvin temperature scale is based on this observation.

To convert between Celsius and Kelvin:

Kelvin = Celsius + 273.15.

Often, the value of 273 is used instead of 273.15. In either case, the number of significant digits is taken to be the same as the temperature measurement used. All examples to follow will use 273 for convenience. For example, 25 °C = 298 K, because 25 + 273 = 298.

Standard temperature is defined as zero degrees Celsius or 273 K.

The Kelvin temperature of a gas is directly proportional to its kinetic energy. Double the Kelvin temperature, you double the kinetic energy.

4. Amount of Gas

The amount of gas present is measured in moles (mol) or in grams (g). Grams will need to be converted to moles at some point. When the generalized variable of amount in moles is discussed, the letter "n" is used as the symbol (note: the letter is in lowercase. The others above are all caps.).

* Know

Standard Temperature and Pressure (STP)
Standard Temperature of a gas is 0°C or 273K. Standard pressure is 1 atm or 760 mm Hg.

Standard Molar Volume of a Gas
The volume of a gas is dependant on the temperature and pressure. If a fixed number of particles, in this case 6.02×10^{23} particles, known collectively as 1 mole, are held at a constant temperature of 1 atm (760 mm Hg) and 0°C (273K) they will occupy a volume of exactly 22.4 Liters.

This volume is the same regardless of what gas sample is used; be it O_2 or N_2 or CO_2 or C_3H_8. If 1 mole of any gas is at STP, it will occupy a volume of 22.4 Liters. This is a convenient relationship to know when working with gas laws and calculations.

Abbreviations	**Conversions**
atm - atmosphere	K = °C + 273
mm Hg - millimeters of mercury	$1\ cm^3$ (cubic centimeter) = 1 mL (milliliter)
torr - another name for mm Hg	$1\ dm^3$ (cubic decimeter) = 1 L (liter) = 1000 mL
Pa - Pascal (kPa = kilo Pascal)	Standard Conditions
K - Kelvin	0.00 °C = 273 K
°C - degrees Celsius	1.00 atm = 760.0 mm Hg = 101.325 kPa = 101,325 Pa

example using conversion factor and dimensional analysis

A gas at 1.2 atm of pressure is cooled and its new pressure is 520 kPa. → ___ kPa   1atm = 101.325 kPa

$1.2\ atm \times \frac{101.325\ kPa}{1\ atm} = 121.59\ kPa$