Pressure is determined by the flow of a mass from a high pressure region to a low pressure region. Pressure measurements are made on the fluid states—liquids and gases. Air exerts a pressure which we are so accustomed to that we ignore it, however the pressure of water on a swimmer is more noticeable. You may be aware of pressure measurements in relations to the weather, your car, or bicycle tires.

What is pressure?

Pressure is a force exerted by the substance per unit area on another substance. The pressure of a gas is the force that the gas exerts on the walls of its container. When you blow air into a balloon, the balloon expands because the pressure of air molecules is greater on the inside of the balloon than the outside. Pressure is a property which determines the direction in which mass flows. If the balloon is released, the air moves from a region of high pressure to a region of low pressure and the balloon deflates.

Atmospheric pressure varies with height just as water pressure varies with depth. As a swimmer dives deeper, the water pressure increases. As a mountain climber ascends to higher altitudes, the atmospheric pressure decreases. His body is compressed by a smaller amount of air above him. The atmospheric pressure at 20,000 feet is only one-half of that at sea level because about half of the entire atmosphere is below this elevation.

Atmospheric pressure at sea level can be expressed in terms of 14.7 lbs/in\(^2\). The pressure in car or bicycle tires is also measured in pounds per square inch. A car should have 26-30 lbs/in\(^2\) and bicycle tires 40-60 lbs/in\(^2\). All gases that occupy a space have a pressure of some measurable degree. Gas Pressure is measured in mmHg (millimeters of mercury) with a barometer, which gives the barometric pressure. The standard atmospheric pressure is "the pressure exerted by a mercury column of exactly 760 mm in height when the density of mercury= 13.5951 g/cm\(^3\) (0 degrees C) and the acceleration due to gravity." This unit of measurement is referred to as a torr, and 760 Torr equal one atm, or atmospheric pressure. However, the SI unit for pressure is the pascal (Pa), which equals approximately 1 kg m\(^{-1}\) s\(^{-2}\). One atm equals 1.01325 x 10\(^5\) Pa. The kPa is sometimes used as a large unit of measure; one atm equals 101.32 kPa. Typically, the standard atmosphere is a better unit of measurement than the pascal due to the fact that the latter is inconveniently small.

Barometer

Pressure is directly measured with a device called a barometer. Invented by Evangelista Torricelli (1608-1647), this mechanism operates similarly as a balance, using mercury as the standard weight. The barometer is a long, hollow, hook-shaped tube, which is filled with mercury on one end and left empty on the other. The empty end, which is filled with nothing but air, has the exact same cross-sectional area of Earth's atmosphere. This produces a perfect balance between the mercury and the atmosphere, and so when the atmosphere changes, the mercury adjusts to stay in equilibrium, thus measuring the atmospheric pressure. The formula for this pressure in the atmosphere is:

\[
\text{force}=\text{mass } \times \text{ acceleration}
\]

or

\[
F=ma
\]
Earth's acceleration of objects is based on its gravitational field and equals approximately 9.80665 m s\(^{-2}\). Additionally, since pressure is the force per the unit area being measured, then

\[ P = \frac{F}{A} = \frac{mg}{A} \]

where \( F \) is the total force, and \( A \) is the area being measured. In order to calculate pressure through the barometer tool, one would substitute the volume of mercury in the barometer into the equation. This would produce the equation

\[ P = \rho gh \]

where \( V = Ah \), so in that the final equation for pressure is defined as the product of density \( (\rho) \), gravity \( (g) \), and the height of the liquid or gas.

The weatherman is likely to give atmospheric pressure or barometric pressure as 30 inches (note that 30 inches is approximately 760 mm). This type of measurement is made with a Torricelli barometer. It consists of a long tube closed at one end, filled with mercury and inverted in a vessel of mercury.

At sea level, the force of the atmospheric pressure will support a column of mercury 760 mm in height. Actually, the weight of the column of mercury is equal to the force of the atmospheric pressure. In a similar fashion, atmospheric pressure forces water in a similar column up to 34 feet high!

### Simple Pressure Related Applications

- **DRINKING STRAW**: A drinking straw is used by creating a suction with your mouth. Actually this causes a decrease in air pressure on the inside of the straw. Since the atmospheric pressure is greater on the outside of the straw, liquid is forced into and up the straw.
- **SIPHON**: With a siphon water can be made to flow "uphill". A siphon can be started by filling the tube with water (perhaps by suction). Once started, atmospheric pressure upon the surface of the upper container forces water up the short tube to replace water flowing out of the long tube.

### Boyle's Law

In 1662 Robert Boyle made the first systematic study of the relationship between volume and pressure in gases. Boyle’s observations can be summed up in the statement: At constant temperature, the volume of a gas varies inversely with the pressure exerted on it.

### Kinetic Molecular Theory Explanation

Observations about pressure may be explained using the following ideas. The rapid motion and collisions of molecules with the walls of the container causes pressure (force on a unit area). Pressure is proportional to the number of molecular collisions and the force of the collisions in a particular area. The more collisions of gas molecules with the walls, the higher the pressure.
Pressure and Boyle's Law

In the 17th Century, Robert Boyle first formulated the relationship among pressure, volume, and temperature as they related to gas through the formula:

\[ P_1V_1 = P_2V_2 \]

where \( P \)= pressure and \( V \)= volume. This formula was a result of his experiments with gas and the observation he made that gas tended to change in pressure when it occupied different-sized containers. This relationship is often referred to as Boyle’s Law.

Additionally, Boyle noted that gases tend to "spring back" to it's original pressure after removed from a container in which it was either being compressed or expanded. Boyle discovered this through his J-tube device, which utilized mercury to measure pressure in the atmosphere. It worked by trapping air with mercury in one closed end and then measuring the difference in height (\( h \)) between the two levels on either side of the curve. The overall difference in height directly correlated with the pressure of the atmosphere. Boyle illustrated this through the formula

\[ P = 1 \text{ atm} + \frac{h \text{ (mm)}}{760 \text{ mm atm}^{-1}} \]

Demonstrations

- Antigravity
- Hanging water
- Magic Leaky Bottle - bottle with holes
- Upside down glass in water
- Battle of Two Balloons
- Balloon Blown Up inside Bottle

Outside Links

- [http://apollo.lsc.vsc.edu/classes/me...g_merc_bar.jpg](http://apollo.lsc.vsc.edu/classes/me...g_merc_bar.jpg)
- [http://dept.physics.upenn.edu/course..be_mercury.gif](http://dept.physics.upenn.edu/course..be_mercury.gif)

Problems

**Boyle’s Law**

1) Using \( P_1V_1 = P_2V_2 \), solve for \( V_2 \).
A gas occupying a 2.4L cylinder is measured with a barometer and found to have a pressure of 1.76 atm. The gas is then transferred to a smaller container, with a volume of 1.76 L. What is the new pressure of the gas?

2) Using $P_1V_1 = P_2V_2$, solve for $P_1$.

O$_2$ is removed from a vessel with a volume of 35 mL, and transferred to a new container of 24 L. The gas is then measured and the pressure obtained is found to be 55 torr. What was the original pressure, in standard atmospheres of the O$_2$ before it was transferred?

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