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Chapter 10: States of matter

Section 1: Properties of Fluids

A **fluid** is a material that has no fixed shape and can flow easily.

Thermal expansion is the increase in the volume of an object when it is heated. It occurs in all states of matter.

Plasma is the fourth state of matter, formed when a gas is heated to a very high temperature so that electrons break free from their atoms, leaving charged particles.

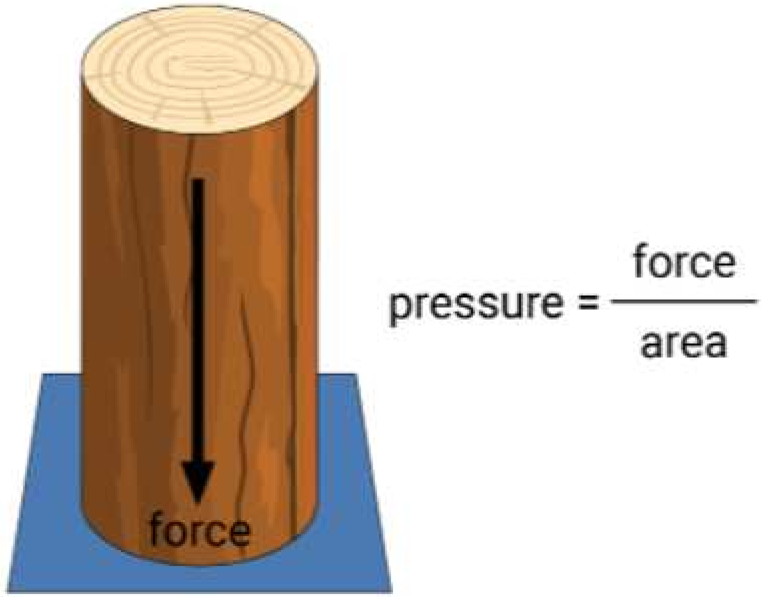
Lightning is plasma

The Sun and other stars are giant balls of plasma

Fluorescent lights and Neon signs contain plasma

Pressure is the amount of force (***F***), in newtons applied perpendicular to the surface of an object per unit area (*A*) in m^2.

$$P = \frac{\boldsymbol{F}}{A}$$



The SI unit of pressure is the **pascal** (Pa)**.** 1 pascal is the pressure exerted by a body that applies a force of 1 N over an area of 1 m^2.

The blade of an axe used to cut logs of wood has an area of 0.0025 m^2.

If the axe hits a log of wood with a perpendicular force of 10 N, how much pressure does the axe exert at the point it strikes the wood?

$A = 0.0025 \, m^2$

$F = 10 \, N$

$$P = \frac{F}{A}$$

$$= \frac{10 \, N}{0.0025}$$

$$= 4000 \, Pa$$

An elephant has a weight of 29,400 N. Calculate the pressure exerted by the elephant on the ground. Each foot has a radius of 0.2 m. (Use $\pi = 3.14$)

$F = 29{,}400\ N$

$A = 4 \times (\pi \times 0.2^2)$

$P = ?$

$P = \frac{F}{A}$

$= \frac{29{,}400}{4 \times (\pi \times 0.2^2)}$

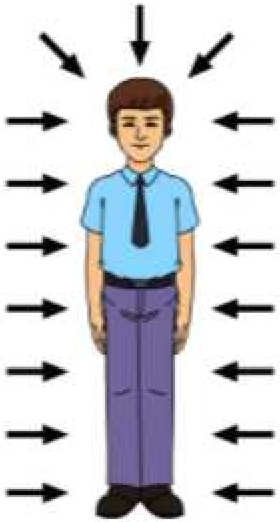
$= 5.85 \times 10^5\ Pa$

The pressure exerted by a liquid increases with depth.

If you make holes in a water bottle, the water coming out of the bottom hole has the highest pressure!

Go to the next tab for cool facts about pressure in the sea.

The air around us exerts pressure on our body from all directions. This pressure is called **atmospheric pressure**.



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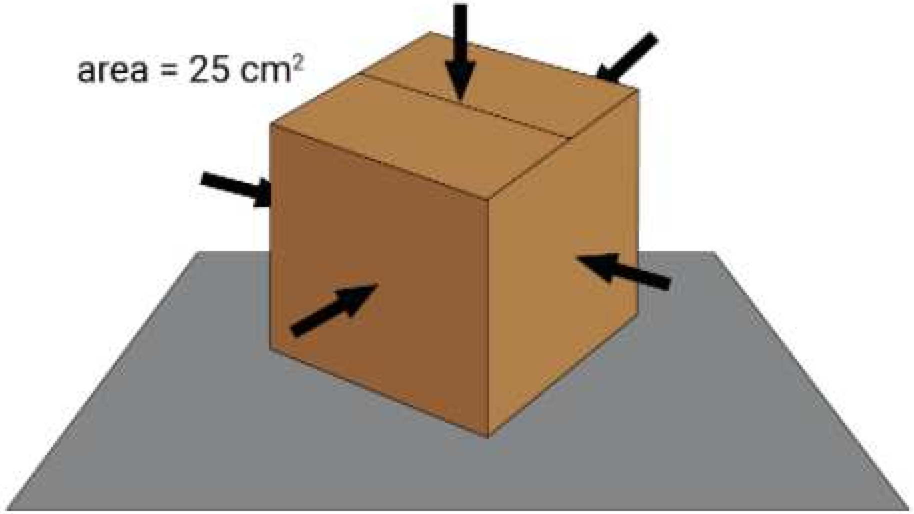
Atmospheric pressure is the pressure exerted by the air in our atmosphere.

Have you felt your ears popping while going up fast in an elevator, or when you are flying in an airplane?

Air pressure, like water pressure, decreases the higher you go.

When you are higher up in the air, the air pressure around you is lower, but the pressure inside your body takes a while to change. That’s why your ears pop.

- The air around a 5 cm × 5 cm × 5 cm cube exerts a 250 N on each side of the box. What is the atmospheric pressure?



$F = 250\,N$

area $A = 25\,cm^2$

$= 25 \times (10^{-2}\,m)^2$

$= 25 \times 10^{-4}\,m^2$

$P = \frac{F}{A}$

$= \frac{250\,N}{25 \times 10^{-4}}$

$= 10 \times 10^5\,Pa$ ✓

Boyle's law states that for gas under constant temperature, pressure and volume are inversely proportional.

$$P \, \alpha \, \frac{1}{V}$$

We can rewrite this as:

$$PV \quad = \text{ constant}$$

or

$$P_1V_1 \; = \; P_2V_2$$

If the volume of a gas sample at 100 kPa is reduced from 0.003 m^3 to 0.002 m^3, the change in its pressure can be calculated as follows:

(temperature is constant)

$V_1 = 0.003\ m^3$

$V_2 = 0.002\ m^3$

$P_1 = 100\ kPa$

$P_2 = ?$

$P_1 V_1 = P_2 V_2$

$$P_2 = \frac{P_1 V_1}{V_2}$$

$$= \frac{100 \times 10^3 \times 0.003}{0.002}$$

$$= 1.5 \times 10^5\ Pa$$

A pump of volume 0.032 m^3 is filled with air at 100 kPa. Calculate the air pressure inside the pump when the piston is pushed slowly halfway down the length of the pump so that the space inside it reduces to 0.016 m^3. Assume that the temperature stays the same.

$V_1 = 0.032 m^3$

$P_1 = 100 kPa$

$V_2 = 0.016 m^3$

$P_2 = ?$

$P_1 V_1 = P_2 V_2$

$P_2 = \frac{P_1 V_1}{V_2}$

$= \frac{100 \times 10^3 \times 0.032}{0.016}$

$= 2.0 \times 10^5 Pa.$

Charles' law states that for gas under constant pressure the volume and absolute temperature in kelvin are directly proportional.

$$V \alpha T$$

We can rewrite this as:

$$\frac{V}{T} = \text{constant}$$

or

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

If the temperature of a 5.4×10^{-3} m^3 gas sample is increased from 292 K to 305 K, the change in its volume can be calculated as follows (assuming the pressure is constant): (Final volume V_2)

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$V_2 = \frac{V_1}{T_1} \times T_2$$

$$= \frac{5.4 \times 10^{-3}}{292} \times 305$$

$$= 5.64 \times 10^{-3} \ m^3$$

A ball with a volume of 7.1×10^{-3} m^3 was left out in the garden all night. Overnight, the temperature dropped from 298 K to 288 K. What was the volume of the ball in the morning? Assume that the pressure stays the same.

$V_1 = 7.1 \times 10^{-3}\ m^3$

$T_1 = 298\ K$

$T_2 = 288\ K$

$V_2 = ?$

Charles' Law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$V_2 = \frac{V_1}{T_1} \times T_2 = \frac{7.1 \times 10^{-3} \times 288}{298}$$

$$= 6.86 \times 10^{-3}\ m^3$$

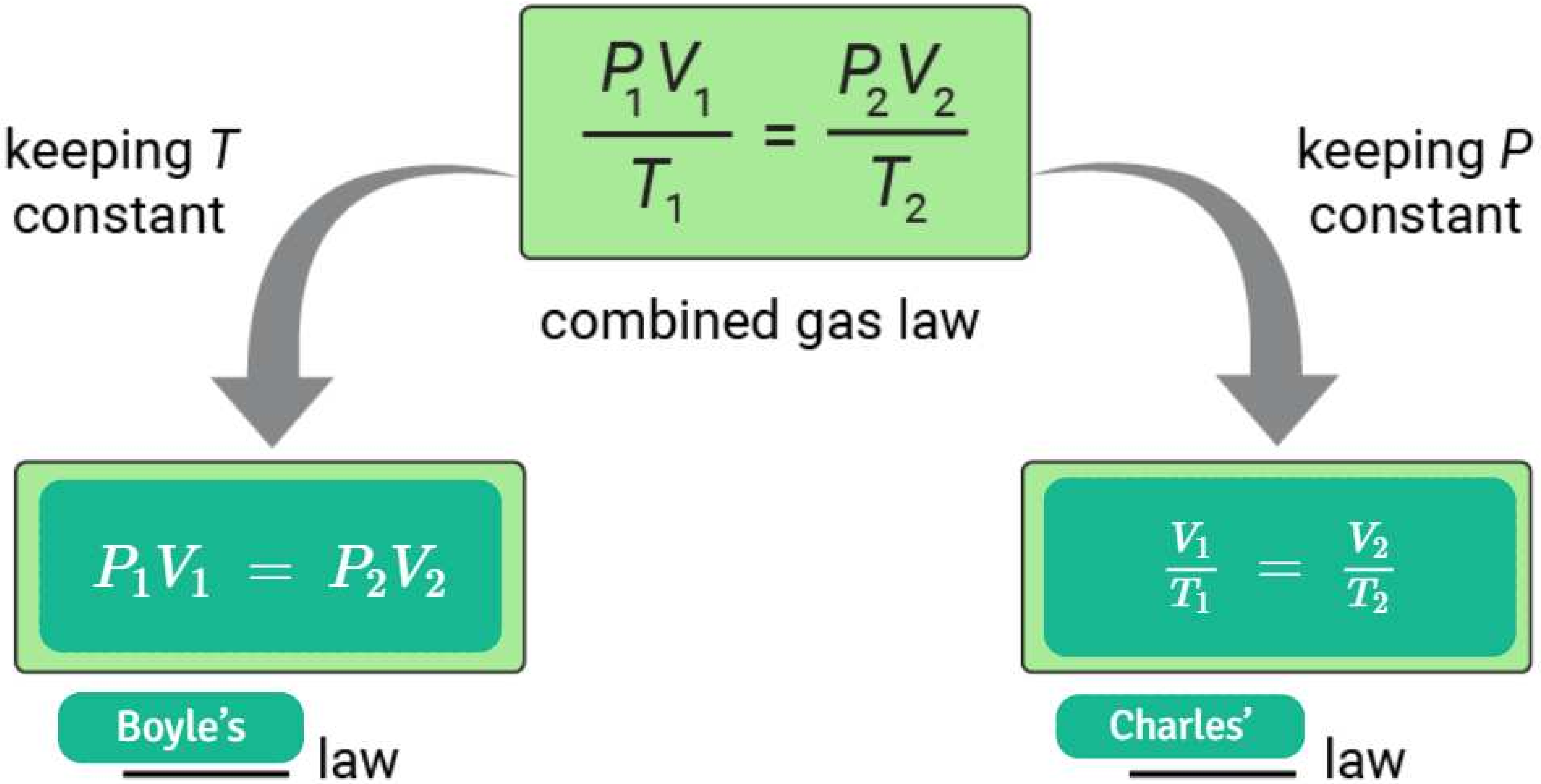
The **combined gas law** states that for a fixed amount of gas, at any time, if the pressure and volume are multiplied and this product is divided by the temperature, the result will be a constant.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{PV}{T} = \text{constant}$$

Or,

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$



$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
combined gas law
keeping T constant
keeping P constant
$P_1V_1 = P_2V_2$
$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Boyle's law
Charles' law

A balloon with a volume of $1.5 \times 10^{-3}\ m^3$, a temperature of 293 K, and a pressure of 120 kPa is left in the Sun for a few hours. If the temperature of the balloon increases to 318 K and its volume increases to $1.7 \times 10^{-3}\ m^3$ at the end of a few hours, what is the final pressure of the balloon?

$V_1 = 1.5 \times 10^{-3}\ m^3$

$T_1 = 293\ K$

$P_1 = 120\ kPa$

$T_2 = 318\ K$

$V_2 = 1.7 \times 10^{-3}\ m^3$

$P_2 = ?$

As pressure, volume and temperature changing use combined gas Law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$P_2 = \frac{P_1V_1T_2}{T_1V_2} = \frac{120 \times 10^3 \times 1.5 \times 10^{-3} \times 318}{293 \times 1.7 \times 10^{-3}}$$

$$= 1.15 \times 10^5\ Pa$$

A **mole** is a unit of measure of a large number of atoms or molecules in a substance. One **mole** contains exactly 6.022×10^{23} atoms or molecules of that substance. The SI unit of the mole is mol.

Avogadro's number is the number of particles in one mole: 6.022×10^{23} mol^{-1}.

The **ideal gas law** states that the product of the pressure and volume of an ideal gas is equal to the product of the number of moles of the gas, its Kelvin temperature, and the constant *R*.

$$PV = nRT$$

How many moles are there in a 4.5×10^{-3} m^3 sample of nitrogen at 297 K temperature and 125 kPa pressure?

$R = 8.31$ $Pa.m^3/(mol.K)$

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

$$= \frac{125 \times 10^3 \times 4.5 \times 10^{-3}}{8.31 \times 297} = 0.23$$

Calculate the pressure exerted by a 6.0×10^{-3} m^3 sample of hydrogen gas at 26°C, that contains 0.542 mol of hydrogen in it. $R = 8.31$ Pa.m^3/(mol.K)

$V = 6.0 \times 10^{-3}\ m^3$

$T = 26 + 273 = 299\ K$

$n = 0.542\ mol$

$R = 8.31$

$P = ?$

$PV = nRT$

$P = \frac{nRT}{V}$

$= \frac{0.542 \times 8.31 \times 299}{6.0 \times 10^{-3}}$

$= 2.24 \times 10^{5}\ Pa$

A 6.5 m^3 of oxygen is stored in a cylinder at 12,000 kPa and 22°C.

a. How will the pressure change if this gas is further compressed and filled into a 4.5 m^3 cylinder at 20°C?

b. Find the number of moles of oxygen in the cylinder.

c. Find the mass of oxygen in the cylinder (molar mass of oxygen is 32 g/mol).

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

a) $$P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{12000 \times 10^3 \times 6.5 \times 293}{295 \times 4.5}$$

$$= 1.72 \times 10^7 \text{ Pa}$$

b) $$n = \frac{PV}{RT} = \frac{12000 \times 10^3 \times 6.5}{8.31 \times 295}$$

$$= 3.2 \times 10^4$$

c) $$m = n \times M$$
$$= 3.2 \times 10^4 \times 32$$
$$= 1.02 \times 10^6 \text{ g}$$

A balloon filled with 0.134 mol of air at 18°C and 1.0135×10^5 Pa is left out in the Sun for a few hours.

a. What was the initial volume of the balloon?
b. Calculate the new pressure in the balloon if its volume increases to 4.0×10^{-3} m^3 and temperature increases to 21°C.
c. Calculate the mass of the air in the balloon (molar mass of air = 29 g/mol).