Chapter 3.2
The Gas Laws

Kinetic Theory of Gases

Pressure

Factors Affecting Pressure

Gas Laws

States of Matter

Focus Points

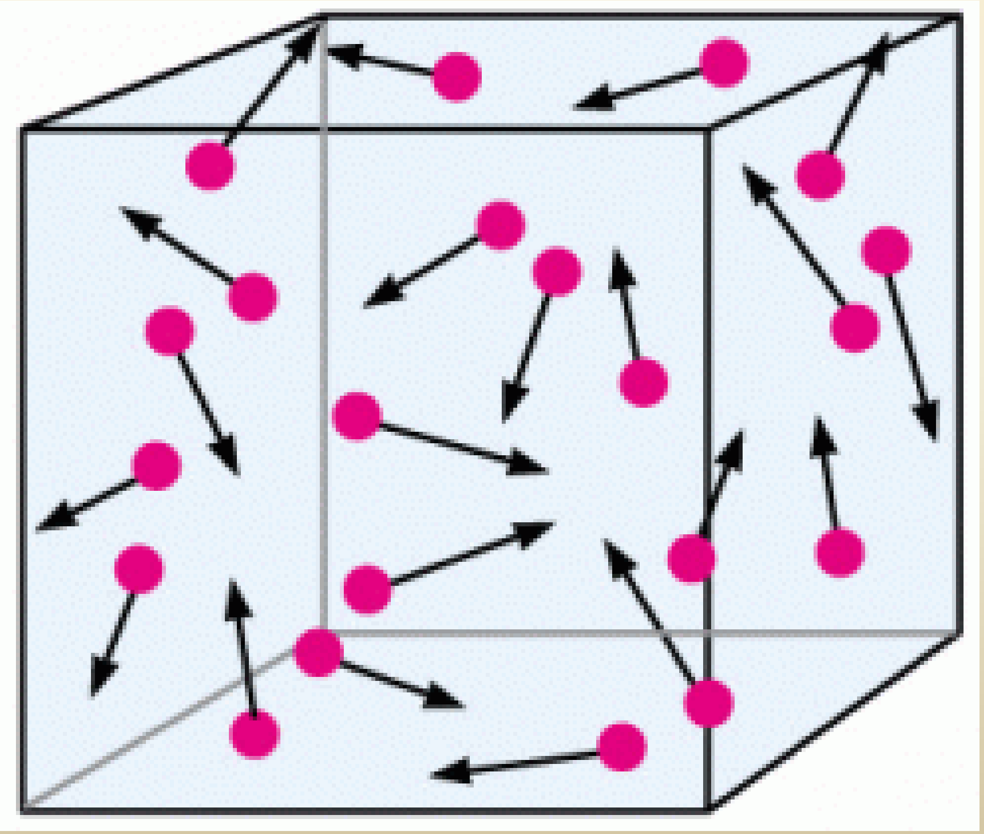
- Explain the behavior of gases based on the kinetic theory of Gases.
- Define pressure, volume, moles, and temperature in relation to gases.
- State and apply Boyle's law, Charles's law, and the combined gas law to calculate the relationships between volume, temperature, moles, and pressure.

Kinetic Theory – Model of a Gas

Properties of Gases

Describe the kind of motion the particles in the box are displaying. Give at least 3 aspects.

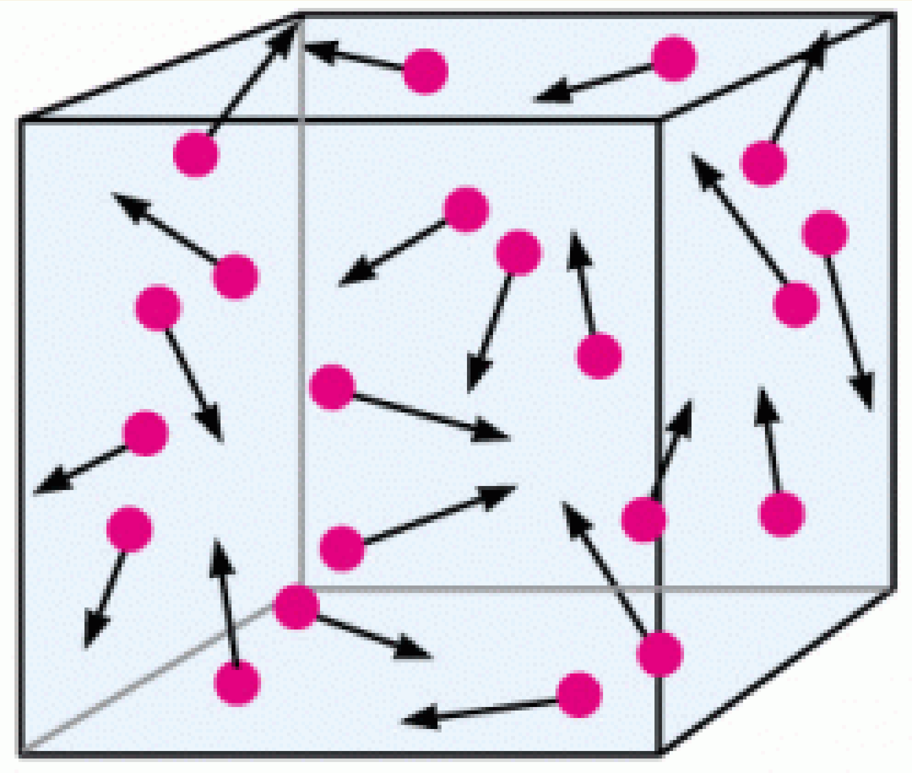
(Hint: pretend you are describing it to a blind person).



Kinetic Theory – Model of a Gas

Properties of Gases (*Assumptions*)

A gas is composed of individual PARTICLES which are in continuous, random, straight-line motion



Kinetic Theory – Model of a Gas

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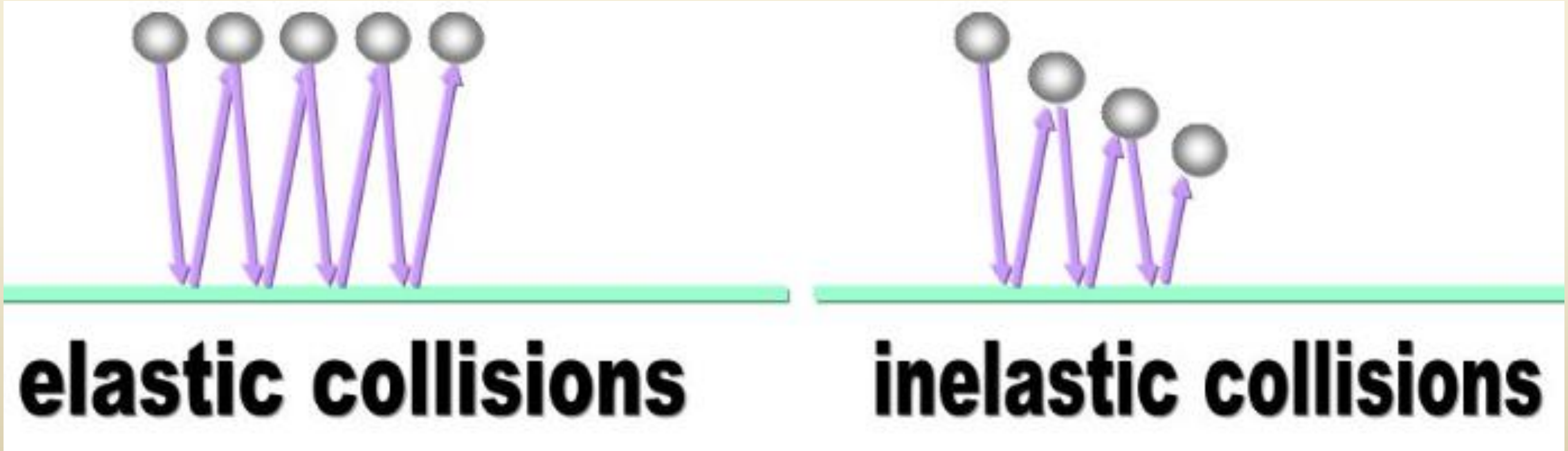
a. Collisions may result in a transfer of energy [***elastic collisions***], but the total net energy of the system remains constant.



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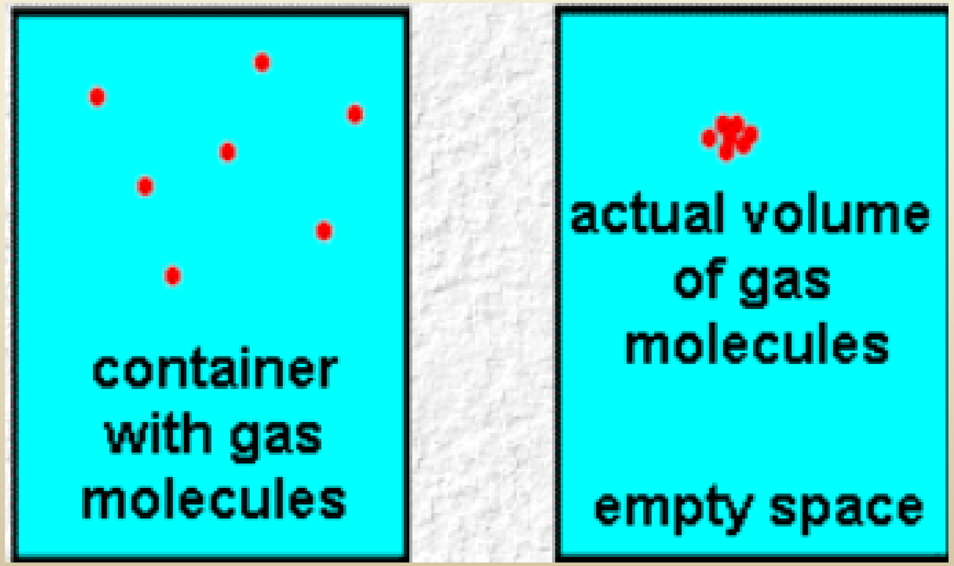
A gas is composed of individual PARTICLES which are in continuous, random, straight-line motion

a. Collisions may result in a transfer of energy [***elastic collisions***], but the total net energy of the system remains constant.

b. The volume of particles is ignored in comparison with the space in which they are *contained (i.e. earth's volume compared to the volume of the solar system*).



Kinetic Theory – Model of a Gas

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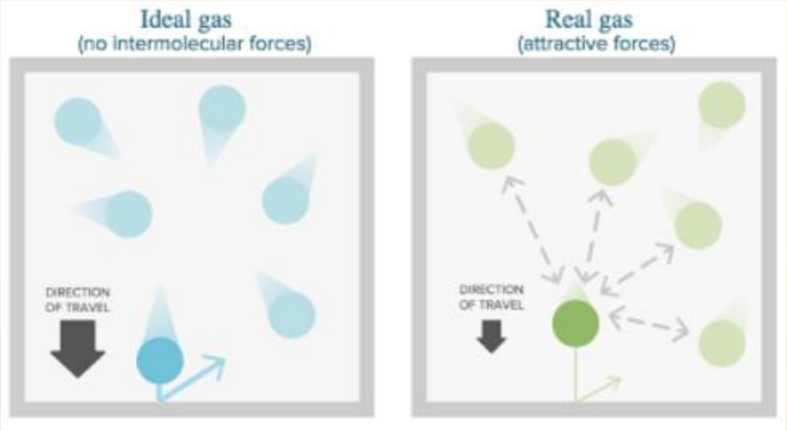
c. Gas particles are considered as having no attraction for each other.



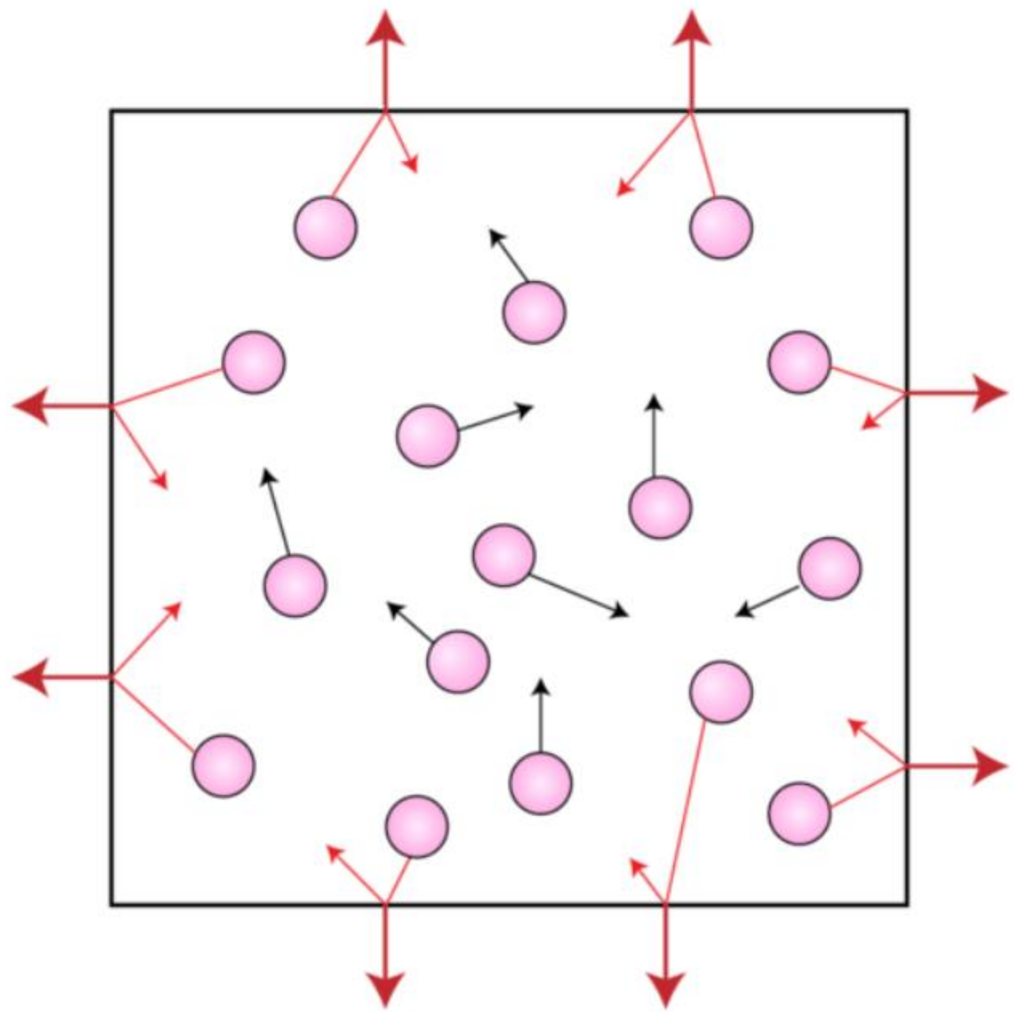
https://screencast-o-matic.com/watch/cFQXDlqmoM (2:01)

Kinetic Theory – Model of a Gas

Gases take the shape and volume of whatever container, room, or space they occupy.

The particles change direction only when they rebound from collisions.

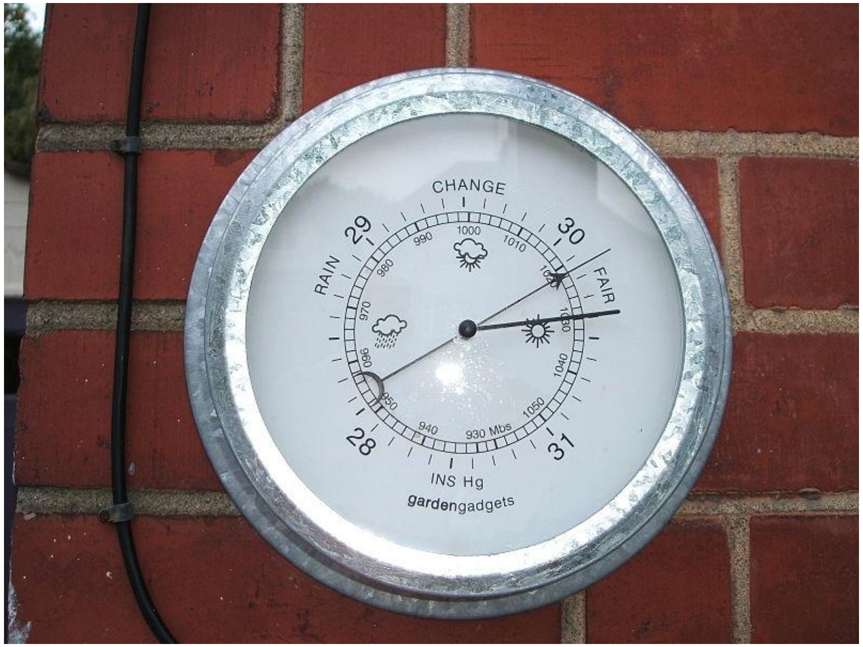
If no particles are present, no collisions can occur, meaning there is no pressure. An empty space with no particles and no pressure is called a **vacuum**.

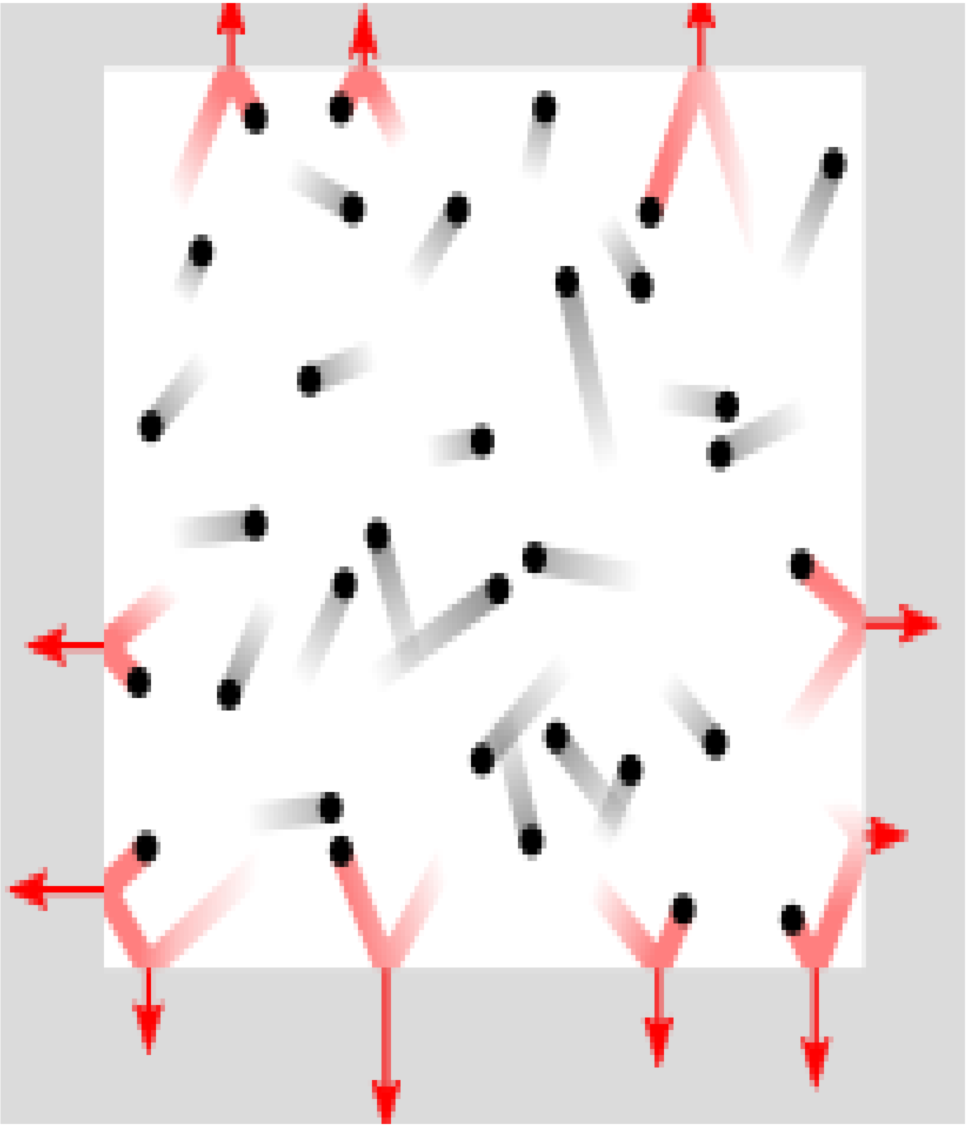


Gas pressure results from collisions with the surface of its container.

Gas Pressure

The force exerted by the particles of a gas colliding with the surface of an object.

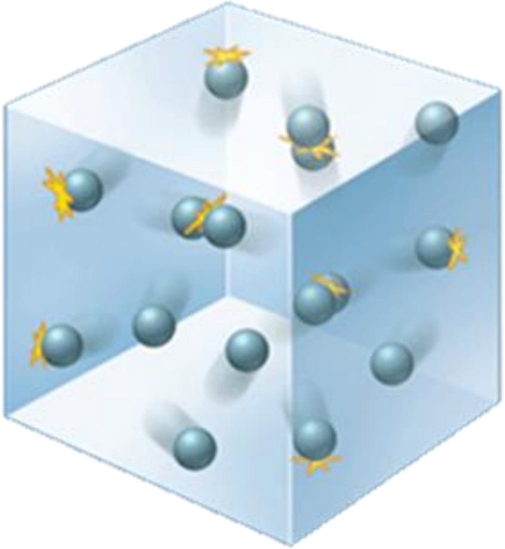


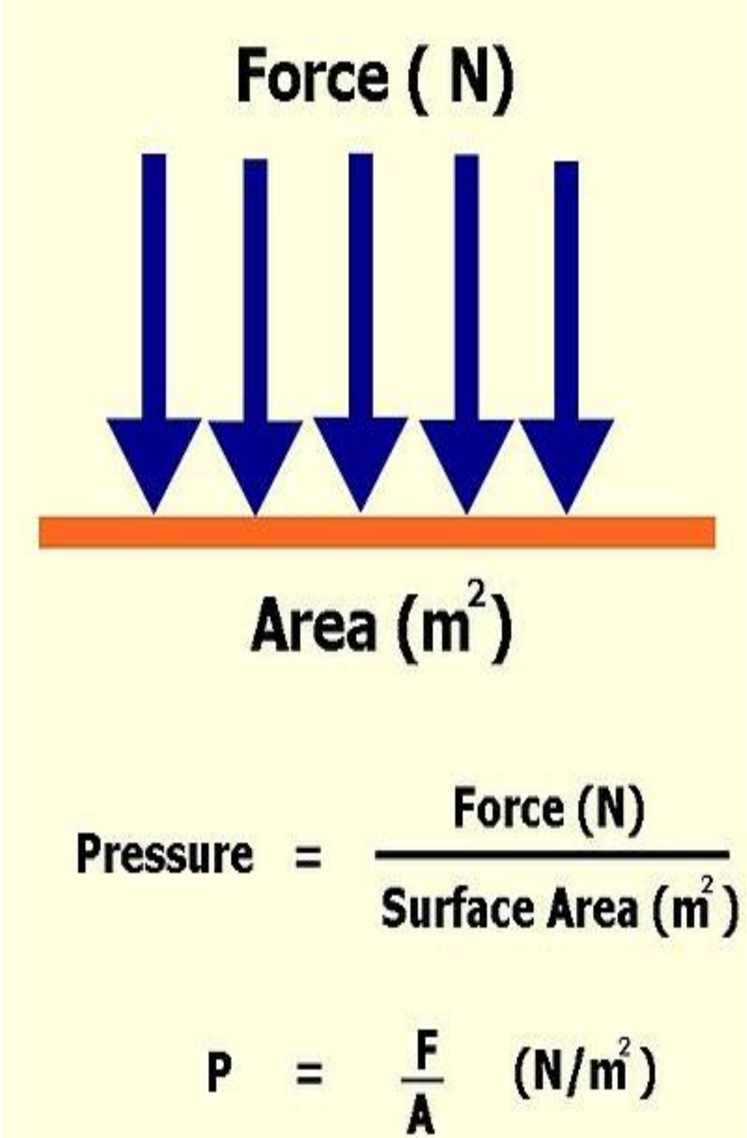


Pressure

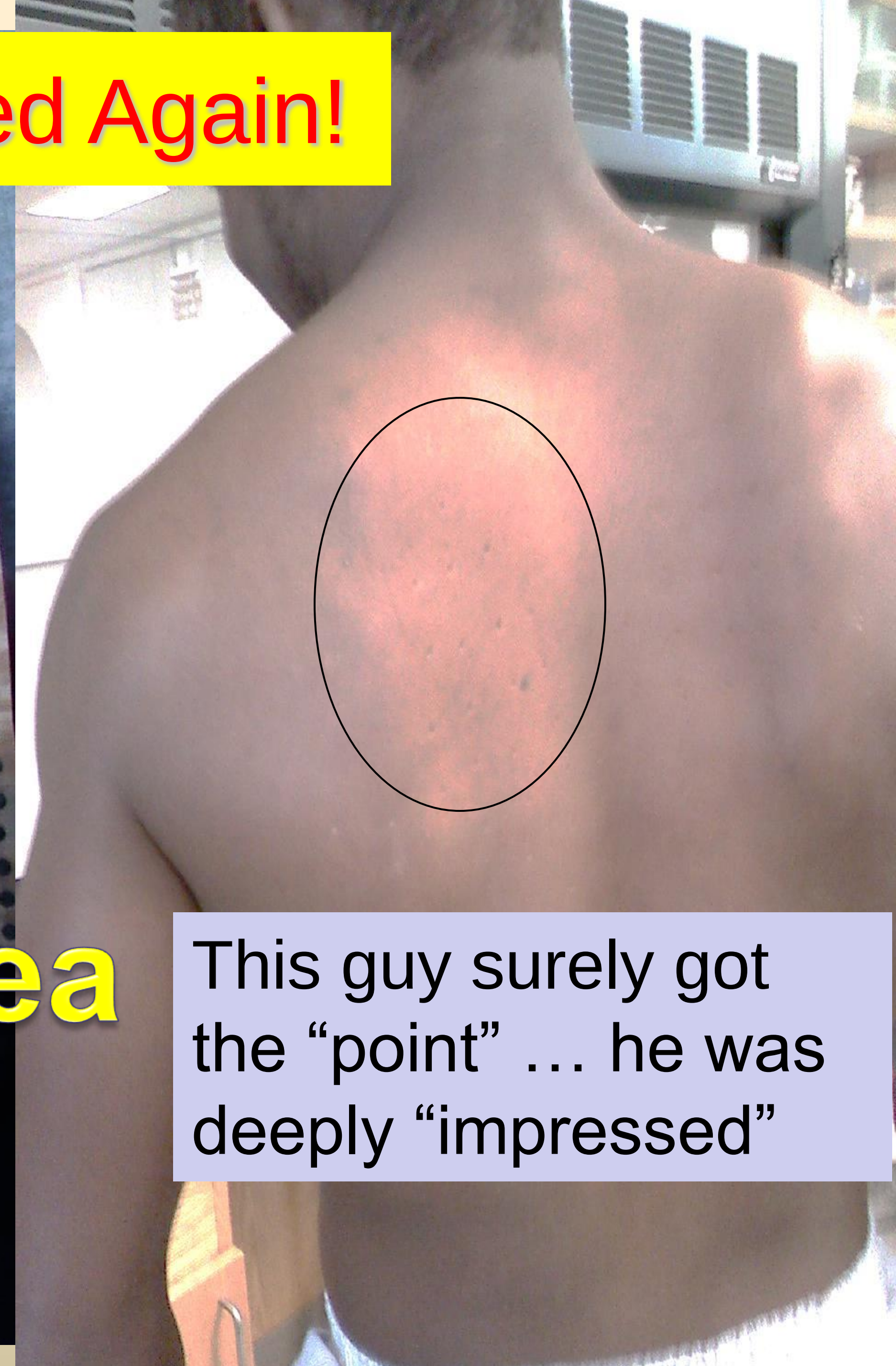
Higher Kinetic Energy → greater collision force → higher pressure

More collisions → greater collision force → higher pressure





Nailed Again!



Force/Area

This guy surely got the “point” … he was deeply “impressed”

Pressure

The pressure exerted on all objects [*force/area*]

Gas pressure is actually the air molecules **<u>colliding</u>** with surfaces. The more molecules, the more collisions → the more pressure.

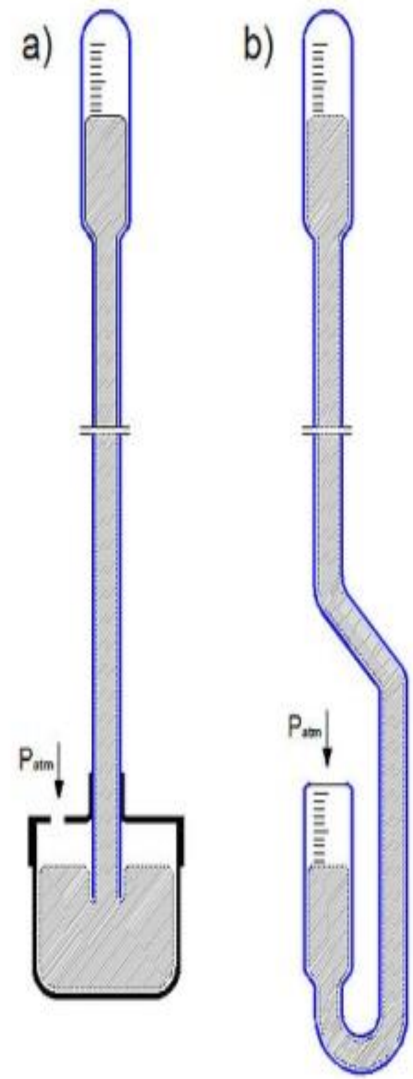
Measuring Pressure of a Gas (ENRICHMENT)

Barometer

device used to measure atmospheric pressure

- Original barometers used mercury
  - Dense
  - Low evaporation rate
- Modern barometers use small cells of air
  - Expansion or contraction moves dial

The pressure of gases can vary greatly. *Not so with liquids and solids.*



ENRICHMENT

Collapsing Can Experiment

Click on the link: (0:47)

https://screencast-o-matic.com/watch/cFQ6XyqEwm

Why did the can collapse?

See the link on Study Place:

FUN Pressure Activities Labs

QUICK CHECK

Which of the following statements describes gases based on the kinetic theory?

a. Particles of gas are in motion part of the time and stationary part of the time.
b. Particles in a gas are arranged in an orderly fashion.
c. Gas particles are not affected by collisions with other gas particles.
d. Forces of attraction between particles can be ignored under ordinary conditions.

What causes the pressure to increase if more gas particles are added to a closed container?

a. an increase in the number of collisions between the gas and the container walls
b. a decrease in the volume of the container
c. a decrease in the size of each particle as the number of particles increases
d. an increase in the number of collisions between air particles and the outside of the container

QUICK CHECK

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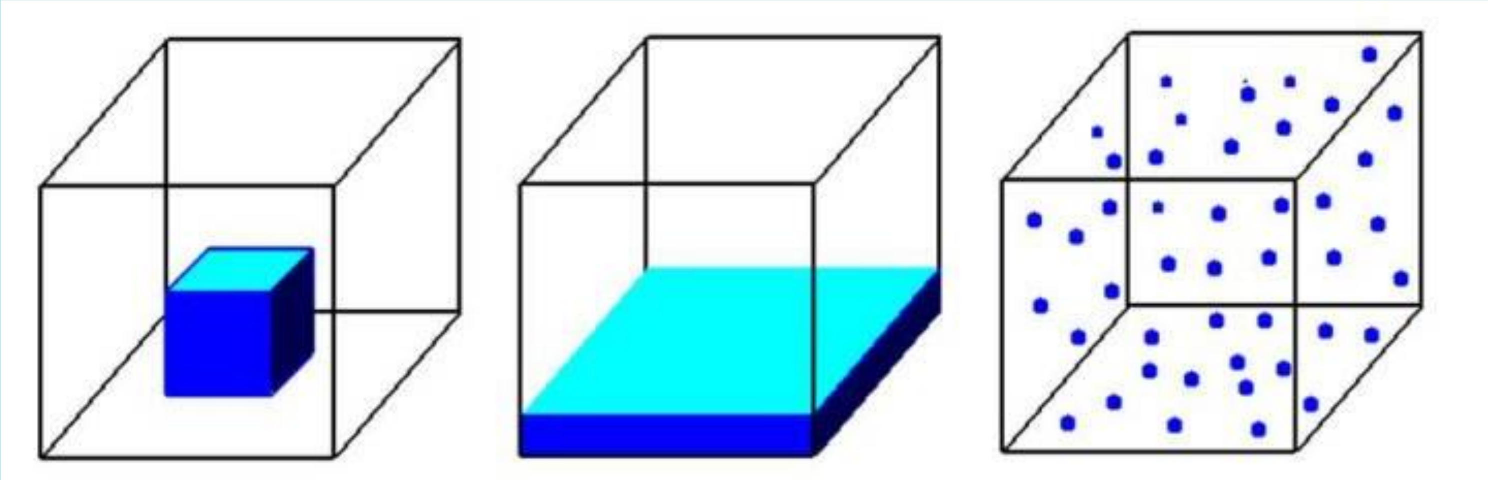
Kinetic Theory (pressure, volume, temperature)

Demonstrations (5:55)

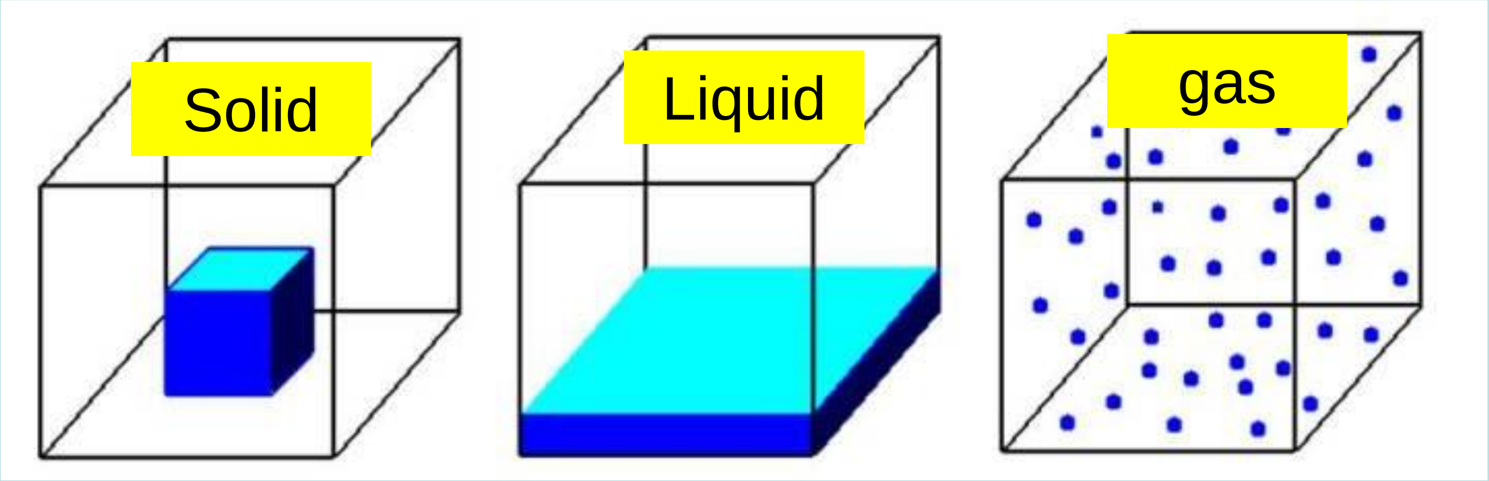
https://screencast-o-matic.com/watch/cFQiDiqp9D

WARM-UP



Label the three states of matter in the diagram & describe their shape, volume, density, molecular attractions, compressibility, expansivity, & what might affect it … in relation to each other.

	Shape	Volume	Density	Molecular Attractions	Compressibility	Expansivity	What might affect it
Solid							
Liquid							
Gas							



Label the three states of matter in the diagram & describe their shape, volume, density, molecular attractions, compressibility, expansivity, & what might affect it … in relation to each other.

	Shape	**Volume**	**Density**	**Molecular Attractions**	**Compressibility**	**Expansivity**	**What might affect it**
Solid	definite	definite	greatest	strongest	little	little	little
Liquid	Takes the shape container	definite	middle	middle	little	little	little
Gas	indefinite	fills container	least	weakest	great	great	T, P

Review of Pressure

Watch the video on Study Place:

https://screencast-o-matic.com/watch/cFeY3gDvx1

Pressure ctr (5:32)

- PSI (Breaking a Board using Atmospheric Pressure)
- Manometer Readings

Ideal Gas Law

ENRICHMENT

The foundation of Gas Laws

$$PV = nRT$$

P = pressure in atm, mm Hg, or kPa

V = volume in liters

n = moles

R = ideal gas constant based on units

T = temperature in Kelvins

Gas Parameters

$$PV = nRT$$

P = collisions

V = space occupied by gas

n = moles (number of particles)

R = ideal gas constant based on units [*enrichment*]

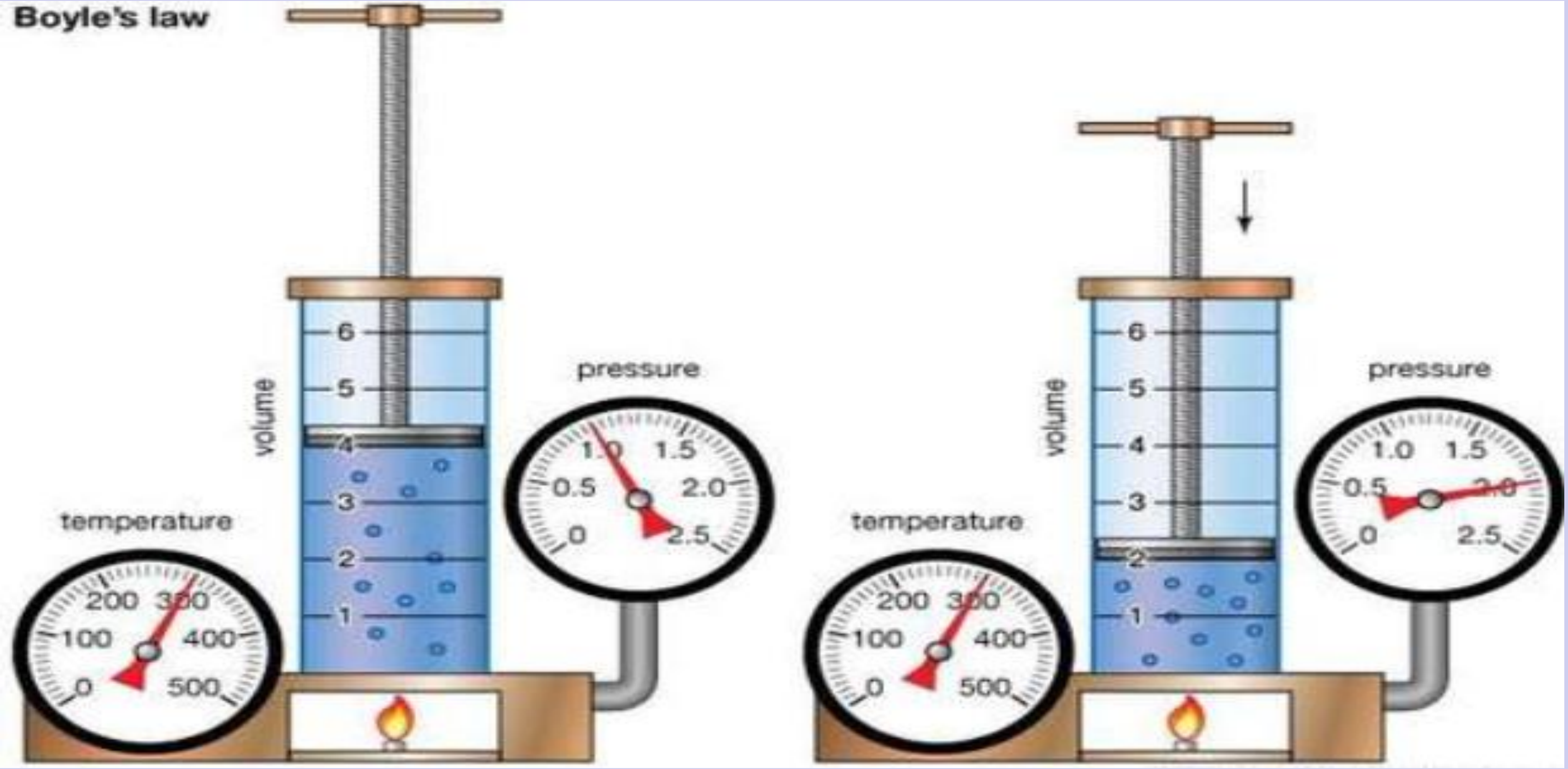
T = average kinetic energy (motion) of molecules

Boyle's Law

Boyle's Law describes the relationship between the volume of a gas and its pressure *at a constant temperature and* number of moles.

Describe the pressure (P) and volume (V) below:

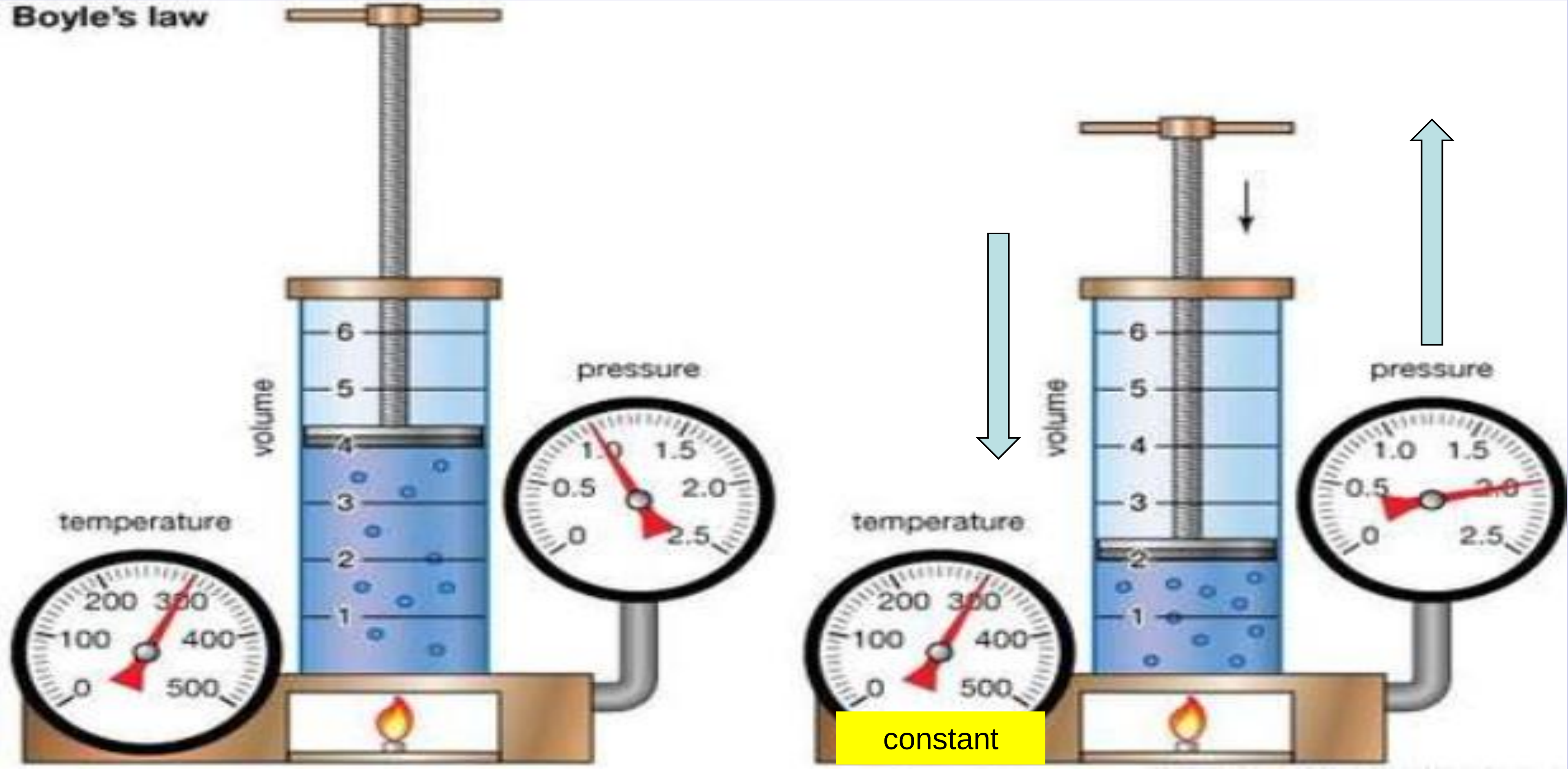
THINK ABOUT IT



Boyle's Law

A gas can be compressed to take up less space:

The higher the pressure applied to the gas, the smaller the volume it will occupy. (e.g. piston chamber in engines)



Boyle's Law

Example

Bubbles in a fish tank increase in size as they move toward the surface of the water experiencing LESS pressure.

Bubbles at the bottom of the tank are smaller, experiencing more pressure than bubbles up higher in the water.

Boyle's Law

Robert Boyle (1627-1691) decided to experiment with only pressure and volume of a gas, so he held the temperature and number of moles of the gas constant.

$$PV = \cancel{nRT} \rightarrow PV = k$$

[enrichment]

What mathematical relationship does this show?

Boyle's Law

Robert Boyle (1627-1691) decided to experiment with only pressure and volume of a gas, so he held the temperature and number of moles of the gas constant.

$PV =$ ~~nRT~~ $\rightarrow$ $PV = k$

INVERSE relationship of P to V

At the same conditions of temperature and moles:

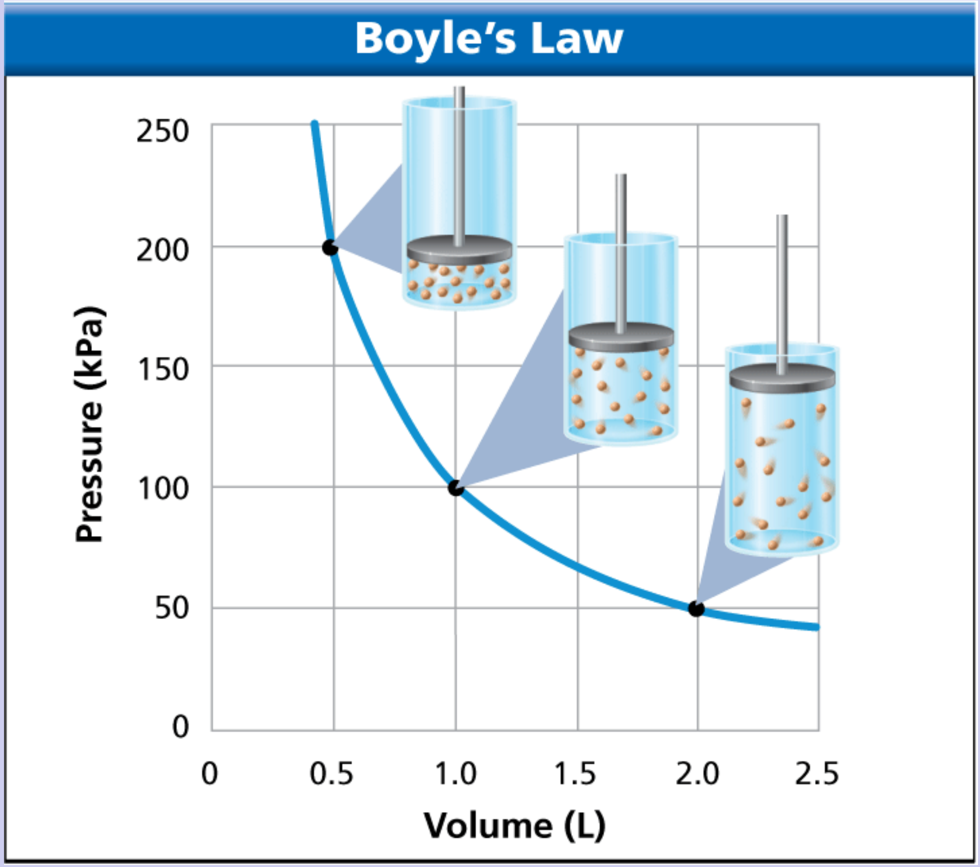
$P_1V_1 = k, \quad P_2V_2 = k$

Thus: $$P_1V_1 = P_2V_2$$

Boyle's Law

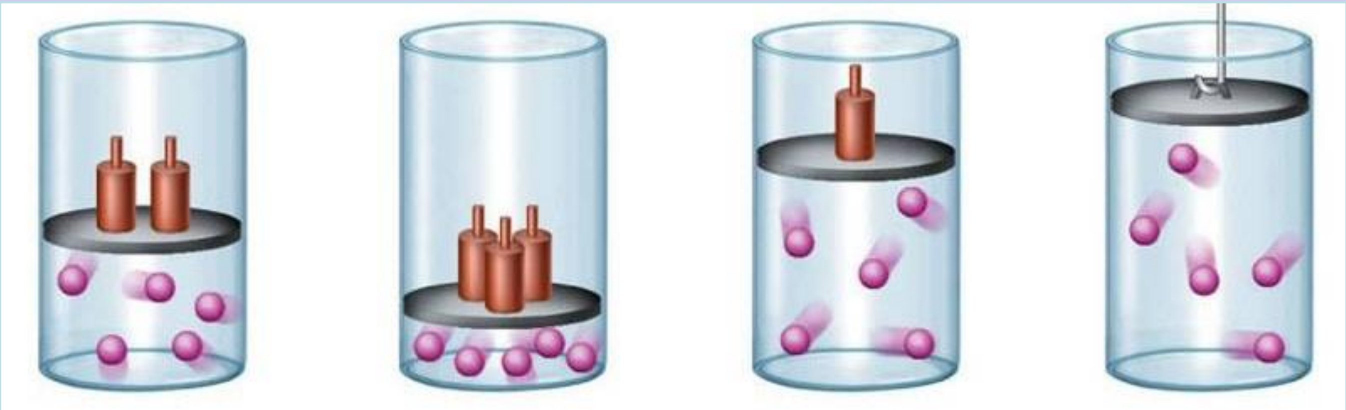
Pressure is inversely proportional to volume:

$$P_1V_1 = P_2V_2$$



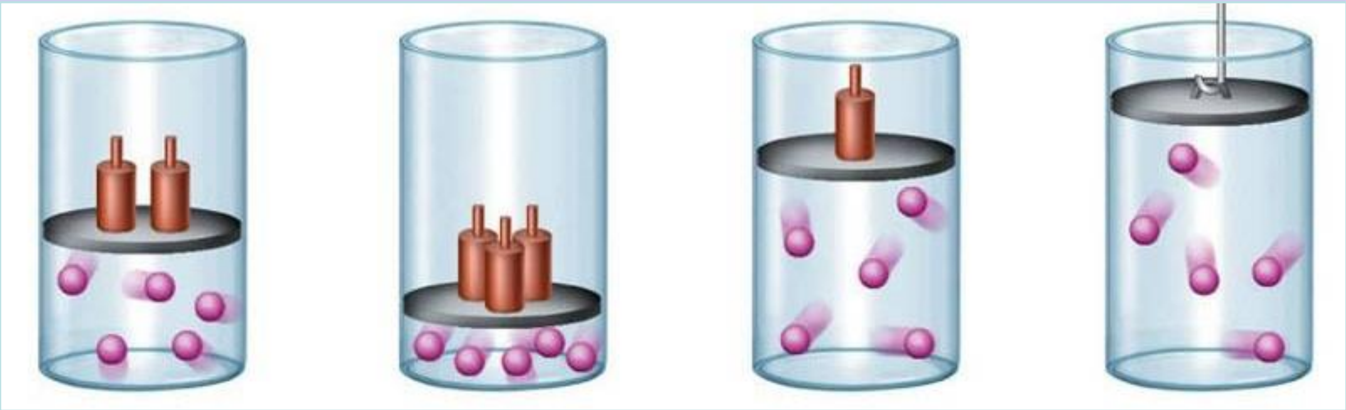
P ↑ V ↓

Boyle's Law



Describe the relationship between pressure and volume in the cylinders. Remember pressure is related to collisions.

Boyle's Law



Describe the relationship between pressure and volume in the cylinders. Remember pressure is related to collisions.

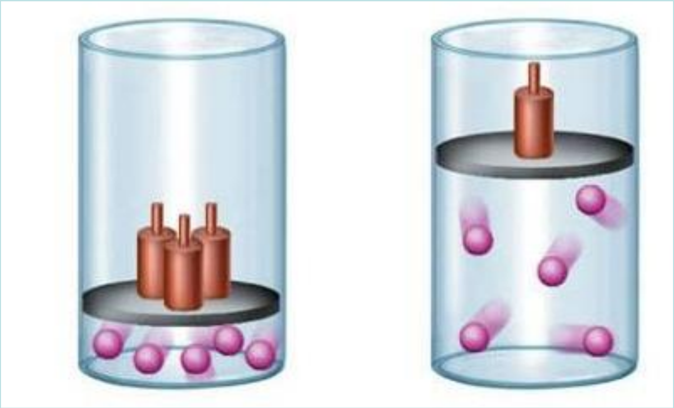
INVERSE relationship:

P ∞ 1/V … as pressure ↑ volume ↓ or vice versa

When molecules are confined to a smaller space (less volume), there are more collisions (more pressure).

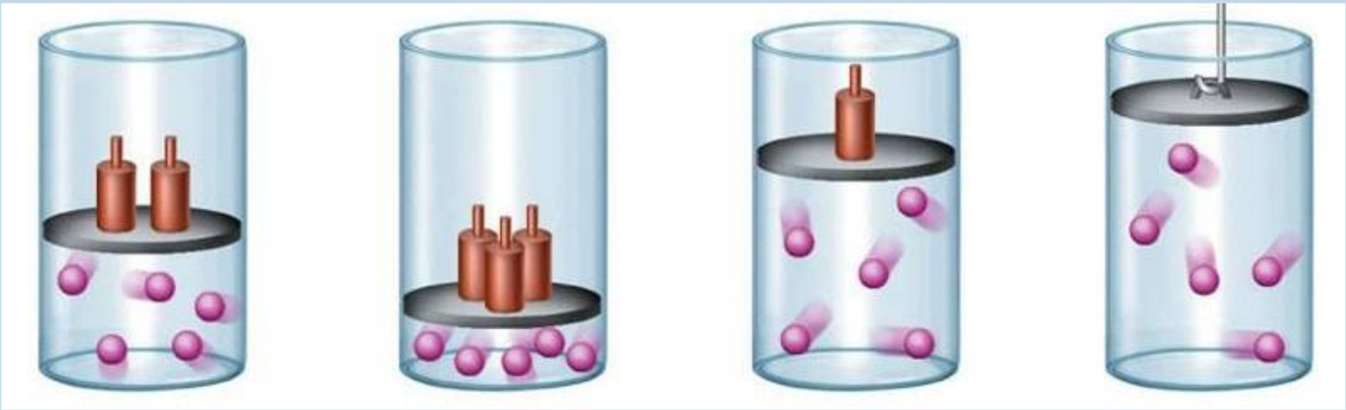
QUICK CHECK

Boyle’s Law



Find the volume of a gas which occupies 200. ml at 2.6 atm when it is at standard pressure (101.3 kPa) and temperature is constant.

Boyle's Law



Find the **volume** (V_2) of a gas which occupies 200. ml (V_1) at 2.6 atm (P_1) when it is at standard pressure (101.3 kPa)(P_2) and temperature is constant.

A: Volume (V_2)

G: 200. ml (V_1) at 2.6 atm (P_1) changed to 101.3 kPa (P_2)

E: $P_1V_1 = P_2V_2$ … solve for $V_2 = P_1V_1 / P_2$

S: V_2 = 200. ml x (2.6 atm/1 atm) = <u>520 ml</u>

(notice P ↓ V ↑)

Charles' Law

Jacques Charles (1746-1823) experimented with only temperature and volume of a gas, so he held the pressure and number of moles of the gas constant.

~~P~~V = ~~nR~~T → V/T = k

[enrichment]

What mathematical relationship does this show?

Charles' Law

Jacques Charles (1746-1823) experimented with only temperature and volume of a gas, so he held the pressure and number of moles of the gas constant.

$$\cancel{P}V = \cancel{n}RT \rightarrow V/T = k$$

DIRECT relationship of V to T

At the same conditions of pressure and moles:

$V_1 = kT_1, \quad V_2 = kT_2$

Thus: $$V_1/T_1 = V_2/T_2$$

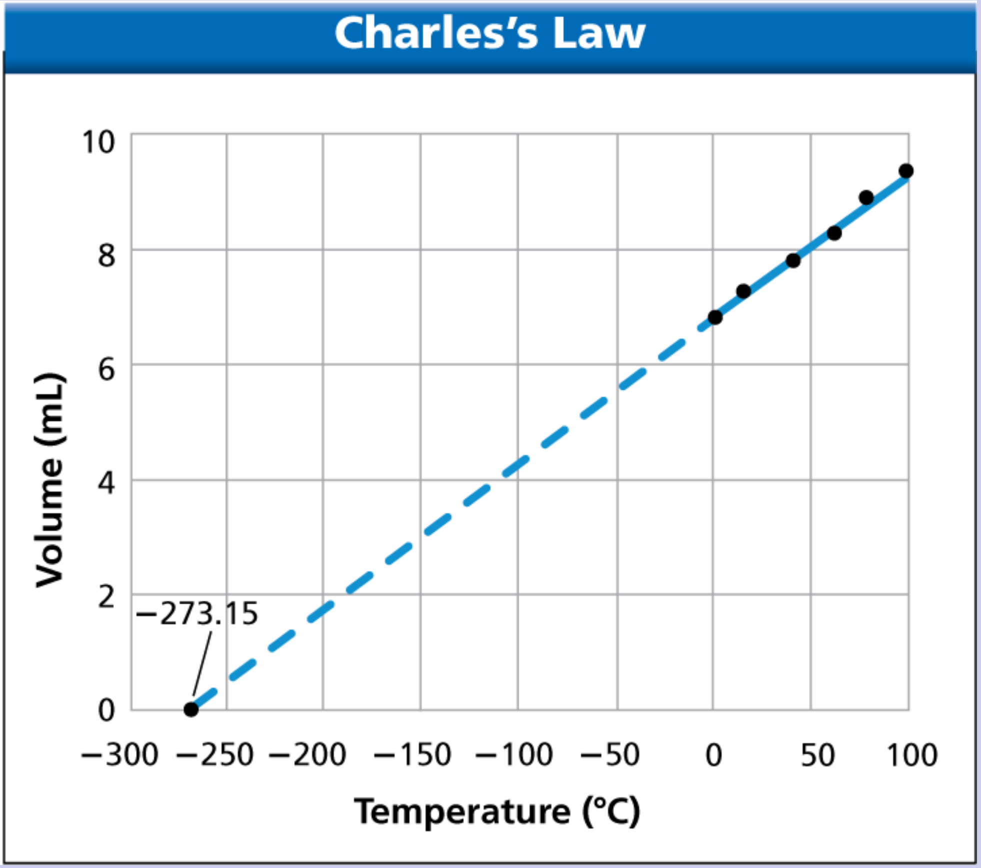
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Charles' Law

Temperature is directly proportional to volume:

$$V_1/T_1 = V_2/T_2$$

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



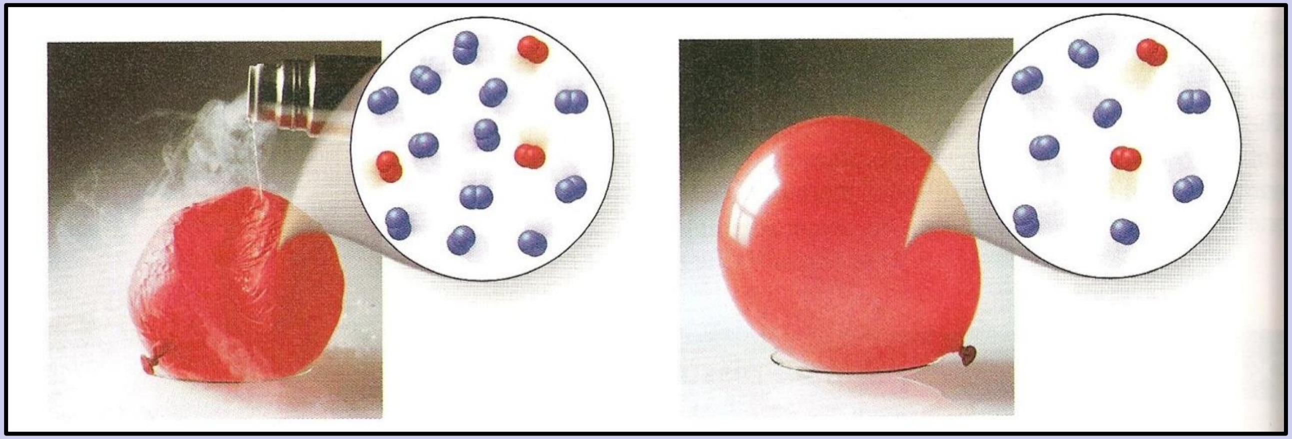
V ↑ T ↑

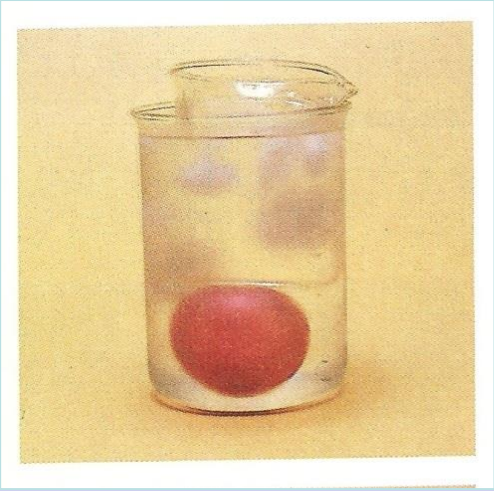
Absolute temperature **K**

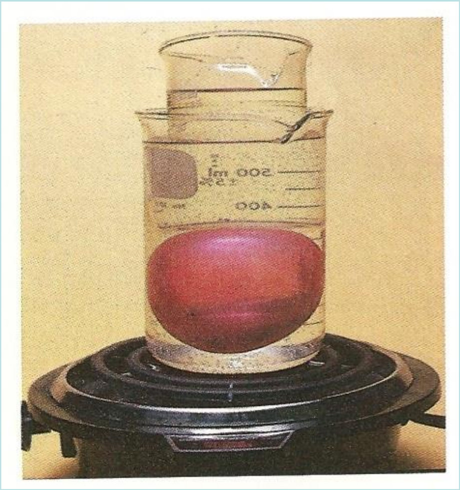
K = ⁰C + 273

Charles' Law

Liquid nitrogen poured on a balloon causes it to shrink.





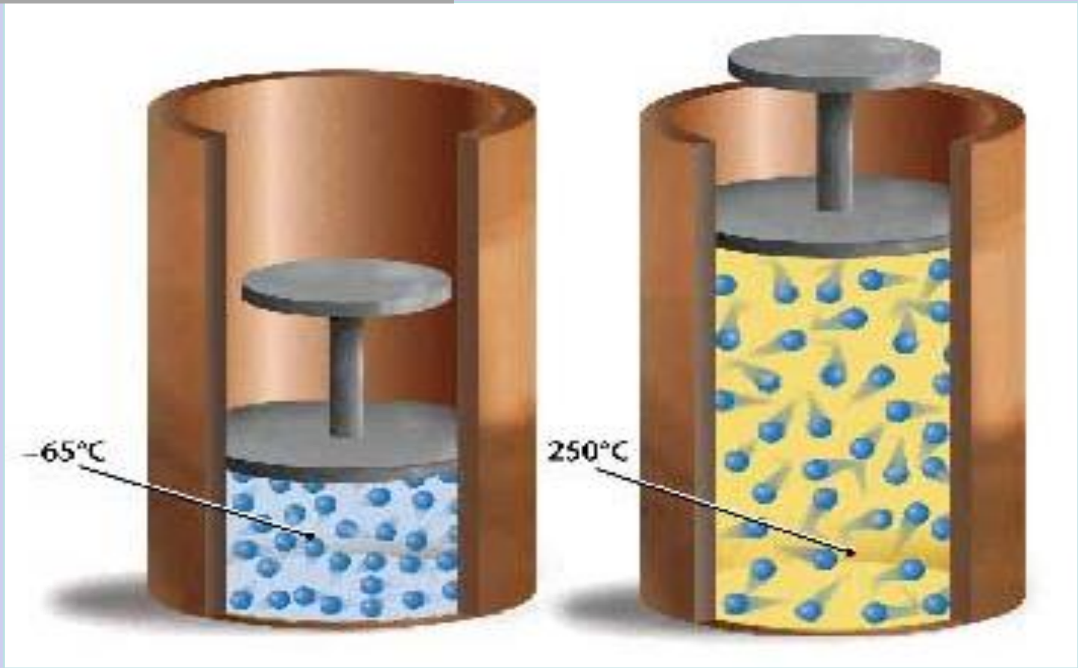


A balloon is smaller in a beaker of ice water than in a beaker of boiling water. The volume of the air in balloon increases with increasing temperature.

Heated gas expands, as in a hot air balloon.

Charles' Law

Describe the relationship between temperature and volume in the cylinders. Remember temperature is related to average kinetic energy of the molecules.



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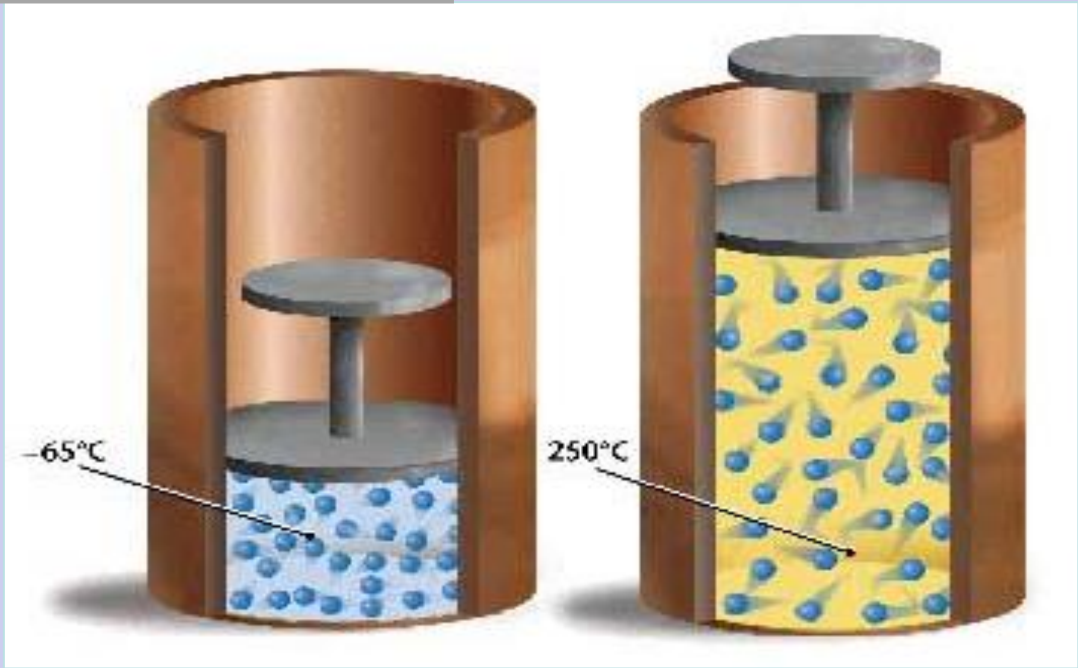


The motion of the molecules (T) increases as volume increases to keep pressure constant.

DIRECT relationship: V ↑ T ↑

Charles' Law

A scientist has an initial volume of 100. ml of a gas at 298 K and constant pressure. If the temperature changes to 373 K, what is the new volume of the gas?

Charles' Law

A scientist has an initial volume of 100. ml (V1) of a gas at 298 K (T1) and constant pressure. If the temperature changes to 373 K (T2), what is the new **volume** (V2) of the gas?

A: Volume (V_2)

G: 100. ml (V1) at 298 K (T1) changes to 373 K (T2)

E: $V_1/T_1 = V_2/T_2$ … solve for $V_2 = T_2V_1 / T_1$

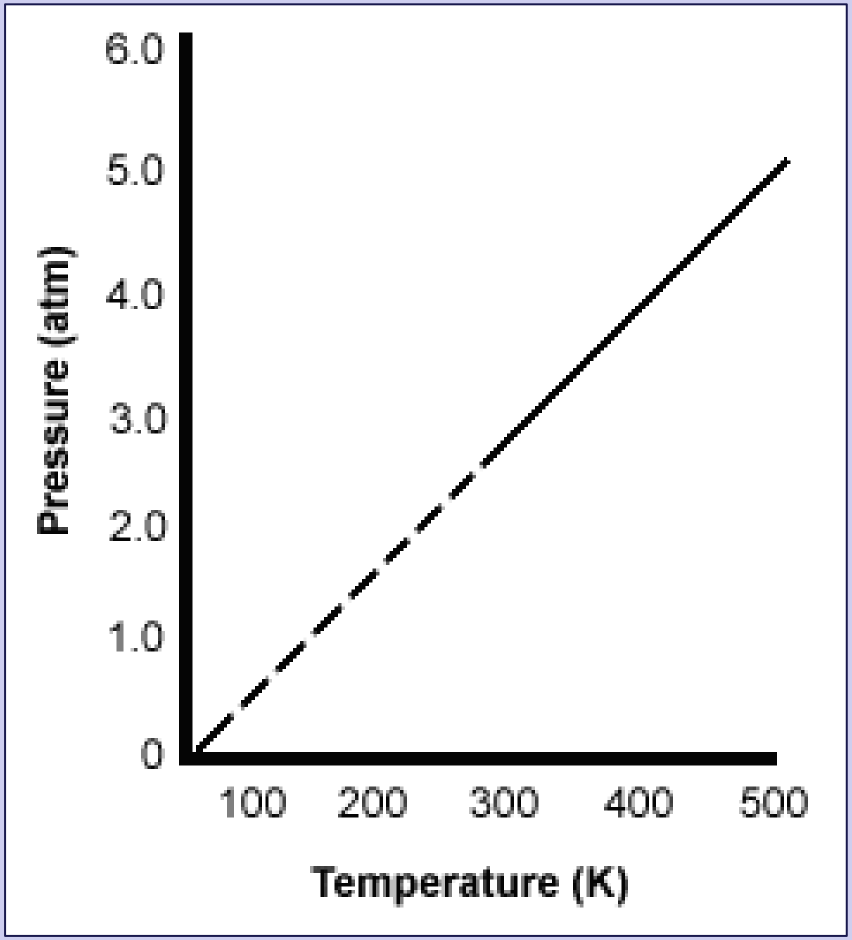
S: V_2 = (373 K) x 100. ml / 298 K) = <u>125 ml</u>

(notice T ↑ V ↑)

Gay-Lussac's Law

Gay-Lussac (1746-1823) experimented with only temperature and pressure of a gas, so he held the volume and number of moles of the gas constant.

DIRECT relationship of P to T



$$P_1/T_1 = P_2/T_2$$

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

P ↑ T ↑

Absolute temperature K

K = ^{0}C + 273

Gay-Lussac's Law

Using Gay-Lussac's law, explain when you need to check the tire pressure more often: in the summer or the winter.

When the temperature of the gas in closed container is increased, the pressure ____.

Gay-Lussac’s Law

Using Gay-Lussac’s law, explain when you need to check the tire pressure more often: in the summer or the winter.

As the tires rotate, the temperature of the air in the tires increases due to friction on the road. The pressure of the air also increases (molecules move faster, more collisions).

On a hot summer day, pressure in a car tire increases over what it would be on a cold winter day. Tire pressure often drops significantly in the winter.

When the temperature of the gas in closed container is increased, the pressure increases.

Combined gas law:

For a fixed quantity of gas, pressure & volume vary inversely while temperature varies directly with pressure & volume

Boyle's law

$$P_1V_1 = P_2V_2$$

Charles's law

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

Gay-Lussac's law

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

What would it look like if we combined all three gas laws?

Remember: inverse direct direct

?

Combined gas law:

For a fixed quantity of gas, pressure & volume vary inversely while temperature varies directly with pressure & volume

Boyle's law

$$P_1V_1 = P_2V_2$$

Charles's law

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

Gay-Lussac's law

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

Combined gas law

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

Combined Gas Law

You *must* have temperature in Kelvin:

1) K includes volume; 2) you can't divide by zero (e.g. 0º C).

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

Cover up Pressure (*it remains constant*) … what do you have?

Cover up Volume (*it remains constant*) … what do you have?

Cover up Temperature (*it remains constant*) … what do you have?

STRATEGY

Combined Gas Law

You *must* have temperature in Kelvin:
1) K includes volume; 2) you can't divide by zero (e.g. 0º C).

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

Cover up **Pressure** (*it remains constant*) … what do you have?

Charles' Law

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

Cover up **Temperature** (*it remains constant*) … what do you have?

Boyle's Law

$$P_1V_1 = P_2V_2$$

Cover up **Volume** (*it remains constant*) … what do you have?

Gay-Lussac's Law

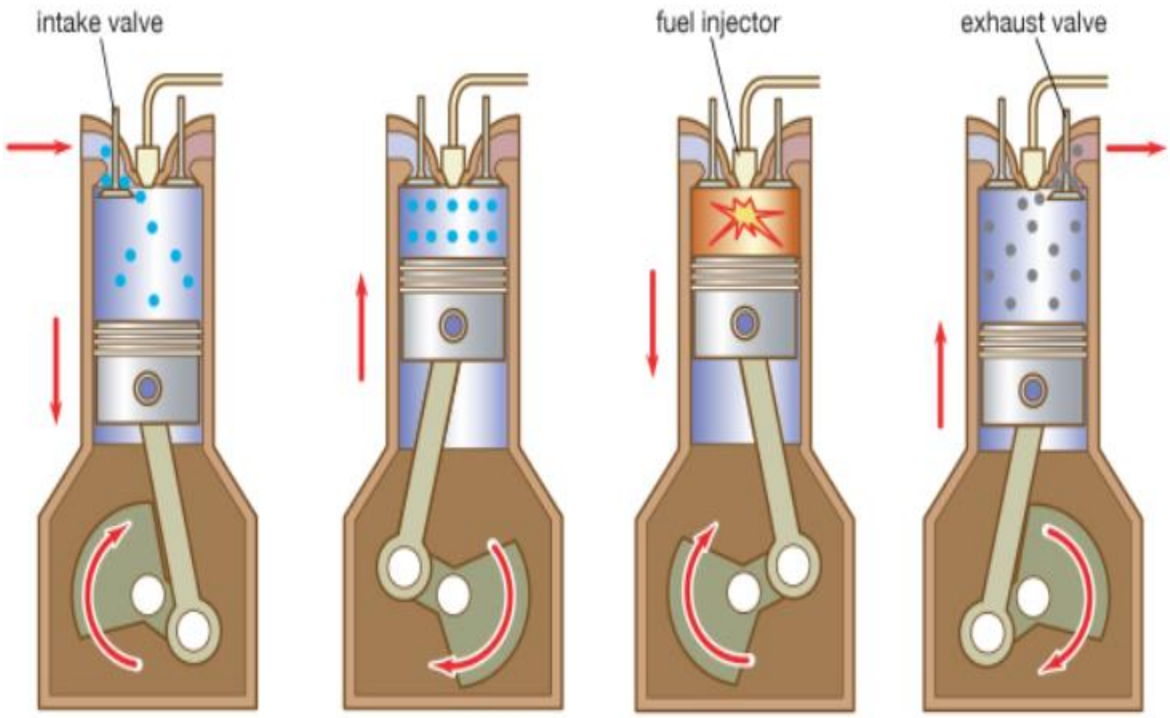
$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Real World Application of the Combined Gas Law

Internal Combustion Engines

Operate on the principle of taking a volume (V) of gas in, compressing it (P), igniting it (T), then pushing the exhaust out.

1. The air-fuel mixture enters the piston chamber.
2. The air-fuel mixture is compressed (piston moves up)
3. The fuel is ignited.



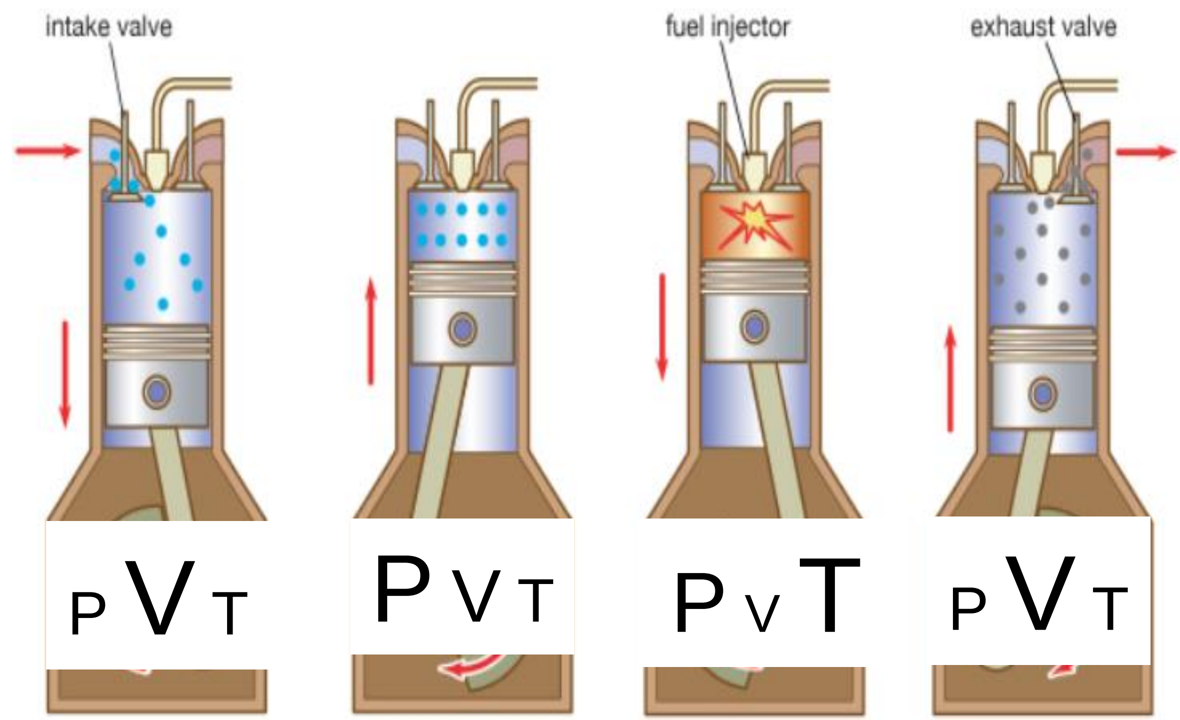
4. The hot, expanding gases force the piston down and the exhaust gases are expelled from the chamber.

Real World Application of the Combined Gas Law

Internal Combustion Engines Notice P, V, T

The volume (V), pressure (P), and temperature (T) interactively vary:

1. The air-fuel mixture enters the piston chamber.
2. The air-fuel mixture is compressed (piston moves up)
3. The fuel is ignited.



4. The hot, expanding gases force the piston down and the exhaust gases are expelled from the chamber.

Real World Application of the Combined Gas Law

Spraying a gas from an aerosol can:

Pressure (P) of gas decreases as it goes from being compressed in the container to being released into the atmosphere. Volume (V) increases substantially.

Kinetic energies of gas molecules decrease. Gas temperature (T) therefore decreases as it is sprayed.

Real World Application of the Combined Gas Law

- Open your hand, palm in, and place near your mouth (~1-2 inches away). Open your mouth wide and blow.
- Repeat the same procedure EXCEPT whistle into your palm.
- Make your observations and explain what happened.

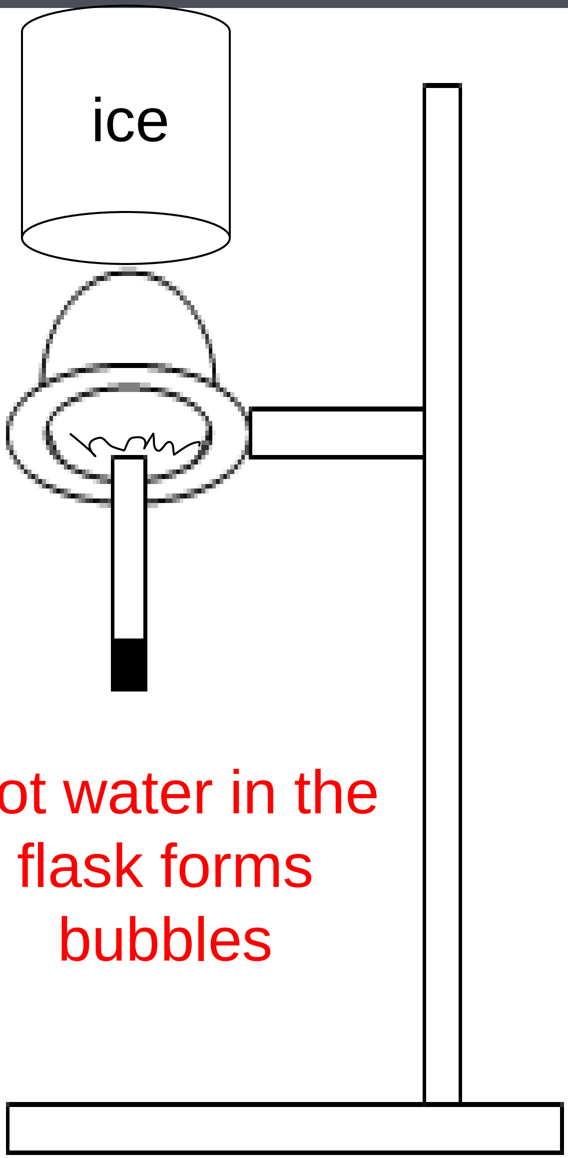
THINK ABOUT IT

Real World Application of the Combined Gas Law

- Open your hand, palm in, and place near your mouth (~1-2 inches away). Open your mouth wide and blow.
- Repeat the same procedure EXCEPT whistle into your palm.
- Notice with mouth wide, it feels warmer, but when whistling it feels cooler (air expands).
- *When whistling, the pressure (P) was relatively high leaving the mouth; Volume (V) INcreased drastically (expansion), Decreasing the perceived temperature (T).*

THINK ABOUT IT

What is the relationship between pressure, temperature, and volume of a gas?



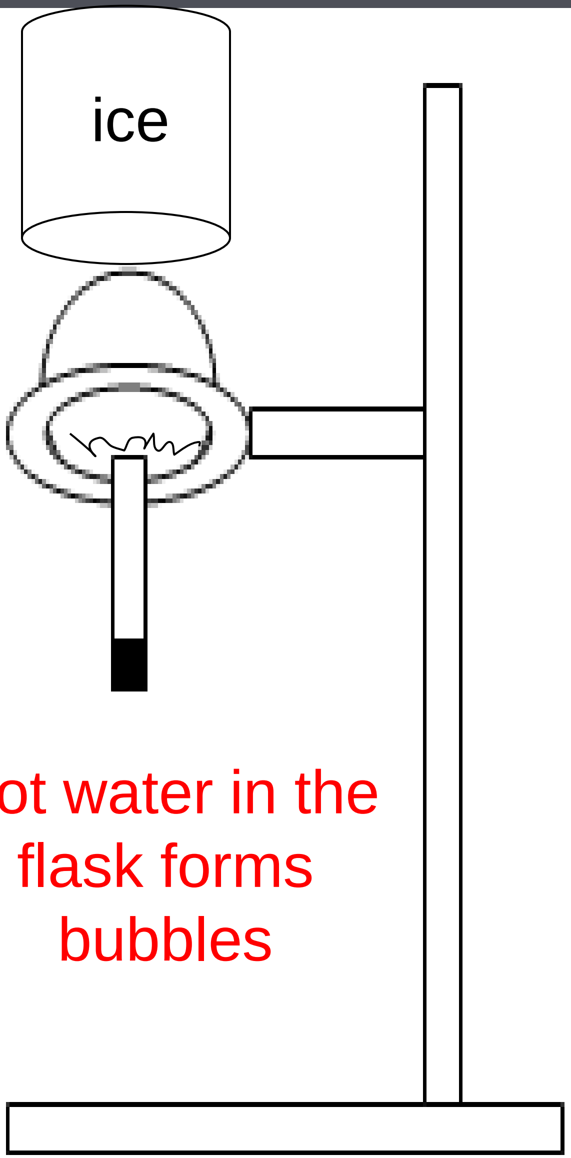
Hot water in the flask forms bubbles

Using **ice** **to make water boil!**

http://somup.com/cFXiDHn19g

(3:08)

What is the relationship between pressure, temperature, and volume of a gas?



Hot water in the flask forms bubbles

Using **ice** **to make water boil!**

http://somup.com/cFXiDHn19g (3:08)

- Ice cools the gas inside the flask (above the water).
- Cooling the gas decreases the pressure of the gas: P ∝ T
- The gas pressure is lower so it matches the vapor pressure of the water. Thus, boiling.
- Volume (V) changes slightly before equilibrium.

Which of the following equations could be used to correctly calculate the final volume of a gas using the combined gas law?

A. $$V_2 = \frac{V_2 \times P_2 \times T_1}{T_2 \times P_1}$$

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

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

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

Which of the following equations could be used to correctly calculate the final volume of a gas using the combined gas law?

A. $V_2 = \dfrac{V_2 \times P_2 \times T_1}{T_2 \times P_1}$

B. $V_2 = \dfrac{V_1 \times P_1 \times T_2}{T_1 \times P_2}$

C. $V_2 = \dfrac{V_1 \times P_1 \times T_1}{T_2 \times P_2}$

D. $V_2 = \dfrac{V_1 \times P_2 \times T_2}{T_1 \times P_1}$

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

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

A weather balloon is filled with helium before it is launched. On the ground, the gas has a temperature of 298 K and a pressure of 1.0 atm. The volume of the balloon is 4.5 kl. As the balloon rises, however, the pressure and temperature change to 0.30 atm and 288 K. What is the new volume of the balloon?

TRY IT

A weather balloon is filled with helium before it is launched. On the ground, the gas has a temperature of 298 K (T1) and a pressure of 1.0 atm (P1) . The volume of the balloon is 4.5 kl (V1). As the balloon rises, however, the pressure and temperature change to 0.30 atm (P2) and 288 K (T2). What is the new volume of the balloon?

TRY IT

A: Volume

G: $T_1 = 298$ K $T_2 = 288$ K $P_1 = 1.0$ atm $P_2 = 0.30$ atm

$V_1 = 4.5\ m^3$ $V_2 = ?$

E: $V_2 = V_1 P_1 T_2 / P_2 T_1$

S: $V_2 = (1.0\ \text{atm})(4.5\ m^3)(288\ \text{K})\ /\ (298\ \text{K})(0.30\ \text{atm})$

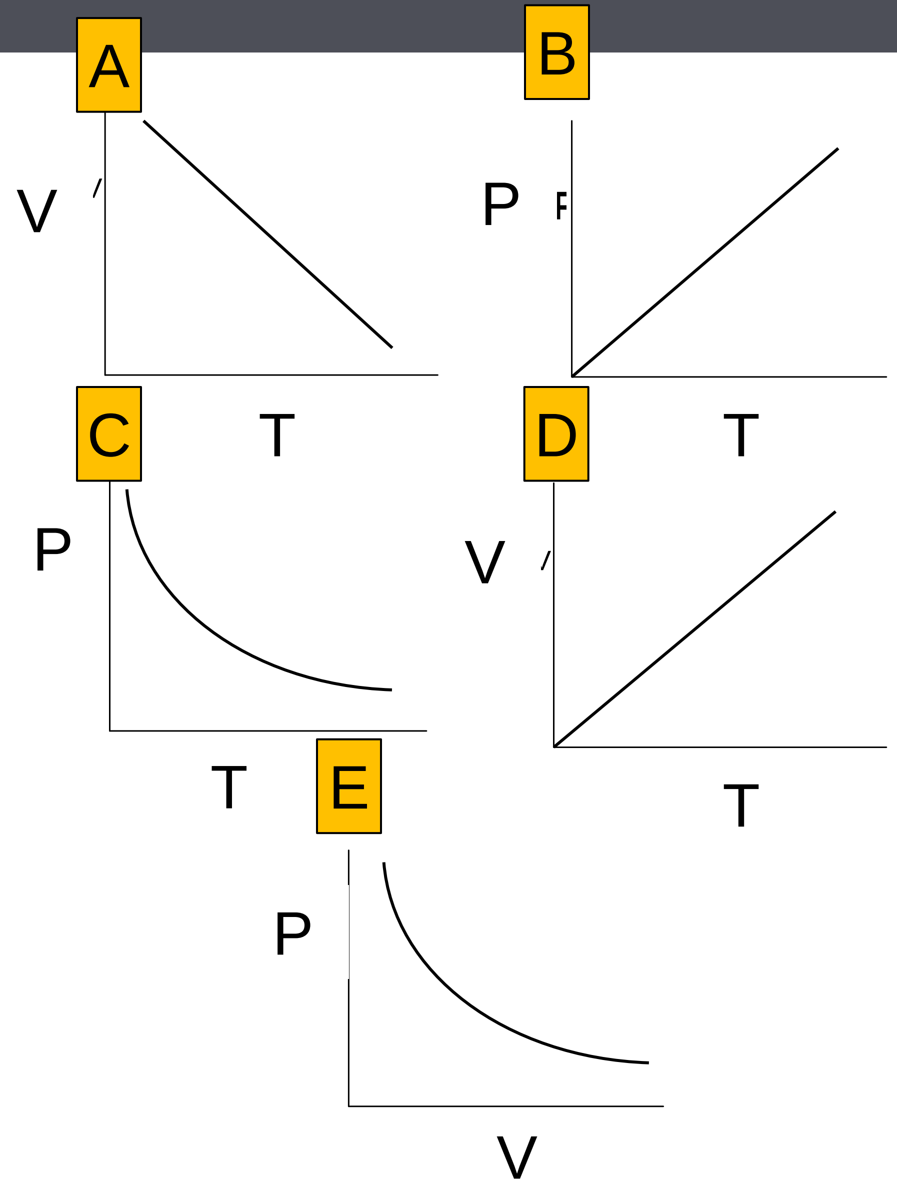
$V_2 = 14$ kl

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

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

Practice matching graphed relationships to the gas laws.

Match one graph shown at right to the gas laws named below:



Charles's law

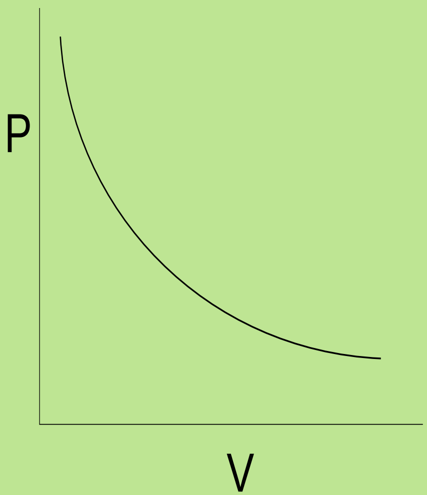
Boyle's law

Gay-Lussac's law

Three Gas Laws

E

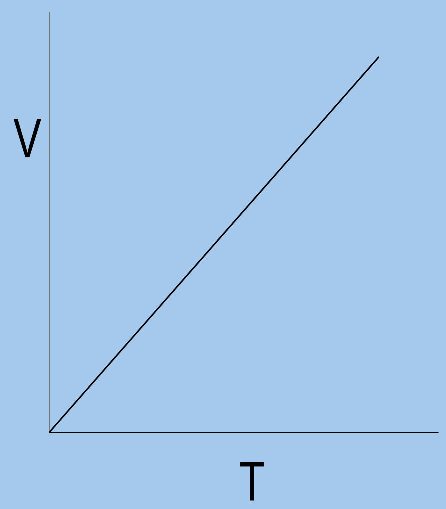
Boyle's law



$$P_1V_1 = P_2V_2$$

D

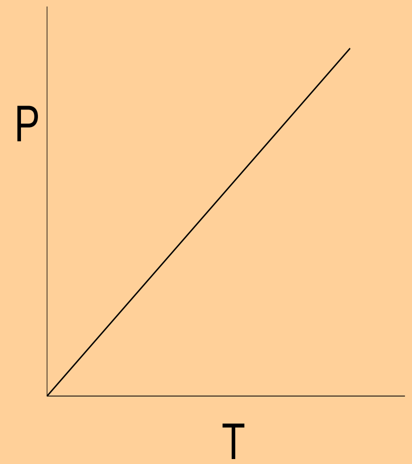
Charles's law



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

B

Gay-Lussac's law



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

A balloon contains 30.0 L of helium gas at 103 kPa. What is the volume of the helium when the balloon rises to an altitude where the pressure is only 25.0 kPa? (Assume that the temperature remains constant.)

Boyle's Law

A balloon contains 30.0 L (V_1) of helium gas at 103 kPa (P_1) . What is the **volume** (V_2) of the helium when the balloon rises to an altitude where the pressure is only 25.0 kPa (P_2)? (Assume that the temperature remains constant.)

A: Volume (V_2)

G: 30.0 L (V_1) at 103 kPa (P_1) … 25.0 kPa (P_2)

E: $P_1V_1 = P_2V_2$ … solve for $V_2 = P_1V_1 / P_2$

S: V_2 = 30.0 L x (103 kPa) / 25.0 kPa = <u>124 L</u>

(notice P ↓ V ↑)

$$V_2 = \frac{30.0\ \text{L} \times 103\ \cancel{\text{kPa}}}{25.0\ \cancel{\text{kPa}}}$$

$$V_2 = 1.24 \times 10^2\ \text{L}$$

A balloon inflated in a room at 24.0^{o}C has a volume of 4.00 L. The balloon is then heated to a temperature of 58.0^{o}C. What is the new volume if the pressure remains constant? Be sure to convert ^{o}C to K.

Charles' Law

A balloon inflated in a room at 24.0°C (T_1) has a volume of 4.00 L (V_1). The balloon is then heated to a temperature of 58.0°C (T_2). What is the new **volume** (V_2) if the pressure remains constant? Be sure to convert °C to K → **K = °C + 273**

A: Volume (V_2)

G: T_1 = 24.0°C + 273 = 297 K T_2 = 58.0°C + 273 = 331 K

4.0 L (V1) at 297 K (T1) changes to 331 K (T2)

E: $V_1/T_1 = V_2/T_2$ … solve for $V_2 = T_2V_1 / T_1$

S: V_2 = (4.0 L) x 331 K / 297 K) = <u>4.46 L</u> (notice T ↑ V ↑)

$$V_2 = \frac{4.00\ \text{L} \times 331\ \cancel{\text{K}}}{297\ \cancel{\text{K}}}$$

Aerosol cans carry labels warning not to incinerate (burn) the cans or store them above a certain temperature. The gas in a used aerosol can is at a pressure of 103 kPa at 25.0^{o}C. If the can is thrown onto a fire, what will the pressure be when the temperature reaches 928^{o}C? Be sure to convert ^{o}C to K.

Gay-Lussac's Law

Aerosol cans carry labels warning not to incinerate (burn) the cans or store them above a certain temperature. The gas in a used aerosol can is at a pressure of 103 kPa (P_1) at 25.0^{o}C (T_1). If the can is thrown onto a fire, what will the **pressure** (P_2) be when the temperature reaches 928^{o}C (T_2)? Be sure to convert ^{o}C to K.

A: Pressure (P_2)

G: T_1 = 25.0^{o}C + 273 = 298 K T_2 = 928.0^{o}C + 273 = 1201 K

103 kPa (P1) at 298 K (T1) changes to 1201 K (T2)

E: $P_1/T_1 = P_2/T_2$ … solve for $P_2 = T_2P_1 / T_1$

S: V_2 = (4.0 L) x 1201 K / 298 K) = 415 kPa (notice P ↑ V ↑)

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

$$P_2 = \frac{P_1 \times T_2}{T_1}$$

$$P_2 = \frac{103\ \text{kPa} \times 1201\ \text{K}}{298\ \text{K}}$$

$$P_2 = 415\ \text{kPa}$$