THERMAL PHYSICS

IB PHYSICS | COMPLETED NOTES

Heat vs Temperature

IB PHYSICS | THERMAL PHYSICS

Temperature – What is it?

Measure of how hot or cold something feels

Quantitative or Qualitative?

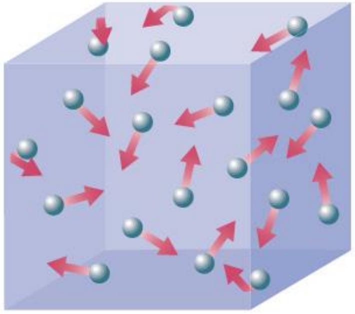
Temperature is the average ____Kinetic Energy____ of the molecules of a substance

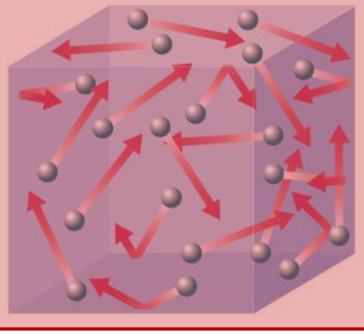
$$E_K = \frac{1}{2}mv^2$$

The faster the particles move, the more temperature __increases__

More velocity

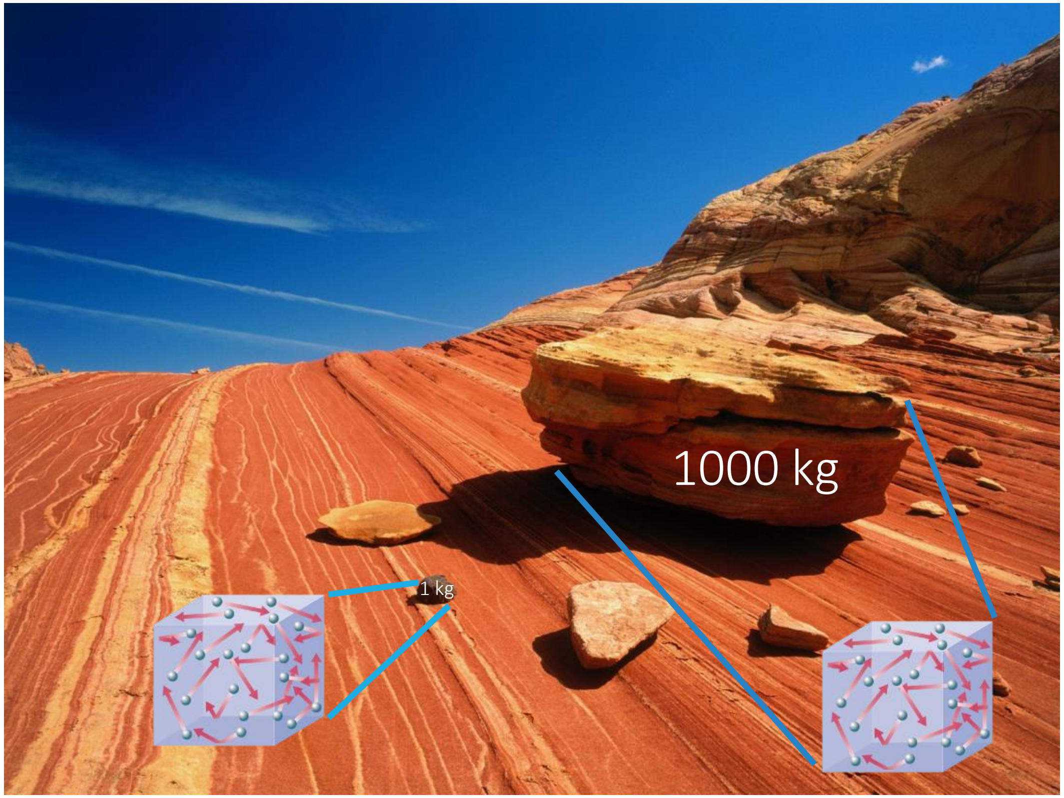
Circle the container with the highest temperature





Temperature

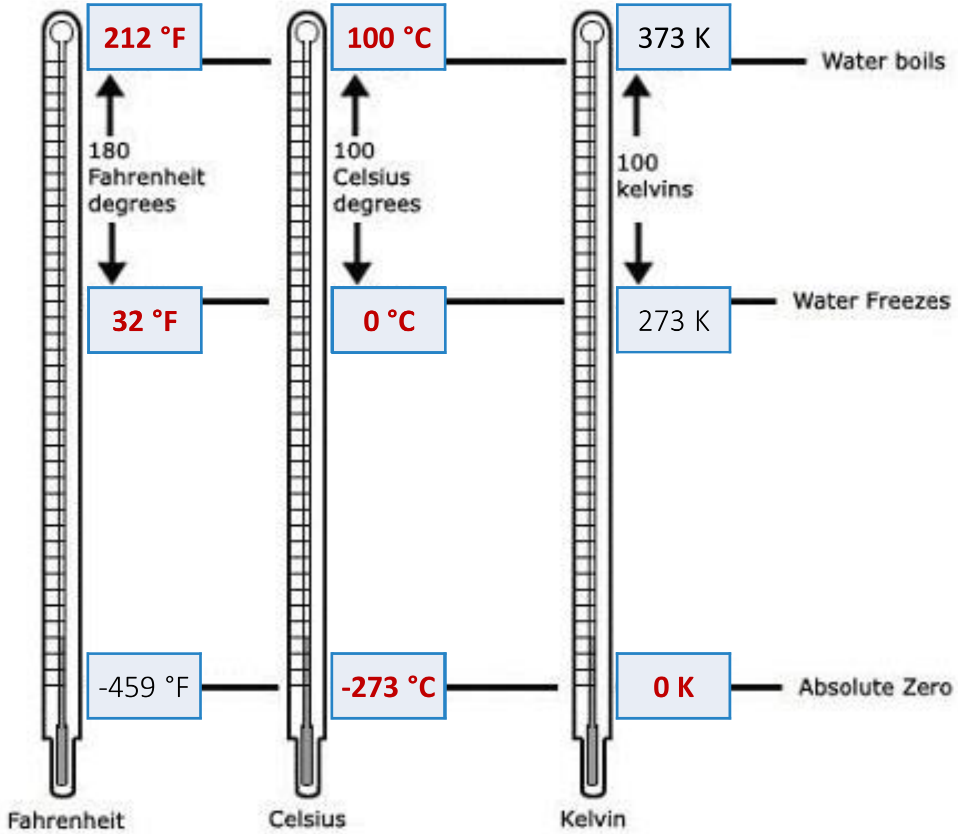
Which rock has a higher temperature (average kinetic energy)?



Same!

Temperature Scales

It is important that we can **quantify** temperature



Which temperature scale is the most precise?

Fahrenheit (smallest increments)

On which temperature scale(s) would an increase of one degree be largest?

Celsius or Kelvin

Absolute Zero

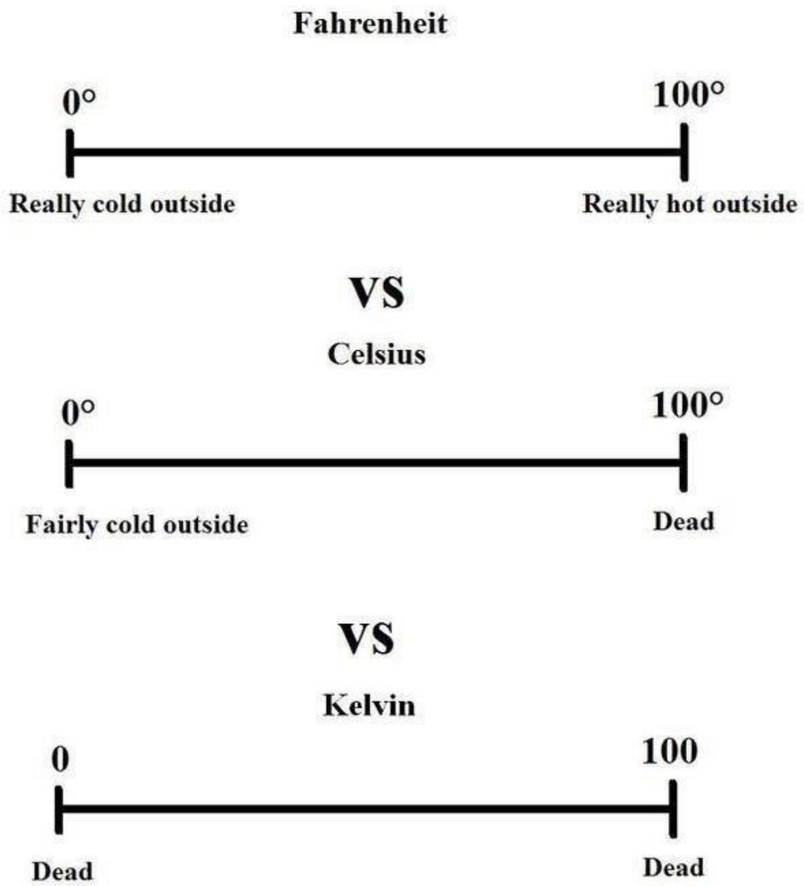
At absolute zero, all molecules ______stop moving______

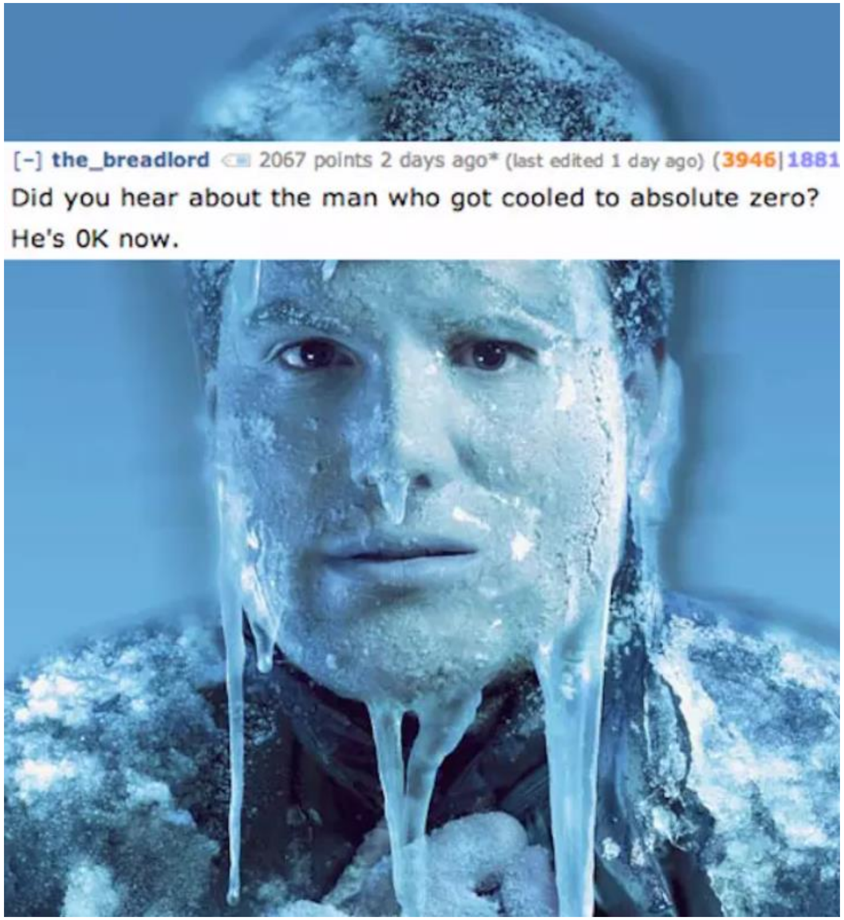
Celsius and Kelvin

$$T\,(\mathrm{K}) = T\,(^\circ\mathrm{C}) + 273$$

-40°C	233 K
0°C	273 K
22°C	295 K
100°C	373 K

Temperature Scales





Temperature

Which has a higher temperature?

Burning Match

Ice Sculpture

Total Internal Energy

$$E_{INT} = E_K + E_P$$

Potential Energy

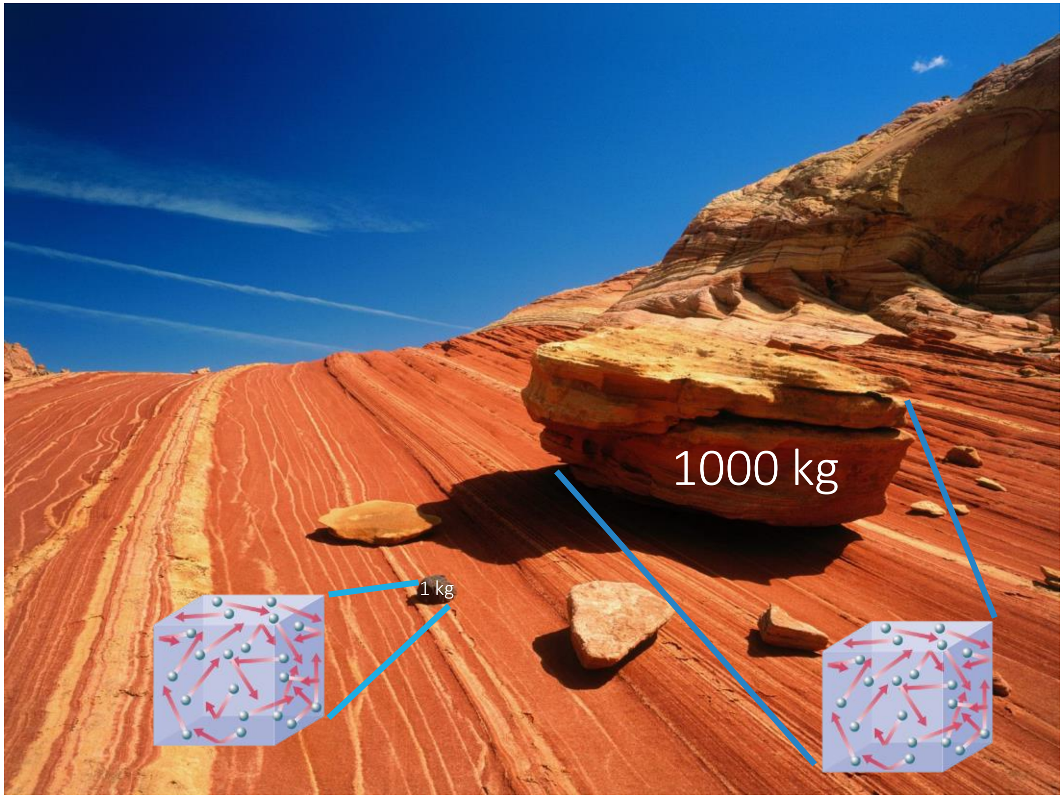
State of Matter

Kinetic Energy

Temperature

Internal Energy

Which rock has a higher internal energy?



Larger Rock

More mass means larger total energy

Internal Energy

Which has more internal energy?

Burning Match

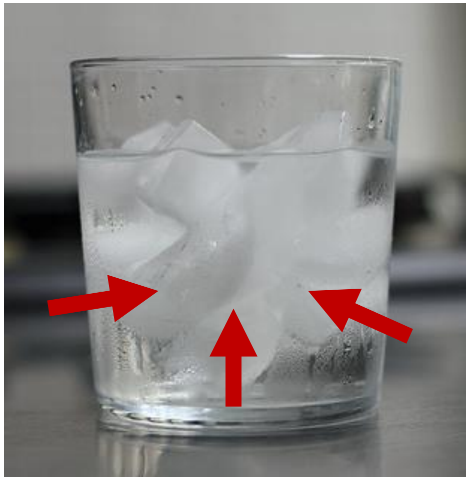
Ice Sculpture

More Mass = Larger Total Energy

Heat

Heat is the __transfer__ of thermal energy

Always flows from __hot__ to __cold__



Heat Flow

Which is correct?

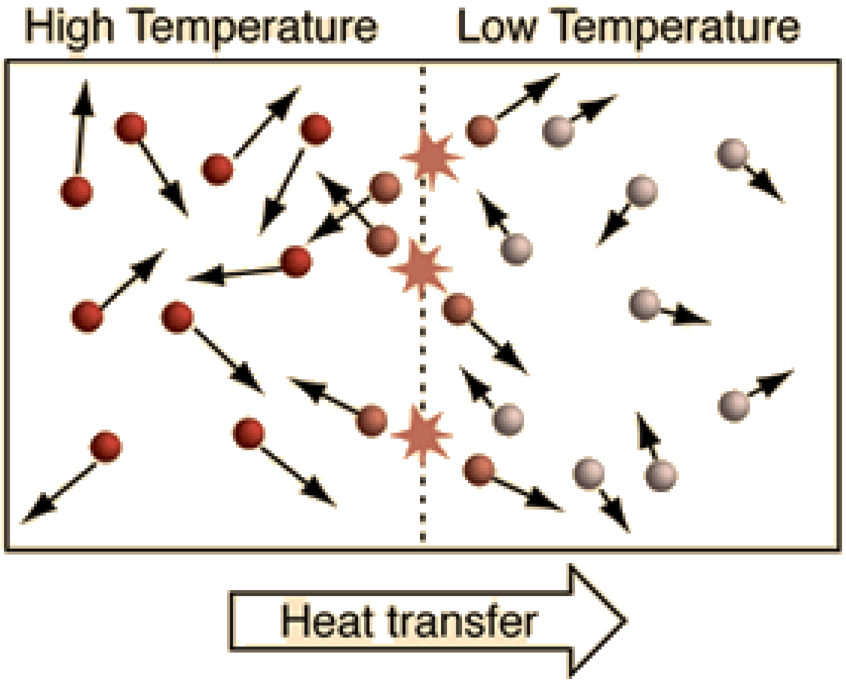
Heat flows from the hand to the ice cube

Heat flows from the ice cube to the hand

Heat Flow

Why does heat flow?

Fast moving particles collide with slow moving particles and increase their velocity, kinetic energy, and temperature



Energy is Energy

r/NoStupidQuestions
MrWaterplant 3.0k points 6 days ago

If kinetic energy is converted into thermal energy, how hard do I have to slap a chicken to cook it?

Lesson Takeaways

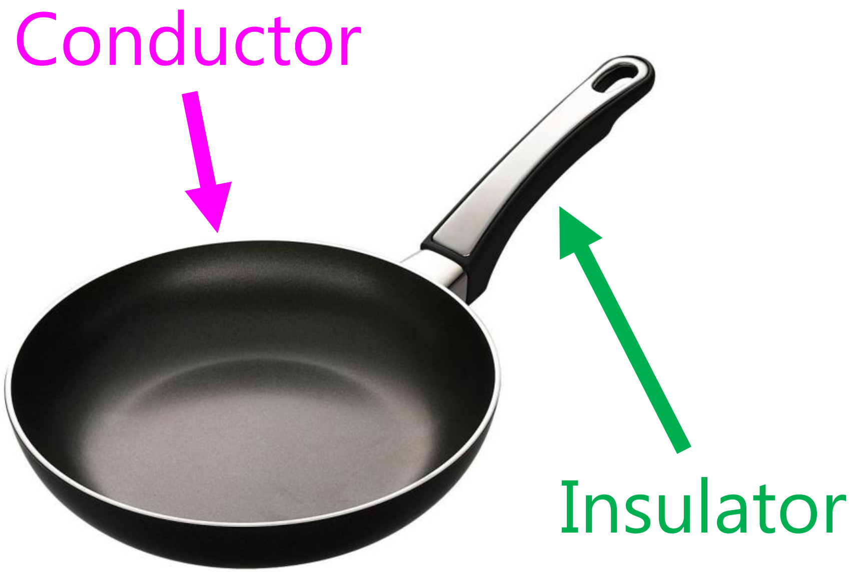
- ❑ I can explain the relationship between temperature and molecular kinetic energy
- ❑ I can describe the energies present in an object’s total internal energy
- ❑ I can convert between Celsius and Kelvin
- ❑ I can describe the nature of molecules when at a temperature of absolute zero
- ❑ I can explain the difference between temperature, internal energy, and heat

Specific Heat

IB PHYSICS | THERMAL PHYSICS

Conductors and Insulators

Label this image



Conductor

A material through which energy can be easily transferred as heat

Insulator

A material that transfers energy poorly

Specific Heat

Specific Heat is the amount of ___**Energy**___ required to raise the temperature of 1 kg of a substance by 1 K

Specific Heat of Copper:

$390\ J\ kg^{-1}\ K^{-1}$

Specific Heat

The ___Lower___ the number, the less energy it takes to heat up

1) Which substance take the most energy to heat up?

Water

2) Which substance take the least energy to heat up?

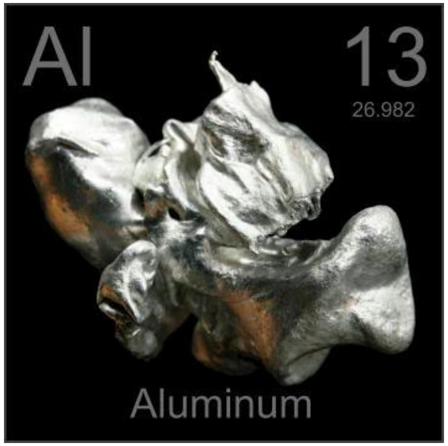
Lead

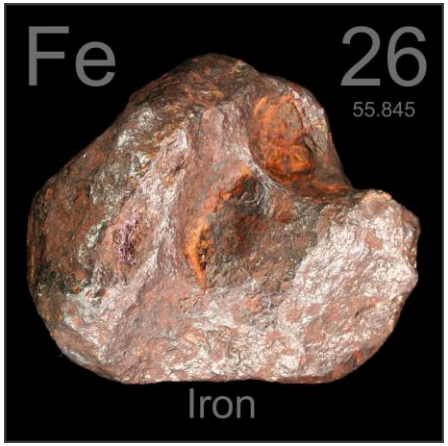
Material	Specific Heat ($J\ kg^{-1}\ K^{-1}$)
Aluminum	910
Copper	390
Iron	448
→ Lead	130
→ Water	4180
Air	1000
Dry Earth	1250

Specific Heat

Which metal will heat up faster, Aluminum or Iron?

Material	Specific Heat ($J\ kg^{-1}\ K^{-1}$)
Aluminum	→ 910
Copper	390
Iron	→ 448
Lead	130
Water	4180
Air	1000
Dry Earth	1250





Specific Heat

If Iron heats up faster based on its specific heat, then why do aluminum fry pans heat up faster?

more mass

Aluminum Skillet
C = 910 J kg^{-1} K^{-1}

Iron Skillet
C = 448 J kg^{-1} K^{-1}

Specific Heat Equations

Quantity	Symbol	Unit
Heat Energy	Q	$[J]$
Mass	m	$[kg]$
Specific Heat	c	$[J\ kg^{-1}K^{-1}]$
Change in Temp	ΔT	$[K]$ or $[°\text{C}]$

$$Q = mc\Delta T$$

Specific Heat Calculations

How much energy is needed to increase the temperature of 0.755 kg of iron 20 K?

$$Q = mc\Delta T = (0.755)(448)(20)$$

$$\boxed{Q = 6{,}765 \text{ J}}$$

How much energy must a refrigerator absorb from 0.225 kg of water to decrease the temperature of the water from 35 °C to 5 °C?

$$Q = mc\Delta T = (0.225)(4180)(5 - 35)$$

$$\boxed{Q = -28{,}215 \text{ J}}$$

Material	Specific Heat ($J\ kg^{-1}\ K^{-1}$)
Aluminum	910
Copper	390
Iron	448
Lead	130
Water	4180
Air	1000
Dry Earth	1250

More Specific Heat Calculations

Air has a density of 1.3 kg m^{-3} and a specific heat capacity of 1000 J kg^{-1} K^{-1}. If 500 kJ was transferred to a room of volume 80 m^3, what was the temperature rise?

$Q = 500{,}000\text{ J}$

$c = 1000\text{ J kg}^{-1}\text{ K}^{-1}$

$m = D \times V = (1.3)(80) = 104\text{ kg}$

$$\Delta T = \frac{Q}{mc} = \frac{500{,}000}{(104)(1{,}000)}$$

$$\boxed{\Delta T = 4.81\text{ K}}$$

How long will it take a 2.20 kW kettle to raise the temperature of 800 g of water from 16.0°C to its boiling point if the specific heat capacity of water is 4180 J kg^{-1} K^{-1}?

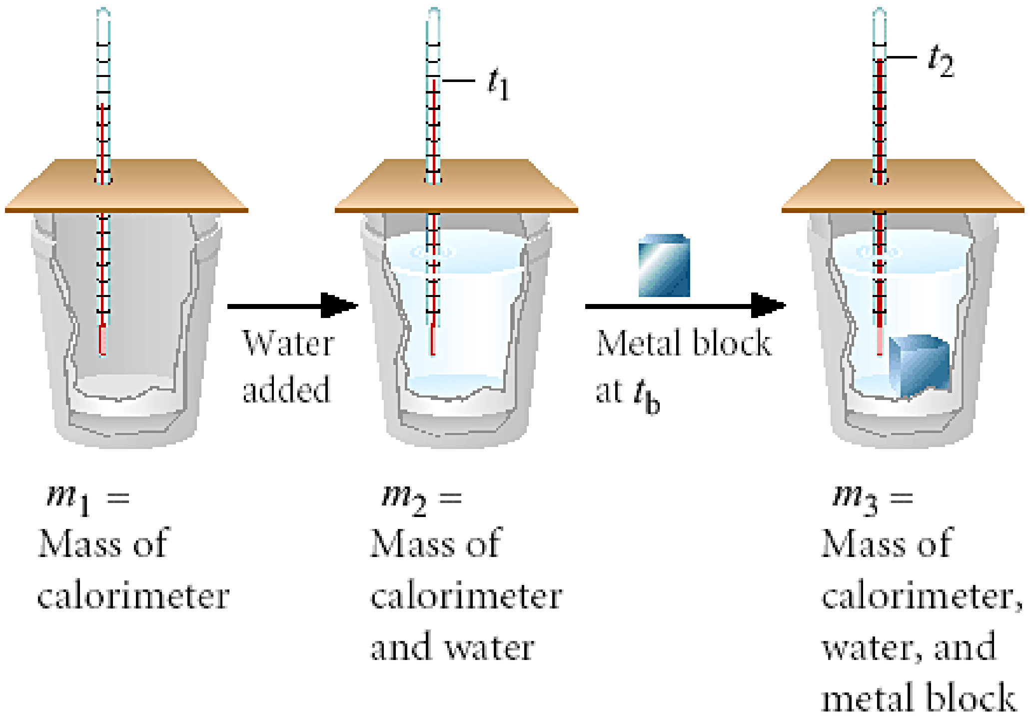
$$Q = mc\Delta T = (0.8)(4180)(100 - 16) = 280{,}896\text{ J}$$

$2.2\text{ kW} = 2{,}200\text{ W} = 2{,}200\text{ J s}^{-1}$

$$\frac{280{,}896\text{ J}}{2{,}200\text{ J s}^{-1}} = \boxed{128\text{ s}}$$

Conservation of Heat

If our system is closed to the surroundings, heat must be conserved



Heat energy lost by the metal

Heat energy gained by the water

Conservation of Heat

Heat energy gained by the water = heat energy lost by the metal

If you have 0.05 kg of water at 20°C and you put in 0.031 kg of an unknown substance that is originally 100°C, you measure that the final temp of everything is 25°C. What is the unknown metal?

Step 1: Find the Heat Energy of the Water

Specific Heat of Water
4180 J kg^{-1} K^{-1}

$$Q = mc\Delta T = (0.05)(4180)(25 - 20)$$

$$Q = 1{,}045 \text{ J}$$

Conservation of Heat

Heat energy gained by the water = heat energy lost by the metal

If you have 0.05 kg of water at 20°C and you put in 0.031 kg of an unknown substance that is originally 100°C, you measure that the final temp of everything is 25°C. What is the unknown metal?

Step 2: Using the heat energy step one. Find mystery specific heat

$$1{,}045\ \mathrm{J} = mc\Delta T = (0.031)(c)(100 - 25)$$

$$c = 449\ \mathrm{J\ kg^{-1}\ K^{-1}}$$

Specific Heat (J/kg*K)	
Water (liquid)	4190
Steam	1870
Ammonia (gas)	2060
Ethanol (liquid)	2440
Aluminum	897
Carbon (graphite)	709
Copper	390
Gold	129
Iron	448
Mercury	140
Lead	129
Silver	234

Lesson Takeaways

- ❑ I can define specific heat capacity with proper units
- ❑ I can describe the effect of larger or smaller specific heat values
- ❑ I can relate specific heat capacity to the heat energy and temperature change
- ❑ I can describe how a calorimeter uses the conservation of heat to study a material's specific heat

Latent Heat and Heating Curves

IB PHYSICS | THERMAL PHYSICS

Review of Specific Heat

Quantity	Symbol	Unit
Heat Energy	Q	[J]
Mass	m	[kg]
Specific Heat	c	[J kg^{-1} K^{-1}]
Change in Temp	ΔT	K or °C

$$Q = mc\Delta T$$

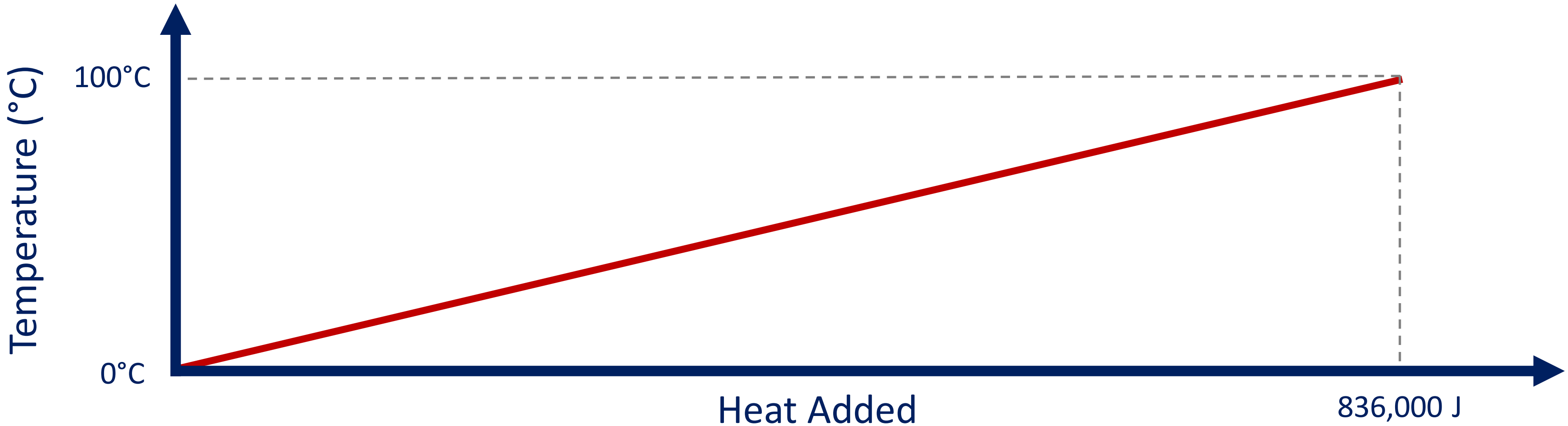
Calculating Heat Transfer

How much heat energy is required to heat up 2 kg of liquid water from its freezing point to its boiling point?

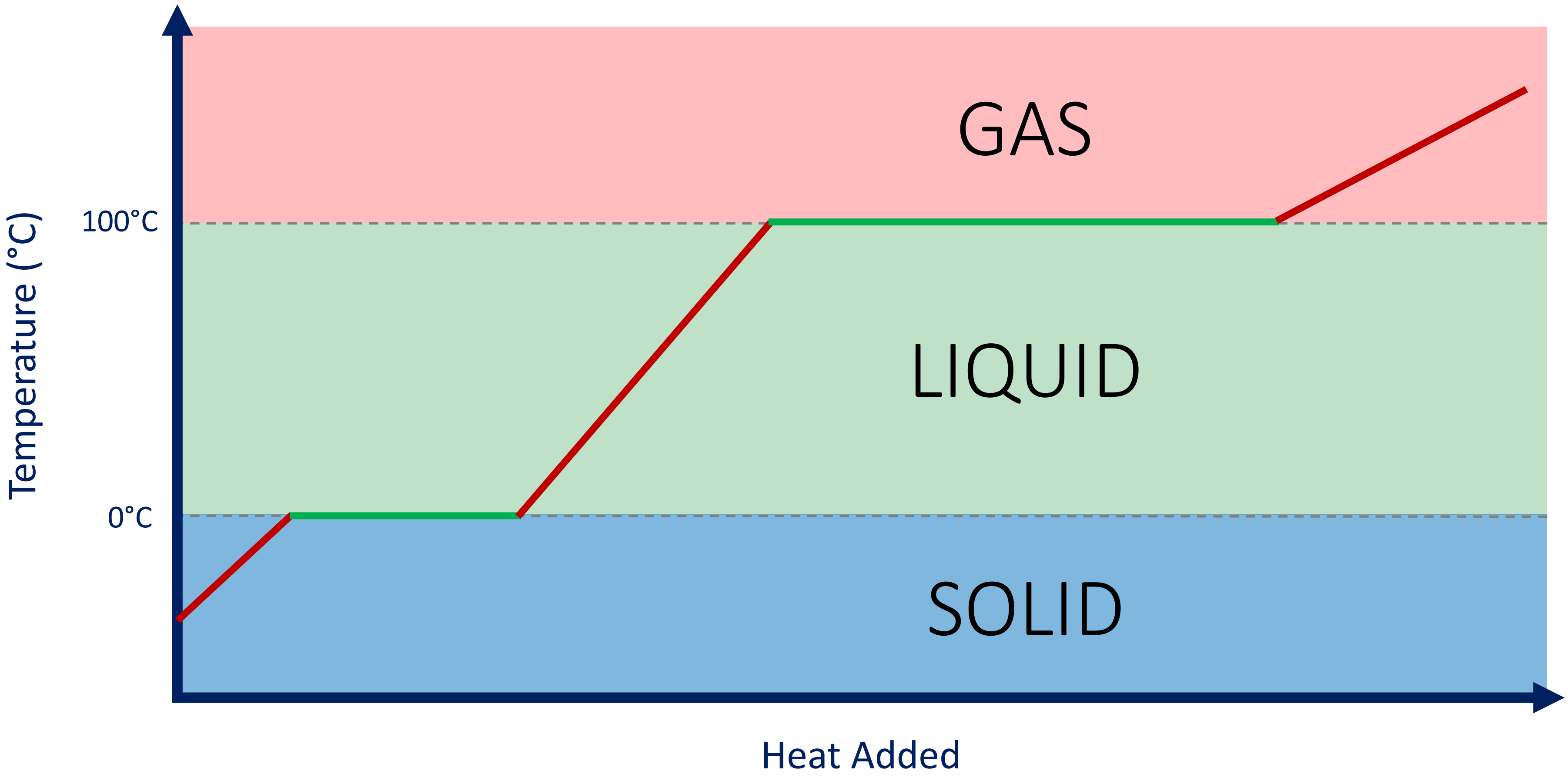
$$Q = mc\Delta T = (2)(4180)(100 - 0)$$

$$\boxed{Q = 836{,}000\ \text{J}}$$

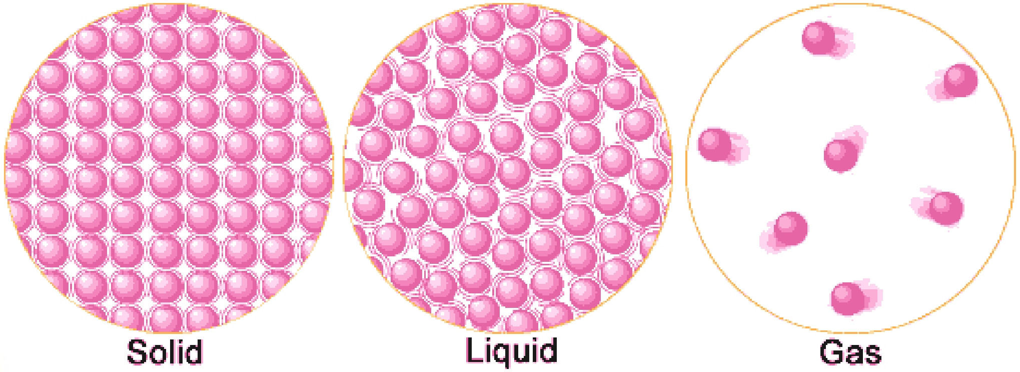
Specific Heat of Water
4180 J kg^{-1} K^{-1}

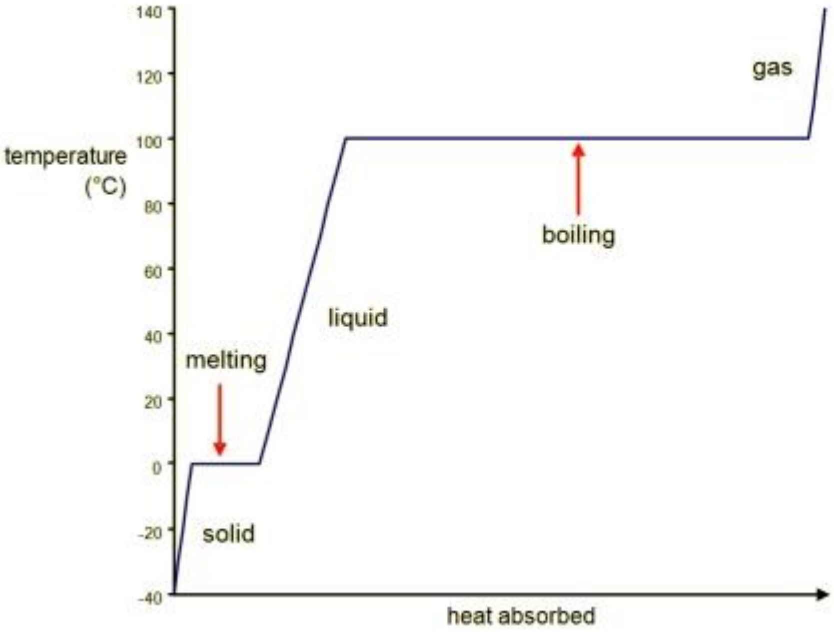


Heating Curve



Why a Plateau?





Bonds are breaking as solid changes to liquid and then again when liquid changes to gas. This takes time!

Adding Heat | Internal Energy

All heat added becomes internal energy

$$E_{INT} = E_K + E_P$$

Changing the temperature of the solid, liquid, or gas?

Changing E_K (Kinetic Energy)

Causing the substance to change phases?

Changing E_P (Potential Energy)

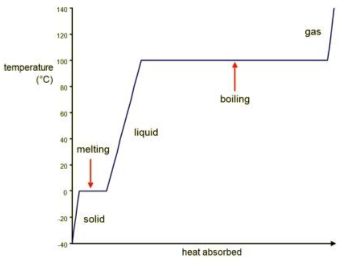
Specific Latent Heat

Specific Latent Heat is the amount energy transferred when 1 kg of the substance changes phase at a constant temp.

Melting or Freezing	Latent Heat of Fusion	L_f
Boiling or Condensing	Latent Heat of Vaporization	L_v

Specific Latent Heat for Water (H_2O):

Latent Heat of Fusion	334,000 J kg^{-1}
Latent Heat of Vaporization	2,260,000 J kg^{-1}



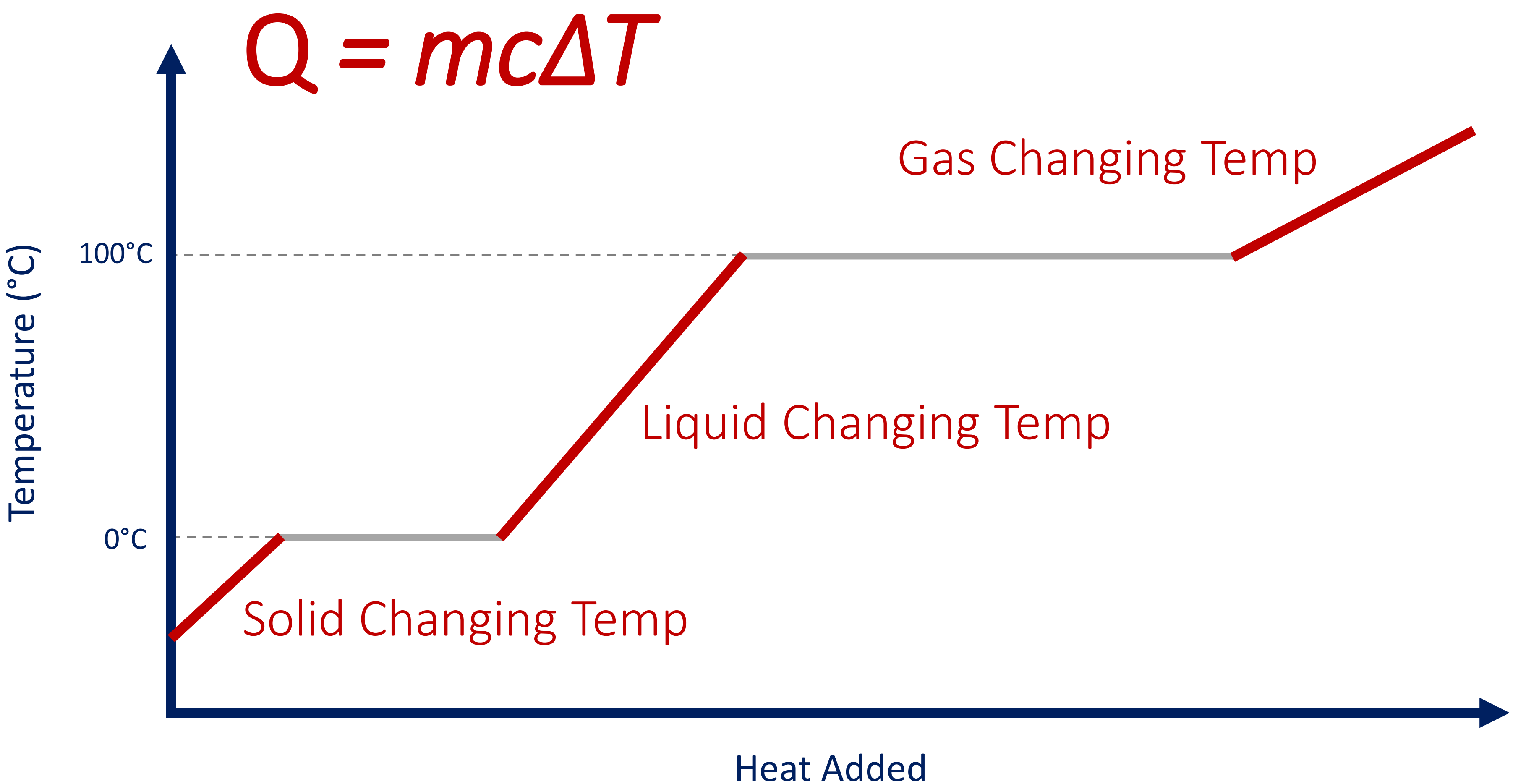
Specific Latent Heat Equation

Quantity	Symbol	Unit
Heat Energy	Q	$[\mathrm{J}]$
Mass	m	$[\mathrm{kg}]$
Specific Latent Heat	L	$[\mathrm{J\ kg^{-1}}]$

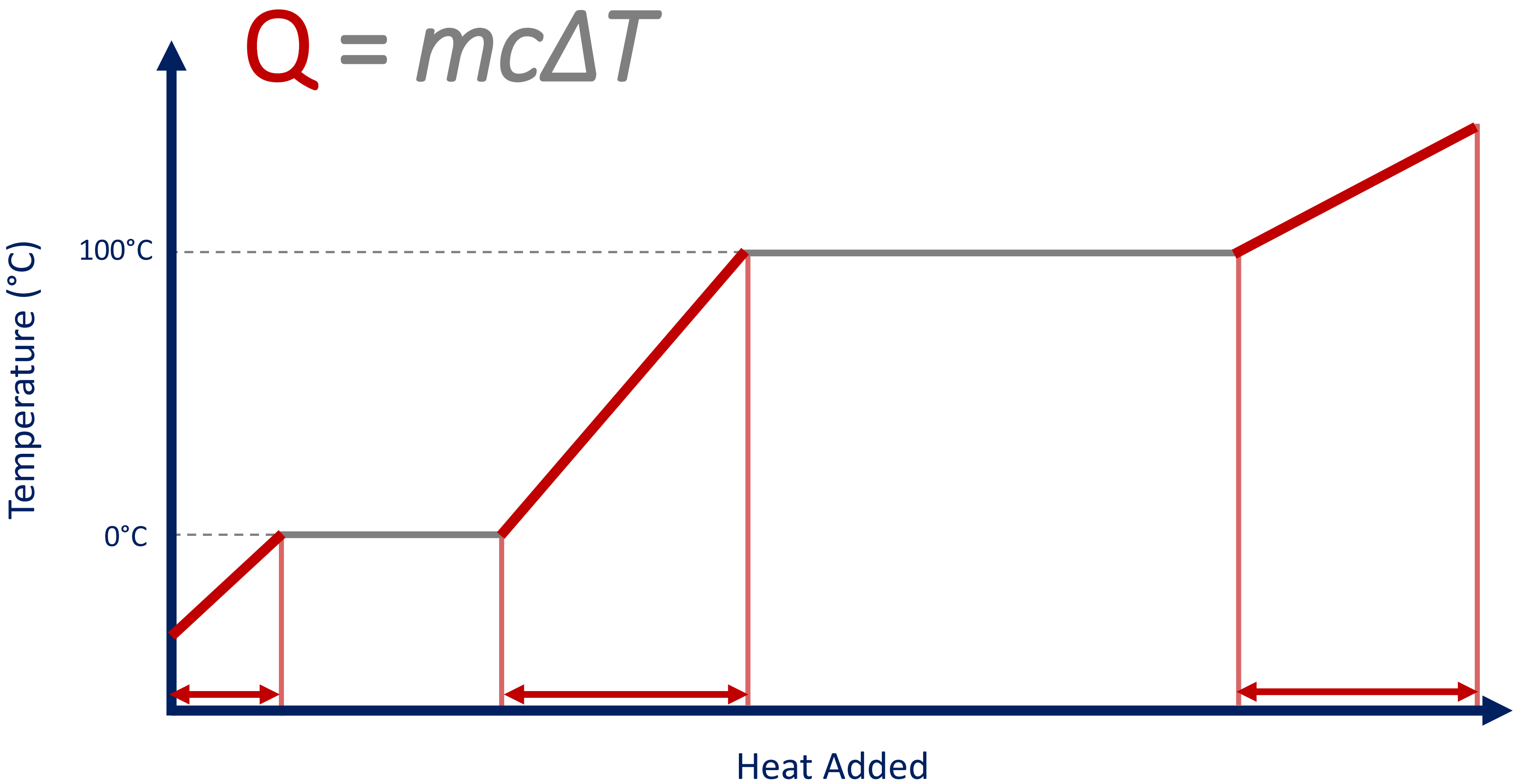
$$\mathrm{Q} = mL$$

This equation works for heat energy gained as well as heat energy lost

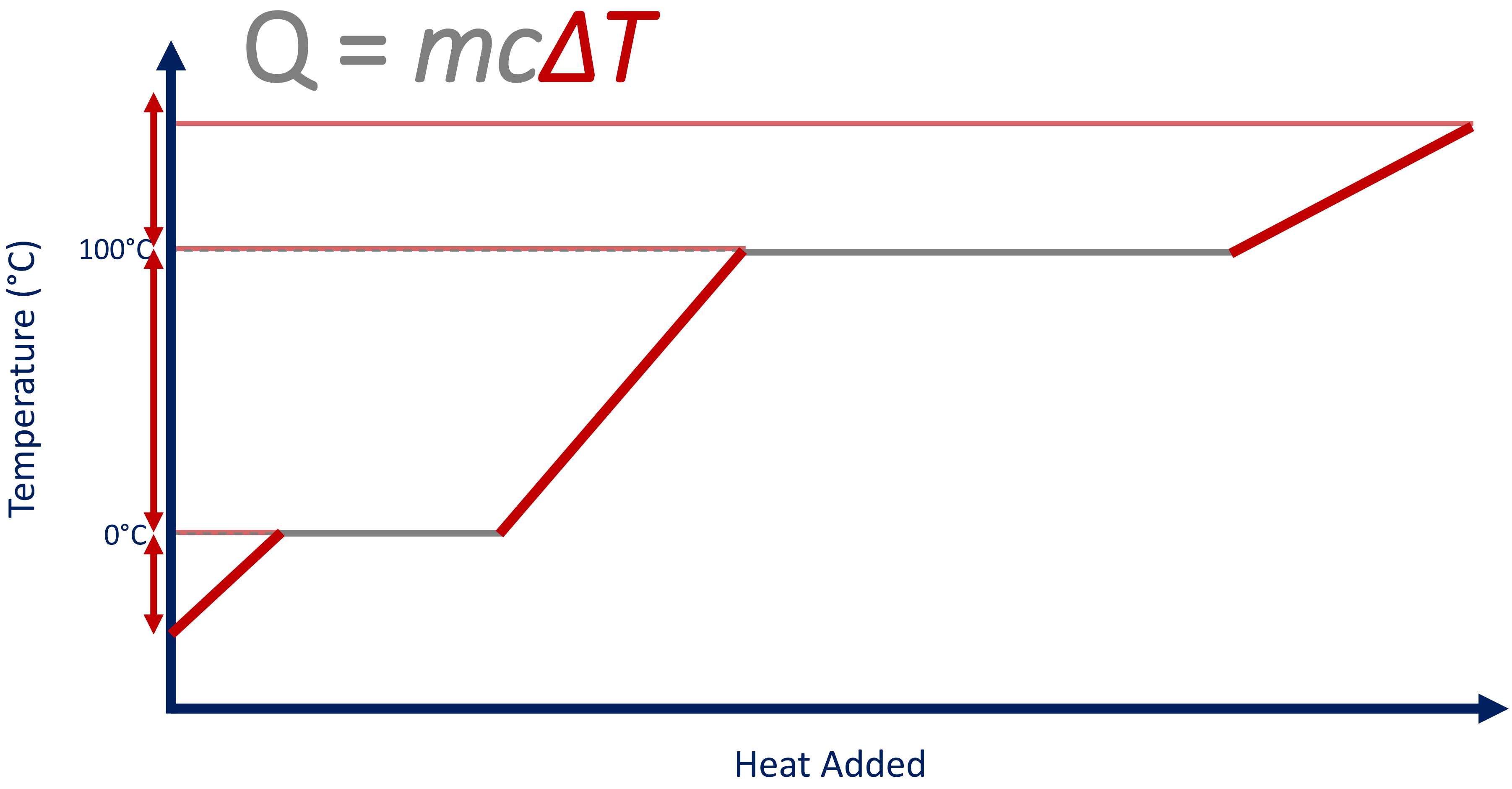
Heating Curve



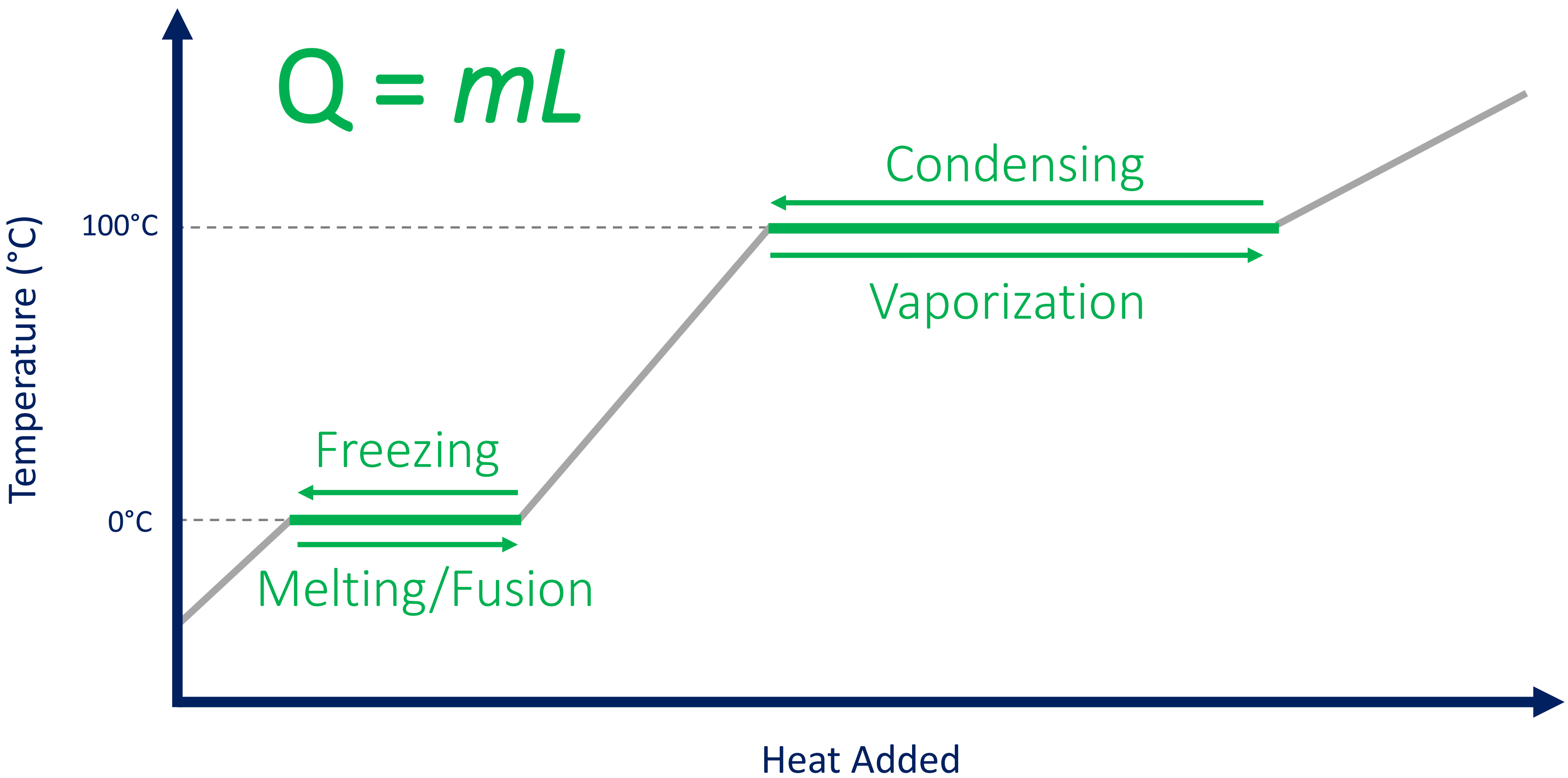
Heating Curve



Heating Curve



Heating Curve



Try This…

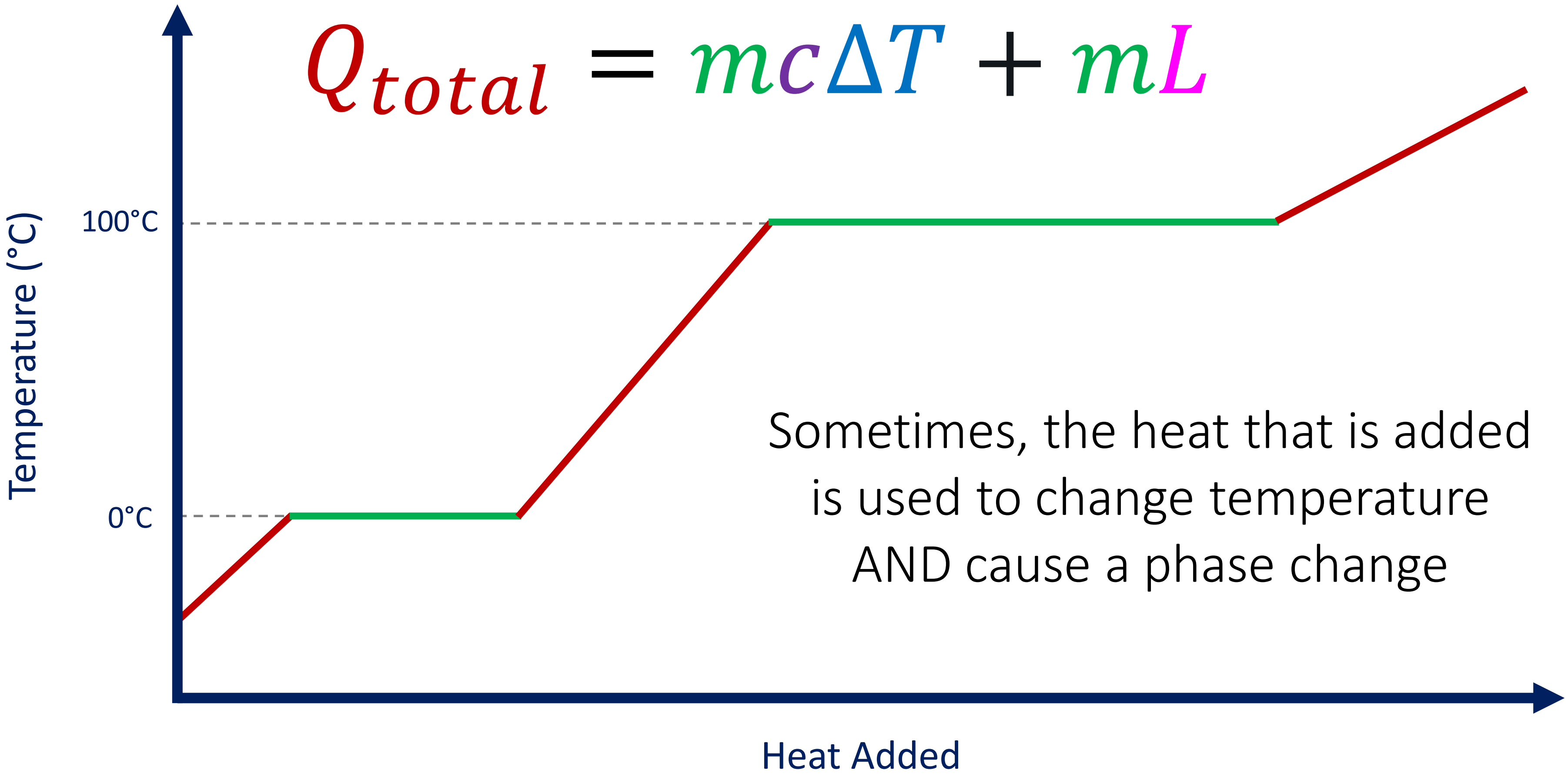
If the latent heat of fusion of a certain kind of chocolate is 160,000 J kg^{-1}, how much thermal energy is removed from you when a 10 g bar of chocolate melts in your mouth?

$$Q = mL = (0.01\ \text{kg})(160{,}000\ \text{J kg}^{-1})$$

$$\boxed{Q = 1{,}600\ \text{J}}$$

Specific Heat Combined

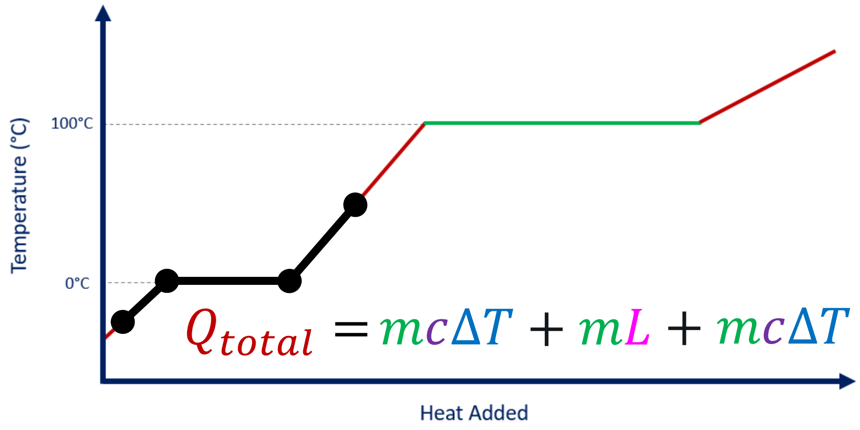
$$Q_{total} = mc\Delta T + mL$$



Sometimes, the heat that is added is used to change temperature AND cause a phase change

Try This...

How much heat is needed to transform 0.5 kg of ice at -20 °C into water at 50 °C ?



Specific Heat of Ice	2090 J kg^{-1} K^{-1}
Specific Heat of Water	4180 J kg^{-1} K^{-1}
Latent Heat of Fusion	334,000 J kg^{-1}
Latent Heat of Vaporization	2,260,000 J kg^{-1}

$\Delta T = 0°C - (-20°C)$

$\Delta T = 50°C - 0°C$

$$Q = (0.5)(2090)(20) + (0.5)(334{,}000) + (0.5)(4180)(50)$$

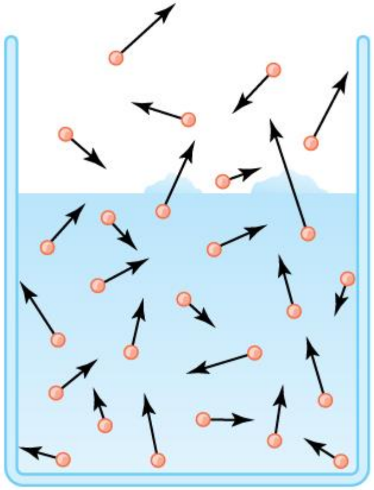
20,900   167,000   104,500

$$Q = 292{,}000 \text{ J}$$

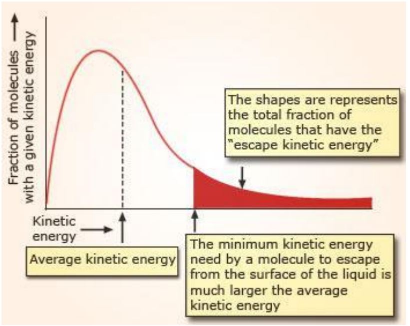
Evaporation vs Boiling

Evaporation:

- Occurs only at the surface of a liquid
- Can occur at any temperature



Some molecules have a KE high enough to escape and become a gas



When these faster molecules are lost, the average KE of the liquid decreases, resulting in evaporative cooling

Boiling:

- Bubbles form throughout liquid
- Occurs at a precise temperature

KE is high enough for molecules to form bubbles within the liquid

Example IB Questions

10. A solid piece of tungsten melts into liquid without a change in temperature. Which of the following is correct for the molecules in the liquid phase compared with the molecules in the solid phase?

	Kinetic energy	Potential energy
A.	same	greater
B.	same	same
C.	greater	greater
D.	greater	same

Changing the temperature of the solid, liquid, or gas?

Changing E_K (Kinetic Energy)

Causing the substance to change phases?

Changing E_P (Potential Energy)

11. The specific latent heat of a substance is defined as the energy required at constant temperature to

A. change the phase.

B. change the phase of 1 kg.

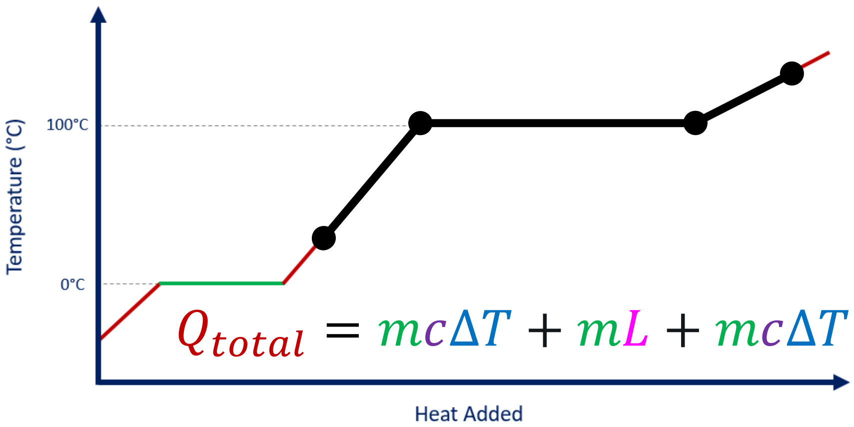
C. change the phase of 1 m^3.

D. change the phase of 1 kg every second.

$L \rightarrow [J\ kg^{-1}]$

Try This...

How much heat is needed to transform 1.4 kg of water at 23°C into water vapor at 120 °C?



$$Q_{total} = mc\Delta T + mL + mc\Delta T$$

Specific Heat of Water Vapor	2000 J kg^{-1} K^{-1}
Specific Heat of Water	4180 J kg^{-1} K^{-1}
Latent Heat of Fusion	334,000 J kg^{-1}
Latent Heat of Vaporization	2,260,000 J kg^{-1}

$$\Delta T = 100°C - 23°C \qquad \Delta T = 120°C - 100°C$$

$$Q = (1.4)(4180)(77) + (1.4)(2{,}260{,}000) + (1.4)(2000)(20)$$

$$450{,}604 \qquad 3{,}164{,}000 \qquad 56{,}000$$

$$Q = 3{,}670{,}604 \text{ J}$$

Lesson Takeaways

- ❑ I can describe the features of a heating curve and why it plateaus during phase changes
- ❑ I can define specific latent heat with proper units
- ❑ I can calculate the heat required to cause a certain amount of a substance to change phases
- ❑ I can compare the processes of evaporation and boiling

Kinetic Molecular Theory

IB PHYSICS | THERMAL PHYSICS

Kinetic Theory of Gases

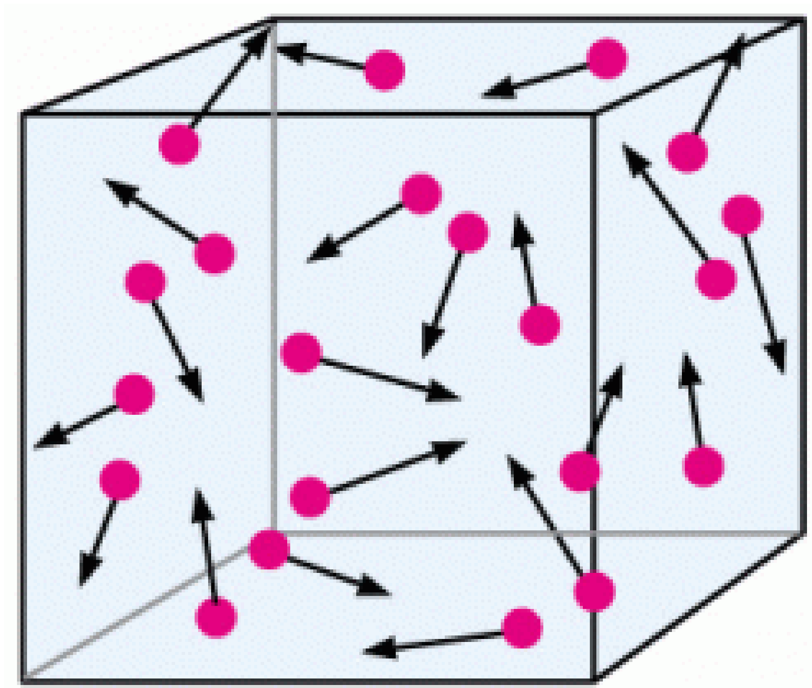
Assumptions:

- Large # of identical molecules
- Volume of molecules is negligible
- Motion is random
- No forces between molecules
- All collisions are <u>elastic</u>

Kinetic Energy is conserved

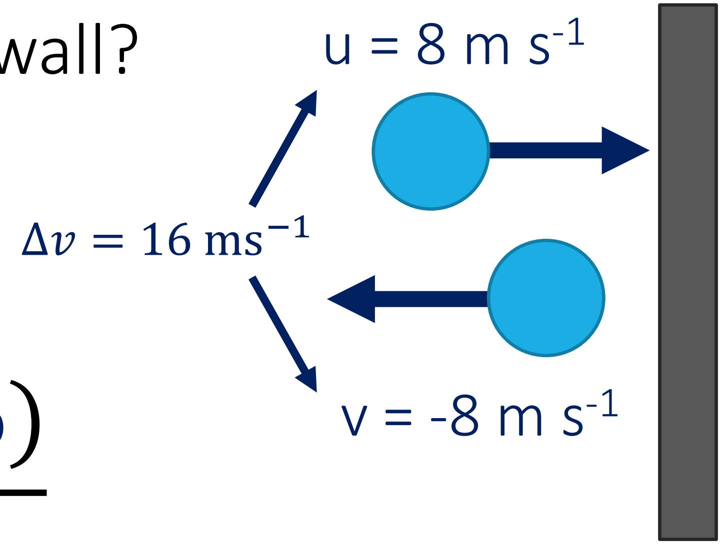
If these assumptions are true we have an

Ideal Gas



Review of Momentum / Collisions

What is the force of this ball on the wall?



$$Impulse = F\Delta t = \Delta p$$

$$F = \frac{\Delta p}{\Delta t} = \frac{m\Delta v}{\Delta t} = \frac{(5)(16)}{(0.2)}$$

m = 5 kg

Δt = 0.2 s

$$\boxed{F = 400\text{ N}}$$

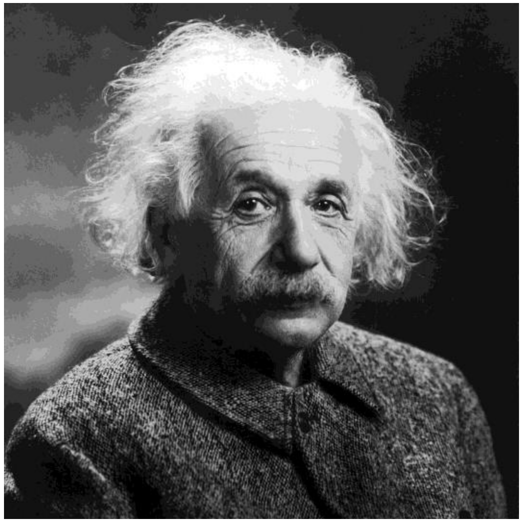
Pressure

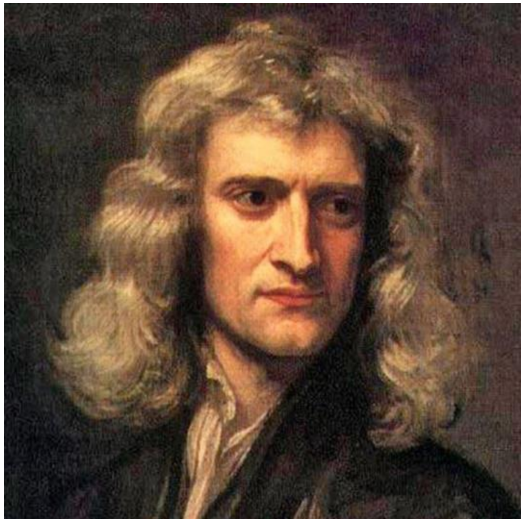
When many molecules collide with the sides of a container it is measured as **pressure**

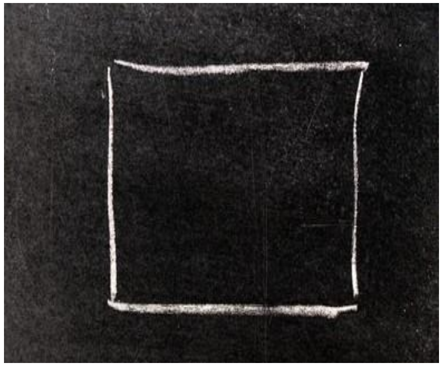
Quantity	Symbol	Unit
Force	F	$[\mathrm{N}]$
Area	A	$[\mathrm{m}^2]$
Pressure	p	$[\mathrm{N\ m}^{-2}] = [\mathrm{Pa}]$ Pascal

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

A brief interlude…







$$\frac{N}{m^2} = Pa$$

Units of Pressure

There are several different units used to measure pressure of a gas

1 atm = 101,325 Pa = 760 Torr = 760 mm Hg

↑

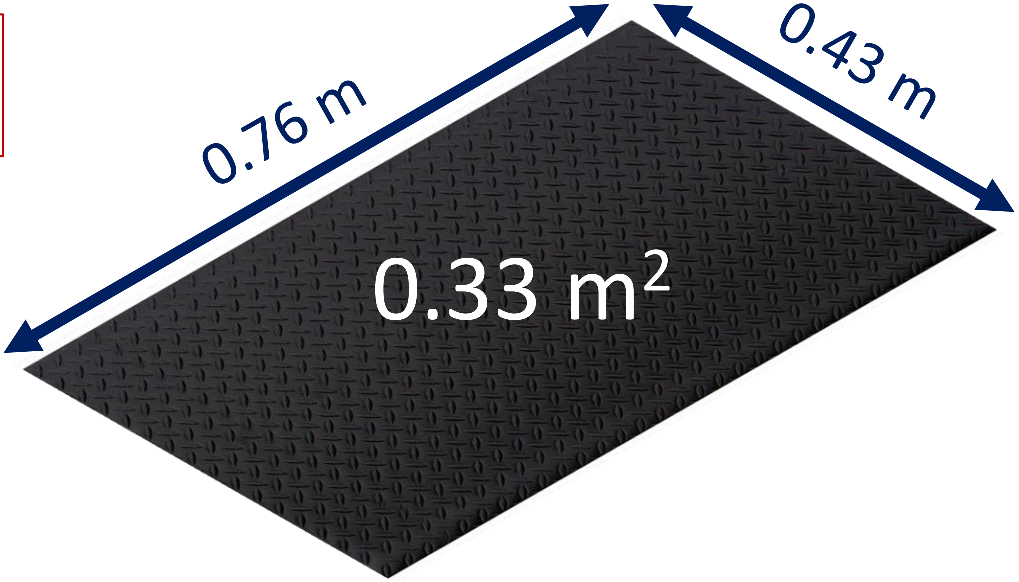
100 kPa *is a pretty good approximation*

Atmospheric Pressure

What is the force from atmospheric pressure on this doormat?

$$(101{,}325\ N\ m^{-2})(0.33\ m^2)$$

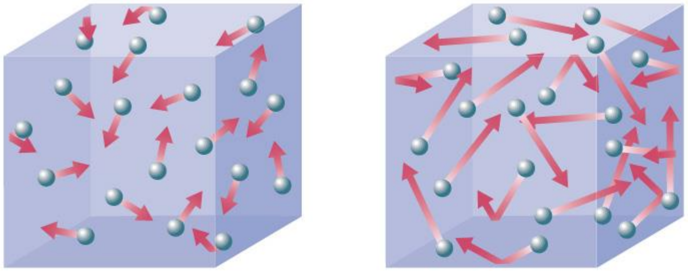
$$F = 33{,}100\ N$$



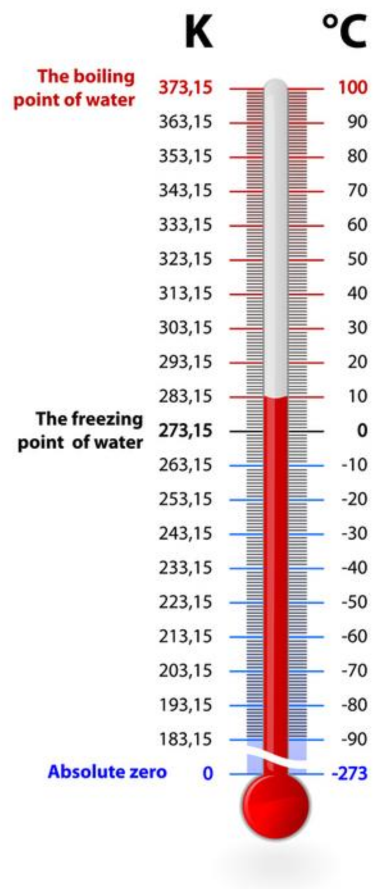
Temperature Review

Measure of how hot or cold something feels

Temperature is the average kinetic energy of the molecules of a substance



Kelvin Scale (K)
Absolute Temperature



Average Kinetic Energy

$$\bar{E}_K = \frac{3}{2} k_B T$$

$k_B \rightarrow Boltzmann's\ constant$

$k_B = 1.38 \times 10^{-23}\ J\ K^{-1}$

Quantity	Symbol	Unit
Average Kinetic Energy	$\bar{E}_K$	[J]
Absolute Temperature	T	[K]

IB Physics Data Booklet

Sub-topic 3.1 – Thermal concepts	Sub-topic 3.2 – Modelling a gas
$Q = mc\Delta T$ $Q = mL$	$p = \frac{F}{A}$ $n = \frac{N}{N_A}$ $pV = nRT$ $\bar{E}_K = \frac{3}{2}k_B T = \frac{3}{2}\frac{R}{N_A}T$

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	$9.81\ \text{m s}^{-2}$
Gravitational constant	G	$6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$
Avogadro's constant	N_A	$6.02 \times 10^{23}\ \text{mol}^{-1}$
Gas constant	R	$8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$
Boltzmann's constant	k_B	$1.38 \times 10^{-23}\ \text{J K}^{-1}$

Try This | 1

Calculate the average translational kinetic energy of molecules in the air at 27°C

$k_B = 1.38 \times 10^{-23}\ \mathrm{J\ K^{-1}}$

$T = 27°\mathrm{C} + 273 = 300\ \mathrm{K}$

$$\bar{E}_k = \frac{3}{2} k_B T = \frac{3}{2}(1.38 \times 10^{-23})(300)$$

$$\bar{E}_k = 6.21 \times 10^{-21}\ \mathrm{J}$$

What is Kinetic Energy?

$$\bar{E}_K = \frac{3}{2} k_B T$$

$k_B \rightarrow Boltzmann's\ constant$

$k_B = 1.38 \times 10^{-23}\ J\ K^{-1}$

$$\bar{E}_K = \frac{1}{2} m v^2$$

Try This | 2

Calculate the average speed for oxygen molecules at 0°C.
(the mass of an oxygen molecule is 5.32×10^{-26} kg)

$m = 5.32 \times 10^{-26}\ \text{kg}$

$k_B = 1.38 \times 10^{-23}\ \text{J K}^{-1}$

$T = 0°\text{C} + 273 = 273\ \text{K}$

$$\bar{E}_k = \frac{3}{2}k_B T = \frac{1}{2}mv^2$$

$$\frac{3}{2}(1.38 \times 10^{-23})(273) = \frac{1}{2}(5.32 \times 10^{-26})v^2$$

$$5.62 \times 10^{-21}\ \text{J} = \frac{1}{2}(5.32 \times 10^{-26})v^2$$

$$\boldsymbol{v = 461\ \text{ms}^{-1}}$$

Which molecules move faster?

H_2 gas at 23°C

1
H
1.01

O_2 gas at 23°C

8
O
16.00

$$\bar{E}_k = \frac{1}{2}mv^2$$

If the gases have the same kinetic energy (temp), the lighter one must be moving faster

Lesson Takeaways

- ❑ I can describe the conditions necessary for a substance to be considered an ideal gas
- ❑ I can define pressure with appropriate fundamental and derived units
- ❑ I can relate average molecular kinetic energy with absolute temperature
- ❑ I can calculate the average molecule speed for a molecule at a certain temperature
- ❑ I can discuss how the mass of a molecule changes its overall speed at a given temperature

The Mole

IB PHYSICS | THERMAL PHYSICS

Grouping Items

We can use many different terms to describe the amount of substance.

A pair of shoes

__2__ shoes

A dozen roses

__12__ roses

BONUS!

A Baker's Dozen = **13**

A Score = **20**

A Gross = **144**

Counting Atoms

The primary counting unit for atoms is called

The Mole

$$1 \text{ mole} = 6.02 \times 10^{23} = N_A$$

*This is also called **Avogadro's Number** named after the scientist who first proposed this concept*

How Big is a Mole??

602,000,000,000,000,000,000,000

How Big is a Mole??

A Mole of Moles

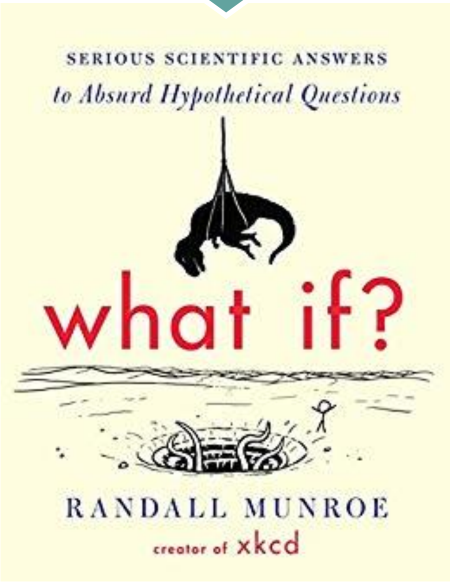
What would happen if you were to gather a mole (unit of measurement) of moles (the small furry critter) in one place?

—Sean Rice

Things get a bit gruesome.

First, some definitions. A mole is a unit. It's not a typical unit, though. It's really just a number—like "dozen" or "billion." If you have a mole of something, it means you have 602,214,129,000,000,000,000,000 of them (usually written 6.022×10^{23}). It's such a big number because it's used for counting numbers of molecules, which there are a lot of.

Taken from the book "What if?" by Randall Munroe



Using Moles in Chemistry

Atoms don't weigh very much on their own:

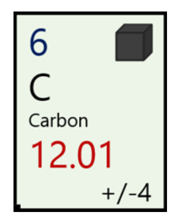
$1 \text{ Carbon Atom} = 1.9927 \times 10^{-23} \text{ g}$

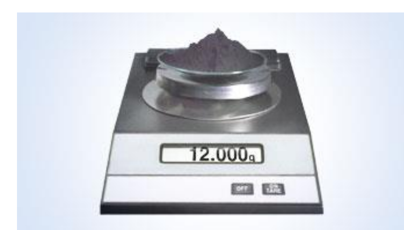
0.000000000000000000000019927 g

1 mole of Carbon Atoms =

$(1.9927 \times 10^{-23} \text{ g}) \times (6.02 \times 10^{23}) = \sim\mathbf{12\ g}$

Where else have you seen this number for Carbon?





Example IB Questions

10. The mole is defined as

A. $\frac{1}{12}$ the mass of an atom of the isotope carbon-12.

B. the amount of a substance that contains as many elementary entities as the number of atoms in 12 g of the isotope carbon-12.

C. the mass of one atom of the isotope carbon-12.

D. the amount of a substance that contains as many nuclei as the number of nuclei in 12 g of the isotope carbon-12.

Molar Mass

Molar Mass – the mass of __1 mole__ of a substance

Unit	$g\ mol^{-1}$

7
N
Nitrogen
14.01
-3

16
S
Sulfur
32.07
-2

Molar mass of N = **14.01** **$g\ mol^{-1}$**

Molar mass of S = **32.07** **$g\ mol^{-1}$**

Molar Mass

1 mole of copper can be represented by this stack of pure copper pennies

How many atoms are in 1 mole of copper?

6.02×10^{23} atoms

29
Cu
Copper
63.55
+2,1

Molar Mass

1 mole of copper can be represented by this stack of pure copper pennies

What is the mass of one mole of copper?

63.55 g

29
Cu
Copper
63.55
+2,1

Molar Mass

1 mole of copper can be represented by this stack of pure copper pennies

What is the mass of one atom of copper?

29

Cu

Copper

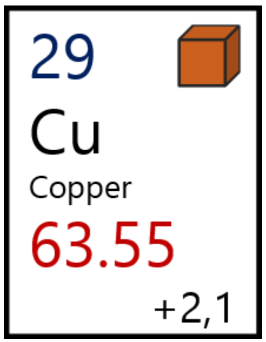
63.55

+2,1

$$\frac{63.55\ \text{g}}{6.02 \times 10^{23}\ atoms} = \mathbf{1.05 \times 10^{-22}\ g}$$

More than one mole...

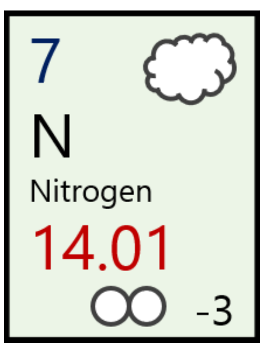
How much mass would 3 moles of Copper have?



$$3\ \mathrm{mol} \times 63.55\ \mathrm{g\ mol^{-1}} =$$

$$\boxed{190.65\ \mathrm{g}}$$

How many moles are in 28 g of Nitrogen?



$$\frac{28\ \mathrm{g}}{14.01\ \mathrm{g\ mol^{-1}}} = \boxed{\sim 2\ \mathrm{mol}}$$

Example IB Questions

11. What is the mass of carbon-12 that contains the same number of atoms as 14 g of silicon-28?

A. 6 g

B. 12 g

C. 14 g

D. 24 g

$$\frac{14\text{ g}}{28\text{ g mol}^{-1}} = 0.5\text{ mol}$$

$$0.5\text{ mol} \times 12\text{ g mol}^{-1} = \mathbf{6\ g}$$

11. A sample contains 4 g of helium and 20 g of neon. The mass number of helium is 4 and the mass number of neon is 20.

What is the ratio $\frac{\text{number of atoms of neon}}{\text{number of atoms of helium}}$?

A. 0.2

B. 1

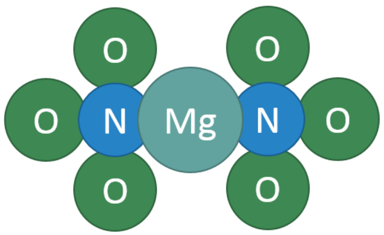
C. 5

D. 80

$$\frac{4\text{ g}}{4\text{ g mol}^{-1}} = 1\text{ mol}$$

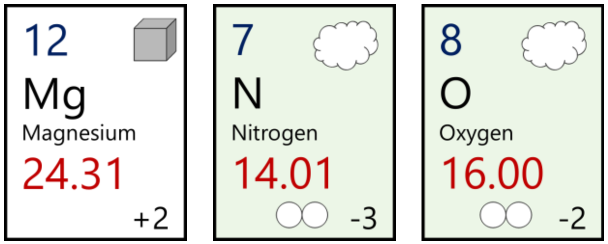
$$\frac{20\text{ g}}{20\text{ g mol}^{-1}} = 1\text{ mol}$$

More than one atom…



What is the mass of one mole of Magnesium Nitrate?

$$Mg(NO_3)_2$$



Mg N O

$$(1 \times 24.31) + (2 \times 14.01) + (6 \times 16.00)$$

$$= \mathbf{148.33\ g\ mol^{-1}}$$

Lesson Takeaways

- ❑ I can describe the importance of having a large quantity like the "mole" defined
- ❑ I can use the average atomic weight of an element or compound to convert between mass and moles and numbers of atoms

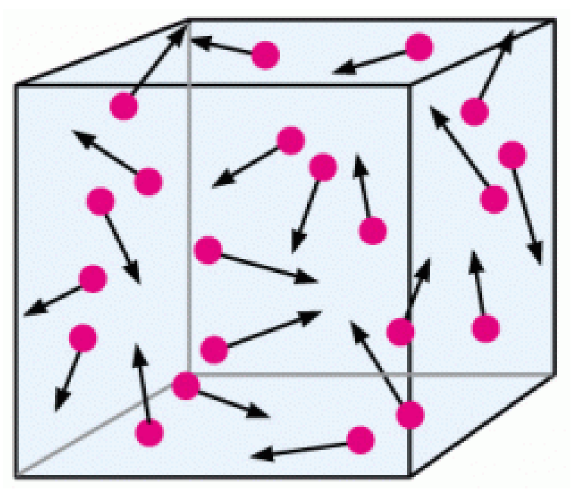
Gas Laws

IB PHYSICS | THERMAL PHYSICS

Ideal Gas

Assumptions:

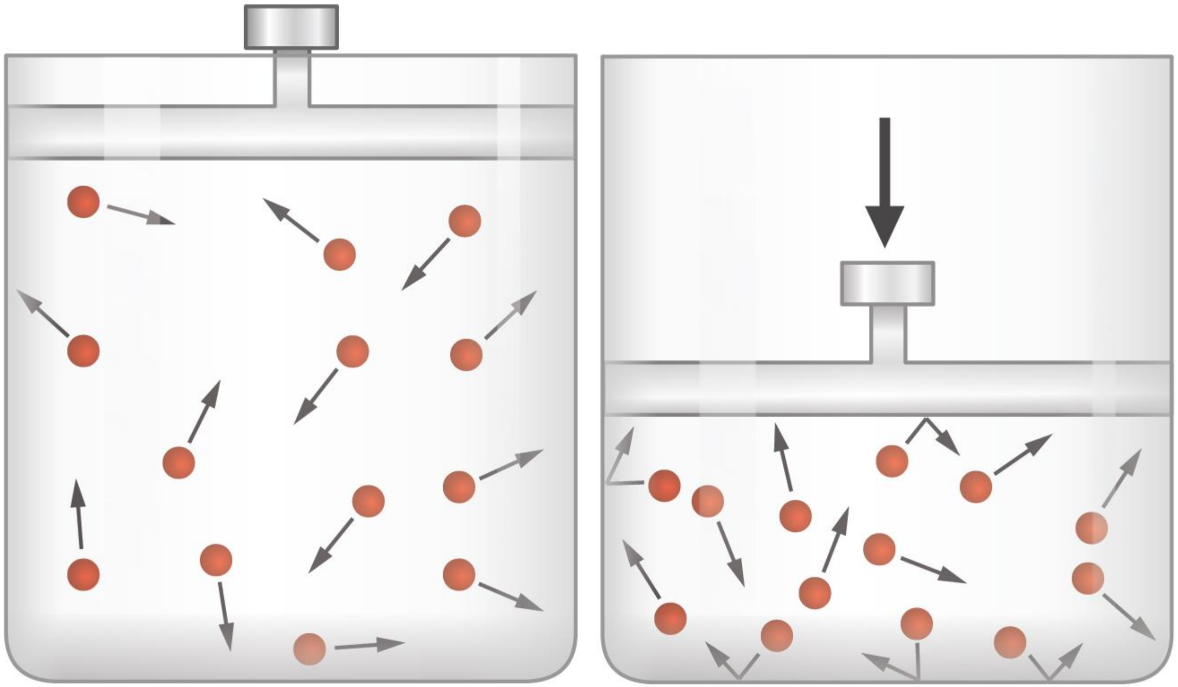
- Large # of identical molecules
- Volume of molecules is negligible
- Motion is random
- No forces between molecules
- All collisions are elastic



No longer ideal when…

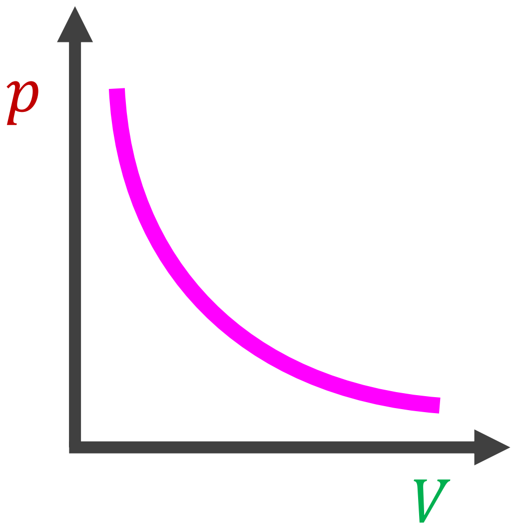
- Compressed
  - Molecules close together
- Close to Phase Change
  - All internal energy is from E_k

Boyle's Law | Volume and Pressure



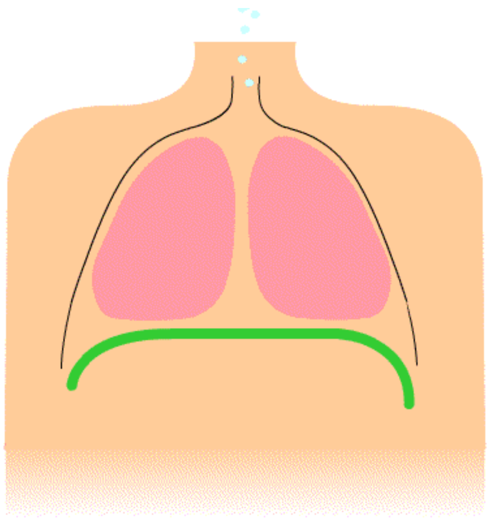
Volume Pressure

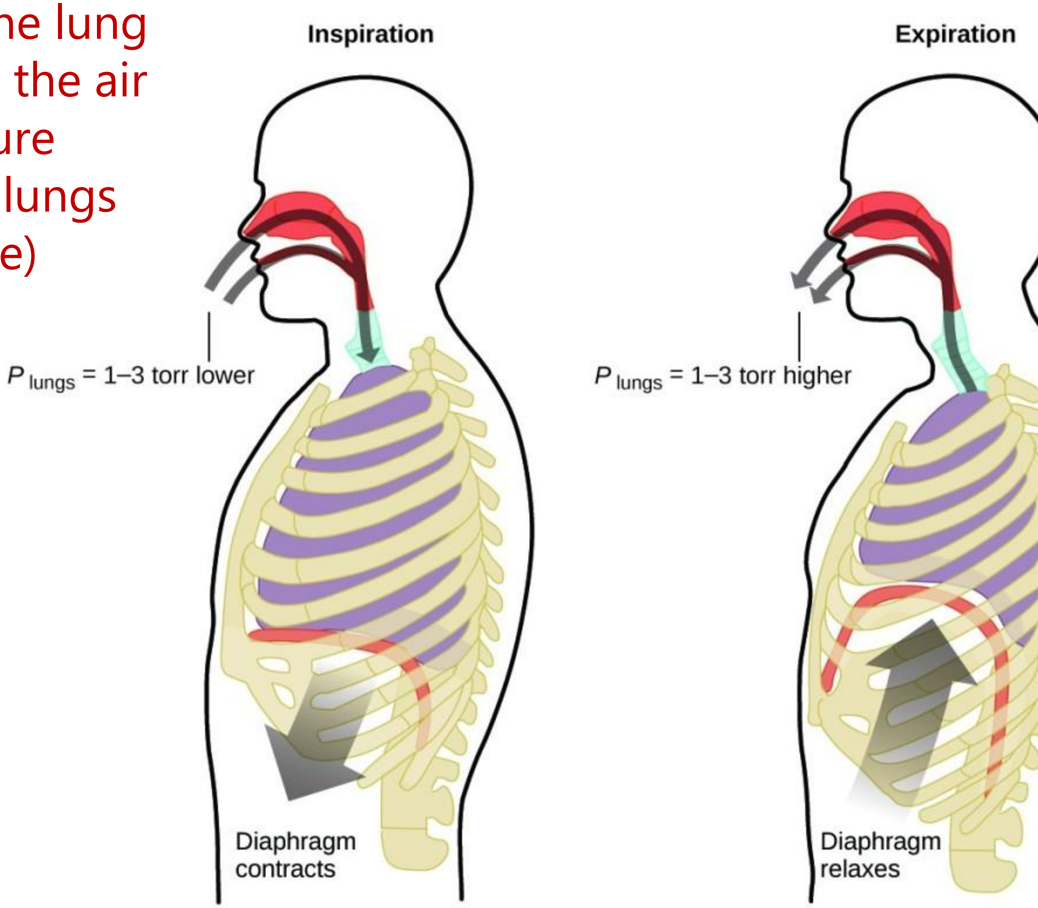
$$p \propto \frac{1}{V}$$



Boyle's Law | Volume and Pressure

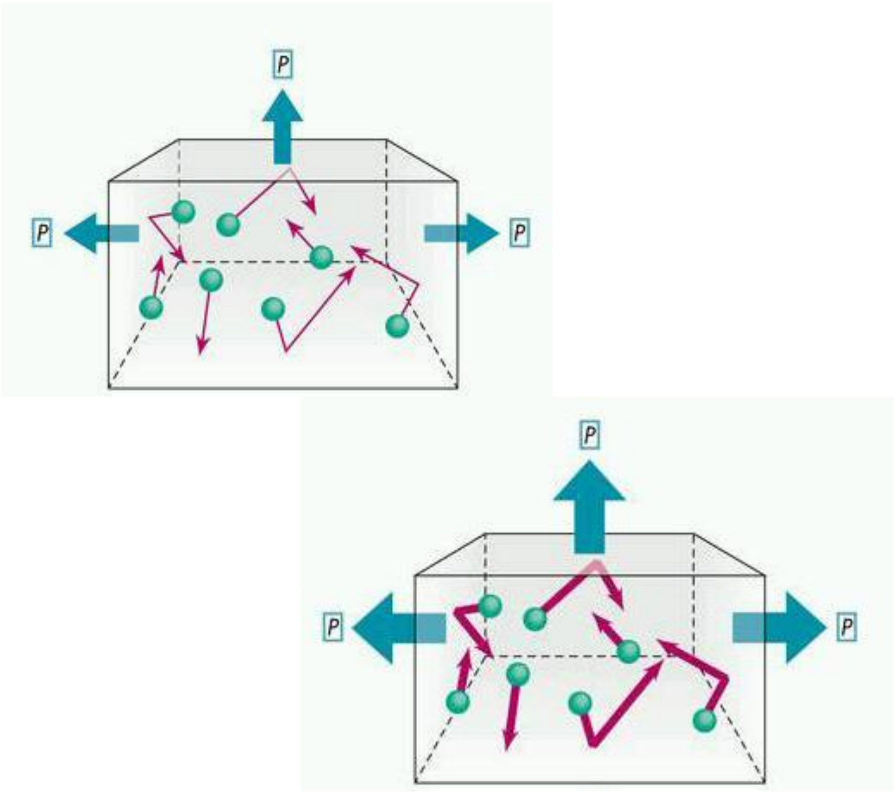
When diaphragm contracts the lung volume increases, decreasing the air pressure inside. With a pressure differential, air flows into the lungs (high pressure to low pressure)

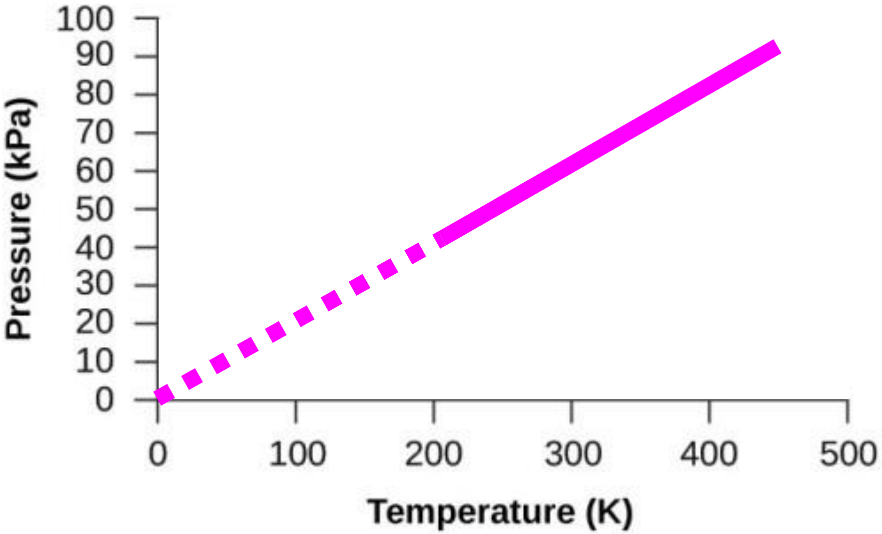




Pressure Law | Temp and Pressure

↑ Temperature ↑ Pressure $p \propto T$





Pressure Law | Temp and Pressure

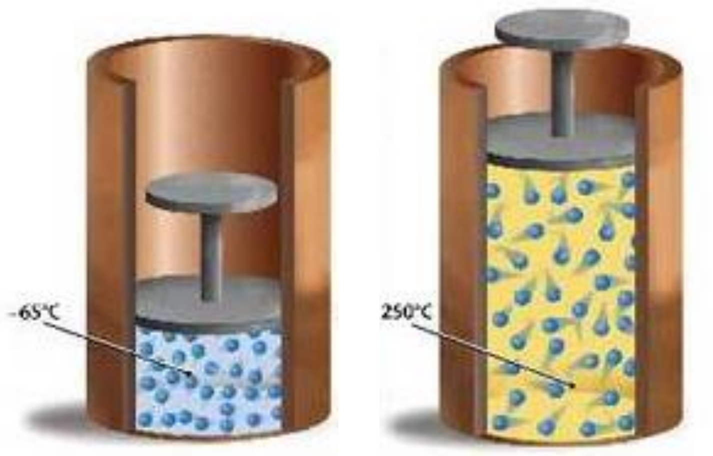
When you spray, the pressure decreases dramatically and the temperature drops

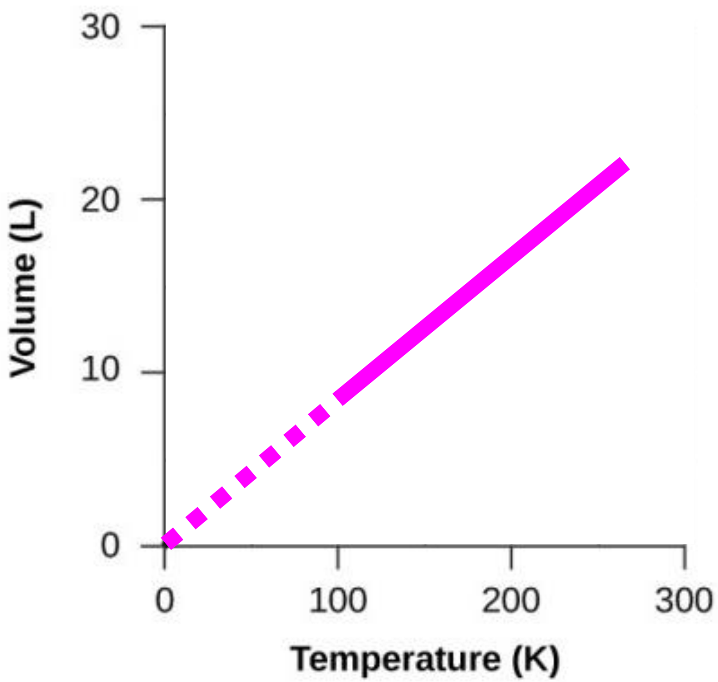
If temperature exceeds a certain amount, the increasing pressure could make a pressurized container explode!

Charles's Law | Temp and Volume

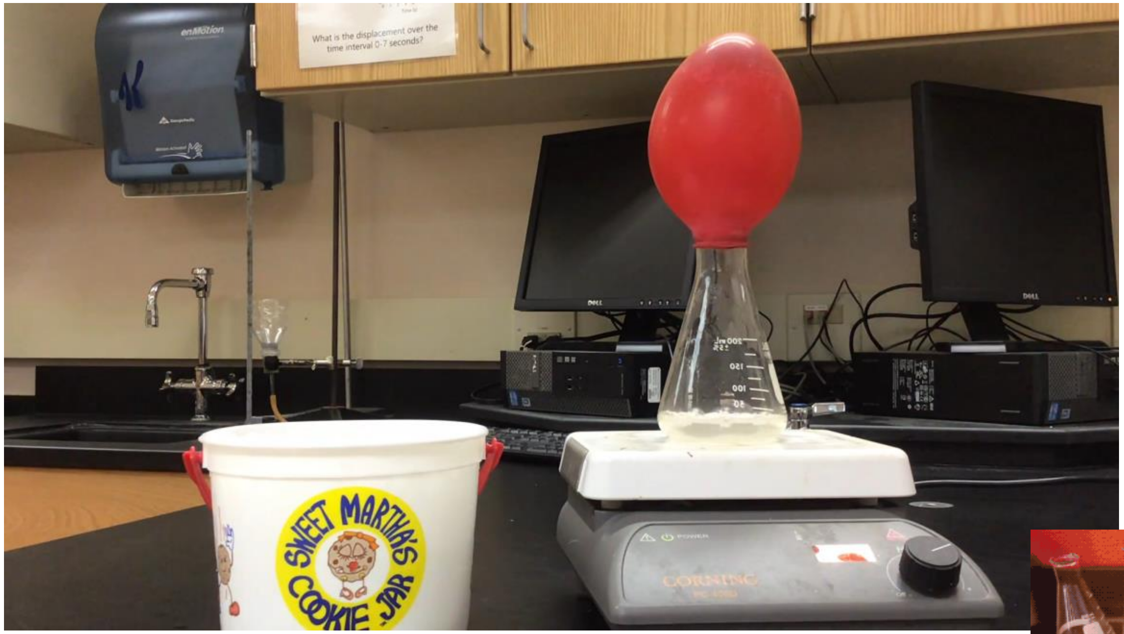
↑ Temperature ↑ Volume

$$V \propto T$$

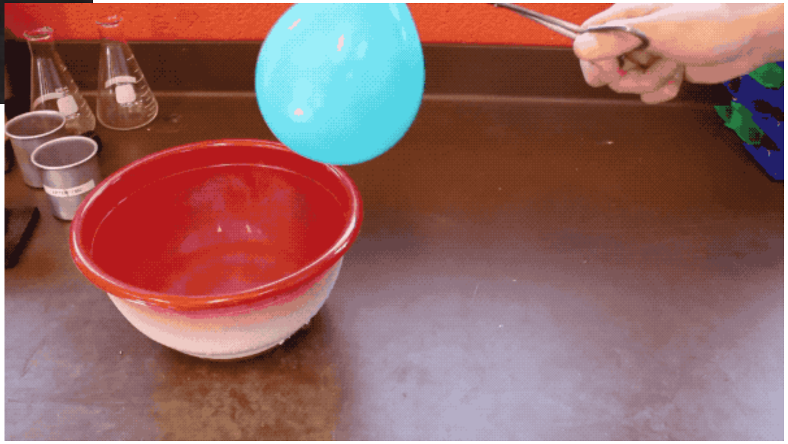




Charles's Law | Temp and Volume



When the temperature of the air inside a balloon decreases, so does the volume. (this effect is even more dramatic when the gas condenses into a liquid)



Ideal Gas Law

$p \propto \frac{1}{V}$ $\quad p \propto T$ $\quad V \propto T$

$$pV = nRT$$

Ideal Gas Law

Quantity	Symbol	Unit
Pressure	p	[Pa]
Volume	V	[m^3]
Amount	n	[mol]
Temperature	T	[K]

$$pV = nRT$$

[atm]

[L]

Gas Constant

$R = 8.31\ J\ K^{-1}\ mol^{-1}$

IB Physics Data Booklet

Sub-topic 3.1 – Thermal concepts	Sub-topic 3.2 – Modelling a gas
$Q = mc\Delta T$ $Q = mL$	$p = \frac{F}{A}$ $n = \frac{N}{N_A}$ $pV = nRT$ $\bar{E}_K = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T$

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	$9.81\ \mathrm{m\,s^{-2}}$
Gravitational constant	G	$6.67 \times 10^{-11}\ \mathrm{N\,m^2\,kg^{-2}}$
Avogadro's constant	N_A	$6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
Gas constant	R	$8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
Boltzmann's constant	k_B	$1.38 \times 10^{-23}\ \mathrm{J\,K^{-1}}$

Try This

What is the pressure of 23 mol of a gas behaving ideally in a 0.25 m^3 container at 310 K?

$p = ?$

$V = 0.25\ \mathrm{m}^3$

$n = 23\ \mathrm{mol}$

$R = 8.31\ J\ K^{-1}\ mol^{-1}$

$T = 310\ \mathrm{K}$

$$pV = nRT$$

$$p(0.25) = (23)(8.31)(310)$$

$$p = 237{,}000\ \mathrm{Pa}$$

Change in Volume

A fixed mass of an ideal gas has a volume of 0.14 m^3 at 301 K. If its temperature is increased to 365 K at the same pressure, what is its new volume, V_2?

$$pV = nRT$$

Rearrange so constants are on one side

$$\frac{V}{T} = \frac{nR}{p}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow \frac{0.14\ \mathrm{m}^3}{301\ \mathrm{K}} = \frac{V_2}{365\ \mathrm{K}}$$

$$V_2 = 0.17\ \mathrm{m}^3$$

Try This

A sample of ammonia is found to occupy 0.250 L under laboratory conditions of 27 °C and 0.850 atm. Find the volume of this sample at 0 °C and 1.00 atm.

$$pV = nRT$$

Rearrange so constants are on one side

$$\frac{pV}{T} = nR$$

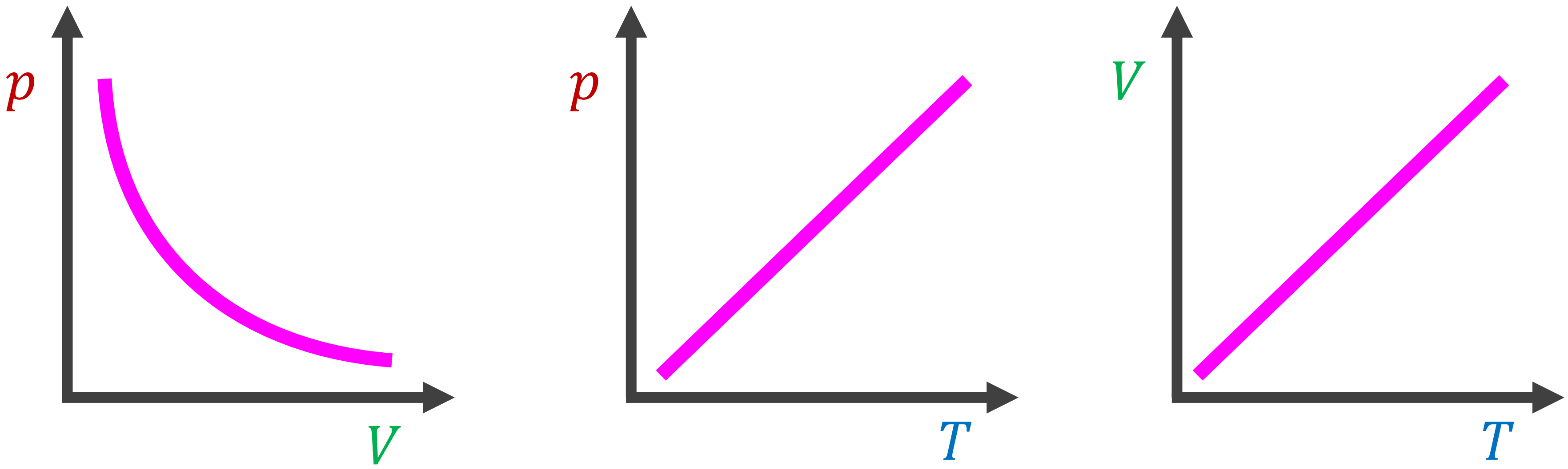
$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$\frac{(0.850)(0.250)}{(27+273)} = \frac{(1.00)(V_2)}{(0+273)}$$

$$V_2 = 0.19\ L$$

Draw these graphs

$$pV = nRT$$



Related Constants

Gas Constant

$R = 8.31\ J\ K^{-1}\ mol^{-1}$

N_A

$$\frac{R}{k_B} = \frac{8.31\ J\ K^{-1}\ mol^{-1}}{1.38 \times 10^{-23}\ J\ K^{-1}} = 6.02 \times 10^{23}\ mol^{-1}$$

Boltzmann's constant

$k_B = 1.38 \times 10^{-23}\ J\ K^{-1}$

Average Kinetic Energy

$$\bar{E}_K = \frac{3}{2}k_B T = \frac{3}{2}\frac{R}{N_A}T$$

Same Constant Value

Boltzmann's constant

$k_B = 1.38 \times 10^{-23}\ J\ K^{-1}$

Gas Constant

$R = 8.31\ J\ K^{-1}\ mol^{-1}$

IB Physics Data Booklet

Sub-topic 3.1 – Thermal concepts	Sub-topic 3.2 – Modelling a gas
$Q = mc\Delta T$ $Q = mL$	$p = \frac{F}{A}$ $n = \frac{N}{N_A}$ $pV = nRT$ $\bar{E}_K = \frac{3}{2}k_B T = \frac{3}{2}\frac{R}{N_A}T$

Quantity	Symbol	Approximate value
Acceleration of free fall (Earth's surface)	g	$9.81\ \text{m s}^{-2}$
Gravitational constant	G	$6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$
Avogadro's constant	N_A	$6.02 \times 10^{23}\ \text{mol}^{-1}$
Gas constant	R	$8.31\ \text{J K}^{-1}\ \text{mol}^{-1}$
Boltzmann's constant	k_B	$1.38 \times 10^{-23}\ \text{J K}^{-1}$

Lesson Takeaways

- ❑ I can identify conditions when a substance is no longer considered an ideal gas
- ❑ I can describe the relationships between volume, temperature, and pressure in an ideal gas
- ❑ I can use the Ideal Gas Law to solve for pressure, volume, amount, or temperature
- ❑ I can use the Ideal Gas Law to describe how changing one or more variable(s) would affect another