Gleniffer High School

S3

Properties of Matter

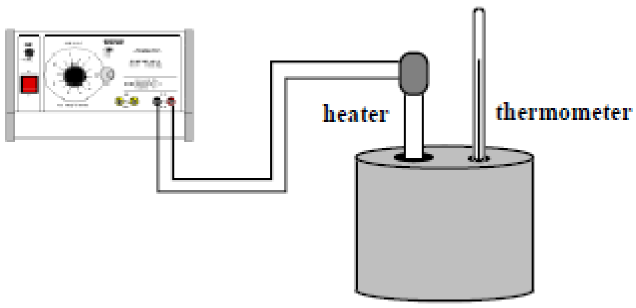
Summary Notes

SPECIFIC HEAT CAPACITY

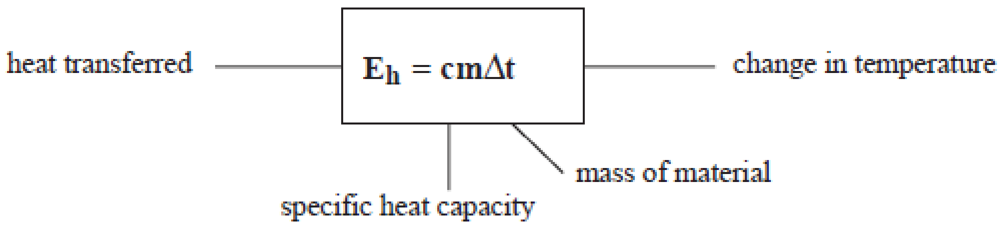
Temperature is a measure of how hot or cold something is. Temperature is a measure of the mean **kinetic energy** of the particles in a substance. Temperature is measured in units called **degrees Celsius (^{0}C).**

Heat is a type of energy. Heat is measured in units called Joules (J) or kilojoules (kJ).

The following experiment could be carried out to show the heat energy required by one kilogram of a material to increase its temperature by 1 ^{0}C. This value is known as the material's **specific heat capacity (c).**



Specific heat capacity is calculated using the following equation:-



where,

E_h is heat energy measured in Joules (J)

c is specific heat capacity measured in Joules per kilogram degrees Celsius ($Jkg^{-1}\,^0C^{-1}$)

m is the mass measured in kilograms (kg)

ΔT (the "Δ" is called delta) is the change in temperature measured in degrees Celsius (^{0}C)

Example One

When a kettle containing 2.5 kg of water (c_{water} = 4180 $Jkg^{-1}\,^0C^{-1}$) is heated from 20 ^{0}C to 80 ^{0}C, calculate the heat taken in by the water.

E_h = ?

c_{water} = 4180 $Jkg^{-1}\,^0C^{-1}$

m = 2.5 kg

ΔT = (80 - 20)

ΔT = 60 ^{o}C

E_h = c x m x ΔT

E_h = 4180 x 2.5 x (80 - 20)

E_h = 4180 x 2.5 x 60

E_h = 627,000J

E_h = 627 kJ

Example Two

A deep fat fryer is used to heat 820 g of oil (c_{oil} = 2130 J kg^{-1} $^0C^{-1}$). The temperature of the oil changes from 20 ^{0}C to 140 ^{0}C. Calculate the heat supplied to the oil.

E_h = ?

c_{oil} = 2130 J kg^{-1} $^0C^{-1}$

m = 820 g = 0.82 kg

ΔT = (140 – 20)

$E_h = cm\Delta T$

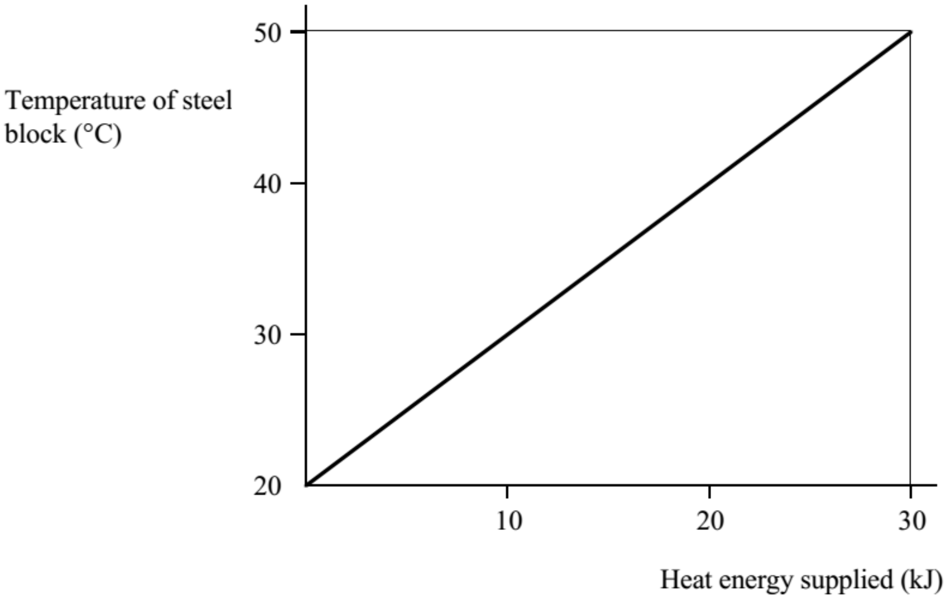
E_h = 2130 x 0.82 x (140 – 20)

E_h = 2130 x 0.82 x 120

E_h = 210000 J (or 2.1 x 10^5 J or 210 kJ)

Example Three

The graph below represents how the temperature of a 2 kg steel block changes as heat energy is supplied. From the graph calculate the specific heat capacity of steel.



E_h = 30 kJ = 30 000 J or 30 x 10^3 J

c = ?

m = 2 kg

ΔT = (50 – 20)

$E_h = c\ m\ \Delta T$

30000 = c x 2 x (50 -20)

30000 = c x 60

c = 500 J kg^{-1} $^oC^{-1}$

Note, that specific heat capacity values can often be found in data table during assessments.

Material	*Specific heat capacity* in $J\,kg^{-1}\,°C^{-1}$
Alcohol	2350
Aluminium	902
Copper	386
Glass	500
Ice	2100
Iron	480
Lead	128
Oil	2130
Water	4180

SPECIFIC LATENT HEAT

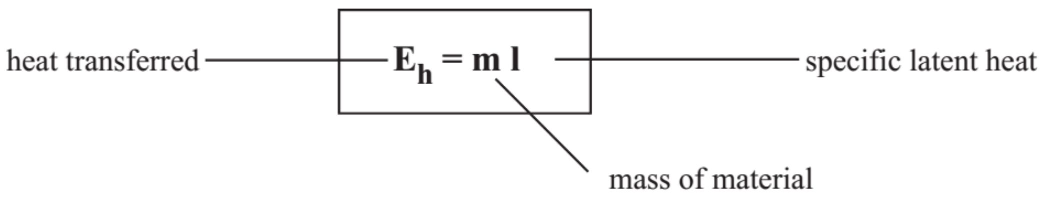
Changes of State

When ice at its melting point of 0 °C gains heat energy, it changes into water, also at 0 °C. When the process is reversed, water at its freezing point of 0 °C changes into ice at 0 °C. In this case, energy is released with no change in temperature.

Specific Latent Heat

The specific latent heat of a substance is the energy involved in changing the state of 1 kg of the substance without any change in temperature.

Specific latent heat is calculated using the formula:



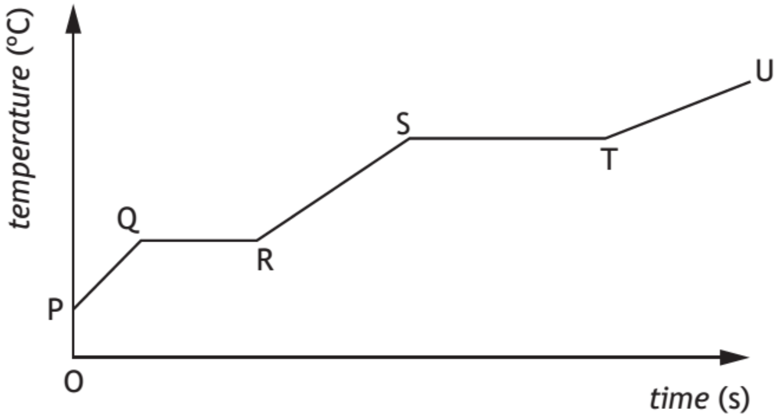
The specific latent heat of **vaporisation** is the heat energy required to change 1 kg of **liquid to vapour** without any change in temperature.

The specific latent heat of **fusion** is the heat energy required to change 1 kg of **solid to liquid** without any change in temperature.

The unit for specific latent heat is the **Joule per kilogram (Jkg^{-1})**

These changes of state are often shown in a graph.

The following graph shows the changes which take place when a solid is heated over a period of time.



P to Q – the solid is heated up

Q to R – the change of state from solid to liquid is taking place without any change in temperature

R to S – the liquid is heated up

S to T - the change of state from liquid to gas (vapour) is taking place without any change in temperature

T to U – the gas (vapour) is heated up

Data tables containing latent heat values are provided during assessments.

Specific latent heat of vaporisation of materials

Material	*Specific latent heat of vaporisation* in $J\,kg^{-1}$
Alcohol	$11{\cdot}2 \times 10^5$
Carbon Dioxide	$3{\cdot}77 \times 10^5$
Glycerol	$8{\cdot}30 \times 10^5$
Turpentine	$2{\cdot}90 \times 10^5$
Water	$22{\cdot}6 \times 10^5$

Specific latent heat of fusion of materials

Material	*Specific latent heat of fusion* in $J\,kg^{-1}$
Alcohol	$0{\cdot}99 \times 10^5$
Aluminium	$3{\cdot}95 \times 10^5$
Carbon Dioxide	$1{\cdot}80 \times 10^5$
Copper	$2{\cdot}05 \times 10^5$
Iron	$2{\cdot}67 \times 10^5$
Lead	$0{\cdot}25 \times 10^5$
Water	$3{\cdot}34 \times 10^5$

Example One

Calculate the energy required to melt 5 kg of ice.

E_h = ?

m = 5 kg

l = 3.34 x 10^5 J kg^{-1} (see data table)

E_h = m x l

E_h = 5 x 3.34 x10^5

E_h = 1.67 x 10^6 J

Example Two

Ammonia of mass 5 kg is vaporised using 13 kJ of heat energy. Calculate the specific latent heat of vaporisation of ammonia.

E_h = 13 kJ or 13,000 J

m = 5 kg

l = ?

E_h = m x l

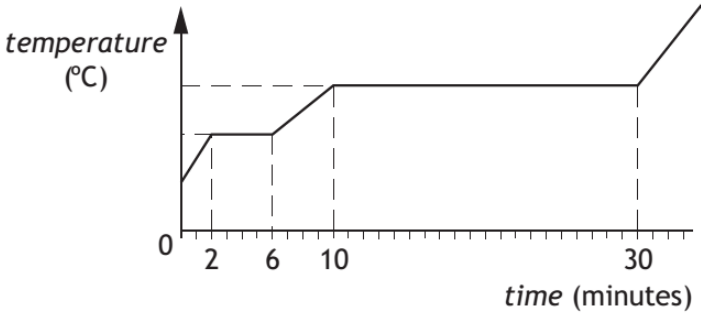
13,000 = 5 x l

l = 2,600 Jkg^{-1}

Example Three

A solid block of lead is placed in an insulated flask and is supplied with 216 kJ of heat by an immersion heater during the change of state from solid to liquid.

The graph shows how the temperature of the lead changes with time.



a) State the time taken during the change of state from solid to liquid.

b) Calculate the mass of the block of lead.

Answer

a) 4 minutes

b)

E_h = 216 kJ = 216 000 J or 216 x 10^3 J

m = ?

l = 0.25 x 10^5 J kg^{-1} (see data table)

E_h = ml

216 000 = m x 0.25 x 10^5

m = 8.64 kg

PRESSURE

Pressure on a surface is defined as the force per unit area, and can be calculated using the formula:

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

where,

p is pressure measured in Pascals (Pa)

F is force measured in Newtons (N)

A is the area in square metres (m^2)

(1 Pascal is the same as 1 Newton per square metre; i.e. 1 Pa = 1 Nm^{-2})

Example One

A box weighs 160 N and has a base area of 4 m^2. Calculate the pressure it exerts on the ground.

p = ?

F = 160 N

A = 4 m^2

p = F / A

p = 160 / 4

p = 40 Pa

Example Two

A textbook covers an area of 0.05 m^2 when placed on a desk. The pressure on the desk is 30 Pa. Calculate the force the textbook exerts on the desk.

p = 30 Pa

F = ?

A = 0.05 m^2

P = F / A

30 = F / 0.05

F = 30 x 0.05

F = 1.5 N

Example Three

A truck has a weight (downwards force) of 16 000 N. The truck exerts a pressure of 196 000 Pa on the ground. Calculate the area of contact between the truck and the ground.

p = 196 000 Pa

F = 16 000 N

A = ?

p = F / A

196 000 = 16 000 / A

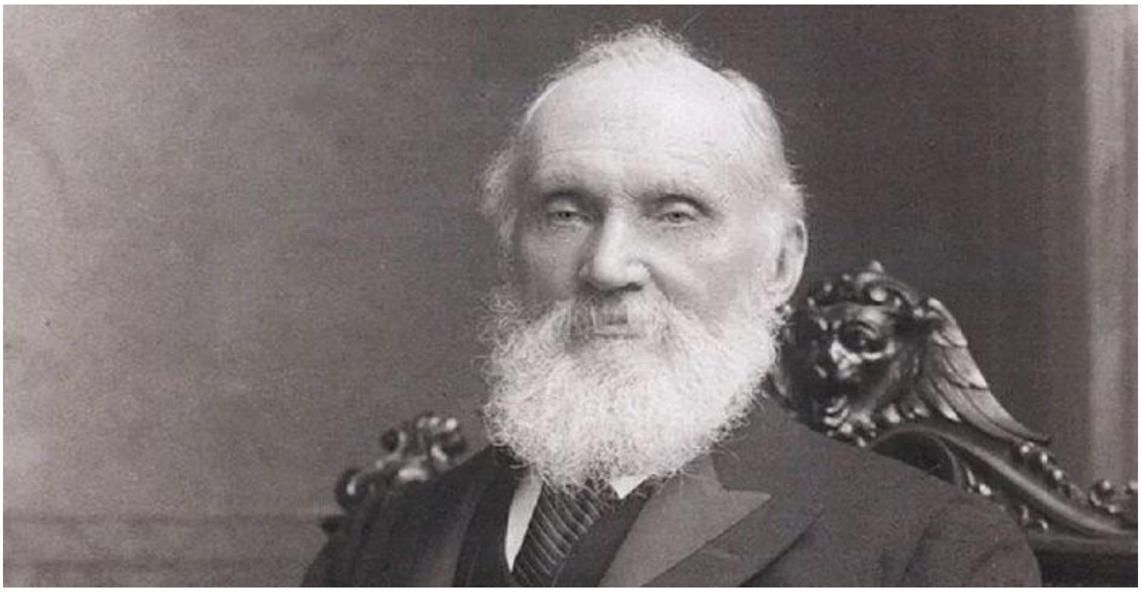
A = 0.08 m^2

KELVIN TEMPERATURE SCALE

From earlier in the notes we found out that temperature is a measure of how hot or cold something is. Temperature is a measure of the mean **kinetic energy** of the particles in a substance. Temperature is measured in units called **degrees Celsius (^{0}C).**

Particles can move and have kinetic energy until the temperature drops to **-273 ^{o}C.** At this temperature **absolutely no particles can move.**

It was **Lord Kelvin** that worked out that no particles can move at -273 ^{o}C and he called this temperature **ABSOLUTE ZERO.**



The temperature at which absolutely no particles can move can be written as:

-273 ^{o}C OR Absolute zero OR Zero Kelvins OR 0 K

To convert a ^{o}C temperature into a Kelvin temperature you add 273.

^{o}C + 273 = Kelvin

For example 37 ^{o}C is the same as 310 K (37 + 273).

To convert a Kelvin temperature into a ^{o}C temperature you take away 273.

Kelvin - 273 = ^{o}C

For example 200 K is the same as -73 ^{o}C (200 – 273).

Note, that **temperature differences are the same in Kelvins as in degrees Celsius.** For example, a temperature increase of 10 ^{o}C (20 ^{o}C to 30 ^{o}C) is the same as a temperature increase of 10 K (293 K to 303 K).

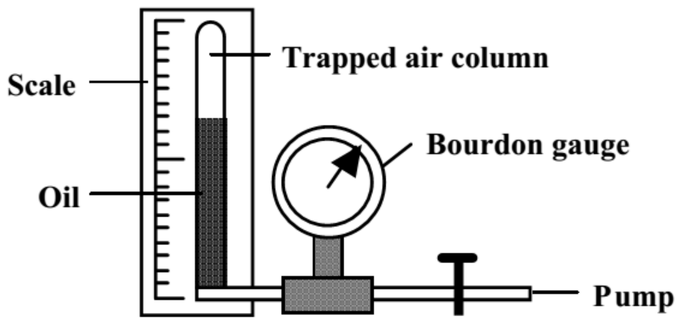
GAS LAWS

Kinetic Theory of Gases

The **kinetic theory** tries to explain the behaviour of gases using a model. The model considers a gas to be composed of a large number of very small particles, which are far apart and which **move randomly at high speeds**, **colliding elastically** (this means without losing energy) with everything they meet. The kinetic theory of gases will be used in the N5 course to explain three gas laws.

Boyle's Law

Boyle's law explains the relationship between pressure and volume for a fixed mass of gas at a constant temperature. Boyle's law can be shown by carrying out an experiment which measures a trapped **volume** of air and takes readings from a special **pressure** meter known as a Bourdon Gauge.



The data from the experiment shows that increasing the pressure decreases the volume and leads to the following statement of Boyle's law.

"For a fixed mass of gas at a constant temperature, the pressure of a gas is inversely proportional to its volume."

This statement means that **if the volume is halved the pressure will double.**

For example, when the volume of the trapped gas is 4 cm^3 and the pressure is noted as 100 kPa, if the volume of trapped gas is halved to 2 cm^3 the pressure will double to 200 kPa.

This statement can also be written as:

$$p \times V = \text{constant}$$

In other words, the first set of data, 4 x 100 = 400, will give the same value as the second set of data, 2 x 200 = 400

Boyle's law can also be presented as an equation:

$$p_1 V_1 = p_2 V_2$$

where,

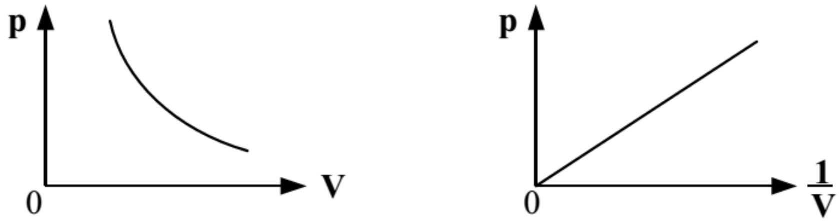
p_1 represents initial pressure

p_2 represents final pressure

V_1 represents initial volume

V_2 represents final volume

Another way to present Boyle's law is in graph form:



Example One

A sealed syringe has 6 cm^3 of air trapped inside it. The plunger of the syringe is adjusted until the volume of trapped air is 18 cm^3 at a pressure of 1.0×10^5 Pa. Calculate the initial pressure of the trapped air.

p_1 = ?

V_1 = 6 cm^3

$p_2 = 1.0 \times 10^5$ Pa

V_2 = 18 cm^3

$p_1V_1 = p_2V_2$

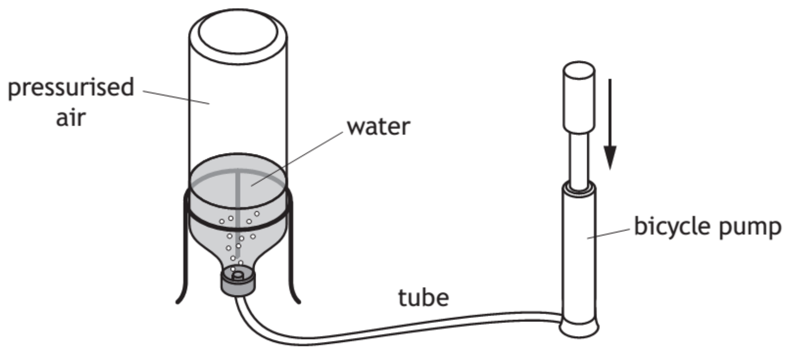
$p_1 \times 6 = 1.0 \times 10^5 \times 18$

$p_1 = (1.0 \times 10^5 \times 18) / 6$

$p_1 = 3.0 \times 10^5$ Pa

Example Two

A water rocket is shown below.



Before being launched the pressure of the air inside the rocket is 185 000 Pa. At one point during the flight, the volume of air in the rocket is 80 cm^3 and the pressure inside the rocket has dropped to 150 000 Pa. Calculate the initial volume of air in the rocket.

p_1 = 185 000 Pa

V_1 = ?

p_2 = 150 000 Pa

V_2 = 80 cm^3

$p_1V_1 = p_2V_2$

$185000 \times V_1 = 150000 \times 80$

$185000 \times V_1 = 12000000$

V_1 = 65 cm^3

Example Three

The pressure of a gas enclosed in a cylinder by a piston changes from 80 kPa to 200 kPa. If there is no change in temperature and the initial volume was 25 litres, calculate the new volume.

$p_1 = 80$ kPa

$V_1 = 25$ l

$p_2 = 200$ kPa

$V_2 = ?$

$p_1V_1 = p_2V_2$

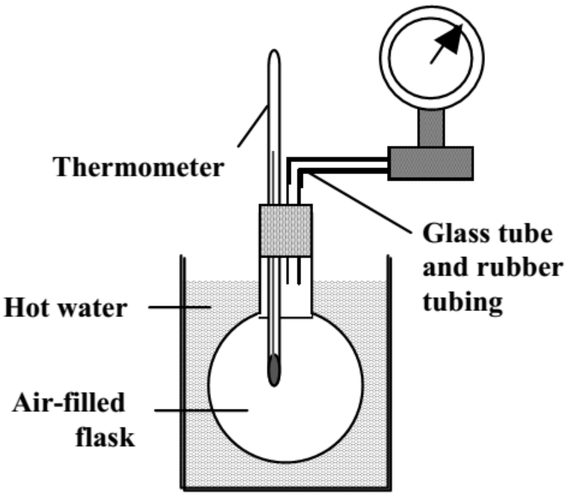
$80 \times 25 = 200 \times V_2$

$2000 = 200 \times V_2$

$V_2 = 10$ l

Gay-Lussac's Law

Gay-Lussac's law explains the relationship between pressure and temperature for a fixed mass of gas at a constant volume. Gay-Lussac's law can be shown by carrying out an experiment which measures the **temperature** of an air-filled flask and takes readings from a special **pressure** meter known as a Bourdon Gauge.



The data from the experiment shows that increasing the temperature increases the pressure and leads to the following statement of Gay-Lussac's law.

"For a fixed mass of gas at a constant volume, the pressure of a gas is directly proportional to its temperature measured in Kelvin."

This statement means that **if the pressure is doubled the temperature in Kelvins will also double.**

For example, when the pressure is noted as 100 kPa and the Kelvin temperature is 300 K, if the pressure doubles to 200 kPa the new temperature would be 600 K. (Note, on the degrees Celsius scale the temperature does not double – it would change form 27 °C to 327 °C)

This statement can also be written as:

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

In other words, the first set of data, 100 000 / 300 = 333, will give the same value as the second set of data, 200 000 / 600 = 333.

Gay-Lussac's law can also be presented as an equation:

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

where,

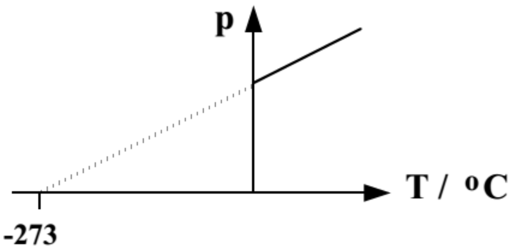
p_1 represents initial pressure

p_2 represents final pressure

T_1 represents initial temperature in Kelvins

T_2 represents final temperature in Kelvins

Another way to present Gay-Lussac's law is in graph form as:



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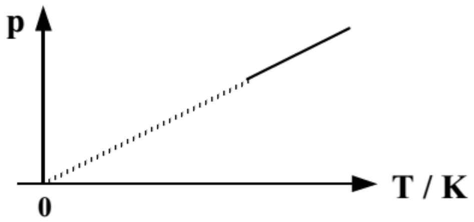


Example One

In a Gay-Lussac's experiment the final pressure of the gas was measured as 115 000 Pa. The temperature was increased from 310 K to 350 K during the experiment. Calculate the initial pressure.

p_1 = ?

T_1 = 310 K

p_2 = 115 000 Pa

T_2 = 350 K

$p_1 / T_1 = p_2 / T_2$

p_1 / 310 = 115 000 / 350

p_1 = (115 000 x 310) / 350

p_1 = 102 000 Pa

Example Two

The initial pressure in a helium balloon is 100 000 Pa. If the pressure drops to 80 000 Pa, when the temperature is 5 °C, calculate the balloon's initial temperature. (Assume no change in the balloon's volume.)

p_1 = 100 000 Pa

T_1 = ?

p_2 = 80 000 Pa

T_2 = 5 °C = (5 + 273) = 278 K

$p_1 / T_1 = p_2 / T_2$

100 000 / T_1 = 80 000 / 278

T_1 = (278 x 100 000) / 80 000

T_1 = 348 K

T_1 = 75 °C

Example Three

Hydrogen in a sealed container at 27 ^{0}C has a pressure of 1.8 x 10^5 Pa. If it is heated to a temperature of 77 ^{0}C, calculate the new pressure?

p_1 = 1.8 x 10^5 Pa

T_1 = 27 ^{0}C = (27 = 273) = 300 K

p_2 =?

T_2 = 77 ^{0}C = (77 + 273) = 350 K

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

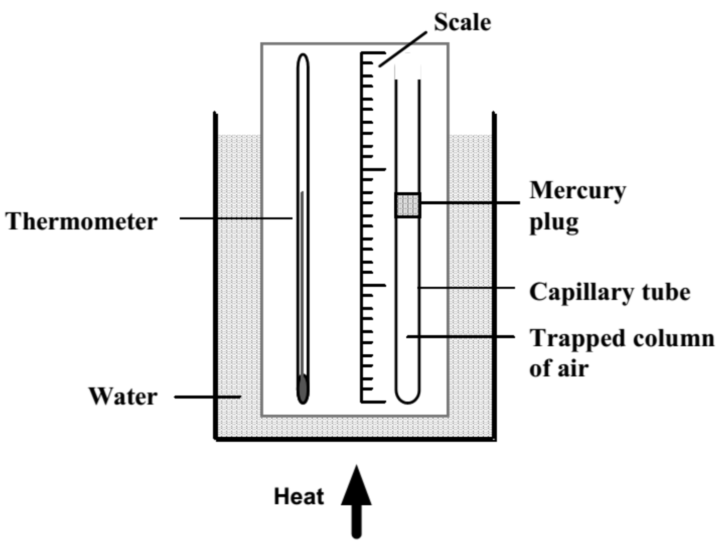
1.8 x 10^5 / 300 = p_2 / 350

p_2 = (1.8 x 10^5 x 350) / 300

p_2 = 2.1 x 10^5 Pa

Charles Law

Charles law explains the relationship between temperature and volume for a fixed mass of gas at a constant pressure. Charles law can also be shown by carrying out an experiment which measures the **temperature** and **volume** of a trapped column of air.



The data from the experiment shows that increasing the temperature increases the volume and leads to the following statement of Charles law.

“For a fixed mass of gas at a constant pressure, the volume of a gas is directly proportional to its temperature measured in Kelvin.”

This statement means that **if the volume is trebled the temperature in Kelvins will also treble.**

For example, when the volume is noted as 0.4 cm^3 and the Kelvin temperature is 270 K, if the volume trebles to 1.2 cm^3 the new temperature would be 810 K. (Note, on the degrees Celsius scale the temperature does not treble – it would change form -3 °C to 537 °C)

This statement can also be written as:

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

In other words, the first set of data, 0.4 / 270 = 1.5×10^{-3}, will give the same value as the second set of data, 1.2 / 810 = 1.5×10^{-3}.

Charles law can also be presented as an equation:

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

where,

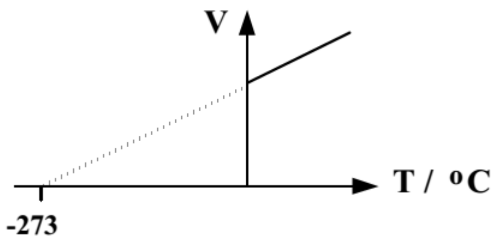
V_1 represents initial volume

V_2 represents final volume

T_1 represents initial temperature in Kelvins

T_2 represents final temperature in Kelvins

Another way to present Charles law is in graph form as:



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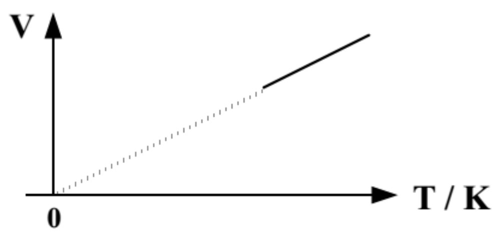

Example One

In a Charles' Law experiment the final volume of the gas was 6 cm^3. The temperature change during the experiment from 323 K to 277 K. Calculate the initial volume of the gas.

V_1 = ?

T_1 = 323 K

V_2 = 6 cm^3

T_2 = 277 K

$V_1 / T_1 = V_2 / T_2$

V_1 / 323 = 6 / 277

V_1 = (6 x 323) / 277

V_1 = 7 cm^3

Example Two

A weather balloon's volume is 15 m^3. The volume of the weather balloon increases to 16.5 m^3, when the temperature rises to 46 °C. Calculate the initial temperature of the weather balloon. (Assume no change in the pressure.)

V_1 = 15 m^3

T_1 = ?

V_2 = 16.5 m^3

T_2 = 46 °C = (46 + 273) = 319 K

$V_1 / T_1 = V_2 / T_2$

15 / T_1 = 16.5 / 319

T_1 = (15 x 319) / 16.5

T_1 = 290 K

T_1 = 17 °C

Example Three

400 cm^3 of air is at a temperature of 20 °C. Assuming no change in pressure, calculate the temperature of the air when the volume increases to 500 cm^3.

V_1 = 400 cm^3

T_1 = 20 °C = (20 + 273) = 293 K

V_2 =500 cm^3

T_2 = ?

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

400 / 293 = 500 / T2

T_2 = (500 x 293) / 400

T_2 = 366 K = 93 °C

$E_p = mgh$

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

$Q = It$

$V = IR$

$R_T = R_1 + R_2 + \ldots$

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

$V_2 = \left(\frac{R_2}{R_1 + R_2}\right)V_s$

$\frac{V_1}{V_2} = \frac{R_1}{R_2}$

$P = \frac{E}{t}$

$P = IV$

$P = I^2 R$

$P = \frac{V^2}{R}$

$E_h = cm\Delta T$

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

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

$p_1V_1 = p_2V_2$

$\frac{p_1}{T_1} = \frac{p_2}{T_2}$

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

$d = vt$

$v = f\lambda$

$T = \frac{1}{f}$

$A = \frac{N}{t}$

$D = \frac{E}{m}$

$H = Dw_R$

$\dot{H} = \frac{H}{t}$

$s = vt$

$d = \bar{v}t$

$s = \bar{v}t$

$a = \frac{v-u}{t}$

$W = mg$

$F = ma$

$E_w = Fd$

$E_h = ml$