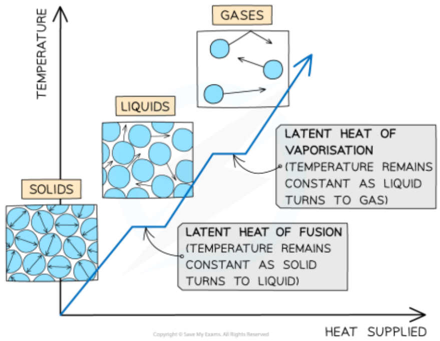
Topic 9: Thermodynamics

0.9 Specification notice:

In order to develop their practical skills, students should be encouraged to carry out a range of practical experiments related to this topic. Possible experiments include investigating the relationship between the volume and temperature of a fixed mass of gas. Mathematical skills that could be developed in this topic include substituting numerical values into algebraic equations using appropriate units for physical quantities. This topic may be studied using applications that relate to thermodynamics, for example space technology.

9.Q Exam questions

9.144 Be able to use the equations ΔE = mcΔθ and ΔE = LΔm

Define Specific Heat capacity, latent heat of fusion and vapourisation and their equations?	• The energy required to raise the temperature of 1kg of substance by 1K [$E=mc\Delta\Theta$] • The energy needed to convert 1kg of a solid to a liquid at its melting point in a steady state [$E=mL_f$] • Vapourisation is from liquid to gas [$E= mL_v$]  *Interestingly enough, sublimation is going straight from solid to gas which is how you can smell soap*
Define Heat	Energy transfer from a body or region of high temperature to a lower temperature
Explain why water is often used as a coolant?	Water has a very high specific heat capacity relative to other substances so can absorb a lot of thermal energy without a large increase in temperature
Define Steady state?	Keeping a system at a **constant** temperature *Could also be called an isothermal state* *No transfer of heat in or out*

9.145 CORE PRACTICAL 12: Calibrate a thermistor in a potential divider circuit as a thermostat.

9.146 CORE PRACTICAL 13: Determine the specific latent heat of a phase change.

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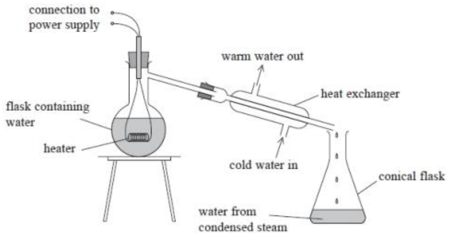
The apparatus shown can be used to determine a value for the specific latent heat of vaporisation of water.



(b) The heater was left on and water continued to boil in the flask. The water was allowed to boil for a few minutes. The conical flask was then placed under the heat exchanger and water was collected in it.

(i) Give a reason why the water was left boiling for a few minutes before the conical flask was put in place.

(1)

Give a reason why the water was left boiling for a few minutes before the concial flask was put in place?
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(b)(i)

- After a short time of boiling in the flask, all the apparatus would be at 100 °C.
Or so energy is not being used to heat up the flask
Or so steam won't condense in the flask (1)

- After a short time of boiling in the flask all the apparatus would be at 100 degrees (1)
- So energy is not being used to heat the flask (1)
- So steam won't condense in the flask (1)
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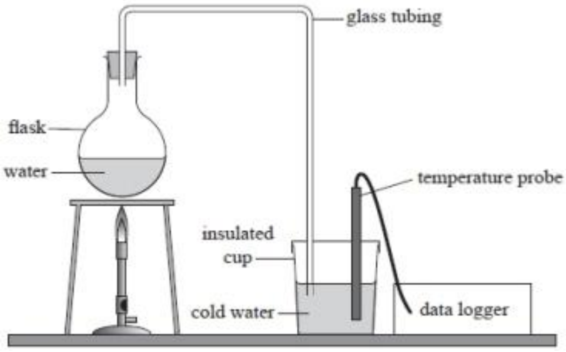

(ii) Identify a significant source of error in this experiment and the steps that should be taken to minimise its effect on the calculated value of the specific latent heat of vaporisation of water.

(2)

How can you minimise the significant sources of error of the calculated value of the SLH of vapourisation of water? (2)
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- Thermal energy will be transferred from the steam/tubing to the surroundings (1)
- Lagging/insulating/shortening the tubing (1)

- Thermal energy will be transferred from the steam/tubing to the surroundings (1)
- Lagging/insulating/shortening the tubing (1)

Accept:

- Thermal energy is transferred to the cup/ probe
- These should have a small a heat capacity
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9.147 understand the concept of *internal energy* as the random distribution of potential and kinetic energy amongst molecules

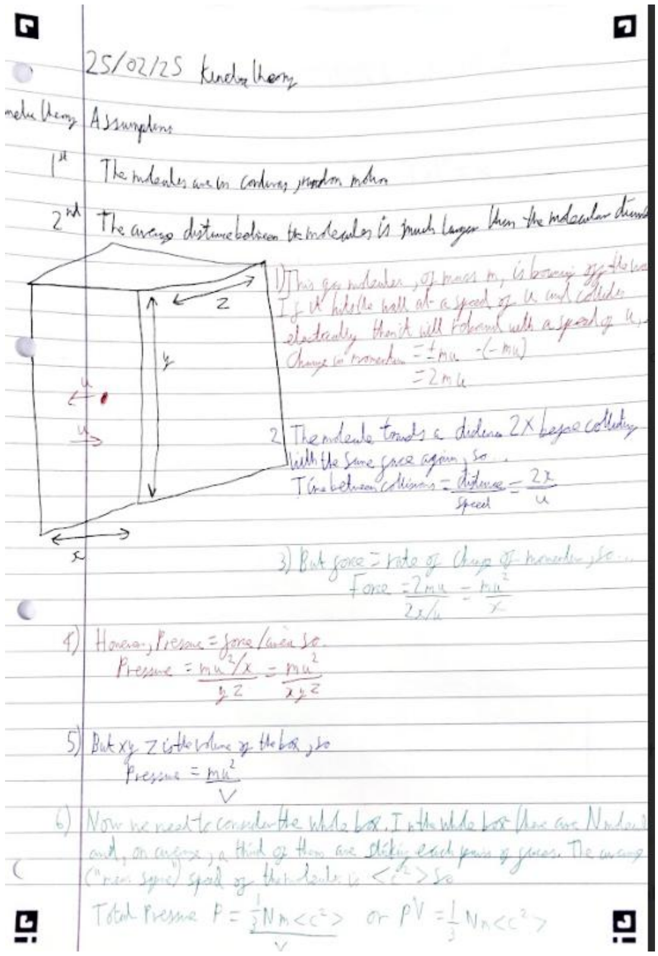
Define internal energy?	Sum of the KE and PE between molecules *This thermal KE is the sum of the energies of all the particles moving different directions. An object as a whole won't move. Whereas mechanical KE is where all the particles are moving in the same direction*

9.148 understand the concept of *absolute zero* and how the average kinetic energy of molecules is related to the absolute temperature

Define Absolute Zero	The temperature at which the molecules in a substance have 0 KE *This means for a system at 0K it is not possible to remove any more energy from it even in space the temperature is roughly 2.7K just above absolute zero*
Define Temperature	Describes the average KE of molecules within a substance measured in Celcius or Kelvin (or Fahrenheit or Rankine)

9.149 be able to derive and use the equation $pV = \frac{1}{3}Nm < c^2 >$ using the kinetic theory model

Derive $pV = \frac{1}{3}Nm < c^2 >$
 	
I highly doubt they would ask you to derive this but make sure to know the explanation which is on the next FC
	• Change in momentum = +mu -(-mu)
	    ○ =2mu
	• Time between collisions = 2x/u
	• Force = rate of change of momentum = 2mu/(2x/u)
	    ○ = mu^2/x
	• Pressure = force/area = $(mu^2/x)/y^2$
	    ○ mu^2/xy^2
	• Pressure = mu^2/V
	• The average V_{rms} of the molecules is $<c^2>$ so
	• Total pressure -> $P=(1/3Nm<c^2>)/V$ or $pV=1/3Nm<c^2>$

	
Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states. * The model of atoms as hard incompressible spheres, moving rapidly and randomly, can be used to explain why gases exert a pressure. Explain, using ideas of momentum, why the pressure exerted by a gas increases as the temperature of the gas increases. (6) Explain using ideas of momentum why the pressure exerted by a gas increases as the temperature of the gas increases?	1. As the temperatures of the gas increases the KE (average speed) of the atoms increases 2. Greater KE (speed) so the momentum of the atoms increases 3. The rate (frequency) of collisions of atoms with the container walls increases [Or the time between collisions with the walls decreases] 4. The rate of change of momentum at the walls increases 5. Rate of change of momentum is equal to the force 6. Pressure is force/area and the force (on the walls) is greater
What assumptions are made in the molecular kinetic theory and mnemonic?	● T - **T**ime taken for collisions is instantaneous ● R - **R**andom motion ● A - no **A**ttraction between particles ● V - particles have negligible **V**olume compared to container ● E - **E**lastic collisions so E_K is conserved

	TRAVE mnemonic
How can you calculate RMS velocity?	$$c_{rms} = \left[\frac{(c_1^2 + c_2^2 + \ldots + c_N^2)}{N}\right]^{1/2}$$ • $KE = 1/2m(C_{rms})^2 = 3/2kT = 3RT/2N_A$ • $Crms = \sqrt{\frac{3kT}{m}}$ *We call this the average speed. The average* ***<u>VELOCITY</u>*** *is zero since we have equal number of molecules travelling in opposite directions.*

9.150 be able to use the equation *pV = NkT (and pV=nRT)* for an ideal gas

What are the 2 forms of the ideal gas Equation and how are they relate?	$$\boxed{PV = nRT = Nk_BT}$$ Since… $$\boxed{k_B = \frac{R}{N_A}} \boxed{n = \frac{N}{N_A}}$$ Where… • P = pressure (Pa) • V = volume (m3) • T = temperature (K) • n = number of moles • N = number of molecules • R = universal gas constant = 8.3145 $Jmol^{-1}k^{-1}$ • k_B = Boltzmann's constant = 1.38×10^{-23} JK^{-1} • N_A = Avagradro's number = 6.023×10^{23} mol^{-1} This is formed by combining all 3 gas laws to form a constant of PV∝ NT as with more molecules, we have greater pressure and then we introduce a constant. This constant is good for proportionality questions.
Describe an Ideal gas?	• Obeys Boyle's Law at all temperatures and

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pressure
● Internal energy is all kinetic and so there are no intermolecular forces)

NO POTENTIAL ENERGY FOR IDEAL GASES Look out for multiple choice questions on this
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<td>What is the mnemonic and symbol to remember the gas Laws?</td>
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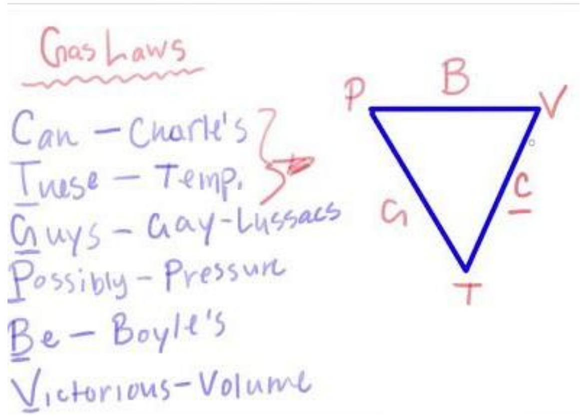

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<td>State Boyle's Law and its equation? (with its graph and justification)</td>
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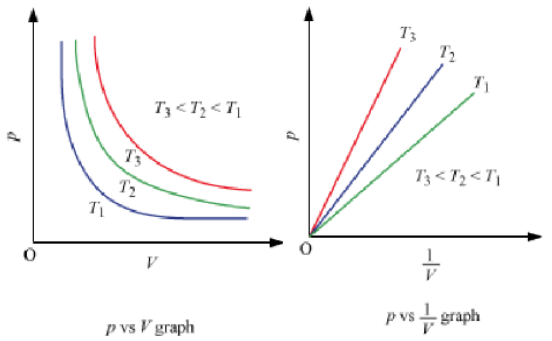
For a fixed mass of gas at constant temperature, pressure is inversely proportional to the volume

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


Left: the high temperature is further from the origin since PV =nRT and increasing T increases constant and thus stretch. Right: nRT is the gradient and increasing T leads to steeper gradient.

● This is since reducing volume means molecules travel less distance between impact as walls -> more impacts / second -> greater force as the speed is constant since temperature is constant
● This is nicely shown below:
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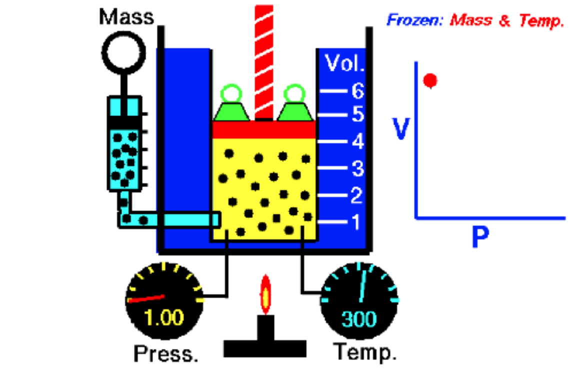

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<td>Draw a Volume/pressure graph to represent Boyle’s Law? As well as a pressure against 1/volume graph?</td>
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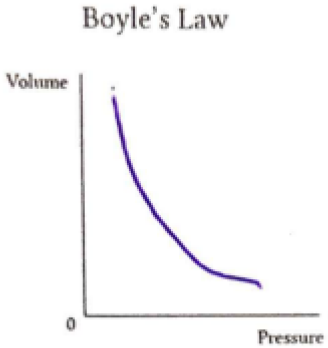

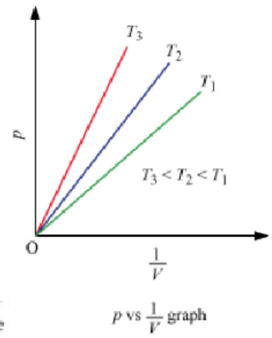

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<td>State Charles’ Law and its equation? (with a graph for different pressures and justification)</td>
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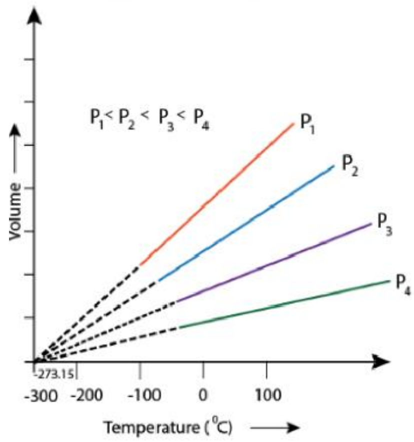
For a fixed mass of gas at constant pressure, the volume is proportional to temperature

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



The smaller gradient means greater pressure since V/T = Nk/P

- As temperature increases, particles gain kinetic energy. Since they must have frequency of collisions with the wall to keep pressure constant, the volume must increase
- This is shown below:
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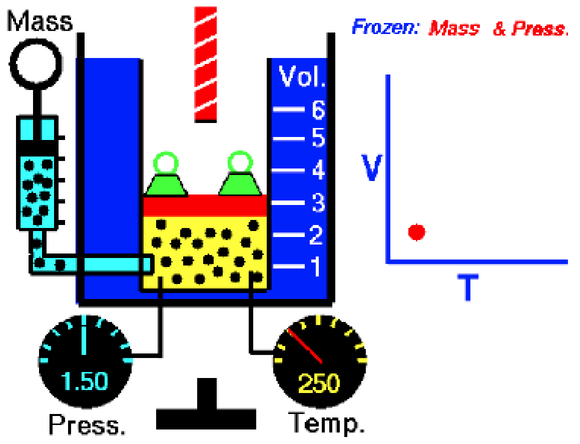
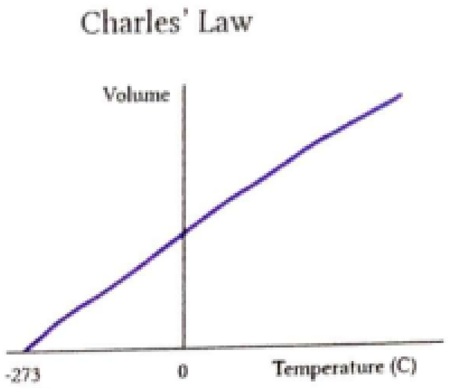
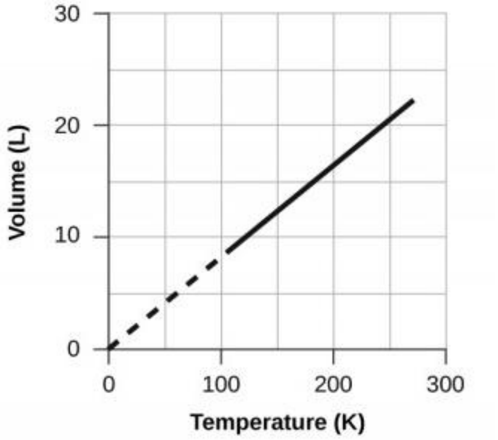
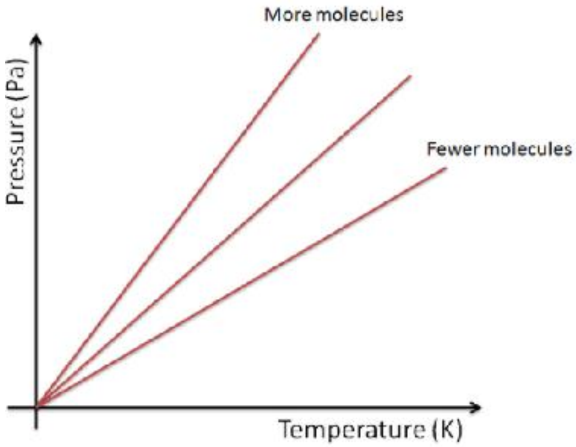
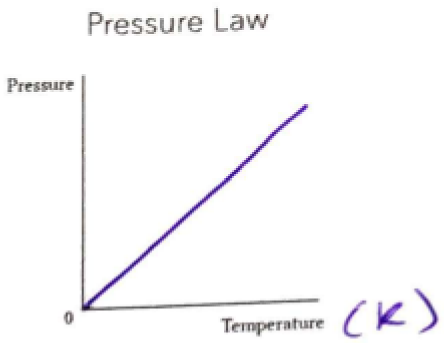
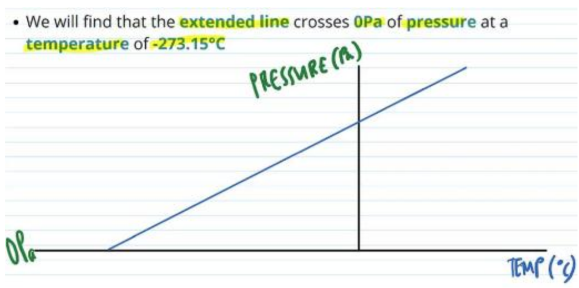
	
Draw the 2 Volume/temp graph to represent Charles' Law?	  Depends on if Temperature is in Celcius or Kelvin
State Pressure Law (Gay-Lussac's Law) and its equation? (with a graph and justification)	For a fixed mass of gas at constant volume, pressure is proportional to temperature $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

	 *Since P = Nk/v * T, steeper gradient means more molecules.* ● If you fix the volume and increase the temperature, the particles have more kinetic energy and thus move faster, have more frequent collisions with the walls increasing pressure.
Draw the 2 Pressure against temp graph to represent Pressure Law (Gay-Lussac's Law)?	  Depends on if Temperature is in Celcius or Kelvin

9.151 CORE PRACTICAL 14: Investigate the relationship between pressure and volume of a gas at fixed temperature.

9.152 be able to derive and use the equation $\frac{1}{2}m < c^2 >= \frac{3}{2}kT$

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Derive the relationship between KE and temperature $\frac{1}{2}m < c^2 >= \frac{3}{2}kT$

I highly doubt they would ask you to derive this but make sure to know the algebraic derivation which is on the next FC

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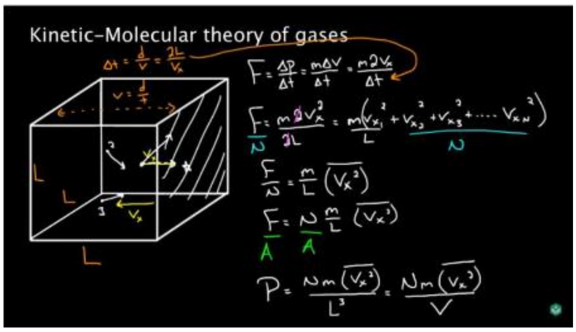
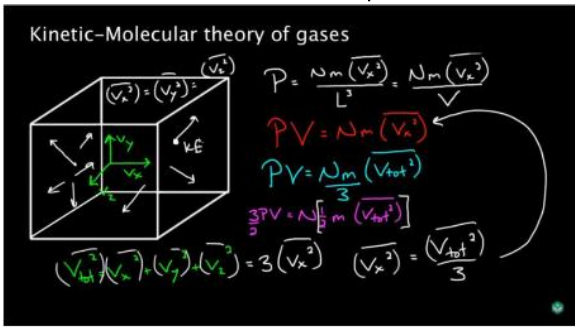
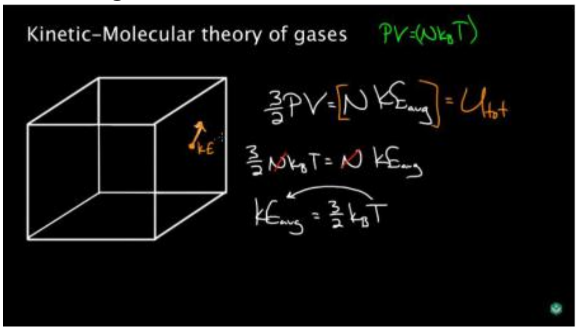


Consider a box of side length L. We can calculate the force by considering the change in momentum when it hits the wall and time between collisions (since this is the change in momentum / s). Then we add all the velocities and divided by the number of molecules. Convert this into pressure.



Now, we know that the v_x^2 is $1/3_{Vtot}^2$ by using pythagoras in 3D. We can get kinetic energy on the right.



Using the ideal gas equation on the right, we can finally relate kinetic energy to temperature

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Derive $\frac{1}{2}m < c^2 >= \frac{3}{2}kT$ using $pV = \frac{1}{3}Nm < c^2 >$ and pV= NkT (2)

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- 1/3Nm<c^2> = NkT
- 1/3m<c^2> = kT
- m<c^2> = 3kT
- 1/2m<c^2> = 3/2kT

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	• Equates right hand sides (1) • Final E_k formula ($\frac{1}{2} m \langle c^2 \rangle = 3/2\ kT$) and k is constant (1) *You can remember this through the rhyme 'Average K.E equals three-halves' kT turn it into a rap thats what I did*

9.153 understand what is meant by a *black body radiator* and be able to interpret radiation curves for such a radiator

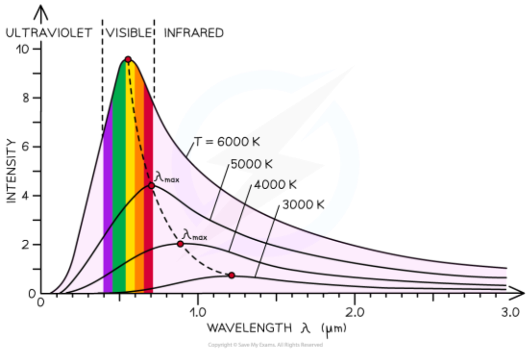
What is a perfect ideal black body	An object that absorbs and emits all of the wavelengths of EM radiation that hits it *Recall from GCSE that a matt black surface is the best absorber and emitter of infrared radiation*
What is a good absorber?	An object that is a good emitter and so they are 'perfect' emitter of radiation

9.154 be able to use the Stefan-Boltzmann law equation $L = \sigma AT^4$ for black body radiators

What are the 2 equations for stefan-boltzmann law equation and the units	● $L = A\boldsymbol{\sigma}T^4$ ● $L = 4\pi r^2\boldsymbol{\sigma}T^4$ ● L is luminosity of a star in Watts (where luminosity is the same as power) ● *Where A is surface area of a star* ● *T = surface temperature of a star in K* *$\boldsymbol{\sigma}$ = stefan-boltzmann constant 5.67×10^{-8} $Wm^{-2}k^{-4}$, T = surface temperature of a star in K (this is not the core temperature of a star)* *These tend to be ratio questions so look at for T^4 and surface area in the form of a radius or diameter*

9.155 be able to use Wien's law equation $\lambda_{max}T = 2.898 \times 10^{-3}$ m K for black body radiators.

What does Wien's Law equation $\lambda_{max}T$	As temperature increases more energy is

$=2.898 \times 10^{-3}$ show about black bodies?	radiated and the peak of radiated intensity λ_{max} moves to shorter wavelengths *Therefore $\lambda_{max} \propto 1/T$*  *The intensity-wavelength graph shows how thermodynamic temperature links to the peak wavelength for four different bodies*

Colour of star	Temperature / K
blue	> 33 000
blue–white	10 000 – 30 000
white	7 500 – 10 000
yellow–white	6 000 – 7 500
yellow	5 000 – 6 000
orange	3 500 – 5 000
red	< 3 500

A table to compare relative surface temperatures with star colours