Subject: A-level Physics	Topic: Thermal	Year Group: 13

Internal energy

1	You can increase the internal energy of a system by … • Heating • Doing work **on** the system by an external force.
2	You can decrease the internal energy of a system by … • Cooling • The system doing work **against** an external force.

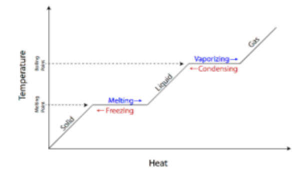
Temperature scale

1	All your work on gases requires you to use temperatures measured in Kelvin (K), apart from temperature changes which be measured in °C.
2	The Kelvin scale starts at absolute zero.
3	Absolute zero = 0 K = -273 °C
4	T (K) = θ (°C) + 273

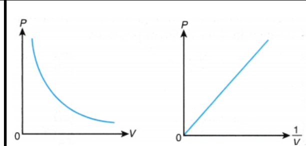
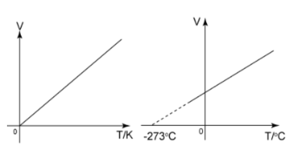
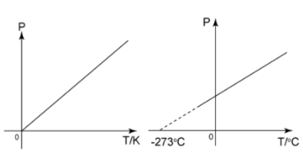
Specific heat capacity

1	Specific heat capacity (c) is the energy needed to raise the temperature of 1 kg of a substance by 1 °C. Its units are $Jkg^{-1}\,°C^{-1}$ or $Jkg^{-1}\,K^{-1}$.	
2	Energy can be transferred …	From an electrical source in which case you can calculate the energy supplied using E = P/t or E = VIt.
		By dropping a mass through a height (h) in which case E = mgh = mcΔθ , or Δθ = gh/c.
		From another object at a higher temperature in which case remember that they will both end up in thermal equilibrium (at the same final temperature).
3	Exam tip: When considering the thermal energy transferred to a liquid and its resultant change in temperature, it is often necessary to account for the E transferred to the container too.	
4	Experimental results for SHC tend to be too high. This is because some of the energy supplied heats the surroundings.	

Latent heat

1	When the solid is initially heated the energy supplied causes the temperature of the solid to increase (because the supplied energy causes the particle's average KE to increase).	
2	Once the melting point is reached the temperature remains constant even though heat is still being supplied (because energy is breaking bonds between atoms, increasing their average potential energy, rather than their KE).	
3	The temperature then rises again until the boiling point is reached. The temperature remains constant until all the liquid has turned to a gas.	
4	The internal energy is always increasing. Sometimes it is the kinetic energy that is increasing (shown by an increase in T), sometimes it is the potential energy that is increasing (shown by a change of state).	

Gas laws

1		Boyle's law: The higher the temperature of the gas, the further the curve is from the origin. If the pressure doubles, the volume halves.
2		Charles' law: At absolute zero, the volume is zero. If T is plotted in K the line passes through the origin, if T is in °C the line meets the T axis at -273 °C.
3		Pressure law: As temperature doubles so does pressure. If T is plotted in K the line passes through the origin, if T is in °C the line meets the T axis at -273 °C.

Key equations

1	Specific heat capacity	$Q = mc\Delta\theta$
2	Latent heat	$Q = ml$
3	Boyle's law	$p_1V_1 = p_2V_2$
4	Charles' law	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
5	Pressure law	$\frac{p_1}{T_1} = \frac{p_2}{T_2}$

Key Vocabulary

1	Internal energy	The sum of the randomly distributed kinetic energy and potential energy of all the particles in a body.
2	Absolute zero	The coldest possible temperature. Atoms have effectively zero kinetic energy.
3	Specific heat capacity	The energy needed to raise the temperature of 1 kg of a substance by 1 °C. Its units are $Jkg^{-1}\,°C^{-1}$ or $Jkg^{-1}\,K^{-1}$.
4	Latent heat of vaporisation	The energy required to change 1 kg of a liquid into 1 kg of gas with no change in temperature.
5	Latent heat of fusion	The energy required to change 1 kg of a solid into 1 kg of liquid with no change in temperature.
6	Boyle's law	The volume of a fixed mass of gas at constant temperature is inversely proportional to its pressure.
7	Charles' law	The volume of a fixed mass of gas at constant pressure is directly proportional to its Kelvin temperature.
8	Pressure law	The pressure of a fixed mass of gas at a constant volume is directly proportional to the Kelvin temperature.

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Ideal gas assumptions

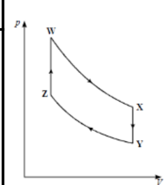
1	All molecules/atoms are identical.
2	Molecules/atoms are in random motion.
3	Newtonian mechanics apply.
4	Gas contains a large number of molecules.
5	The volume of the gas molecules is negligible compared to the volume occupied by the gas.
6	No force acts between the molecules except during collisions.
7	Collisions are elastic.
8	Collisions are of negligible duration.

Ideal gas equation

1	See equations in 'Key equations' box. Derived by combining the three gas laws.	
2	N	Number of molecules in gas.
	k	Boltzmann constant.
	n	Number of moles of the gas.
	R	Molar gas constant.
	N_A	Avogadro's constant.

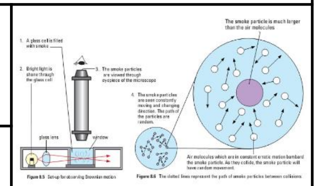
Work done

1	When a gas expands it does work (unless it is in a vacuum) because it is pushing back the atmosphere.
2	Work done = pressure x change in volume
3	WZ & XY: no work done as V stays the same. YZ: work is done **on** the gas as an outside force is compressing it. WX: work is done **by** the gas as it is pushing back the atmosphere outside as it expands.



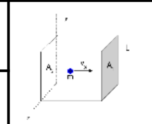
Brownian motion

1	Brownian motion is the observable random movement of particles such as smoke particles, caused by the high speed thermal motion of liquid or gas particles.
2	Smoke particles are larger than air molecules and so can be seen under a microscope. They have a jittery motion.
3	This is due to air molecules colliding with them.
4	This proves the air particles must be moving **randomly** at very **high speeds** to have sufficient momentum to cause much heavier smoke particles to exhibit this jittery motion.



Kinetic theory

1	You need to be able to derive an equation for the pressure of an ideal gas in a box. $pV = \frac{1}{3}Nm(c_{rms})^2$
2	Key things to remember when deriving the equation: • Assume the particle collides elastically with the wall. • So the change in momentum = mv – (- mv) = 2mv • Time between consecutive collisions of molecule with wall A_1 is time = distance/speed = 2l/v. • Number of collisions per second is therefore v/2l. • Rate of change of momentum = Δp/Δt = 2mv x v/2l • Newton's 2^{nd} law states F = Δp/Δt = $2mv^2/2l = mv^2/l$ • Pressure = Force / Area There are more steps but these are key.
3	In any sample of gas the molecules have a range of speeds. But the hotter the sample, the higher the **average** speed and **average** kinetic energy of the gas molecules.
4	Mean square speed, $(c_{rms})^2$: Sum of the squares of the speed of all N molecules in the gas divided by N. Unit: m^2s^{-2}.
5	The root mean square speed, c_{rms}, is the square root of $(c_{rms})^2$.
6	Average kinetic energy **per molecule** = ½ m $(c_{rms})^2$
7	Total KE of a gas = average KE per molecule x N.



Key equations

1	Ideal gas equation	$pV = NkT = nRT$ $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$
2	Number of moles	$n = \frac{N}{N_A}$
3	Molar mass	$Molar\ mass = molecular\ mass \times N_A$
4	Work done	$W = p\Delta V$
5	Mean square speed	$(c_{rms})^2 = \frac{c_1^2 + c_2^2 + c_3^2 + \cdots + c_N^2}{N}$
6	Kinetic theory	$pV = \frac{1}{3}Nm(c_{rms})^2$
7	Average kinetic energy per molecule	$\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$

Key Vocabulary

1	Ideal gas	A gas that obeys the gas laws under all conditions.
2	Mole	The number of atoms in 12 grams of carbon-12 and is equal to 6.02 x 10^{23} atoms.
3	Molar mass	The mass of one mole of a substance.
4	Avogadro constant	The number of particles in 1 mole of a substance = 6.02 x 10^{23}.
5	Kinetic theory	Liquids and gases are made up f small particles which are in constant random motion.
6	Mean square speed	The sum of the squares of all the molecules' speeds divided by the number of molecules.
7	Root mean square speed	The square root of the mean square speed.