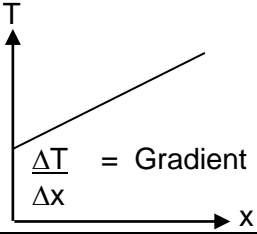
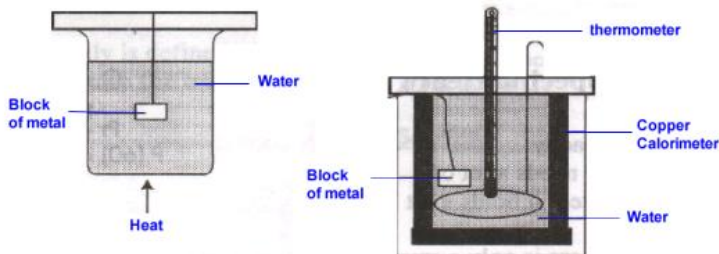
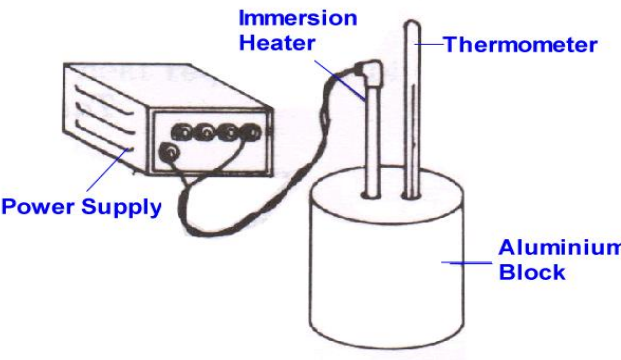


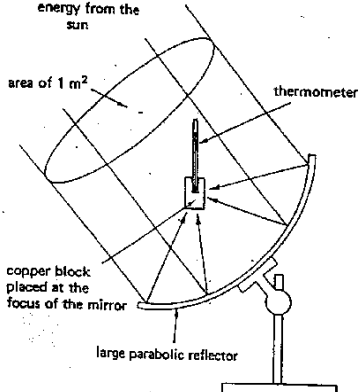
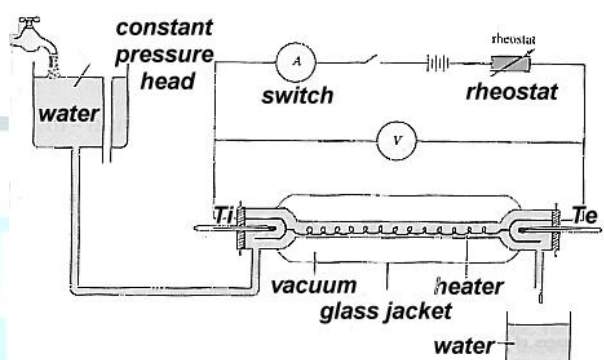
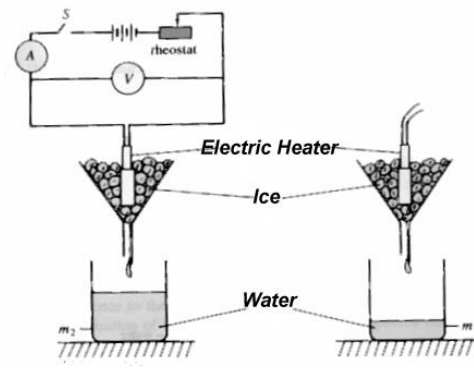
Formulae and Notes - Heat

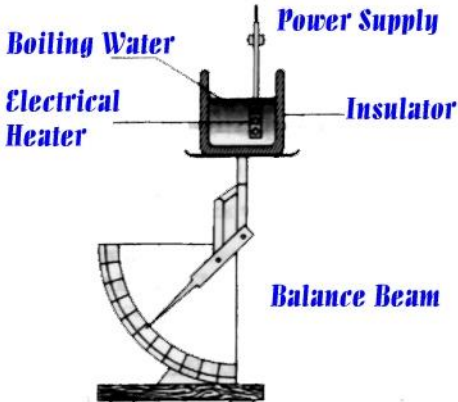
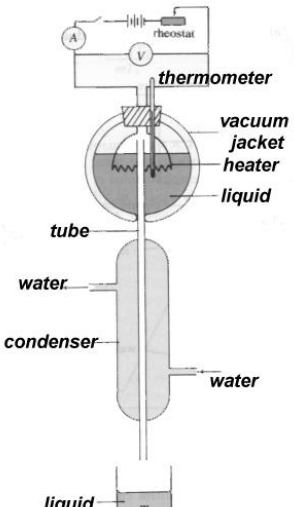
EQUATION		MEANING OF SYMBOLS			
Temperature					
1.	Zeroth law of thermodynamics	The zeroth law of thermodynamics states that if two bodies are in thermal equilibrium with a third body, then they must be in thermal equilibrium with each other.			
2.	Empirical scale	assumes the linear thermometric variation with temperature, where in actual fact, they only agree on the 2 fixed points: at 0°C and 100°C and the estimated scale is derived from experiment by determining the points of the ice and steam point			
3.	Thermodynamics scale	is independent of thermometric properties of materials as it is based on the ideal gas equation $PV = nRT$			
4.	Triple point of water	single (unique) temperature and pressure at which saturated water, water vapour and ice co-exist in equilibrium at 273.16K or 0.01°C			
<p>a. Fixed Points for Scale Temperatures which have the background shaded in grey are the fixed points used in the derivation of the temperature scale for each of the column.</p> <p>b. Centigrade Scale The temperature scale used as Centigrade lacks accuracy and is based on 100 divisions. It is an empirical scale.</p> <p>c. Celsius Scale Subsequently the centigrade scale has been improved to 2 decimal points using the thermodynamic temperatures of ice and steam and renamed the Celsius scale. Celsius scale is actually a shifted thermodynamics scale and hence not an empirical scale. The apparent sharing is only for convenience as the people have already been accustomed to using the centigrade scale.</p>					
		Centigrade	Degree Fahrenheit	Degree Celsius	Kelvin
Absolute Zero		~ -273°C	-459.67 °F	-273.15 °C	0.00 K
Melting Point of Ice at 760mmHg		~ 0°C	*32 °F	0.00 °C	273.15 K
Triple Point of Water		~ 0°C	32.018 °F	0.01 °C	273.16 K
Temperature of Human Body		37°C	96 °F	37.00°C	310.15 K
Steam Point at 760mmHg		~ 100°C	212 °F	100.00 °C	373.15 K
		$T / ^\circ\text{C}$	$T / ^\circ\text{F} = \text{Centigrade} \times 1.8 + 32$	$T / ^\circ\text{C} = T / \text{K} - 273.15$	$T / \text{K} = \text{Celsius} + 273.15$
5.	Examples of Thermometric Properties	Volume of fluid – Mercury or alcohol in glass thermometer Pressure – Constant Volume Gas thermometer Resistance – Platinum Resistance thermometer Emf - Thermocouple			

EQUATION		MEANING OF SYMBOLS	
Thermometer		Advantages	
Mercury Thermometer -39 to 357°C	<ul style="list-style-type: none"> • Portable • Easy to deploy Normal use in lab	Disadvantages <ul style="list-style-type: none"> • Limited range • Less accurate • Easy to damage 	
Constant Volume Gas Thermometer -270 to 1500°C		<ul style="list-style-type: none"> • Very Sensitive • Very Accurate • Very Large range Use for calibrating other types of thermometer and use as standard thermometer for temperatures below -183°C	<ul style="list-style-type: none"> • Difficult to use and time consuming to set up • Slow responsiveness since Volume of flask is large and not good for point measurement of temperature
Thermometer		Advantages	
Platinum Resistance Thermometer -200 to 1200°C	<ul style="list-style-type: none"> • Very Accurate • Very Large Range Use for accurate temperature measurement and use as standard thermometer for temperatures -183°C to 630°C, main use is in industries whereby it is robust and easy to deploy	Disadvantages <ul style="list-style-type: none"> • Not suitable for rapid change in temperature because it takes time to attain thermal equilibrium with the surrounding 	
Thermocouple -250 to 1500°C		<ul style="list-style-type: none"> • High responsive • Very Sensitive • Fairly Accurate • Large Range Use for rapid changes in temperature and temperature measurement of small isolated places , and as a standard thermometer for temperatures -630°C to 1063°C	<ul style="list-style-type: none"> • Less accurate if millivoltmeter is used to measure emf. • Potentiometer is preferred as a means for accurate measurement of the emf
6.	$T/^{\circ}\text{C} = T/\text{K} - 273.15$	$T/^{\circ}\text{C}$ – degrees Celsius NOT centigrade scale T/K – Kelvin	
7.	$T_0 = \frac{(PV)_0 \times T_{tr}}{(PV)_{273.16}}$	T_0 is the temperature of gas in K; PV is the product of the pressure and volume in Pa m ³ at temperature T_0 and 273.16K; T_{tr} is the temperature of triple point of water in K	
8.	For a constant volume gas $T_0 = \lim_{P_{tr} \rightarrow 0} \frac{P_0 \times T_{tr}}{P_{273.16}}$ Or $T_0 = \lim_{P \rightarrow 0} \frac{P_0 \times T_{tr}}{P_{273.16}}$	$\lim_{P_{tr} \rightarrow 0}$ means in the limit of vanishing P_{tr} or as in the inferred scenario when P_{tr} or P is gradually reduced to zero. $\lim_{P_{tr} \rightarrow 0} \frac{P}{P_{tr}}$ can be obtained from the P/P_{tr} intercept of a graph of P/P_{tr} against P_{tr} or P as P_{tr} or P is extrapolated to zero In the limit of vanishing P_{tr} or P , all real gases satisfy the equation of state for an ideal gas	

	EQUATION	MEANING OF SYMBOLS
9.	$\frac{\Delta T}{100} = \frac{\Delta x}{x_{100} - x_0}$ <p><u>Formula:</u></p> $T_0 = \frac{x - x_0}{x_{100} - x_0} \times 100$ <p><u>Graphical:</u></p> 	<p>Δx – change in thermometric reading (eg length of mercury column)</p> <p>ΔT – change in temperature</p> <p>T_0 is the temperature of thermometer;</p> <p>x_0 – thermometric reading (eg length of mercury column) when temperature is at ice point</p> <p>x_{100} – thermometric reading (eg length of mercury column) when temperature is at steam point</p> <p>x – thermometric reading (eg length of mercury column) when temperature is T_0</p>
	<p style="text-align: center;">Empirical Scale</p> <ul style="list-style-type: none"> scale assumes the linear thermometric variation with temperature, where in actual fact, they only agree on the 2 fixed points: at 0°C and 100°C estimated scale is derived from experiment by determining the points of the ice and steam point 	<p style="text-align: center;">Absolute Thermodynamic Scale</p> <ul style="list-style-type: none"> scale is independent of thermometric properties of materials as it is based on the ideal gas equation
Thermal Properties		
10.	Specific heat capacity	Is the heat energy required to raise per unit temperature of per unit mass of substance
11.	Specific latent heat of fusion	Is the heat energy required to change per unit mass of substance from solid to liquid at constant temperature
12.	Specific latent heat of vaporization	Is the heat energy required to change per unit mass of substance from liquid to gas at constant temperature
13.	Specific Heat Capacity	of a body is defined as the amount of heat required to raise the temperature of 1kg of body by 1K/1°C (1) specific heat capacity is a material constant and can only be changed by having a different material (2) lower specific heat capacity is a better heat conductor
14.	Heat Capacity	of a body is defined as the amount of heat required to raise the temperature of the body by 1K/1°C (1) heat capacity can be changed by increasing mass (2) heat capacity can also be changed by changing material (3) lower heat capacity is a better heat conductor
15.	Latent heat of fusion	is the heat energy that is required to be taken in when a body undergoes a phase changes from solid to liquid at constant melting (freezing) temperature. Unit: J
16.	Specific latent heat of fusion	of a substance is the quantity of heat required needed to change unit mass of the substance from solid to liquid state at constant temperature. Unit: J/kg

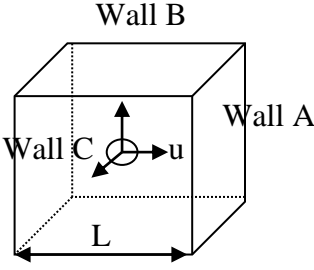
	EQUATION	MEANING OF SYMBOLS
17.	Latent heat of vaporization	is the heat energy that is required to be taken in when a body undergoes a phase change from liquid to gas at constant boiling temperature. Unit: J
18.	Specific latent heat of vaporization (L) $Q = m \cdot L$	of a substance is the quantity of heat required needed to change unit mass of the substance from liquid to vapour state at constant temperature. Unit: J/kg
19.	$Q = mc\Delta T$	Q – Heat energy given or taken by the body in J m – mass of the body c – Specific Heat Capacity in $\text{Jkg}^{-1}\text{K}^{-1}$ ΔT – change in temperature
20.	$Q = C\Delta T$ $C = mc$	Q – Heat energy given or taken by the body in J C – Heat Capacity in JK^{-1} ΔT – change in temperature m – mass of the body c – Specific Heat Capacity in $\text{Jkg}^{-1}\text{K}^{-1}$
21.	Experiment to determine the specific heat capacity of a metal by calorimeter method $m_{\text{solid}}c_{\text{solid}}(\theta_{\text{solid}} - \theta_{\text{final}}) = m_{\text{calorimeter}}c_{\text{copper}}(\theta_{\text{final}} - \theta_{\text{initial}}) + m_{\text{water}}c_{\text{water}}(\theta_{\text{final}} - \theta_{\text{initial}})$	 <p>θ - Temperature measured by the thermometer at 3 instances: (1) temperature of heated water = temperature of solid, (2) steady temperature of water in calorimeter before adding heated metal and (3) after adding the heated metal</p>
22.	Experiment to determine the specific heat capacity of a metal by electrical method $Q = VIt = mc\Delta T$	 <p>V – emf across electrical source in V I – current pass through the heating element in A t – time taken in heating the block in s</p>

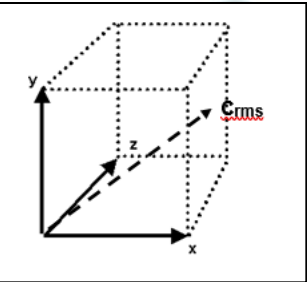
	EQUATION	MEANING OF SYMBOLS
23.	<p>Heat energy collected by the reflector = Intensity x Area $[Wm^{-2}] \quad [m^{-2}]$</p> <p>where Intensity = $\frac{\text{Power of Sun}}{\text{Area of Sphere}}$</p>	
24.	<p>$VIt = mc(T_e - T_i) + L$</p> <p>Use 2 sets of data:</p> <p>$V_1 I_1 = (m_1/t_1)c(T_e - T_i) + L_1/t_1$</p> <p>$V_2 I_2 = (m_2/t_2)c(T_e - T_i) + L_2/t_2$</p> <p>Note that $L_1 \neq L_2$</p> <p>Since $L_1/t_1 = L_2/t_2$,</p> <p>$V_1 I_1 - V_2 I_2 = (m_1/t_1 - m_2/t_2)c(T_e - T_i)$</p>	<p><u>Callendar and Barnes' Method</u> L/t or heat loss per unit time to environment is constant and shc of the liquid is to be determined</p>  <p>c = specific heat capacity of liquid to be determined in $J \text{ kg}^{-1} \text{ K}^{-1}$ L = heat energy loss in J t = time in s V = emf/pdf in V I = current in A m = mass of water flowing in kg $T_e - T_i$ = change in temperature of fluid during entry and exit in K</p>
25.	<p>Experiment to determine specific latent heat of fusion</p> <p>$Q = VIt = m \cdot L$</p> <p>Where m is the mass of ice being boiled melted and L is the specific latent heat of fusion</p>	

	EQUATION	MEANING OF SYMBOLS
26.	Experiment to determine specific latent heat of vaporization $Q = VIt = m \cdot L$ Where m is the mass of water being boiled away and L is the specific latent heat of vaporisation	
27.	$VIt = ml + L$ Use 2 sets of data: $V_1 I_1 = (m_1/t_1)l + L_1/t_1$ $V_2 I_2 = (m_2/t_2)l + L_2/t_2$ Note that $L_1 \neq L_2$ Since $L_1/t_1 = L_2/t_2$, $\frac{V_1 I_1 - V_2 I_2}{m_1/t_1 - m_2/t_2} = l$	$l = \text{specific latent heat of vaporization of liquid to be determined in } \text{J kg}^{-1} \text{ K}^{-1}$ $L = \text{heat energy loss in J}$ $t = \text{time in s}$ $V = \text{emf/pdf in V}$ $I = \text{current in A}$ $m = \text{mass of water that has been boiled in kg}$ 

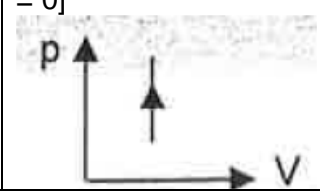
Believe in yourself

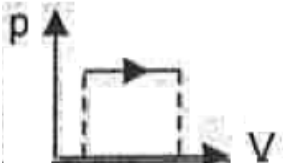

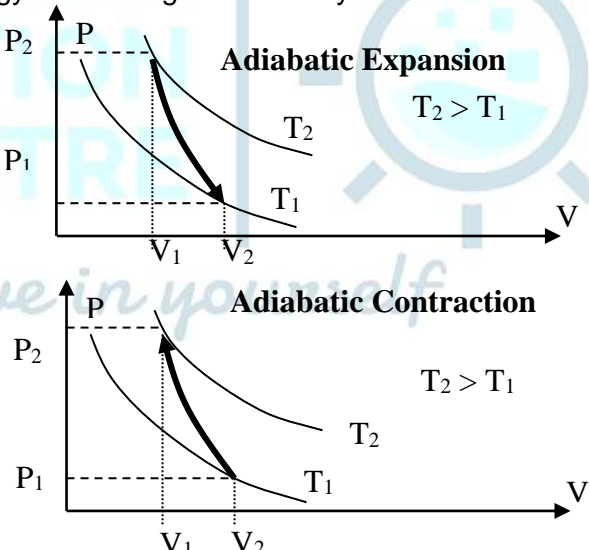
Ideal Gas		
1.	Key assumptions for ideal Gas	Gas particles of an ideal gas has negligible intermolecular forces amongst each other and each particle occupies negligible volume as compared to the volume of the gas
2.	Conditions for ideal gas	(1) High Temperature (2) Low Pressure
3.	Ideal gas is a gas that obeys the equation of state $PV = nRT$ $= (m/M_r).RT$ at all values of P, V and T	P = pressure of gas in Pa or Nm^{-2} V = volume of gas in m^3 R = ideal gas constant T = Thermodynamic temperature of ideal gas in K n = number of moles = m/M_r where m = mass of gas in g M_r is relative molecular/atomic mass of gas in $g\ mol^{-1}$
4.	$PV = nRT$ $= (N/N_A).RT$ $= NkT$	P = pressure of gas in Pa or Nm^{-2} V = volume of gas in m^3 R = ideal gas constant T = Thermodynamic temperature of ideal gas in K N = number of molecules N_A = Avogadro constant k = Boltzmann constant & $k = R/N_A$
5.	Various Graphs of Ideal Gas	

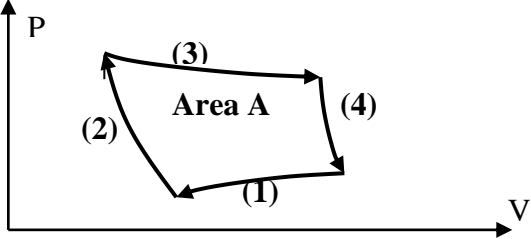
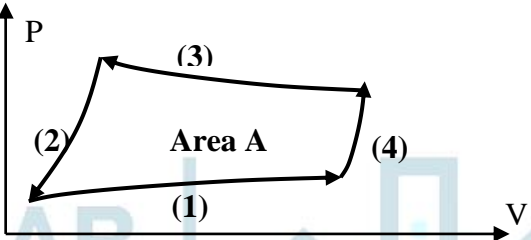
Ideal Gas	
6.	$PV = \frac{1}{3} Nm\langle c^2 \rangle$
 <p style="text-align: center;">Total particles N</p>	<p>P = pressure of gas in Pa or Nm^{-2}; V = volume of gas in m^3; N = total number of gas particles; m = is the mass of individual gas particle; $\langle c^2 \rangle$ = mean square speed of gas particle in $(\text{m/s})^2$</p>
	<p>Diagram models a gas molecule and the arrow indicate the direction that the gas molecules can take. <i>Mass of gas molecule: m</i> <i>Velocity before impact on wall: +u</i> <i>Velocity after impact on wall: -u (since collision is elastic)</i></p> <ul style="list-style-type: none"> When a gas molecule impacts on wall, the change in momentum of the gas molecule is as follows: $\Delta p = m (u - (-u)) = 2mu$ <p>Assumptions:</p> <ol style="list-style-type: none"> collision of gas particles on wall is elastic gas particles obey Newton's law of motion gas particles are incident perpendicularly onto wall <ul style="list-style-type: none"> The duration for the collision to take place is equivalent to the time taken for the gas particles to move from one wall to the opposite wall and to return. <p>Duration x speed = distance between the wall x 2 $\Delta t \times u = 2L$ $\Delta t = \frac{2L}{u}$</p> <p>Assumptions:</p> <ol style="list-style-type: none"> duration of collision by gas particles on wall is negligible as compared to time taken between collisions Total volume of the gas molecules is <i>negligible</i> compared to the volume of the container; molecules do not collide with each other and only with the wall <ul style="list-style-type: none"> Force exerted on wall by each molecule is as follows: $F = \frac{\Delta p}{\Delta t} = \frac{2mu}{2L/u}$ $F = \frac{\Delta p}{\Delta t} = \frac{mu^2}{L}$

		<p>Assumptions:</p> <p>(1) duration of collision by gas particles on wall is negligible as compared to time taken between collisions</p> <p>(2) gas particles obey Newton's law of motion</p> <p>(3) gas particles are incident perpendicularly onto wall</p> <ul style="list-style-type: none"> Pressure exerted on wall for N molecules is as follows: <p>Pressure = Force exerted by N molecules divided by Area</p> <p>Force exerted by N molecules = $\frac{Nmu^2}{L}$</p> <p>$L \times \text{Area } (L^2) = \text{Volume of the Vessel } (V)$</p> <p>$P = \frac{F}{A} = \frac{Nmu^2}{L \times L^2} = \frac{Nmu^2}{V}$</p> <p>A simple method to convert the above expression to the formula: $p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$ is</p> <p>(1) $\frac{1}{3}$ of total N molecules hit each wall in x or y or z direction</p> <p>(2) u is better represented by root mean square value (see overleaf for explanation) of speed of a gas molecule</p> <div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> <ul style="list-style-type: none"> In reality, all molecules will be moving in three dimensions equally Splitting the velocity into its components c_x, c_y and c_z to denote the amount in the x, y and z directions, c^2 can be defined using <u>pythagoras'</u> theorem in 3D: $c^2 = c_x^2 + c_y^2 + c_z^2$ Since there is nothing special about any <u>particular direction</u>, it can be determined that: $\langle c_x^2 \rangle = \langle c_y^2 \rangle = \langle c_z^2 \rangle$ Therefore, $\langle c_x^2 \rangle$ can be defined as: $\langle c_x^2 \rangle = \frac{1}{3} \langle c^2 \rangle$ </div>
7.	<p>Total KE of Gas particles</p> <p>$= \frac{3}{2} NkT = \frac{3}{2} PV$</p> <p>$= \frac{1}{2} Nm \langle c^2 \rangle$</p>	<p>N = total number of gas particles, $k = R/L$ in JK^{-1} where R is the ideal gas constant and L is the avogadro's constant;</p> <p>T = temperature of ideal gas in K</p> <p>Total KE of a specified gas is dependent on the Temperature and its mass/no of particles</p>

8.	Mean KE of Gas particles = $\frac{3}{2} kT$ = $\frac{1}{2} m\langle c^2 \rangle$	$k = R/L$ in JK^{-1} where R is the ideal gas constant and L is the avogadro's constant; $T =$ temperature of ideal gas in K <u>The thermodynamic temperature of an ideal gas is proportional to the mean kinetic energy of the molecules of the gas.</u>
9.	Root mean square speed of Gas particles = $\sqrt{3RT/Mr}$	R is the ideal gas constant; $T =$ temperature of ideal gas in K; Mr is the mass of per mole of gas particles in kg mol^{-1} <u>Rms speed of a gas particle is dependent on the Temperature and its Ar/Mr</u>
10.	$P = \frac{1}{3} \rho \langle c^2 \rangle$	$P =$ Pressure of gas in Pa $\rho =$ density of gas particles in kgm^{-3} $\langle c^2 \rangle =$ mean square speed of gas particle in $(\text{m/s})^2$
11.	$\sqrt{\langle c^2 \rangle}$ = $\sqrt{\{(u_1^2 + u_2^2 + u_3^2 + \dots)/N\}}$	$c -$ Root mean square speed of gas particle - Average speed of gas particles with a range of speeds at a specified temperature and is a better representation of the average speed of gas particles $\langle c^2 \rangle$ is the mean square speed $u_1, u_2, u_3 \dots$ are the various speeds of gas particles $N -$ total number of particles present in the gas
<p>$pV = NkT$ --- (1)</p> <p>$p = \frac{1}{3} \rho \langle c^2 \rangle = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$ --- (2)</p> <p>From (2), $pV = \frac{1}{3} Nm \langle c^2 \rangle$ --- (3)</p> <p>From (1) and (3), $\frac{1}{3} Nm \langle c^2 \rangle = NkT$</p> <ul style="list-style-type: none"> • Thus, average KE per molecule = $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ • Total KE for N molecules = $\frac{3}{2} NkT$ • Average KE per mole = $\frac{3}{2} RT$ • Total KE for n moles = $\frac{3}{2} nRT$ 		
12.	Ideal gas has negligible potential energy	Gas molecules exert no intermolecular forces except during collisions

1st law of Thermodynamics		
1.	Internal energy of an ideal gas	Equal to the random distribution of molecular kinetic energy or kinetic energy of molecules
2.	$W = P \times \Delta V$ [Provided P is constant] $P\Delta V = nR\Delta T \rightarrow$ $W = nR \Delta T$	$W =$ work done by System in J $P =$ Pressure in Nm^{-2} or Pa $\Delta V =$ change in volume of fluid in m^3 $V_{\text{final}} - V_{\text{initial}} > 0$ for expansion (WD by system) $V_{\text{final}} - V_{\text{initial}} < 0$ for contraction (WD on system)
3.	$\Delta U = \frac{3}{2} nR\Delta T$ ΔU $= \frac{3}{2} [(PV)_{\text{final}} - (PV)_{\text{initial}}]$	$\Delta U =$ change in internal energy of an ideal gas in J $n =$ number of moles, $R =$ ideal gas constant $\Delta T =$ change in temperature of ideal gas in K $P =$ pressure of gas in Pa or Nm^{-2} $V =$ volume of gas in m^3
4.	First law of thermodynamics	States that the sum of increase in internal energy of the system (ΔU) and the work done (ΔW) by the system is the heat supplied (ΔQ) to the system. The internal energy of the system depends only on its state. Or States that the sum of heat supplied (ΔQ) to the system and the work done (ΔW) on the system is the increase in internal energy of the system (ΔU). The internal energy of the system depends only on its state.
5.	$\Delta Q = \Delta U + \Delta W$ [ΔW - work done BY system/+ve]	$\Delta U =$ change in internal energy of an ideal gas in J in system $\Delta Q =$ heat supplied to system in J (+ve) $\Delta Q =$ heat released by system to environment in J (-ve) Work done BY GAS (+ve) \rightarrow Expansion of gas
6.	$\Delta U = \Delta Q + \Delta W$ [ΔW - work done ON system/+ve]	$\Delta U =$ change in internal energy of an ideal gas in J in system $\Delta Q =$ heat supplied to system in J (+ve) $\Delta Q =$ heat released by system to environment in J (-ve) Work done ON GAS (+ve) \rightarrow Contraction/Compression of gas
7.	$\Delta Q = \Delta U$ [isochoric process; $\Delta W = 0$] 	$\Delta W = 0$ since $\Delta V = 0$ $\Delta U = \frac{3}{2} nR\Delta T$ [using equation 21] $\Delta Q = \Delta U$ hence $n C_{v,m} \Delta T = \frac{3}{2} nR\Delta T \rightarrow C_{v,m} = \frac{3}{2} R$ $C_{v,m}$ is molar heat capacity of a gas which is heat energy required to increase the temperature of 1 mole of gas by 1K at constant volume

8.	$\Delta Q = \Delta U + p\Delta V$ [isobaric process and ΔW – work done BY system/+ve] 	$\Delta W = P\Delta V$ since pressure is constant $PV = nRT \rightarrow P\Delta V = nR\Delta T$ $\Delta W = nR\Delta T$ $\Delta U = \frac{3}{2} nR\Delta T$ [using equation 21] $\Delta Q = P\Delta V + \frac{3}{2} nR\Delta T$ hence $n C_{p,m} \Delta T = \frac{3}{2} nR\Delta T + nR\Delta T \rightarrow C_{p,m} = \frac{5}{2} R$ $C_{p,m}$ is molar heat capacity of a gas which is heat energy required to increase the temperature of 1 mole of gas by 1K at constant pressure
9.	$\Delta Q = \Delta W$ [isothermal process; $\Delta U=0$ and ΔW – work done BY system/+ve] 	$\Delta U=0$ as $\Delta T=0$ heat exchange takes place in a system surrounded by good conductor such that temperature of gas cannot be raised or reduced and change is gradual to allow heat energy to exchange between system and its surrounding
10.	$\Delta U = \Delta W$ [Adiabatic process and ΔW – work done BY system/+ve] Adiabatic expansion coincides with a drop in temperature. internal energy of gas decreases as energy is translated to work done by gas as adiabatic expansion occurs. Adiabatic compression coincides with an increase in temperature.	$\Delta Q=0$ as system is well insulated such no heat energy is given off or taken in and change is fast to minimize heat energy to exchange between system and its surrounding 

11.	<p>$\Delta Q = \Delta W$ [cyclic process]</p> <p>Clockwise cycle → Heat energy is supplied to gas to allow work done by gas [example of such equipment: engine]</p> <p>Anti-clockwise cycle → heat energy is given off to environment as work is done ON gas [example of such equipment: heat pump]</p>	<p>Power cycle: heat input → mechanical work output $\Delta U=0$ as $\Delta T=0$ since start and endpoint temperature is the same</p>  <p>Clockwise → $WD > 0$ → WD by system; $\Delta Q > 0$</p> <p>Heat pump cycle: mechanical work input → heat energy released to the environment</p>  <p>Anti-Clockwise → $WD < 0$ → WD ON system; $\Delta Q < 0$</p>
12.	Internal energy of a Real Gas	is the sum of molecular kinetic energy and potential energy of all the molecules in the gas. Molecular potential energy for a real gas is not equal to zero as there is intermolecular bonding between the molecules. So internal energy is not only dependent on temperature.

Believe in yourself