TOPIC B

Paper 2 Exam Questions

1.

(a) Calculate the volume of 1.0 mol of helium gas at temperature 273 K and pressure 1.0×10^5 Pa. [2]

(b)

(i) Determine the volume that corresponds to each molecule of helium. [2]

(ii) The diameter of an atom of helium is about 31 pm. Discuss whether or not the ideal gas is a good approximation to the helium gas in (a). [2]

(c) Consider now 1.0 mol of lead (molar mass 207 g mol^{-1}, density 11.3×10^3 kg m^{-3}). Determine the volume that corresponds to each atom of lead. [3]

(d) Hence estimate the ratio: separation of helium atoms to separation of lead atoms. [2]

Question 1		Answers	Marks
a		$pV = nRT \Rightarrow V = \frac{nRT}{p}$ ✓ $V = \frac{1.0 \times 8.31 \times 273}{1.0 \times 10^{5}} = 2.27 \times 10^{-2} \approx 2.3 \times 10^{-2}\ \text{m}^3$ ✓	2
b	i	There are $N_A = 6.02 \times 10^{23}$ molecules✓ so to each molecule corresponds a volume $\frac{2.27 \times 10^{-2}}{6.02 \times 10^{23}} = 3.77 \times 10^{-26} \approx 3.8 \times 10^{-26}\ \text{m}^3$ ✓	2
b	ii	Assuming a cube of this volume the side is $\sqrt[3]{3.77 \times 10^{-26}} = 3.35 \times 10^{-9} \approx 3.4 \times 10^{-9}\ \text{m}$, which is therefore an estimate of the separation of the molecules✓ This separation is much larger than the diameter of the helium atom and so the ideal gas approximation is good✓	2
c		One mole of lead has a mass of 0.207 kg and a volume of $V = \frac{m}{\rho} = \frac{0.207}{11.3 \times 10^{3}} = 1.83 \times 10^{-5} \approx 1.8 \times 10^{-5}\ \text{m}^3$ ✓ To each molecule corresponds a volume $\frac{1.83 \times 10^{-5}}{6.02 \times 10^{23}} = 3.04 \times 10^{-29} \approx 3.0 \times 10^{-29}\ \text{m}^3$ ✓ Assuming a cube of this volume the side is $\sqrt[3]{3.04 \times 10^{-29}} = 3.12 \times 10^{-10} \approx 3.1 \times 10^{-10}\ \text{m}$ which is therefore an estimate of the separation of the molecules✓	3
d		$\frac{3.35 \times 10^{-9}}{3.12 \times 10^{-10}}$ ✓ ≈ 10 ✓	

2.

(a) State what is meant by the *specific heat capacity* of a substance. [1]

(b) The energies required to increase the temperature of 1 mol of aluminium and 1 mol of copper by the same amount are about the same. Yet the specific heat capacities of the two metals are very different. Suggest a reason for this. [2]

Question 2		Answers	Marks
a		Specific heat capacity is the amount of energy required to change the temperature of a 1 kg of a substance by 1 K✓	**1**
b		One mole of any substance contains the same number of molecules; to raise the temperature by 1 K the internal energy will increase by the same amount and so the same heat must be provided✓ But one kg of different substances contains different numbers of molecules and so different amounts of energy are required to increase the temperature by 1 K✓	**2**

3.

A hair dryer consists of a coil that warms air and a fan that blows the warm air out. The coil generates thermal energy at a rate of 600 W. The specific heat capacity of air is 990 J kg^{-1} K^{-1}. The dryer takes air from a room at 20 °C and delivers it at a temperature of 40 °C.

(a) Calculate the mass of air that flows through the dryer per second. [2]

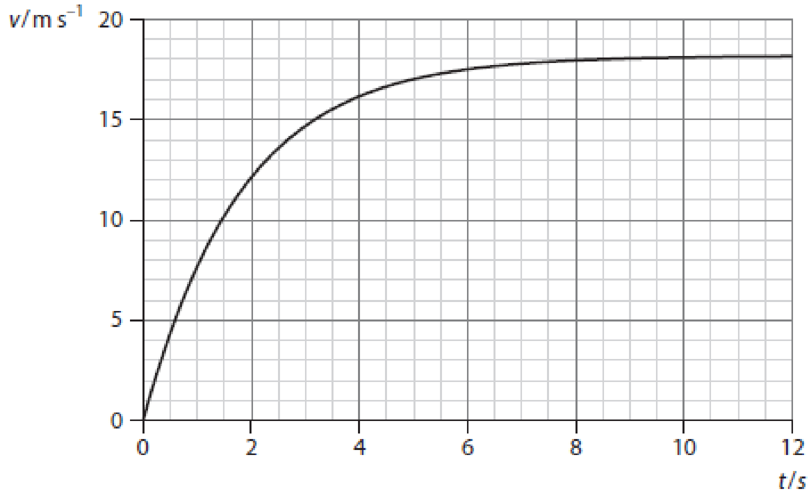
(b) The warm air makes water in the hair evaporate. If the mass of the water in the hair is 80 g, estimate how long it will take to dry the hair. The heat required to evaporate 1 g of water at 40 °C is 2200 J. Assume that energy is provided to the wet hair at a rate of 600 W. [2]

(c) Suggest why in practice it will take longer to dry the hair. [1]

Question 3		Answers	Marks
a		From $\frac{\Delta Q}{\Delta t}=\frac{\Delta m}{\Delta t}c\Delta T$ we find $600=\frac{\Delta m}{\Delta t}\times 990\times(40-20)$ ✓ so that $\frac{\Delta m}{\Delta t}=3.0\times 10^{-2}\ \text{kg s}^{-1}$ ✓	1
b		The energy required is $Q=mL=80\times 2200=1.76\times 10^{5}$ J ✓ $t=\frac{1.76\times 10^{5}}{600}=293\text{ s}\approx 4.9\text{ min}$ ✓	2
c		Because not all the energy will go into evaporating the water; some will go into warming surrounding air✓	1

4.

The graph shows the variation with time of the speed of an object of mass 8.0 kg that has been dropped (from rest) from a certain height.



The body hits the ground 12 seconds later. The specific heat capacity of the object is 320 J kg^{-1} K^{-1}.

(a)

(i) Explain how it may be deduced that there must be air resistance forces acting on the object. [1]

(ii) Estimate the height from which the object was dropped. [2]

(iii) Calculate the speed the object would have had if there were no air resistance forces. [2]

(b) Estimate the change in temperature of the body from the instant it was dropped to just before impact. List any assumptions you make. [4]

Question 4		Answers	Marks
a	**i**	The graph is a curve✓ If there was no air resistance the acceleration would have been constant and the velocity – time graph a straight line✓	**2**
a	**ii**	We must estimate the area under the graph by counting squares with one small square equal in area to 0.5 m✓ There about 370 small squares so the height is about 185 m✓	**2**
a	**iii**	$v=\sqrt{2gh}=\sqrt{2\times 9.8\times 185}$ ✓ $v=60.2\approx 60\text{ m s}^{-1}$ ✓	**2**
b		The impact speed is about 18 m s^{-1} implying a loss of mechanical energy of $\frac{1}{2}\times 8.0\times(60.2^2-18^2)=1.32\times 10^4\text{ J}$ ✓ Assuming all of this goes into heating the ball and that this amount of energy warms the entire body uniformly✓ $mc\Delta T=1.32\times 10^4$ ✓ and so $\Delta T=\frac{1.32\times 10^4}{8.0\times 320}\approx 5\text{ K}$ ✓	**4**

5.

A piece of tungsten of mass 50 g is placed over a flame for some time. The metal is then quickly transferred to a well-insulated aluminum calorimeter of mass 120 g containing 300 g of water at 22 °C. After some time, the temperature of the water reaches a maximum value of 31 °C.

(a) State what is meant by the *internal energy* of a piece of tungsten. [2]

(b) Calculate the temperature of the flame. You may use these specific heat capacities: water 4.2×10^3 J kg^{-1} K^{-1}, tungsten 1.3×10^2 J kg^{-1} K^{-1} and aluminum 9.0×10^2 J kg^{-1} K^{-1}. [3]

(c) State and explain whether the actual flame temperature is higher or lower than your answer to (b). [2]

Question 5		Answers	Marks
a		The sum of the random kinetic energy of the molecules✓ And the total intermolecular potential energy of the molecules✓	**2**
b		Energy lost by tungsten: $0.050\times130\times(T-31)$ ✓ Energy gained by water and aluminum: $0.300\times4200\times(31-22)+0.120\times900\times(31-22)$ ✓ $0.050\times130\times(T-31)=0.300\times4200\times(31-22)+0.120\times900\times(31-22)$ and so $T=1925\approx1900$ °C ✓	**3**
c		The calculated temperature is $T=\dfrac{Q}{m_{\mathrm{w}}c_{\mathrm{w}}}+31$ where Q is the heat that went into the water and calorimeter✓ The actual Q would have been higher because some was transferred into the air during the move of the metal into the water, so estimate is an underestimate✓	**2**

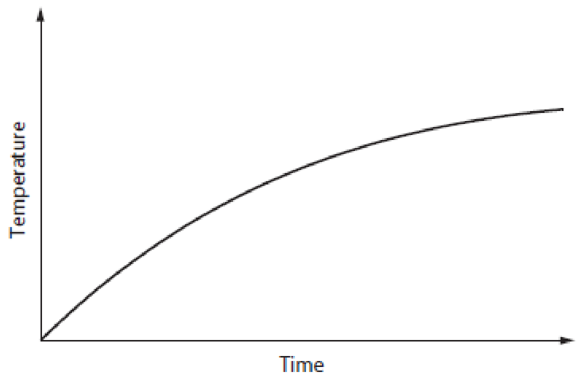
6.

(a) (i) Explain the origin of *intermolecular potential energy* in a solid. [2]

(ii) Hence state why the intermolecular potential energy of an ideal gas is zero. [1]

(b) A student claims that the kelvin temperature of a body is a measure of its internal energy. Explain why this statement is not correct by reference to a solid melting. [2]

(c) In an experiment, a heater of power 35 W is used to warm 0.240 kg of a liquid in an uninsulated container. The graph shows the variation with time of the temperature of the liquid.



The liquid never reaches its boiling point.

Suggest why the temperature of the liquid approaches a constant value. [2]

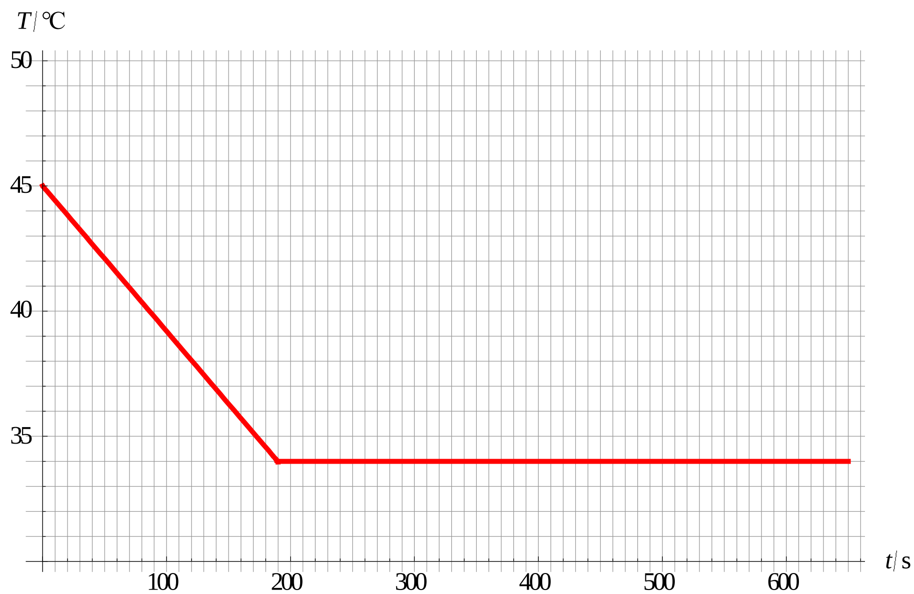
(d) After the liquid reaches a constant temperature the heater is switched off. The temperature of the liquid decreases at an initial rate of 3.1 K min^{-1}.

Use this information to estimate the specific heat capacity of the liquid. [3]

Question 6		Answers	Marks
a	**i**	There are forces between molecules in a solid ✓ Intermolecular potential energy is the (negative) work done by these forces as the separation of the molecules increases ✓	**2**
a	**ii**	There are no forces between the molecules in an ideal gas and so no work is involved in increasing their separation ✓	**1**
b		Energy must be provided to a solid for it to melt, thus increasing the internal energy✓ But the temperature of the solid stays constant during melting✓ So statement is not correct.	**2**
c		The rate at which energy is provided to the liquid✓ Is equal to the rate at which the liquid is losing energy✓	**2**
d		$P=\frac{\Delta Q}{\Delta t}=mc\frac{\Delta T}{\Delta t}$ ✓ $35=0.240\times c\times\frac{3.1}{60}$ ✓ $c=\frac{35\times 60}{0.240\times 3.1}=2.8\times 10^{3}\text{ J kg}^{-1}\text{ K}^{-1}$ ✓	**3**

7.

(a) In an experiment, a quantity of 52 g of liquid butter is placed outside on a cold day. The graph shows the variation with time of the temperature of the butter.



At 650 s all the butter has solidified. The specific heat capacity of liquid butter is $2.0\times10^{3}\ \text{J kg}^{-1}\text{K}^{-1}$.

(i) Show that the rate at which thermal energy is transferred out of the butter is about 6 W. [2]

(ii) State the main method by which the thermal energy in (i) gets transferred. [1]

(iii) Estimate the specific latent heat of fusion of butter according to this experiment. [2]

(b) Suggest

(i) what can be deduced about the internal energy of the butter from the fact that during solidifying the temperature remains constant, [3]

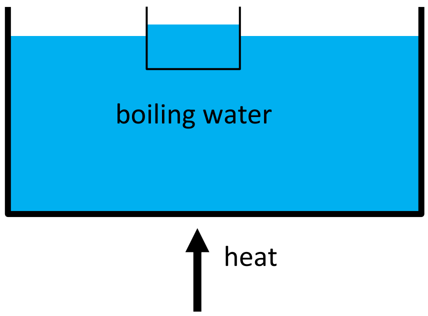
(ii) the changes, if any, to the graph above if the ambient outside temperature was even lower. [2]

Question 7		Answers	Marks
a	**i**	$Q = mc\Delta\theta = 0.052 \times 2000 \times 11 = 1144$ J ✓ $\bar{P} = \frac{1144}{190} = 6.02 \approx 6$ W ✓	**2**
a	**ii**	Conduction from the butter into the air ✓	**1**
a	**iii**	$Q = Pt = 6.02 \times (650 - 190) = 2.77 \times 10^3$ J ✓ $L = \frac{Q}{m} = \frac{2.77 \times 10^3}{0.052} = 5.3 \times 10^4$ J kg^{-1} ✓	**2**
b	**i**	The energy removed from the butter decreases the internal energy of the butter✓ This decrease is due to a decrease in the intermolecular energy of the butter ✓ The temperature stays constant, so the random kinetic energy of the molecules is unchanged ✓	**3**
b	**ii**	The rate at which energy gets transferred out of the butter is proportional to the difference in temperature between the butter and the outside temperature ✓ Hence the rate would now increase, and the melting point would be reached faster✓	**2**

8.

(a) State what determines the direction of thermal energy transfer. [1]

(b) A large container of water is heated and the water starts to boil. A smaller container of water initially at 80 °C is placed in the large container as shown.



Explain why

(i) the temperature of the water in the small container will reach 100 °C , [2]

(ii) it will not come to a boil. [2]

Question 8		Answers	Marks
a		The difference in temperature✓	**1**
b	**i**	The water in the large container is warmer than that in the small container so heat will be transferred to the water in the small container✓ until the temperatures become equal i.e. 100 °C ✓	**2**
b	**ii**	For the water to boil additional energy in the form of latent heat must be provided✓ But this cannot happen because the temperature difference is now zero and no further energy can be transferred✓	**2**

9.

The volume of air in a car tyre is 1.50×10^{-2} m^3 at a temperature of 0.0 °C and pressure 250 kPa.

(a) Calculate the number of molecules in the tyre. [2]

(b) Explain why, after the car is driven for a while, the pressure of the air in the tyre will increase. [3]

(c) Calculate the new pressure of the tyre when the temperature increases to 45 °C and the volume expands to 1.60×10^{-2} m^3. [1]

(d) The car is parked for the night and the volume, pressure and temperature of the air in the tyre return to their initial values. A small leak in the tyre reduces the pressure from P_1 = 250 kPa to P_2 = 230 kPa in 8 hours.

(i) Show that the fraction of air molecules that escaped is $\frac{P_1 - P_2}{P_1}$. [2]

(ii) Show that the number of molecules that escaped is about 8×10^{22}. [1]

(iii) Estimate the rate of loss of mass of air in kg per second (take the molar mass of air to be 29 g mol^{-1}). [3]

Question 9		Answers	Marks
a		$PV = NkT \Rightarrow N = \frac{PV}{kT} = \frac{250\times10^{3}\times1.50\times10^{-2}}{1.38\times10^{-23}\times273}$ ✓ $N = 9.95\times10^{23} \approx 1.0\times10^{24}$ molecules✓	2
b		As the tyre rolls on the road the tyre gets deformed where it touches the road; this means there is work done by the external forces which is being transferred as thermal energy that heats the air in the tyre increasing the temperature ✓ The increase in volume is very small ✓ So, $P = \frac{NkT}{V}$ increases ✓	3
c		$P = \frac{NkT}{V} = \frac{9.95\times10^{24}\times1.38\times10^{-23}\times(273+45)}{1.60\times10^{-2}} = 2.73\times10^{5}\ \text{Pa} \approx 270\ \text{kPa}$ ✓	1
d	i	$N_1 - N_2 = \frac{(P_1-P_2)V}{kT}$ ✓ $\frac{N_1-N_2}{N_1} = \frac{\frac{(P_1-P_2)V}{kT}}{\frac{P_1V}{kT}}$ ✓ $= \frac{P_1-P_2}{P_1}$	2
d	ii	$\frac{P_1-P_2}{P_1}\times N = \frac{250-230}{250}\times9.95\times10^{23} = 7.96\times10^{22} \approx 8\times10^{22}$ ✓	1
d	iii	$\frac{7.96\times10^{22}}{6.02\times10^{23}} = 0.1322$ moles lost✓ Mass $0.1322\times29 = 3.834$ g ✓ Rate of loss $\frac{3.834\times10^{-3}}{8.0\times60\times60} = 1.3\times10^{-7}\ \text{kg s}^{-1}$ ✓	3

10.

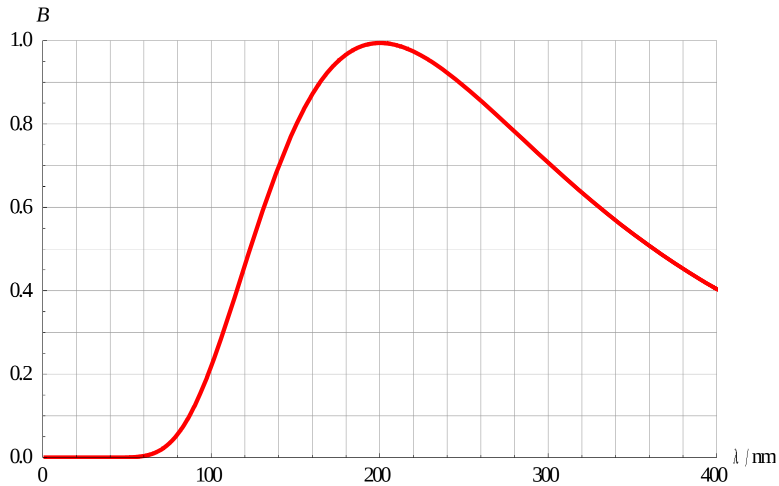
(a) On a hot summer day there is usually a breeze from the sea to the shore. Explain this observation. [3]

(b) Explain why walking on a day when the temperature is 22 °C would be described by most people as very comfortable but swimming in water of the same temperature would be uncomfortable. [2]

Question 10		Answers	Marks
a		Air over land is warmer than air over water✓ The warm air rises in convection currents✓ And so cooler air from the sea takes its place✓	**3**
b		Air is not a good conductor of heat✓ Water is a better conductor ✓ (plus people normally wear clothes when walking!)	**2**

11.

A black body has temperature *T*. The graph shows the variation with wavelength λ of the spectral intensity *B* of the body. The units of *B* are arbitrary.



(a) (i) Describe what is meant by a *black body.* [2]

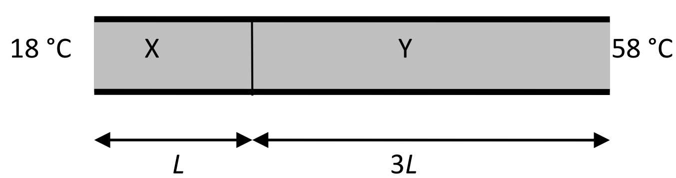
(ii) Estimate *T*. [2]

(b) On a copy of the axes above sketch a graph to show the variation with wavelength of the spectral intensity of a grey body of emissivity 0.5 and temperature *T*. [2]

(c) (i) Describe the conduction mechanism of heat transfer. [3]

(ii) State and explain whether you would expect a typical solid or a typical gas to be the better conductor of heat. [2]

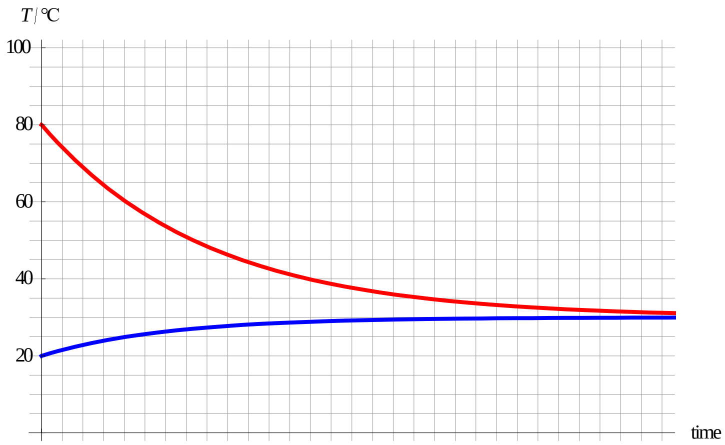
(d) Two insulated pipes, X and Y, of the same material and cross-sectional area are joined together. X has length *L* and Y length 3*L*. The ends are kept at the constant temperatures shown.



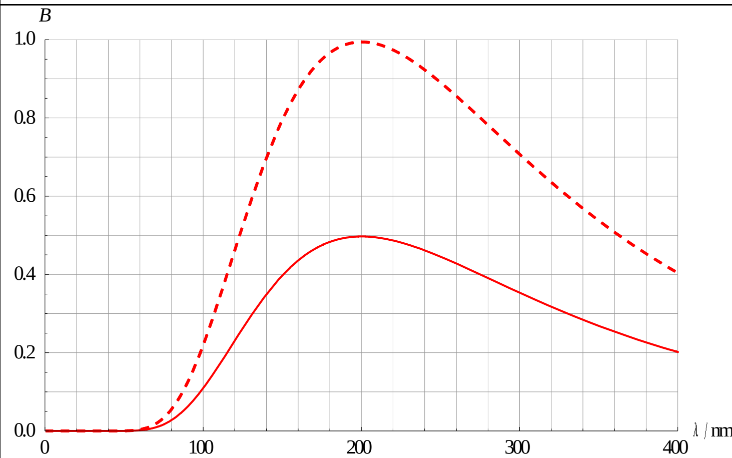
(i) Draw an arrow to indicate the direction of energy transfer. [1]

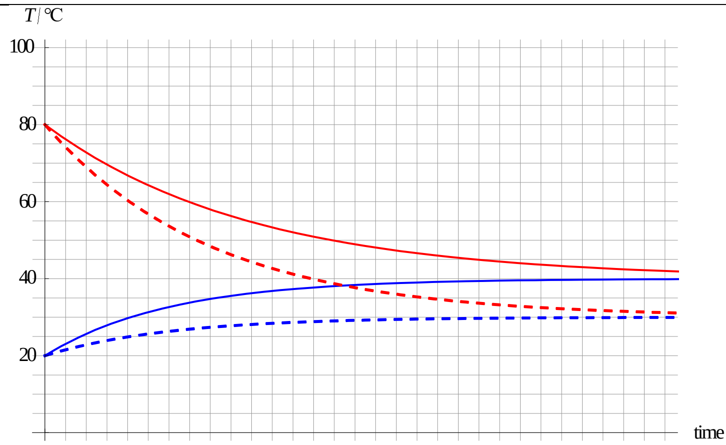
(ii) Calculate the temperature at the point where the pipes join. [2]

(e) The red curve shows the cooling curve of a hot solid object thrown into a container of cooler water. The blue curve shows the variation of the temperature of the water.

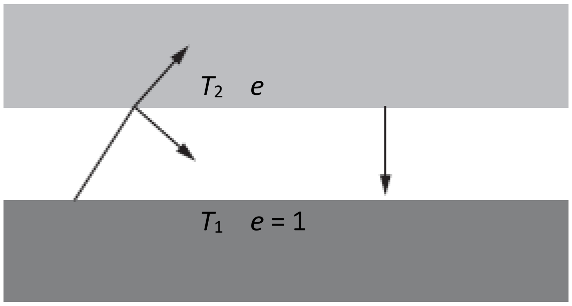


A second solid object of the same mass and initial temperature but of higher specific heat capacity is thrown into an identical container of water (same mass and initial temperature). Draw, on the axes above, the corresponding curves for this solid and the water. [2]

Question 11		Answers	Marks
a	i	A black body is a theoretical body that absorbs all the radiation incident on it, reflecting none ✓ Radiating intensity σT^4 ✓	2
a	ii	The peak wavelength is 2.0×10^{-7} m ✓ By Wien's law $T=\frac{2.9\times10^{-3}}{2.0\times10^{-7}}=1.45\times10^{4}$ K ✓	2
b		 Same peak wavelength✓ Half the max height✓	2
c	i	Atoms/electrons at the hot end vibrate/move faster and collide with neighboring atoms✓ Transferring energy to them so they too begin to vibrate faster✓ Since average kinetic energy is proportional to absolute temperature, temperature increases✓	3
c	ii	Gases are not good conductors of heat✓ In a gas, molecules are further apart from each other than in a solid (and the intermolecular forces are much weaker) for effective transfer of energy from molecule to molecule ✓	2
d	i	X $\longleftarrow$ Y	1
d	ii	$kA\frac{T-18}{L}=kA\frac{58-T}{3L}$ ✓ $T=28\,^{\circ}\mathrm{C}$ ✓	2
e		(The dashed lines are the original curves)	2

		 Same shapes as before✓ Approaching a higher temperature✓	

12. The diagram shows a black body of temperature T_1 emitting radiation towards a grey body of lower temperature T_2 and average emissivity e. No radiation is transmitted through the grey body.



(a) Using all or some of the symbols T_1, T_2, e and σ, state expressions for the intensity:

(i) radiated by the black body [1]

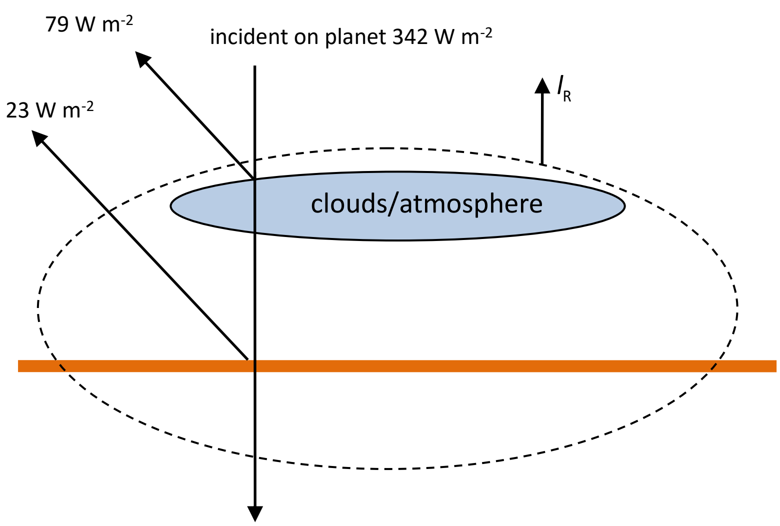
(ii) radiated by the grey body [1]

(iii) absorbed by the grey body [1]

(iv) reflected by the grey body. [1]

(b) The net intensity leaving the black body is zero. Show that $T_1 = T_2$. [2]

(c) A climate model assumes an incident intensity of 342 W m^{-2} at the top of the atmosphere. An intensity 79 W m^{-2} is reflected by the clouds and 23 W m^{-2} from the surface. None of the incident radiation is absorbed by the clouds. The diagram describes the energy balance of the planet **as a whole**. Interactions between the surface and the clouds are not relevant and are not shown.



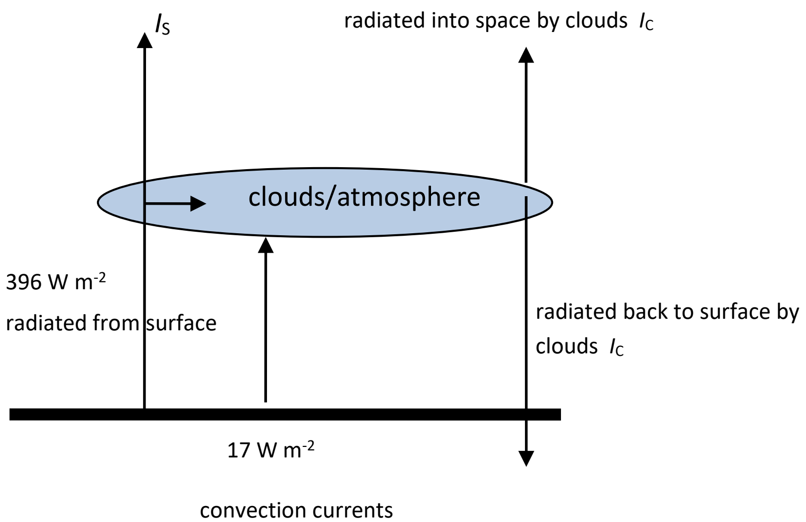
Calculate

(i) the albedo of the planet. [2]

(ii) the total intensity I_R radiated back into space from the planet. [1]

(iii) The intensity absorbed by the surface. [1]

(d) The diagram shows interactions between the clouds/atmosphere and the surface for the model in (c).



Using the answers to (c), determine

(i) I_C, [3]
(ii) the part, I_S, of the surface radiated intensity that escapes into space, [1]
(iii) Hence, calculate the part of the surface radiated intensity that is absorbed by the clouds, [1]
(iv) Explain the significance of I_C,
(v) Verify that the cloud/atmosphere system is also in equilibrium. [2]

(d) Hence determine the equilibrium temperature of the surface by making the simplifying assumption that the surface radiates like a black body in the infrared. [2]

Question 12		Answers	Marks
a	i	σT_1^4 ✓	1
a	ii	$e\sigma T_2^4$ ✓	1
a	iii	$e\sigma T_1^4$ ✓	1
a	iv	$(1-e)\sigma T_1^4$ ✓	1
b	ii	Net intensity $\sigma T_1^4-(1-e)\sigma T_1^4-e\sigma T_2^4$ ✓ $I_{\text{net}}=e\sigma(T_1^4-T_2^4)=0$ ✓ Hence the result.	2
c	i	Total reflected intensity $23+79=102\text{ W m}^{-2}$ ✓ $\alpha=\frac{102}{342}=0.298\approx 0.30$ ✓	2
c	ii	$I_{\text{R}}=342-(79+23)=240\text{ W m}^{-2}$ ✓	1
c	iii	$342-(79+23)=240\text{ W m}^{-2}$ ✓	1
d	i	Equilibrium of surface In: $(240+I_{\text{C}})\text{ W m}^{-2}$ ✓ Out: $(396+17)\text{ W m}^{-2}$ ✓ Hence $I_{\text{C}}=173\text{ W m}^{-2}$ ✓	3
d	ii	$I_{\text{S}}=240-173=67\text{ W m}^{-2}$ ✓	1
d	iii	$I_{\text{absorbed}}=396-67=329\text{ W m}^{-2}$ ✓	1
d	iv	This is radiation that is emitted by greenhouse gases that have absorbed part of the radiation emitted by the surface ✓ Part of this radiation that is absorbed by the surface provides extra heating of the surface ✓	2
d	v	In: $(342+17+329)=688\text{ W m}^{-2}$ ✓ Out: $(263+79+2\times 173)=688\text{ W m}^{-2}$ ✓	2
e		$\sigma T^4=396\text{ W m}^{-2}$ ✓ $T=\sqrt[4]{\frac{396}{5.67\times 10^{-8}}}=289\text{ K}$ ✓	2

13. The power radiated by the Sun is P and the Earth–Sun distance is d. The average albedo of the Earth's atmosphere is α.

(a) (i) Deduce that the solar constant (i.e. the intensity of the solar radiation) at the position of the Earth is $S = \dfrac{P}{4\pi d^2}$ [2]

(ii) State what is meant by *albedo*. [1]

(iii) Suggest why we refer to an *average* albedo. [2]

(b) (i) Explain why the average intensity absorbed by the entire Earth surface is $\dfrac{S(1-\alpha)}{4}$ [3]

(ii) $P = 3.8 \times 10^{26}$ W, $d = 1.5 \times 10^{11}$ m and $\alpha = 0.30$. Assuming the Earth surface behaves as a black body in the infrared, estimate the average equilibrium temperature of the Earth. [2]

(c) The average Earth temperature is much higher than the answer to (b) (ii). Suggest why this is so. [3]

Question 13		Answers	Marks
a	i	Intensity is the power received per unit area✓ The power radiated is received over an area $4\pi d^2$ ✓ which gives the result.	2
a	ii	The fraction of the incident intensity that is reflected✓	1
a	iii	The albedo varies because it depends on latitude which affects the angle at which light is received✓ And the type of surface, vegetation, ice cover and cloud cover✓	2
b	i	The intensity reaching Earth is $(1-\alpha)S$ since a part αS will be reflected✓ The radiation incident on the Earth has to pass through a disc of radius R where R is the radius of the Earth so the power through the disc is $P=\pi R^2\times S\times(1-\alpha)$ ✓ Distributed over the entire Earth surface of area $4\pi R^2$ ✓ gives the answer.	3
b	ii	$S=\dfrac{3.8\times 10^{26}}{4\pi\times(1.5\times 10^{11})^2}=1340\ \mathrm{W\,m^{-2}}$ ✓ $\dfrac{S(1-\alpha)}{4}=\sigma T^4 \Rightarrow T=\sqrt[4]{\dfrac{S(1-\alpha)}{4\sigma}}=\sqrt[4]{\dfrac{1340\times(1-0.30)}{4\times 5.67\times 10^{-8}}}=254\ \mathrm{K}$ ✓	2
c		The calculation ignores the greenhouse effect i.e. that greenhouse gases in the atmosphere absorb infrared radiation radiated by the Earth✓ The gases subsequently re-radiate this radiation in all directions✓ Including back down to the surface of the earth, warming it further✓	3

14. Two equations obeyed by an ideal gas are $PV = NkT$ and $P = \frac{1}{3}\rho c^2$.

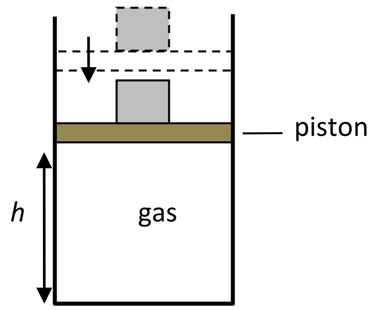
(a) Use these equations to show that the average kinetic energy of molecules is proportional to the kelvin temperature. [3]

(b) The mass of a molecule of a gas is 3.2×10^{-26} kg. Calculate the r.m.s. speed of molecules of this gas at a temperature of 23 °C. [2]

(c) The volume of a fixed mass of the ideal gas in (b) is doubled at constant pressure. Calculate the new r.m.s. speed of the molecules. [3]

Question 14		Answers	Marks
a		$\frac{1}{3}\frac{M}{V}c^2 = \frac{NkT}{V}$ ✓ $Nmc^2 = 3NkT$ ✓ $\frac{1}{2}mc^2 = \frac{3}{2}kT$ ✓	3
b		$\frac{1}{2}\times 3.2\times 10^{-26}\times c^2 = \frac{3}{2}\times 1.38\times 10^{-23}\times 296$ ✓ $c = 618.8 \approx 620 \text{ m s}^{-1}$ ✓	2
c		The density is halved ✓ From $P = \frac{1}{3}\rho c^2$, c^2 is doubled ✓ So, $c = 618.8\sqrt{2} = 875 \approx 880 \text{ m s}^{-1}$ ✓	3

15. A fixed mass of an ideal gas is trapped in a container with a movable piston of negligible mass. The cross-sectional area of the piston is 0.14 m^2. When a mass m = 280 kg is placed on top of the piston, the piston moves down compressing the gas. The piston is in equilibrium when h = 35 cm. The atmospheric pressure is 100 kPa.



(a) Show that the pressure of the gas when compressed is 120 kPa. [2]

(b) The temperature of the gas is constant at 22 °C. Calculate the number of moles in the gas. [2]

(c) Another mass is placed on the piston compressing the gas quickly so that h = 32 cm and the temperature rises to 28 °C.

(i) Calculate the new pressure of the gas. [2]
(ii) Determine the additional mass that was placed on the piston. [2]
(iii) Explain in terms of molecular motion why the pressure increased. [3]

(d) With both masses on the piston, it is required to keep the piston in equilibrium with h = 18 cm at a temperature of 45 °C. Determine the amount of gas that must be removed. [3]

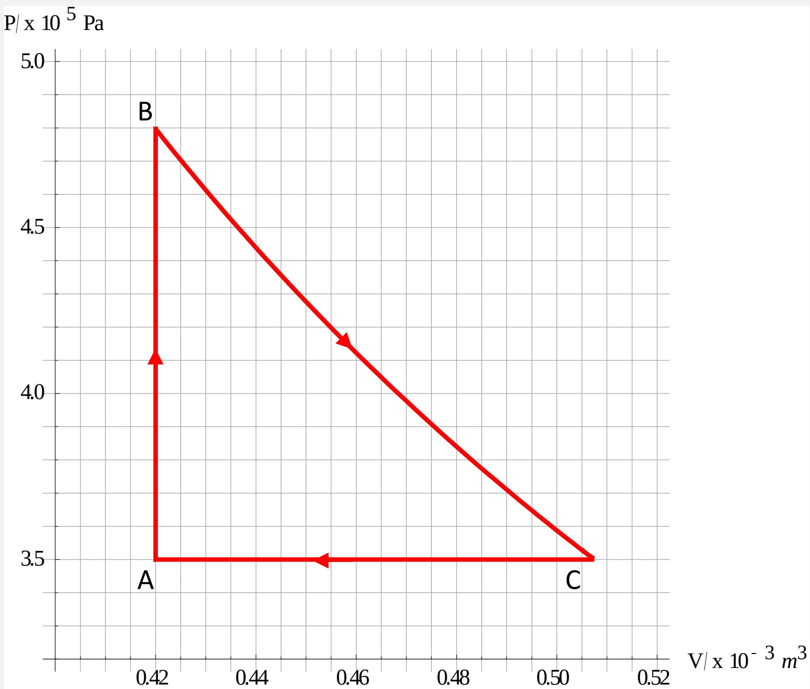
Question 15		Answers	Marks
a		$\frac{280\times 9.8}{0.14}=1.96\times 10^4$ Pa ✓ $P=1.00\times 10^5+1.96\times 10^4=1.196\times 10^5$ Pa ✓ $P\approx 120$ kPa	2
b		$PV=nRT\Rightarrow n=\frac{PV}{RT}$ ✓ $n=\frac{1.196\times 10^5\times 0.14\times 0.35}{8.31\times (273+22)}=2.391\approx 2.4$ ✓	2
c	i	$\frac{P_1V_1}{T_1}=\frac{P_2V_2}{T_2}\Rightarrow \frac{120\times A\times 0.35}{295}=\frac{P_2\times A\times 0.32}{301}$ ✓ $P_2=120\times \frac{0.35\times 301}{0.32\times 295}=133.9\approx 134$ kPa ✓	2
c	ii	Additional pressure is $133.9-120.0=13.9$ kPa ✓ $\frac{M\times 9.8}{0.14}=13.9\times 10^3$ Pa $\Rightarrow M=198.6\approx 200$ kg ✓	2
c	iii	Molecules are moving faster because temperature increased✓ Molecules collide with the walls more frequently (because they move faster and because volume has decreased) ✓ Pressure depends on the speed of molecules and the frequency of collisions✓	3
d		$\frac{P_1V_1}{n_1T_1}=\frac{P_2V_2}{n_2T_2}\Rightarrow \frac{133.9\times A\times 0.32}{2.391\times 301}=\frac{133.9\times A\times 0.18}{n_2\times 318}$ ✓ $n_2=2.391\times \frac{0.18\times 301}{0.32\times 318}=1.273$ ✓ So $2.391-1.273=1.12\approx 1.1$ mol must be removed✓	3

16.

(a) (i) State what is meant by the internal energy of a system. [2]

(ii) Two identical steel balls are dropped from the same height. One ball falls through a vacuum and the other through air. Describe the changes in the internal energy of each ball. [2]

(b) A gas undergoes the changes shown in the graph.



The temperature at A is 290 K.
The change B to C is adiabatic.
The work done from B to C is 36 J.

(i) Determine the temperature at B. [2]

(ii) Show that the thermal energy supplied to the gas during the change A to B is about 82 J. [2]

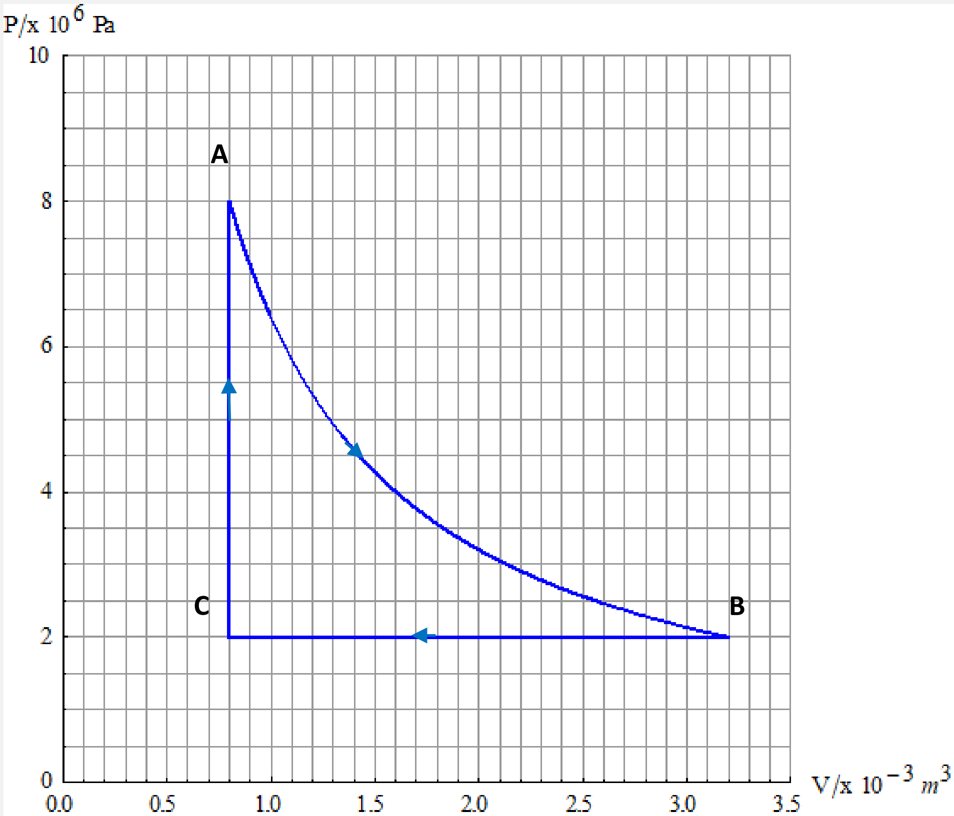
(iii) Estimate the net work done during the cycle. [1]

(iv) Calculate the efficiency of the cycle. [1]

(c) State and explain the change in entropy of the gas during the change from B to C. [2]

Question 16		Answers	Marks
a	i	The sum of the total random kinetic energy of the molecules✓ And the total intermolecular potential energy of the molecules✓	2
a	ii	There will be no change in the internal energy of the ball falling through the vacuum since no work and no heating takes place✓ There will be an increase in the internal energy of the ball falling through air because thermal energy will be generated, part of which will stay in the ball✓	2
b	i	$\frac{P_1}{T_1}=\frac{P_2}{T_2}\Rightarrow\frac{3.5}{290}=\frac{4.8}{T}$ ✓ $T=397.7\approx 400\text{ K}$ ✓	2
b	ii	$Q=\Delta U+W=\Delta U+0$ ✓ $Q=\Delta U=\frac{3}{2}Nk\Delta T=\frac{3}{2}\times\frac{3.5\times10^{5}\times0.42\times10^{-3}}{290}\times(397.7-290)=81.9\approx 82\text{ J}$ ✓ ***OR*** $Q=\Delta U=\frac{3}{2}V\Delta P=\frac{3}{2}\times0.42\times10^{-3}\times(4.8-3.5)\times10^{5}=81.9\approx 82\text{ J}$	2
b	iii	$W_{net}=36-3.5\times10^{5}\times(0.507-0.42)\times10^{-3}=5.55\text{ J}$✓	1
b	iv	$e=\frac{5.55}{81.9}=6.8\%$ ✓	1
c		Zero✓ Because no heat was taken out or given to the gas✓	2

17. An ideal gas undergoes a cycle ABCA. AB is an isothermal. The temperature at A is 1280 K.



(a) Determine the number of moles in the gas. [1]

(b) Determine the heat

(i) taken out of the gas along BC [2]

(ii) provided to the gas along CA [2]

(c) Compare the magnitude of the change in entropy along BC to that along CA. [3]

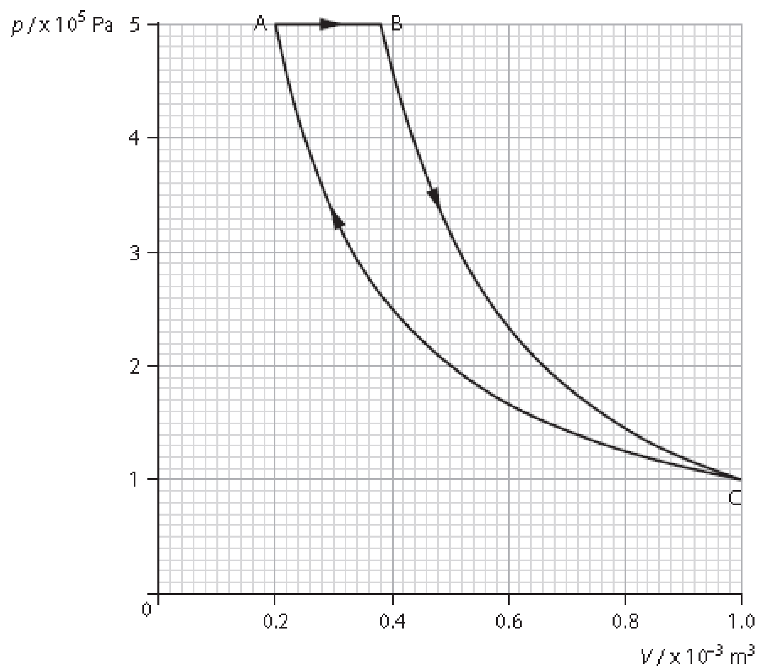
(d) (i) Calculate the energy that must be removed from 2.0 kg of water at $0\,^\circ\mathrm{C}$ to turn the water into ice at $0\,^\circ\mathrm{C}$. The specific latent heat of fusion of ice is 334 kJ kg^{-1}. [1]

(ii) Determine the change in the entropy of the water. [1]

(iii) Explain how the result in (ii) is consistent with the second law of thermodynamics. [2]

Question 17		Answers	Marks
a		$PV = nRT \Rightarrow n = \frac{PV}{RT} = \frac{8.0\times10^{6}\times0.80\times10^{-3}}{8.31\times1280} = 0.60$ ✓	1
b	i	$Q = \Delta U + W = -\frac{3}{2}P\Delta V - P\Delta V = -\frac{5}{2}P\Delta V$ ✓ $Q = -\frac{5}{2}\times2.0\times10^{6}\times(3.2-0.80)\times10^{-3} = -1.2\times10^{4}\text{ J}$ ✓	2
b	ii	$Q = \Delta U + 0 = \frac{3}{2}V\Delta P$ ✓ $Q = \frac{3}{2}\times0.80\times10^{-3}\times(8.0-2.0)\times10^{6} = 7.2\times10^{3}\text{ J}$ ✓	2
c		$\Delta S_{cycle} = 0 = \Delta S_{AB} + \Delta S_{BC} + \Delta S_{CA}$ ✓ $\Delta S_{BC} + \Delta S_{CA} = -\Delta S_{AB} < 0$ ✓ $-\|\Delta S_{BC}\| < -\Delta S_{CA} \Rightarrow \|\Delta S_{BC}\| > \Delta S_{CA}$ ✓	3
d	i	$Q = mL = 2.0\times334\times10^{3} = 6.68\times10^{5} \approx 6.7\times10^{5}\text{ J}$ ✓	1
d	ii	$\Delta S = \frac{Q}{T} = -\frac{6.68\times10^{5}}{273} = -2.4\times10^{3}\text{ J K}^{-1}$ ✓	1
d	iii	The second law states that the entropy of the Universe never decreases✓ Since the entropy of the water decreased by some amount, the entropy of the surroundings must have increased by at least that amount✓	2

18. The diagram shows a thermodynamic cycle in which an ideal gas expands from A to B to C and is then compressed back to A. BC is an adiabatic curve and CA is an isothermal curve.



(a) (i) State what is meant by an adiabatic curve. [1]

(ii) Explain using the first law of thermodynamics why, in an adiabatic expansion of an ideal gas, temperature decreases. [2]

(b) Justify that CA is isothermal. [1]

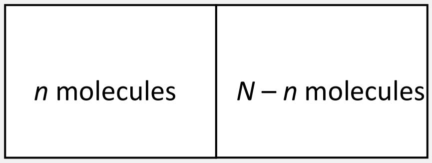
(c) The temperature of the gas at A is 300 K.
Calculate the temperature
(i) at B, [2]
(ii) at C. [1]

(d) The work done on the gas from C to A is 160 J.
Calculate
(i) the energy transferred out of the gas, [1]
(ii) the energy transferred into the gas, [2]
(iii) the net work done in the cycle, [2]
(iv) the efficiency of the cycle. [1]

Question 18		Answers	Marks
a	i	A curve on a *P-V* diagram representing a process in which no heat is exchanged✓	1
a	ii	$Q=\Delta U+W \Rightarrow \Delta U=-W$ ✓ The work is done is positive since gas expands and so $\Delta U<0$ ✓	2
b		Taking a few points on the curve and verifying that PV = constant✓	1
c	i	$\frac{V_1}{T_1}=\frac{V_2}{T_2} \Rightarrow \frac{0.20}{300}=\frac{0.38}{T_B}$ ✓ $T_B=570$ K ✓	2
c	ii	T_C = 300 K✓	1
d	i	$Q_{CA}=\Delta U+W=0-160=-160$ J ✓	1
d	ii	$Q_{AB}=\Delta U+W=\frac{3}{2}P\Delta V+P\Delta V=\frac{5}{2}P\Delta V$ ✓ $Q=\frac{5}{2}\times 5.0\times 10^5\times(0.38-0.20)\times 10^{-3}=225$ J ✓	2
d	iii	$W_{net}=Q_{in}-Q_{out}$ ✓ $W_{net}=225-160=65$ J ✓	2
d	iv	$e=\frac{65}{225}=0.289\approx 29\%$ ✓	1

19.

A box is divided into two equal parts by a partition. There are n molecules in the left part of the box and the remaining molecules in the right part.



The number of ways of doing this is $\dfrac{N!}{n!(N-n)!}$.

(a) Initially all N molecules are in the left part of the box. The partition is removed, and the gas expands to fill the entire box.

Determine the change in the entropy of the system. (You will need the approximation $\ln N! \approx N \ln N - N$.) [4]

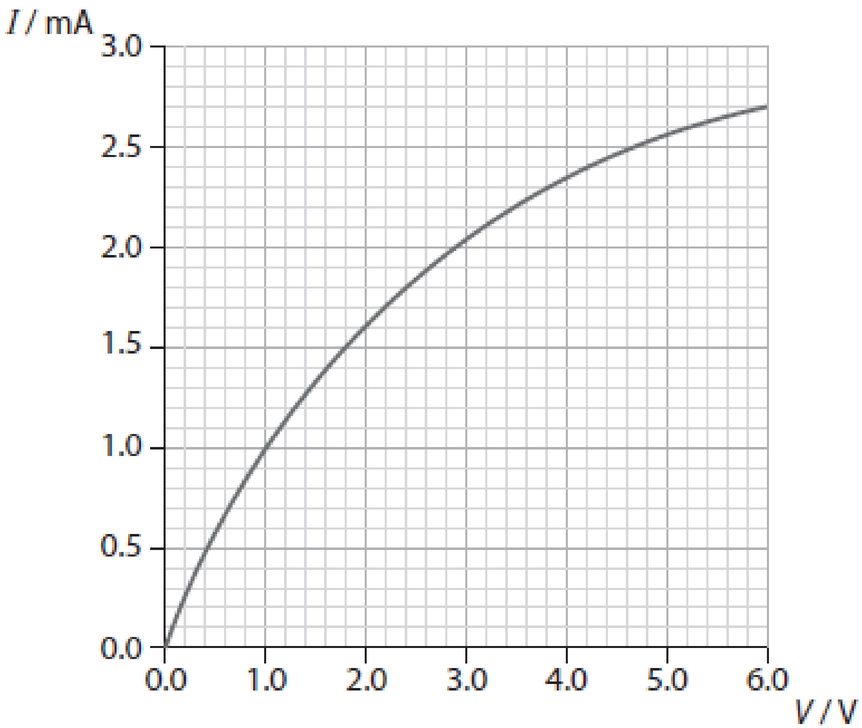
(b) Hence deduce that the gas will never occupy half the container leaving the other half empty. [2]

Question 19		Answers	Marks
a		The initial entropy is $S_i = k\ln\frac{N!}{N!0!} = k\ln 1 = 0$ ✓ There will now be $\frac{N}{2}$ molecules in each half✓ So $S_f = k\ln\frac{N!}{(\frac{N}{2})!(\frac{N}{2})!}$ ✓ $S_f = k\ln N! - 2k\ln(\frac{N}{2})! \approx k\left(N\ln N - N\right) - 2k\left(\frac{N}{2}\ln(\frac{N}{2}) - \frac{N}{2}\right)$ $= kN\ln N - kN - kN\ln N + kN\ln 2 + kN$ ✓ $= Nk\ln 2$ The change in entropy is then $\Delta S = Nk\ln 2$.	**4**
b		The change in entropy would be negative without the performance of work ✓ This would violate the second law of thermodynamics ✓	**2**

20.

(a) A light bulb is rated as 60 W at 120 V. The resistivity of the filament of the lamp is 4.0×10^{-7} Ω m. The radius of the filament is 2.5×10^{-5} m. Calculate the length of the filament. [3]

(b) The graph shows the variation of the current *I* though a device with the voltage *V* across the device.



Suggest whether the device obeys Ohm's law. [1]

(c) Two devices whose *I*–*V* characteristics are given by the graph above are connected in parallel to a battery of negligible internal resistance. The current leaving the battery is 5.0 mA. Estimate

(i) the emf of the battery, [2]

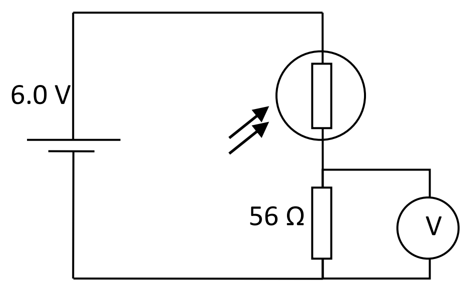
(ii) the power dissipated in each device. [1]

(d) Thermal energy is generated in a filament lamp when it is operating. Describe the mechanism by which this energy is generated. [3]

Question 20		Answers	Marks
a		$P=\frac{V^2}{R}\Rightarrow R=\frac{120^2}{60}=240\ \Omega$ ✓ $R=\rho\frac{L}{A}=\rho\frac{L}{\pi r^2}\Rightarrow L=\frac{\pi r^2 R}{\rho}$ ✓ $L=\frac{\pi\times(2.5\times10^{-5})^2\times240}{4.0\times10^{-7}}=1.18\approx1.2\text{ m}$ ✓	**3**
b		It does not because the graph is not a straight line through the origin✓	**1**
c	**i**	Each device takes the same current, 2.5 mA✓ The potential difference across each is 4.6 V and hence the emf of the battery is 4.6 V✓	**2**
c	**ii**	The power in each device is $P=VI=4.6\times2.5\times10^{-3}=1.15\times10^{-2}$ W ✓	**1**
d		The electric field established inside the wires and lamps forces electrons to accelerate✓ The accelerated electrons collide with atoms of the lamp filament transferring energy to them and increasing their random kinetic energy✓ The increased kinetic energy of the atoms shows up macroscopically as increased temperature since the average random kinetic energy is proportional to temperature✓	**3**

21.

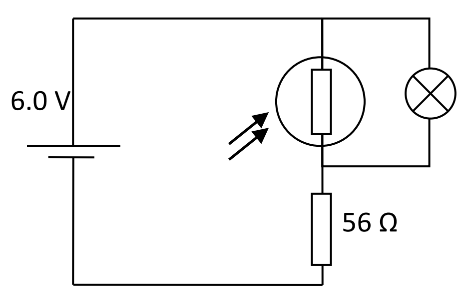
A circuit contains a light dependent resistor (LDR) connected in series to a resistor of constant resistance 56 Ω. The cell has emf 6.0 V and no internal resistance.



(a) Suggest what will happen to the reading of the voltmeter when the intensity of light incident on the LDR increases. [2]

(b) For a particular intensity of light, the reading of the voltmeter is 2.6 V. Calculate the resistance of the LDR. [3]

(c) A lamp is connected in parallel to the LDR. The lamp lights if the potential difference across it is 3.0 V or higher. The resistance of the light bulb is 28 Ω.



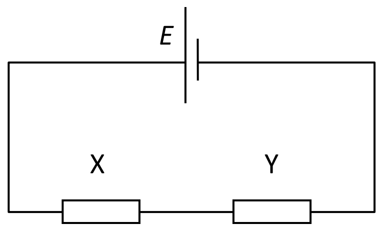
The circuit is placed in a dark room. Explain why the lamp will not light. [3]

(d) Suggest a change to the circuit so that the lamp may light in the dark. [1]

Question 21		Answers	Marks
a		The total resistance will decrease and so the total current will increase✓ So, the voltmeter reading will increase✓	**2**
b		Voltage across LDR = 6.0 – 2.6 = 3.4 V✓ Current is $\frac{2.6}{56}=4.643\times10^{-2}$ A ✓ $R=\frac{3.4}{4.643\times10^{-2}}=73.2\approx73\ \Omega$ ✓	**3**
c		The resistance of the LDR is very large in the dark so it takes no current✓ The lamp and the resistor are in series✓ And so the voltage across the lamp is 2.0 V✓ So, it won't light.	**3**
d		Replace the resistor with one of resistance lower than the lamp's✓	**1**

22.

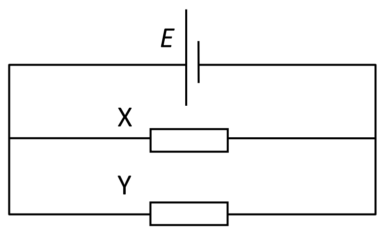
Two resistors, X and Y, are connected in series to a cell of emf *E* and negligible internal resistance.



The resistance of X is double that of Y. The total power dissipated in the circuit is 60 W.

(a) Determine the power dissipated in X. [2]

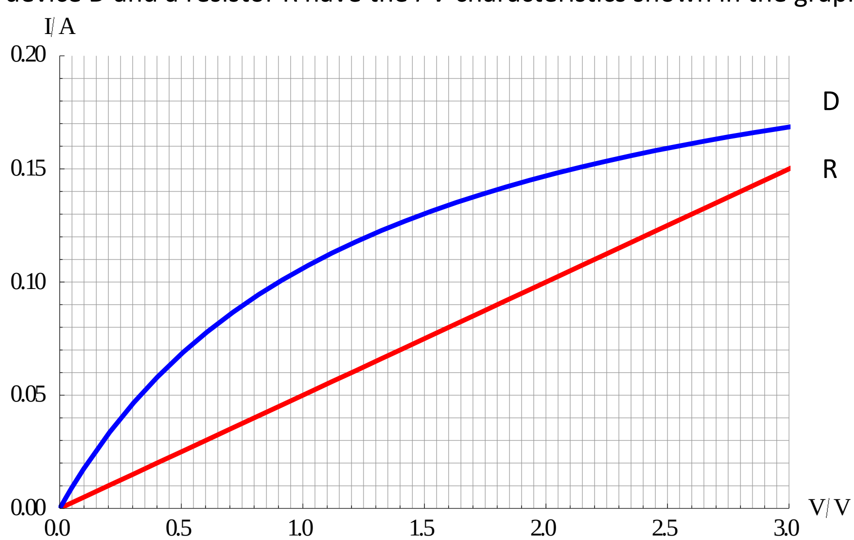
(b) X and Y are now connected in parallel to the same cell as in (a).



(i) Calculate the total power dissipated in this circuit. [3]

(ii) State and explain which resistor dissipates the greatest power. [2]

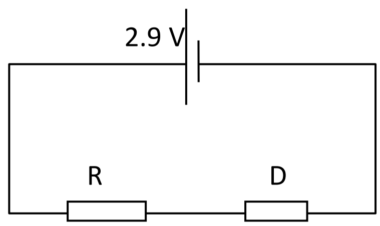
(c) A device D and a resistor R have the *I*-*V* characteristics shown in the graph.



(i) Determine the resistance of R. [1]

(ii) Describe the variation of the resistance of D with voltage. [2]

(d) R and D are connected in series to a cell of emf 2.9 V.

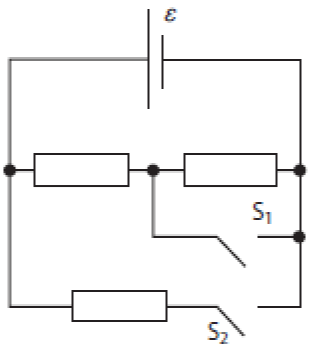


Calculate the resistance of D. [3]

Question 22		Answers	Marks
a		X has double the resistance and takes the same current as Y so it dissipates double the power✓ Hence 40 W✓	2
b	i	From the circuit in series: $60 = \frac{E^2}{3R}$ ✓ The total resistance in the parallel circuit is: $\frac{1}{2R} + \frac{1}{R} = \frac{1}{R_T}$ so $R_T = \frac{2R}{3}$ ✓ $P = \frac{3E^2}{2R} = \frac{9}{2} \times \frac{E^2}{3R} = \frac{9}{2} \times 60 = 270\text{ W}$ ✓	3
b	ii	Y✓ Because it has the lower resistance✓	2
c	i	$R = \frac{V}{I} = \frac{3.0}{0.15} = 20\ \Omega$ ✓	1
c	ii	The current is increasing proportionately less than the voltage✓ So the resistance increases with increasing voltage✓	2
d		Voltages must add up to 2.9 V✓ By trial and error this occurs for a current of 0.10 A✓ $R = \frac{V}{I} = \frac{0.90}{0.10} = 9.0\ \Omega$ ✓	3

23.

The three resistors in the circuit shown are identical and may be assumed to have constant resistance. Each resistor is rated as 1200 W at 240 V. The emf of the source is 240 V and its internal resistance is negligible.



(a) Calculate the resistance of one of the resistors. [2]

(b) Calculate the total power dissipated in the circuit when:

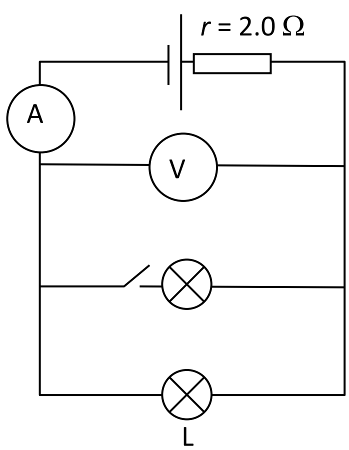
(i) S_1 is closed and S_2 is open [1]

(ii) S_1 is closed and S_2 is closed [1]

(iii) S_1 is open and S_2 is open [1]

(iv) S_1 is open and S_2 is closed. [1]

(c) In the circuit below the cell has internal resistance 2.0 Ω. When the switch is open, the voltmeter reads 11 V and the current in the ammeter is 0.50 A.



(i) Determine the emf of the cell. [2]

The switch is closed.

(ii) State and explain the effect, if any, of closing the switch on the brightness of lamp L. [4]

(iii) Suggest how the answer to (c) (ii) might change if the cell had no internal resistance. [1]

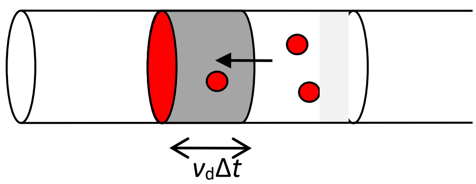
Question 23		Answers	Marks
a		From $P=\frac{V^2}{R} \Rightarrow R=\frac{V^2}{P}$ ✓ $R=\frac{240^2}{1200}=48\,\Omega$ ✓	2
b	i	The top right device is short circuited and no current passes through the lower device. Hence $P=1200\text{ W}$ ✓	1
b	ii	The top right device is short circuited and the top left and lower devices are connected n parallel so $P=2400\text{ W}$ ✓	1
b	iii	The lower device takes no current and the upper two are now in series for a total resistance of 96 Ω. The total power is $\frac{240^2}{96}=600\text{ W}$ ✓	1
b	iv	The lower device dissipates 1200 W and the upper two 300 + 300 = 600 W for a total of 1800 W✓	1
c	i	We use $V=E-Ir$ to find $11=E-0.50\times 2.0$ ✓ Hence $E=12\text{ V}$ ✓	2
c	ii	With the switch closed the total resistance of the circuit decreases ✓ Hence the current leaving the cell increases ✓ Thus, the voltage across each lamp decreases ($V=E-Ir$) ✓ Hence the brightness of L decreases ✓	4
c	iii	There would be no change since the voltage would not change ✓	1

24.

(a) The mass of an atom of copper is 1.1×10^{-25} kg. The density of copper is $8900\,\text{kg}\,\text{m}^{-3}$. Each atom of copper contributes one free electron.

Show that the number of free electrons per m^3 of copper is 8.1×10^{28}. [2]

(b) A conductor has n free electrons per unit volume. The charge of each electron is e and the cross-sectional area of the conductor is A. The electrons have speed v_d.

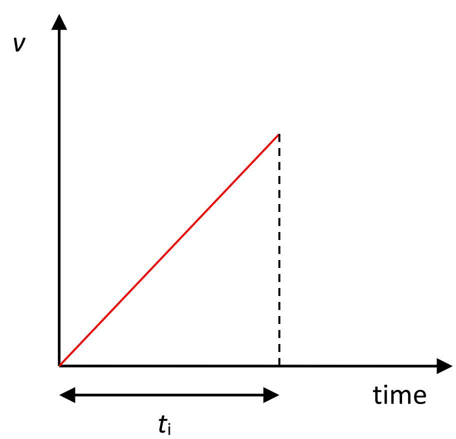


The electrons which will go through the red cross-sectional area of the conductor in time Δt will lie within the part of the conductor shaded gray.

Show that the current in the conductor is given by [3]

$$I = nev_dA$$

(c) In a simple, classical model of conduction the electrons are accelerated by an electric field E inside the conductor until they collide with lattice ions. The speed of electrons is modelled by the following graph.



The time between collisions for the i^{th} electron is t_i. The average of the t_i's is τ.

(i) Show that the average speed at which the electrons are carried forward (the drift speed) is

$$v_d = \frac{eE}{m}\tau$$

where *m* is the mass of an electron. [2]

(ii) The mean time between collisions is $\tau = 2.5\times10^{-14}$ s. The electric field in a copper wire of radius 2.0 mm is $15\,\text{mV m}^{-1}$. Estimate how many electrons go through the cross-sectional area of the wire in one second. [3]

(d) Using the model in (c), explain why the passage of current through a conductor increases the temperature of the conductor. [3]

(e) The current in a conductor is also given by $I = \frac{V}{R}$ where *V* is the potential difference across the ends of the conductor and *R* is its resistance. Use (b) and (c) to deduce that

$$R = \rho \frac{L}{A}$$

where $\rho = \frac{m}{ne^2\tau}$ and *L* is the length of the conductor. [3]

(f) By considering the effect of temperature on τ, suggest the effect of an increase in temperature on the resistance of a copper wire. [2]

Question 24		Answers	Marks
a		One m^3 of copper has mass 8900 kg and so contains $\frac{8900}{1.1\times10^{-25}}=8.09\times10^{28}\approx8.1\times10^{28}$ atoms of copper✓ Each atom contributes one electron so this is also the number of free electrons in 1 m^3 ✓	2
b		Number of electrons in shaded cylinder is $nAv_d\Delta t$ ✓ Charge in cylinder is $enAv_d\Delta t$ ✓ Current: $I=\frac{\Delta Q}{\Delta t}=\frac{enAv_d\Delta t}{\Delta t}$ ✓ As required.	3
c	i	Acceleration of electron: $a=\frac{F}{m}=\frac{eE}{m}$ ✓ $v_d=\bar{v}=a(\frac{t_1+t_2+\ldots+t_N)}{N}=a\tau$ ✓ $v_d=\frac{eE}{m}\tau$	2
c	ii	$v_d=\frac{1.6\times10^{-19}\times15\times10^{-3}}{9.1\times10^{-31}}\times2.5\times10^{-14}=6.33\times10^{-5}\text{ m s}^{-1}$ ✓ $I=1.6\times10^{-19}\times8.1\times10^{28}\times6.33\times10^{-5}\times\pi\times(2.0\times10^{-3})^2=10.3\text{ A}$ ✓ Number of electrons in 1 s: $\frac{10.3}{1.6\times10^{-19}}=6.4\times10^{19}$ ✓	3
d		The accelerated electrons give off their kinetic energy to atoms at each collision✓ The atoms increase their kinetic energy of vibration✓ Hence temperature increases since temperature is a measure of the average kinetic energy✓	3
e		$R=\frac{V}{I}=\frac{EL}{env_d A}$ ✓ $R=\frac{V}{I}=\frac{EL}{env_d A}$ ✓	3

		$R=\dfrac{EL}{en\dfrac{eE\tau}{m}A}$ ✓ $R=\left(\dfrac{m}{ne^2\tau}\right)\dfrac{L}{A}=\rho\dfrac{L}{A}$	
f		We expect that with increasing temperature, τ will decrease since the increased vibration of atoms increases the probability of collisions✓ Thus, resistance will increase✓	**2**