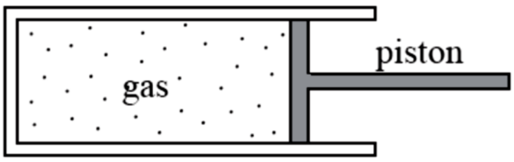
THE PR:IME! PACKAGE PART 4

Thermal Physics and Electricity & Magnetism 1 (Thermal Physics, Electric Fields, Current of Electricity, D.C. Circuits)

MCQ

1 A gas is contained in a cylinder fitted with a piston as shown below.

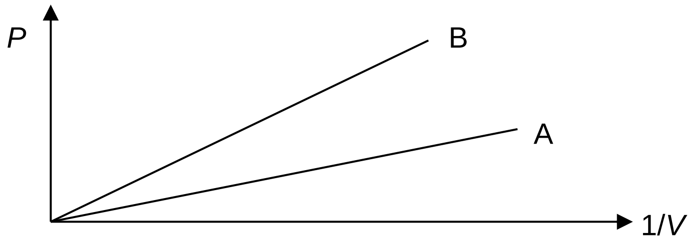


When the gas is compressed rapidly by the piston its temperature rises because the molecules of the gas

A are squeezed closer together.
B collide with each other more frequently.
C collide with the walls of the container more frequently.
D gain energy from the moving piston.

[ACJC 2012]

2 The graph below shows two plots of pressure versus the inverse of volume for two different gases. Which of the following best describes the difference between gas A and gas B?



A There are more moles of gas B than there are of gas A.
B The number of moles of B is changing at a higher rate than the number of moles of A.
C There are less moles of gas B than there are of gas A and A is at a lower temperature.
D There are more moles of gas B than there are of gas A and B is at a higher temperature.

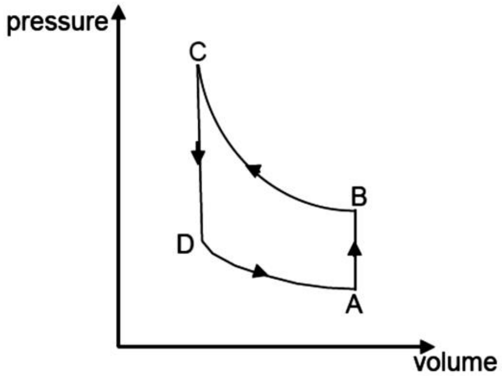
[CJC 2012]

$pV = nRT$

$$p = nRT\left(\frac{1}{V}\right)$$

Option A is correct only if gas B is either at the same temperature or higher temp than gas A. If A is at a higher temperature, then this option would be wrong.
Option B is completely wrong.
Option C is wrong because it could be wrong. We need to look at the combined value of *nRT* to compare, so if *n* is lower for B but *T* is higher it may cause the graph for B to be steeper, but you cannot say for sure that n is lower because if *n* is much lower and *T* is only slightly higher it can cause the steepness of B to be less.
Option D is correct if both *n* and *T* are higher for B, then the graph will be steeper.

3 A heat pump takes a gas through a cycle from A $\rightarrow$ B $\rightarrow$ C $\rightarrow$ D $\rightarrow$ A represented below.



The information about each section of the cycle is as shown in table below:

section of cycle	heat supply to gas/J	work done on gas/J
A → B	280	0
B → C	0	190
C → D	–400	Y
D → A	0	X

Which of the following correctly states the values of X and Y?

	X	Y
A	–70	0
B	140	–70
C	70	0
D	–140	70

[DHS 2012]

4 Equal masses of four different liquids at 20 °C are separately heated at the same rate. Their boiling points and specific heat capacities are as shown below.
Which liquid will start to boil first?

liquid	boiling point/°C	specific heat capacity/J kg^{-1} K^{-1}
A	50	1000
B	60	530
C	80	850
D	360	140

[HCI 2012]

Power supplied by heater $P = \dfrac{mc\Delta\theta}{t}$

For the same power supplied to the same mass of liquid, time to boil = $c\Delta\theta$. Thus for shortest time to boil, the product of $c\Delta\theta$ must the smallest i.e. c (boiling point – 20) must be the smallest
For liquid A, the product = 1000 (50 – 20) = 30000 s
For liquid B, the product = 530 (60 – 20) = 21200 s
For liquid C, the product = 850 (80 – 20) = 51000 s
For liquid D, the product = 140 (360 – 20) = 47600 s
Since the product is the smallest for liquid B, it will take the shortest time to boil.

5 In an ideal gas at 300 °C, the molecules are travelling at a root-mean-square speed v. Both the pressure and volume of the gas are then doubled.
In this situation, which row describes the values of the temperature of the gas and the root-mean-square speed of the molecules?

	temperature/°C	root-mean-square speed of molecules
A	1200	2v
B	1200	4v
C	2000	4v
D	2000	2v

[*HCI 2012*]

Using Equation of State $pV = nRT$ *we* have $pV \propto T$

Since both p and V are doubled, T is quadrupled. $T = 4(300 + 273) = 2292$ K $= 2019$ °C

KE of a molecule = $\frac{1}{2}mv_{rms}^{2} \propto T$. Hence both *KE* and T (in K) are both proportional to v_{rms}

Hence, since T is quadrupled, v_{rms} is doubled.

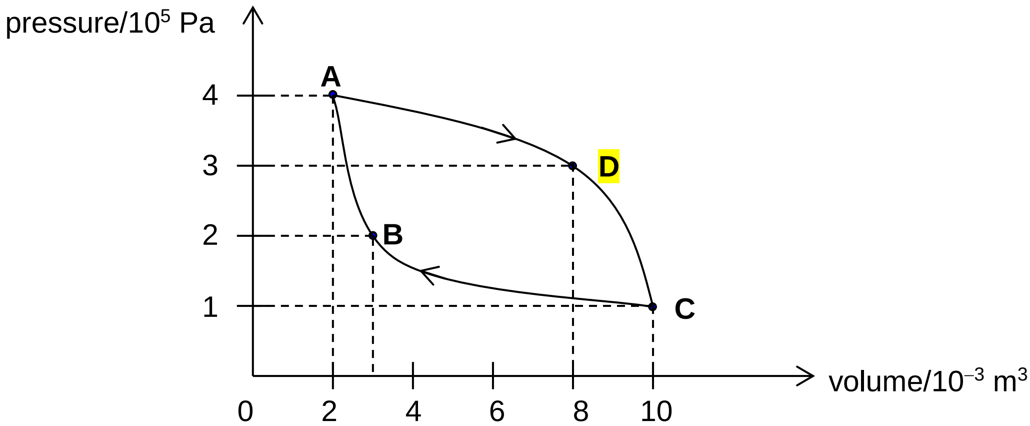
6 An ideal gas is contained in a cylinder with a movable piston. At pressure p, volume V and temperature T, it has N_v molecules per unit volume. If the pressure of the gas is changed to 0.40p, and the temperature to 1.6 T, the number of molecules per unit volume becomes

A 0.5 N_v **B** 4.0 N_v **C** $1.8 \times 10^{22}\,\frac{p}{T}$ **D** $3.0 \times 10^{-2}\,\frac{p}{T}$

[MJC 2012]

$$pV = NkT$$
$$N_V = \frac{N}{V} = \frac{p}{kT}$$
$$p' = 0.40p$$
$$T' = 1.6T$$
$$N_V{}' = \frac{0.4p}{1.6kT} = 0.25\frac{p}{kT} = 1.8 \times 10^{22}\,\frac{p}{T}$$

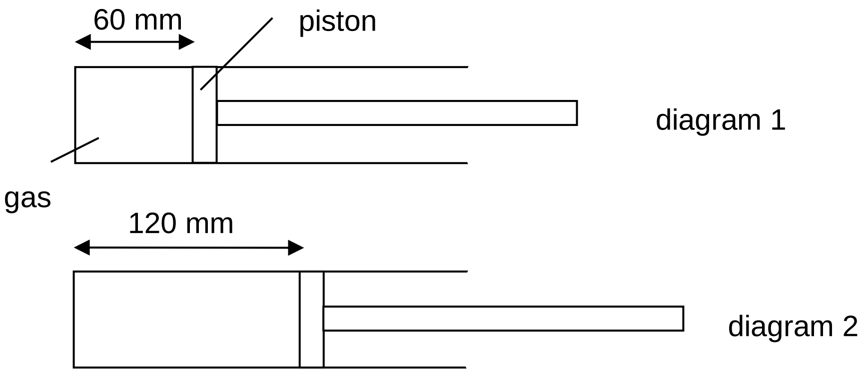
7 A fixed mass of ideal gas undergoes a cycle of changes as shown in the figure. At which point on the graph does the gas has the highest internal energy?



[MJC 2012]

For a fixed mass of ideal gas, U is proportional to T. Since $pV = nRT$, U is proportional to pV. Product of p and V is the largest for point D.

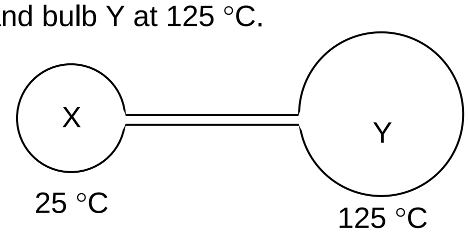
8 A gas is enclosed in a cylinder by a frictionless piston of cross-sectional area 3.0×10^{-3} m^2. When atmospheric pressure is 1.01×10^5 N m^{-2}, the piston settles 60 mm from the end of the cylinder as shown in diagram 1. The gas is then heated and it expands by pushing the piston against atmospheric pressure until the piston is 120 mm from the end of the cylinder as shown in diagram 2. What is the work done by the gas?



A 6.6 J **B** 18.2 J **C** 27.3 J **D** 54.5 J

[NJC 2012]

9 Two glass bulbs X and Y are connected by a narrow tube, where volume of Y is twice the volume of X. The bulbs are filled with the same ideal gas and a steady state is established with bulb X maintained at 25 °C and bulb Y at 125 °C.



The amount of gas and pressure in X is n and P respectively.
What is the amount of gas and pressure in Y?

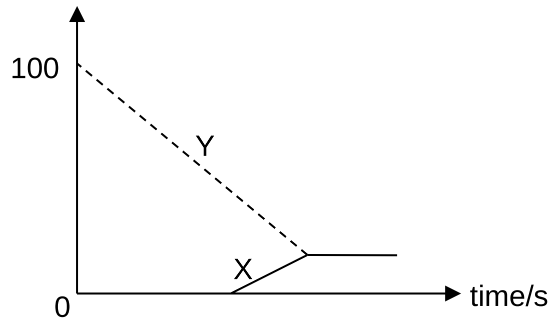
	amount of gas in Y	pressure in Y
A	0.40n	P
B	1.5n	P
C	n	0.67P
D	n	2.5P

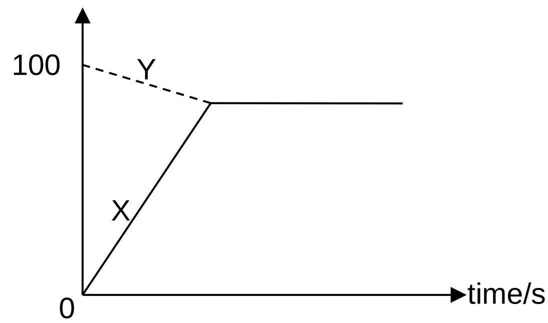
[RVHS 2012]

10 80 g of ice at 0 °C is mixed with 100 g of boiling water at 100 °C in an insulated container. Given the following data:
specific heat capacity of water = 4200 J kg^{-1} K^{-1}
specific latent heat of ice = 340000 J kg^{-1}
specific latent heat of vaporization of water = 2260000 J kg^{-1}
Which of the following graphs would best represent the variation of temperature with time of the mixture?

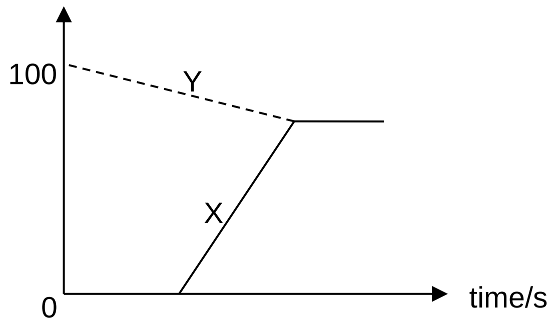
A **B**

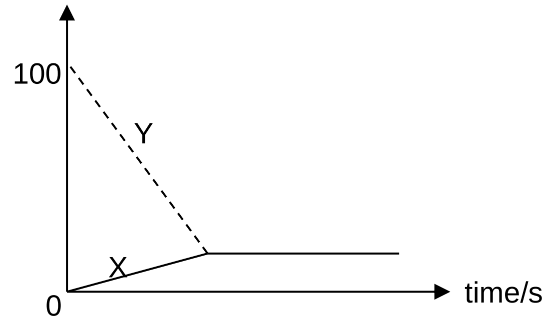
temperature/°C





C **D**





[TJC 2012]

11 A cylinder contains a mixture of helium and argon gas in equilibrium at a temperature *T*. Which of the following statements is correct about the mixture?

A Each gas molecule has the same translational kinetic energy.
B The gas molecules have the same root-mean-square speed.
C The argon gas molecules have greater kinetic energy compared with the helium gas molecules.
D Both types of gas molecules have the same mean translational kinetic energy.

[PJC 2013]

Mean translational kinetic energy per gas molecule = $\frac{3}{2}kT$ and is independent of mass.

12 An ideal gas expands at a constant temperature, doing 2500 J of external work in the process. What is the thermal energy absorbed by the gas in this process?

A zero **B** less than 2500 J **C** equal to 2500 J **D** more than 2500 J

[AJC 2013]

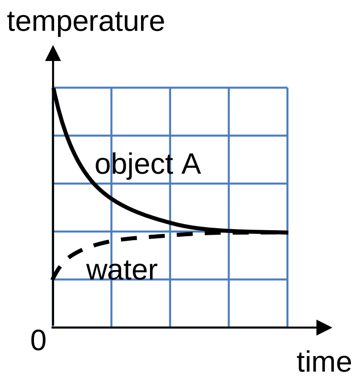
$\Delta U = Q + W$. Since process is at constant temperature, $\Delta U = 0$.
$Q = -W$, hence energy supplied is equal to work done by the gas

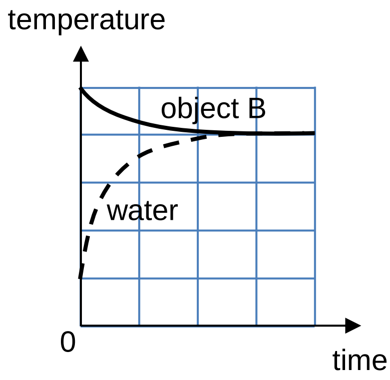
13 Which statement about internal energy is correct?

A The internal energy of a system can be increased without transfer of energy by heating.
B The internal energy of a system depends only on its temperature.
C When two systems have equal internal energies, they are in thermal equilibrium.
D When work is done on a gas, its internal energy always rises.

[TPJC 2013]

14 Object A is dropped into a thermally insulated container of water, and the object and water are then allowed to come to thermal equilibrium. The experiment is repeated again with a different object, B. The two objects have the same mass and initial temperature, and the mass and initial temperature of the water are the same in the two experiments. For each of the experiments, the following graphs show the temperatures of the object and the water with respect to time.





A $c_A = \frac{1}{9}c_B$ **B** $c_A = \frac{1}{3}c_B$ **C** $c_A = 3c_B$ **D** $c_A = 9c_B$

[HCI 2013]

For water, $(\Delta\theta_{water})_B = 3(\Delta\theta_{water})_A$

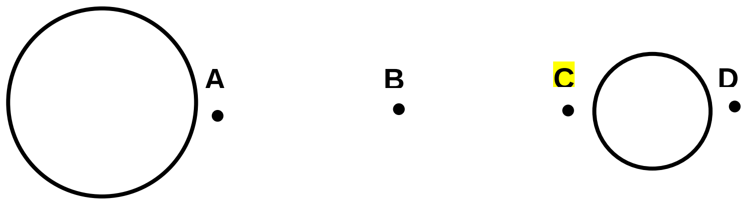
Gain in heat, $Q_{water} \propto \Delta\theta_{water}$, hence $(Q_{water})_B = 3(Q_{water})_A$

Loss in heat for objects to water, $Q_B = 3\ Q_A$

For objects, $c \propto \dfrac{Q}{\Delta\theta}$

$$\frac{c_A}{c_B} = \frac{Q_A}{Q_B}\frac{\Delta\theta_B}{\Delta\theta_A} = \left(\frac{1}{3}\right)\left(\frac{1}{3}\right) = \frac{1}{9}$$

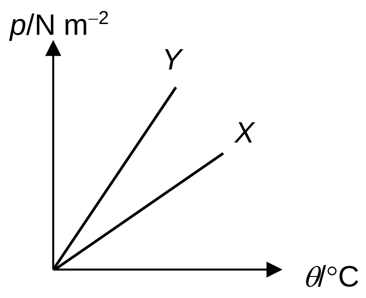
15 When isolated, the conducting sphere on the left has a positive net charge Q while the smaller conducting sphere on the right has zero net charge.

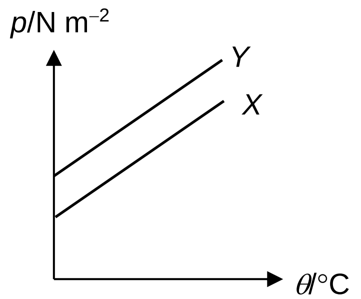


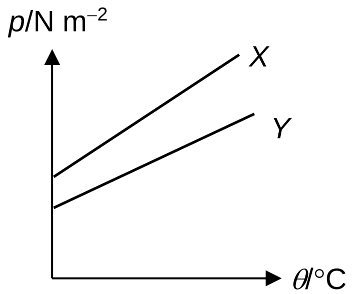
When the two conducting spheres are placed near each other as shown, at which point will the magnitude of electric field strength be the largest?

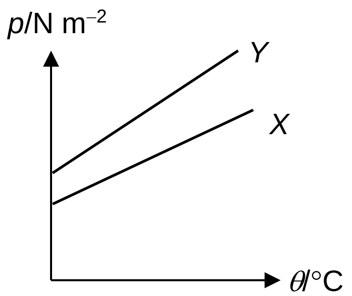
[ACJC 2012]

16 Two closed vessels X and Y contain equal masses of an ideal gas. X has a greater volume than Y. When the temperature changes, which of the following represents the variation of the pressure p (in N m^{-2}) of the gas in each vessel with temperature θ (in °C)?

A


B


C


D


[HCI 2013]

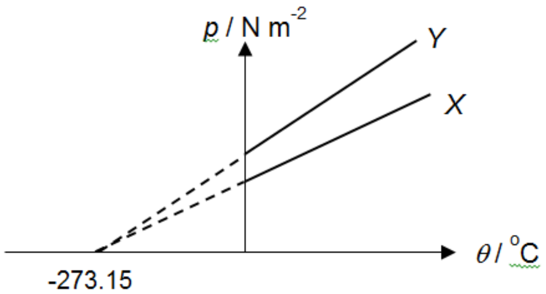
Total number of moles of gas in each vessel, $n = \dfrac{M}{mN_A}$

Since we have equal mass of the same gas in each vessel, $n_X = n_Y$
Also, for ideal gas,

$$pV = nRT$$

$$p = \left(\frac{nR}{V}\right)(\theta + 273.15)$$

Given $V_X > V_Y$ and knowing $n_X = n_Y$, for the 2 graphs, gradient$_X$ < gradient$_Y$

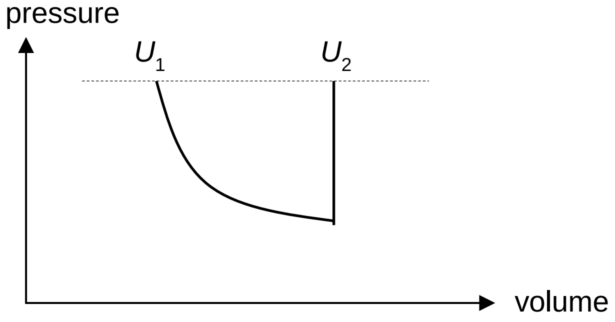


17 Oxygen molecules in the Earth's atmosphere have a root mean square speed of about 500 m s^{-1}. The mean translational kinetic energy of the oxygen molecules is E.
The relative molecular mass of oxygen and helium are 32 and 4 respectively.
What are the best approximation of the root mean square speed and the average translational kinetic energy of a helium molecule in the atmosphere?

	root mean square speed of helium molecules	average translational kinetic energy of the helium molecules
A	180	E
B	180	$8E$
C	1400	E
D	1400	$8E$

[ACJC 2015]

18 A sample of an ideal gas initially having internal energy U_1 is allowed to expand adiabatically performing external work W. Heat Q is then supplied to it, keeping the volume constant at its new value, until the pressure rises to its original value.
The internal energy of the sample is then U_2.



The increase in internal energy, $U_2 - U_1$, is equal to

A W **B** $Q - W$ **C** Q **D** $W - Q$

[ACJC 2015]

19 A student wants to determine the specific latent heat of vaporisation of an unknown liquid. He used two different heaters, one at 50 W and the other at 100 W, to vaporize the liquid. The liquid is found to vaporize at a rate of 0.0429 kg s^{-1} and 0.0875 kg s^{-1} respectively.
What is the best estimate of the specific latent heat of vaporisation of the liquid?

A 1.12×10^3 J kg^{-1} **B** 1.14×10^3 J kg^{-1} **C** 1.15×10^3 J kg^{-1} **D** 1.17×10^3 J kg^{-1}

[ACJC 2015]

20 There is one temperature, about 0.01 °C, at which water, water vapour and ice can co-exist in equilibrium.
Which statement about the properties of the molecules at this temperature is correct?

A Ice molecules are closer to one another than water molecules.
B The mean kinetic energy of water molecules is greater than the mean kinetic energy of ice molecules.
C Water vapour molecules are less massive than water molecules.
D Water vapour molecules have the same mean square speed as both ice and water molecules.

[AJC 2015]

Since ice is less dense than water, ice molecules must be further apart than water molecules. Since $KE \propto T$, the mean KE at the same temperature is the same hence mean square speed is same. Water vapour molecules are identical to water molecules, hence both have the same mass.

21 Before the invention of the modern refrigerator, ice was manufactured industrially and delivered to households. One method used is the evaporation of ammonia.
Energy was required to make the ammonia evaporate and 75% of this energy came from liquid water at 0 °C, turning the water into ice.
In six hours 8.0×10^4 kg of ice was produced. At what rate did the ammonia need to be evaporated?
The specific latent heat of fusion of water is 330 kJ kg^{-1}.
The specific latent heat of vaporisation of ammonia is 1370 kJ kg^{-1}.

A 0.67 kg s^{-1} **B** 1.2 kg s^{-1} **C** 12 kg s^{-1} **D** 20 kg s^{-1}

[AJC 2015]

$$\text{loss of } E_{water} = 0.75\left(\text{gain in } E_{ammonia}\right)$$
$$m_{water} l_f = 0.75 m_{ammonia} l_v$$
$$\frac{m_{water}}{t} l_f = 0.75\left(\frac{m_{ammonia}}{t} l_v\right)$$
$$\frac{m_{ammonia}}{t} = \frac{80000(330000)}{6(3600)(1370000)(0.75)}$$
$$= 1.1895 \text{ kg s}^{-1}$$

22 Two blocks A and B are brought into contact and allowed to reach thermal equilibrium. The mass of A is greater than the mass of B. Initially, A has a higher temperature than B. What can be said about the final temperature of each block?

A They are equal.
B Block A has a higher final temperature.
C Block B has a higher final temperature.
D Inconclusive. Information on the specific heat capacity of each block is needed.

[CJC 2015]

When two objects are in 'thermal equilibrium', they have the same temperature.

23 A student carries out an experiment to determine the specific latent heat of vaporization of a liquid Z. Liquid Z is boiling in a beaker with an electric heater. The mass *m* of liquid Z evaporated in 5.0 minutes is determined.
When the power supplied to the heater is 120 W, $m = 10.1$ g
When the power supplied to the heater is 80 W, $m = 5.2$ g
The specific latent heat of vaporization of liquid Z is

A 41 J g^{-1} **B** 2400 J g^{-1} **C** 3600 J g^{-1} **D** 4600 J g^{-1}

[CJC 2015]

Heat loss to the surroundings must be accounted for.
$Pt = mL + h$
Experiment 1: $Pt = mL + h \quad ... \quad (1)$
Experiment 2: $P't = m'L + h \quad ... \quad (2)$
(1) – (2):
$(P - P')t = (m - m')L$
$$L = \frac{(P - P')t}{m - m'}$$
$$= \frac{(120 - 80)(5.0 \times 60)}{10.1 - 5.2}$$
$$= 2400 \text{ J g}^{-1}$$

24 A container of volume ($V \times 10^{-3}$) m^3 contains *N* number of Helium-4 atoms at pressure ($P \times 10^4$) Pa and temperature θ ˚C. The root-mean-square speed of the atoms is c_{rms} m s^{-1}. The system of Helium-4 atoms may be treated as an ideal gas. Which of the following expressions give the total internal energy of the system of Helium-4 atoms?

A 1.5 *PV*
B $(2.1 \times 10^{-23})(\theta + 273.15)$
C $(2.1 \times 10^{-23})N\theta$
D $(3.3 \times 10^{-27})Nc_{rms}^2$

[CJC 2015]

For an ideal gas,
Internal energy, U = total KE of the atoms present
Average translational KE $= \frac{1}{2}mc_{rms}^2 = \frac{3}{2}kT$

Total KE of N atoms $= \frac{1}{2}Nm{c_{rms}}^2 = \frac{3}{2}NkT = \frac{3}{2}pV \quad (\because pV = NkT)$

Therefore,

$U = \frac{1}{2}Nm{c_{rms}}^2 = \frac{1}{2}N(4u){c_{rms}}^2 = \frac{1}{2}N\left[4\left(1.66\times10^{-27}\right)\right]{c_{rms}}^2 = \left(3.3\times10^{-27}\right)N{c_{rms}}^2$ OR

$U = \frac{3}{2}NkT = \frac{3}{2}N\left(1.38\times10^{-23}\right)(\theta+273.15) = \left(2.07\times10^{-23}\right)N(\theta+273.15)$ OR

$U = \frac{3}{2}pV = \frac{3}{2}\left(p\times10^{4}\right)\left(V\times10^{-3}\right) = 15pV$

25 A fixed mass of an ideal gas initially at room temperature and pressure is brought to half its initial volume via the following processes independently:

(i) Compression at constant temperature.
(ii) Compression at constant pressure.
(iii) Adiabatic compression in a perfectly insulated chamber.

Which statement is correct?

A The work done on the gas is greatest for process (i).
B The work done on the gas is greatest for process (ii).
C The work done on the gas is greatest for process (iii).
D The work done on the gas is the same for all 3 processes as the final volume is the same.

[DHS 2015]

26 The specific heat capacity of magnesium is about five times that of tin. A cube of tin and a cube of magnesium, both of equal mass at 20.0 °C are placed in two different styrofoam cups, each filled with 100 g of water at 40.0 ℃. The styrofoam cups have negligible heat capacities. Assume that no heat is lost to the environment. After equilibrium has been attained,

A the temperature of the tin is lower than that of the magnesium.
B the temperature of the tin is higher than that of the magnesium.
C the temperatures of the water in the two cups are the same.
D it cannot be determined whether tin or magnesium has a higher temperature since the mass is not given.

[HCI 2015]

For the same mass of metal, the larger the specific heat capacity of the metal, the larger the total heat it can absorbed from water and the lower the final temperature of the water.
Magnesium has a higher specific heat capacity, so it will reach a lower final temperature (able to cool the water more than tin).

27 A fixed mass of an ideal gas absorbs 3000 J of heat as it expands slowly at a constant pressure of 2.0×10^4 Pa, from a volume of 0.050 m^3 to a volume of 0.100 m^3. What is the effect on the internal energy of the gas?

A it increases by 2000 J
B it increases by 4000 J
C it decreases by 2000 J
D it decreases by 4000 J

[HCI 2015]

$\Delta Q = 3000$ J
Expansion of gas, i.e. work done by gas.
$W = -\left(2.0\times10^{4}\right)(0.100-0.050) = -1000$ J
Apply 1st Law of Thermodynamics,

$$\begin{aligned}\Delta U &= Q + W\\ &= 3000 + (-1000)\\ &= 2000 \text{ J}\end{aligned}$$

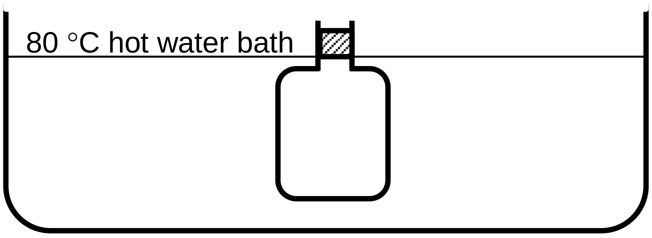
The internal energy of gas increases by 2000 J

28 Two masses *X* and *Y*, made of the same material, are at temperatures T_X and T_Y respectively, where T_X is greater than T_Y. The two masses are then brought into contact and reach a final temperature *T*. There is no exchange of heat between the masses and the surroundings. Given that the mass of *X* is greater than the mass of *Y*, which of the following statements is correct?

A The final temperature *T* is the average of T_X and T_Y.
B The final temperature *T* is closer to T_X than T_Y.
C The final temperature *T* is closer to T_Y than T_X.
D It is not possible to predict the relationship of the final temperature *T* to T_X and T_Y

[NJC 2015]

29 A closed container is filled with ideal gas initially at room temperature (27 °C) and atmospheric pressure. It was then placed into a hot water bath maintained at 80 °C where the container achieved thermal equilibrium with the hot water bath as shown below.

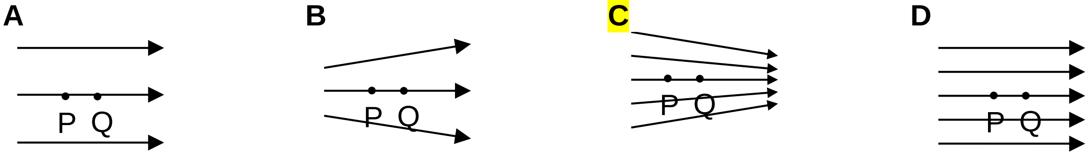


When the container is opened while immersed in the hot water bath, some of the gas escapes the container. What is the percentage of the original amount of ideal gas remaining in the container at equilibrium state?

A 15% **B** 34% **C** 66% **D** 85%

[NJC 2015]

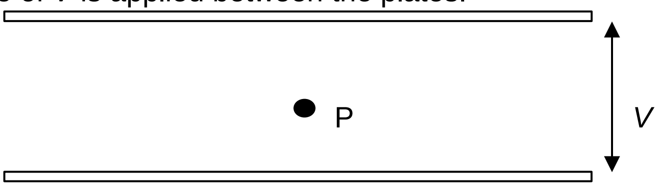
30 The diagrams below show four arrangements of electric field lines. In each arrangement, a proton is released from rest at point P and is then accelerated through point Q by the electric field. Points P and Q have equal separations in the four arrangements. Deduce the case where the linear momentum of the proton is greatest when it reaches point Q.



[AJC 2012]

Density of field lines greater throughout compared to other options.

31 A small negatively charged particle P is balanced halfway between two horizontal plates where a potential difference of *V* is applied between the plates.



When *V* is increased, P rises towards the upper plate.
When *V* is decreased, P falls towards the lower plate.
Which statement is correct?

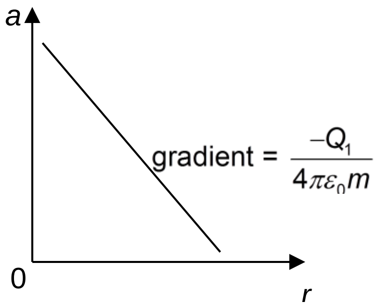
A The change of electric potential energy of the particle must equal the change in gravitational potential energy of the particle.
B Increasing V increases both the gravitational and electric potential energy of the particle.
C Decreasing V decreases both the gravitational and electric potential energy of the particle.
D Decreasing V decreases the gravitational potential energy and increases the electric potential energy of the particle.

[HCI 2012]

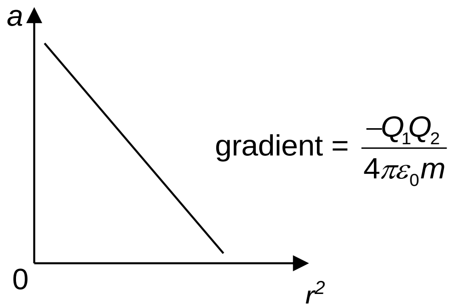
In order for the particle to stay balanced, the electric force must be acting upwards and the weight downwards.
When V decreases, the particle moves downwards which is opposite to the direction of the electric force. Work done by electric force is negative and hence work done by the external force is positive. Hence the EPE increases.

32 A charge Q_1 is fixed in position. When a small charge Q_2 of mass m is released a distance r away, it moves towards Q_1 with acceleration a.
Which one of the following graphs shows the correct relationship between a and r?

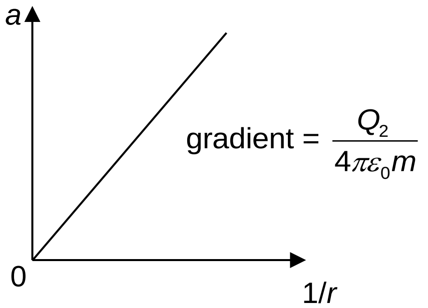
A



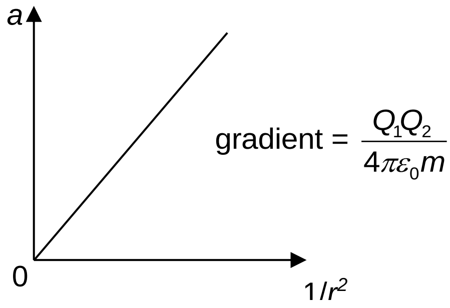
B



C

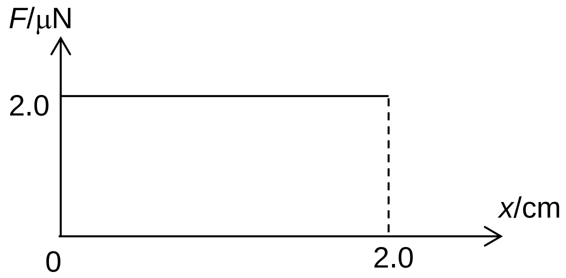


D



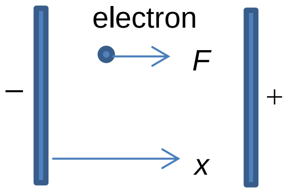
[RI 2012]

33 The force F experienced by an electron when placed in an electric field varied with displacement x as shown in the graph below. Calculate the change in electric potential energy of the electron when electron was moved from $x = 1.0$ cm to $x = 2.0$ cm in the direction of the force.



A 4.0×10^{-8} J **B** -4.0×10^{-8} J **C** 2.0×10^{-8} J **D** -2.0×10^{-8} J

[VJC 2013]



Positive work is done on the electron by the electric field. This can come about only because of a decrease in electric potential energy (EPE).

$$\begin{aligned}\Delta U &= -W \\ &= -\text{area under } F - x \text{ graph} \\ &= -\left(2.0 \times 10^{-6}\right)\left[(2.0 - 1.0)10^{-2}\right] \\ &= -2.0 \times 10^{-8} \text{ J}\end{aligned}$$

34 A metal sphere of radius 0.10 m was insulated from its surroundings and given a large positive charge. A small charge was brought from a distant point to a point 1.00 m from the sphere's centre. The work done against the electric field was *W* and the force on the small charge in its final position was *F*. If the small charge had been moved to 0.50 m from the centre of the sphere, what would have been the values for the work done and the force?

	work done	force
A	2*W*	2*F*
B	2*W*	4*F*
C	4*W*	2*F*
D	4*W*	4*F*

[VJC 2013]

From $U = \dfrac{Qq}{4\pi\varepsilon_0 r}$, we have $U \propto \dfrac{1}{r}$

since Q and q are constants

$$\frac{W'}{W} = \frac{r}{r'}$$

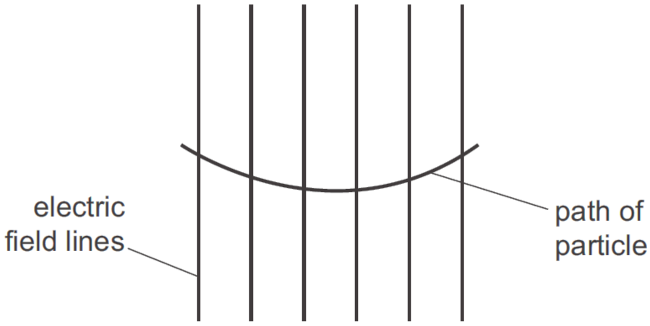
$$W' = \left(\frac{r}{r'}\right)W = \left(\frac{1.00}{0.50}\right)W = 2W$$

From $F = \dfrac{Qq}{4\pi\varepsilon_0 r^2}$, we have $F \propto \dfrac{1}{r^2}$

$$\frac{F'}{F} = \left(\frac{r}{r'}\right)^2$$

$$F' = \left(\frac{r}{r'}\right)^2 F = \left(\frac{1.00}{0.50}\right)^2 F = 4F$$

35 The diagram shows the path of a charged particle through a uniform electric field, having vertical field lines.



What could give a path of this shape?

A a positive charge travelling left to right in a field directed downwards
B **a** positive charge travelling right to left in a field directed downwards
C a negative charge travelling right to left in a field directed upwards
D a negative charge travelling left to right in a field directed downwards

[AJC 2013]

The path of the particle indicates that it experiences an upward force. A negatively charged particle (e.g. an electron) in an electric field directed downwards experiences an upward force. Here, the path of the particle is independent of the direction of travel (e.g. left to right), and not to be confused with magnetic forces.

36 An electron and proton are simultaneously released from rest in a uniform electric field. Assume that the only forces exerted on the particles are electrical forces due to the electric field. At a later time when the particles are still in the field, the electron and the proton will have the same

A magnitude of velocity
B magnitude of momentum
C kinetic energy
D magnitude of acceleration

[HCI 2013]

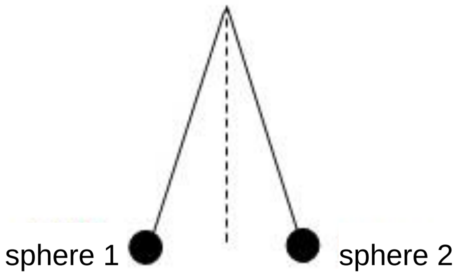
Both feel the same magnitude of force, $F = eE$. But the proton is more massive, so it will accelerate less. Thus options A and D are not correct.
$\Delta E_k = F\Delta x$. The electron will have a greater displacement, thus it will gain a larger amount of kinetic energy. Thus option C is incorrect.
$\Delta p = F\Delta t$. Both particles feel the same magnitude of force for the same amount of time, therefore they will end up with the same magnitude of momentum.

37 An electron moves in a direction opposite to an electric field. Which of the following statements is correct?

	work done by the field on the electron	potential energy of electron	kinetic energy of electron
A	positive	increases	decreases
B	positive	decreases	increases
C	negative	increases	decreases
D	negative	decreases	increases

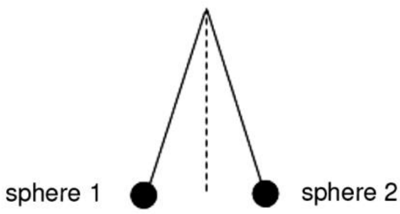
[NJC 2013]

38 Two equally charged spheres of the same mass are suspended from strings and hang apart at an angle as shown in the figure below.

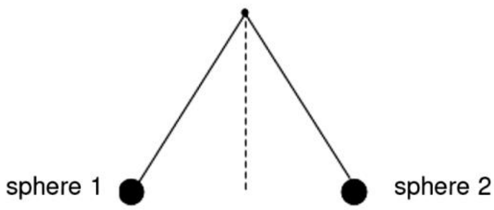


If the charge on sphere 1 alone is doubled, how would the two spheres hang?

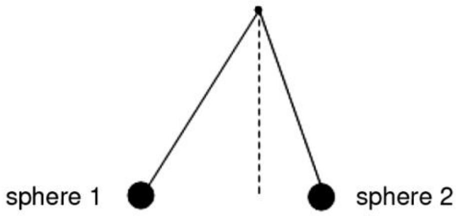
A



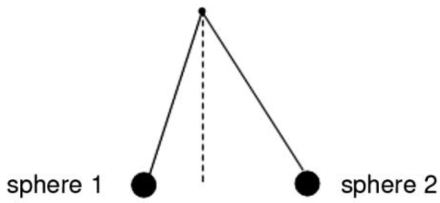
B



C

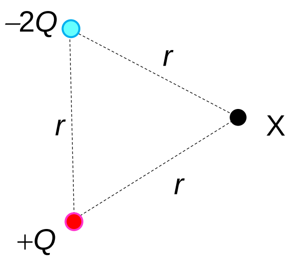


D



[TJC 2012]

39 Two point charges of charged $-2Q$ and $+Q$ are arranged at two corners of an equilateral triangle of side r in vacuum.

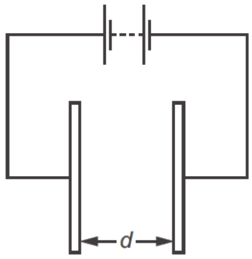


What can be deduced about the electric potential V, and the magnitude and direction of electric field strength E at point X?

	V	magnitude of E	direction of E
A	$-\dfrac{Q}{4\pi\varepsilon_0 r}$	$\dfrac{Q}{4\pi\varepsilon_0 r} < \lvert E\rvert < \dfrac{3Q}{4\pi\varepsilon_0 r^2}$	
B	$-\dfrac{Q}{2\pi\varepsilon_0 r}$	$\lvert E\rvert < \dfrac{3Q}{4\pi\varepsilon_0 r^2}$	
C	$-\dfrac{Q}{4\pi\varepsilon_0 r}$	$\lvert E\rvert < \dfrac{Q}{4\pi\varepsilon_0 r^2}$	
D	$-\dfrac{Q}{4\pi\varepsilon_0 r}$	$\lvert E\rvert = \dfrac{Q}{4\pi\varepsilon_0 r^2}$	

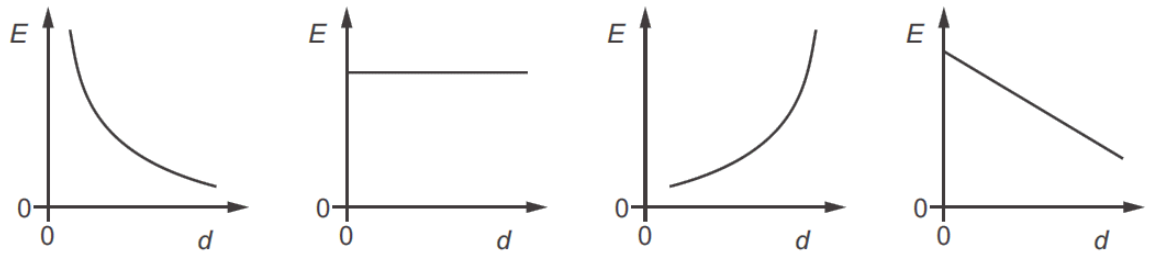
[ACJC 2015]

40 The diagram shows two metal plates connected to a constant high voltage.



Which graph shows the variation of the electric field strength E midway between the two plates as the distance d between the two plates is increased?

A **B** **C** **D**



[AJC 2015]

$E = \frac{V}{d}, E \propto \frac{1}{d}$

41 Which of the following is **not** always true about the electric field lines around a charged conductor?

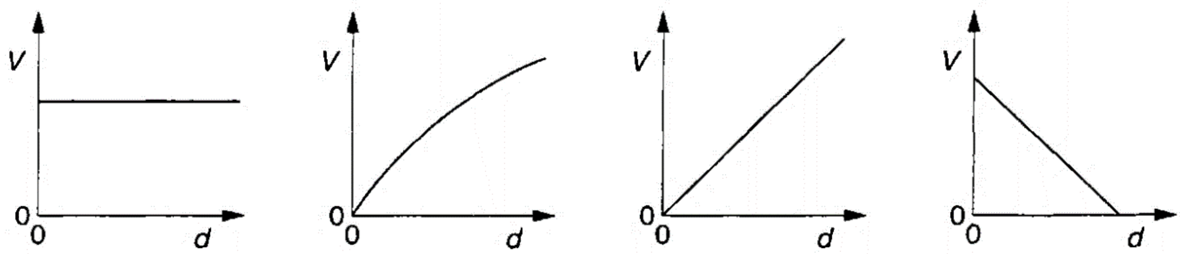
A The field lines never cross.
B The field within the conductor is zero.
C The field lines are always spaced equally apart.
D The field lines at the surface are always drawn perpendicular to the surface.

[CJC 2015]

For irregularly shaped conductors, the charge will distribute unevenly, meaning the field lines will bunch at corners.

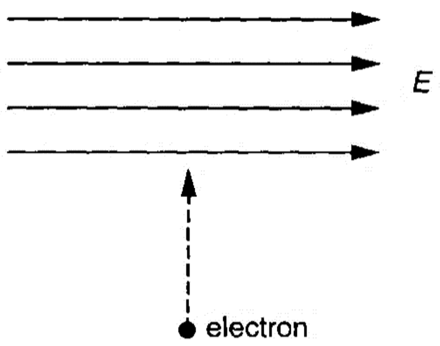
42 A constant electric field is to be maintained between two large parallel plates for which the separation d can be varied.
Which graph shows how the potential difference V between the plates must be adjusted to keep the field strength at a constant value?

A **B** **C** **D**



[DHS 2015]

43 An electron is projected at right angles to a uniform electric field E.

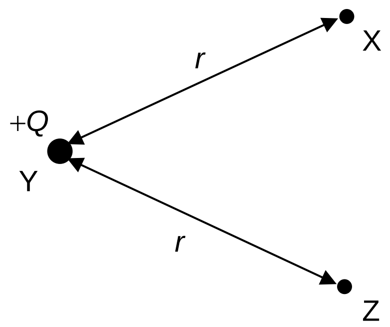


In the absence of other fields, in which direction is the electron deflected?

A into the plane of the paper **B** out of the plane of the paper
C to the left **D** to the right

[DHS 2015]

44 A positive point charge Q is placed at Y as shown. X and Z are two points that are at a distance r from Y.



Consider the following statements:

(i) The magnitude of the electric field strength at X is equal to the magnitude of the electric field strength at Z.
(ii) The electric field strength at Z acts along ZY in the direction from Z to Y.
(iii) No work is done in taking a charge from X to Z.

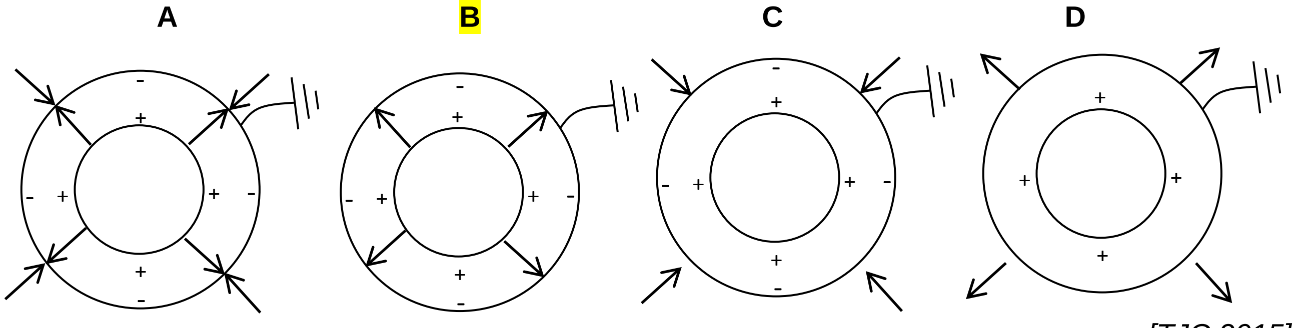
Which of the above statements is/are correct?

A I only **B** III only **C** I and II only **D** I and III only

[HCI 2015]

Statement (I) is correct as X and Z are equal distance from the point charge $+Q$ at Y. Statement (II) is incorrect as the direction of the electric field strength acts along ZY in the direction from Y to Z (as the point charge at Y is positive). Statement (III) is correct as the points X and Z lie on the same equipotential line due to the point charge at Y.

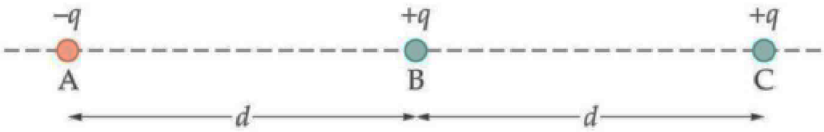
45 Two isolated concentric spheres are arranged such that the inner sphere is charged positively and the outer is earthed.
Which diagram best represents the electric field lines and distribution of charges in this arrangement?



[TJC 2015]

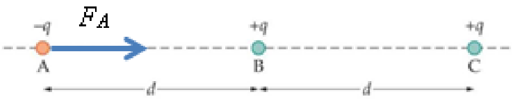
Field lines begin from positive charge and end on negative charge. Since the spheres are isolated, no field lines are present beyond earthed sphere.

46 Consider the electric charges A, B, C shown in the figure below, where q is a positive number. Which answer correctly describes the magnitude of the net force experienced by the charges?



A $F_A > F_B > F_C$ **B** $F_A > F_C > F_B$ **C** $F_B > F_A > F_C$ **D** $F_A = F_B = F_C$

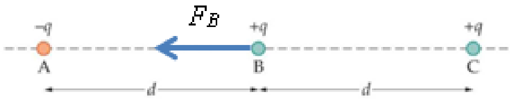
[VJC 2015]



The net force acting on A is due to charges B and C and acts towards the right.

$$F_A = \frac{1}{4\pi\varepsilon_0}\left[\frac{q^2}{d^2} + \frac{q^2}{(2d)^2}\right]$$

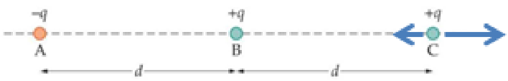
$$= \frac{5q^2}{16\pi\varepsilon_0 d^2}$$



The net force acting on B is due to charges A and C and acts towards the left.

$$F_B = \frac{1}{4\pi\varepsilon_0}\left(\frac{q^2}{d^2} + \frac{q^2}{d^2}\right)$$

$$= \frac{q^2}{2\pi\varepsilon_0 d^2}$$



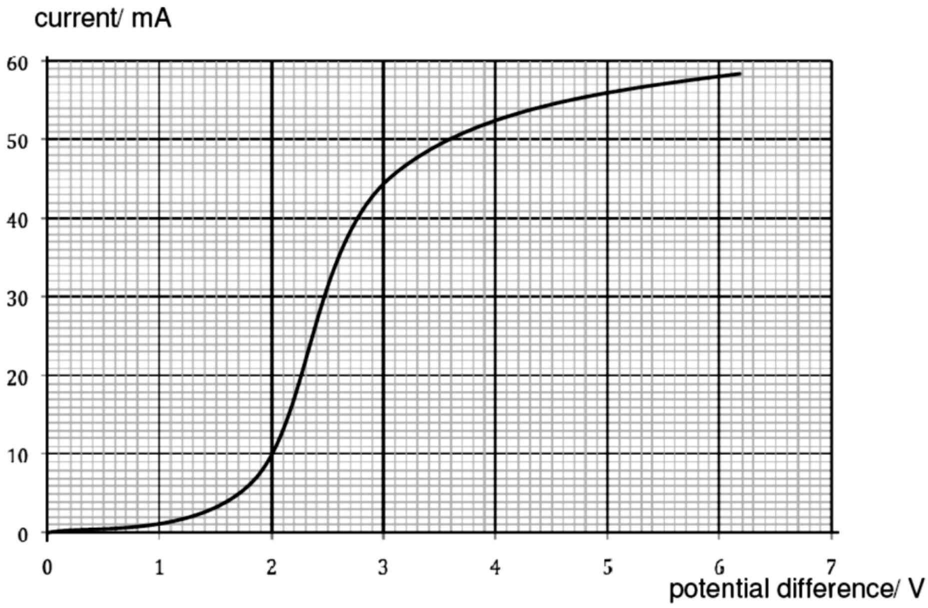
The net force acting on C is due to charge B to the right and charge A to the left. The overall magnitude is

$$F_C = \frac{1}{4\pi\varepsilon_0}\left[\frac{q^2}{d^2} - \frac{q^2}{(2d)^2}\right]$$

$$= \frac{3q^2}{16\pi\varepsilon_0 d^2}$$

Comparing all three net forces, we get
$F_B > F_A > F_C$

47 A graph of current against potential difference for a component is given below.

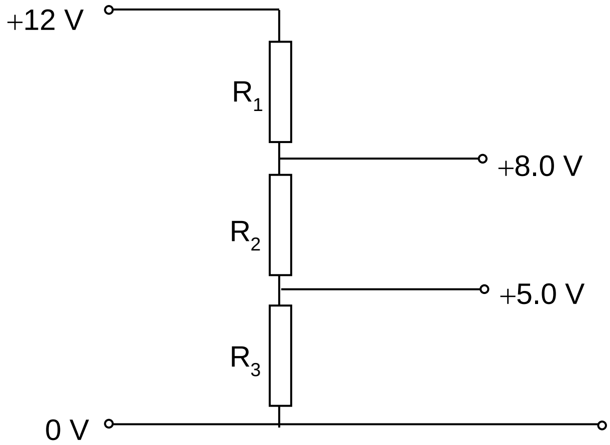


What is the potential difference across the component when its resistance is at its lowest?

A 0.90 V **B** 2.50 V **C** 3.00 V **D** 5.00 V

[ACJC 2012]

48 The diagram shows a potential divider setup giving outputs of 5.0 V and 8.0 V from a 12 V source.



What are the possible values for the resistances of R_1, R_2 and R_3?

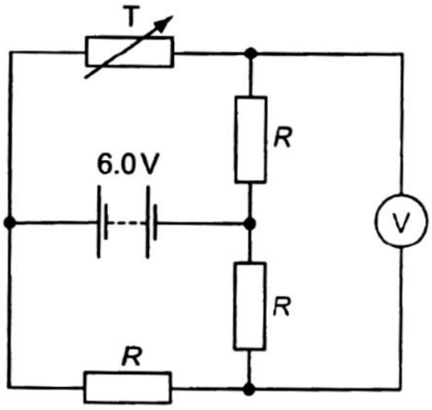
	R_1/kΩ	R_2/kΩ	R_3/kΩ
A	4	3	12
B	8	3	5
C	8	6	10
D	12	8	5

[AJC 2012]

$V_{R_1} = \left(\frac{R_1}{R_1+R_2+R_3}\right)E = 4.0\text{ V}$ $V_{R_2} = \left(\frac{R_2}{R_1+R_2+R_3}\right)E = 3.0\text{ V}$ $V_{R_3} = \left(\frac{R_3}{R_1+R_2+R_3}\right)E = 5.0\text{ V}$

Hence ratio of $R_1 : R_2 : R_3$ is 4 : 3 : 5.

49 A battery of e.m.f. 6.0 V and negligible internal resistance is connected to three resistors, each of resistance *R*, and a variable resistor T, as shown.

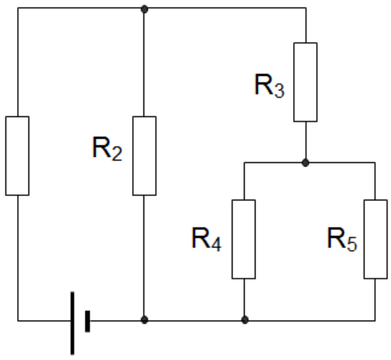


The resistance of T changes from *R* to 5*R*.
What is the change in the reading of the high resistance voltmeter?

A zero **B** 2 V **C** 4 V **D** 5 V

[DHS 2012]

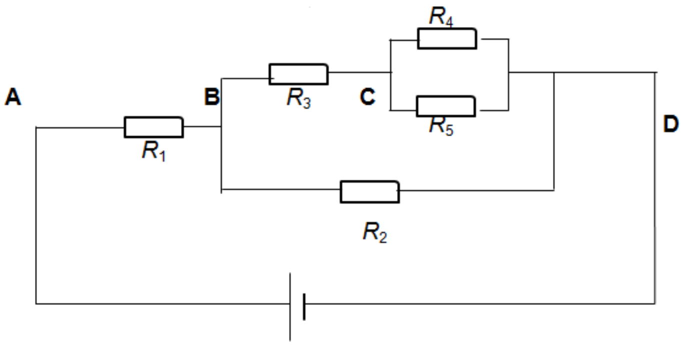
50 Five identical resistors are connected to a dry cell of negligible internal resistance.



Which resistor dissipates the most power?

A R_1 **B** R_2 **C** R_3 **D** R_4

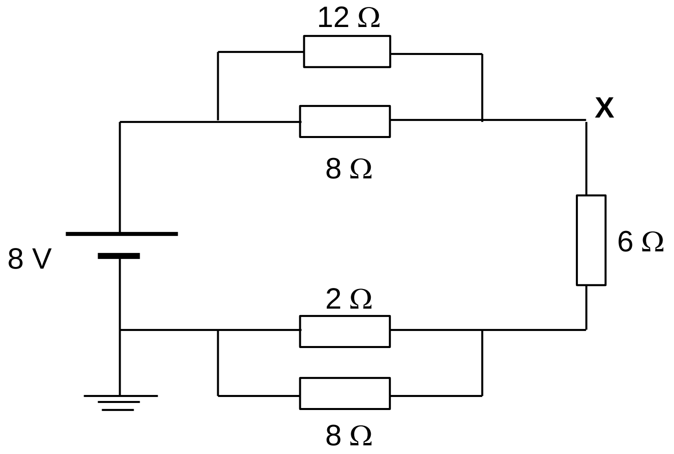
[HCI 2012]



$R_{AB} = R$ $R_{CD} = \frac{R}{2}$ $R_{BD} = \left(\frac{1}{R} + \frac{1}{R + \frac{R}{2}}\right)^{-1} = \frac{3R}{5}$

Hence p.d. across AB is greater than p.d. across BD since resistance across AB is greater than resistance across BD. Thus p.d. is the largest across R_1. Since power is proportional to the square of the potential difference, R_1 has the largest power.

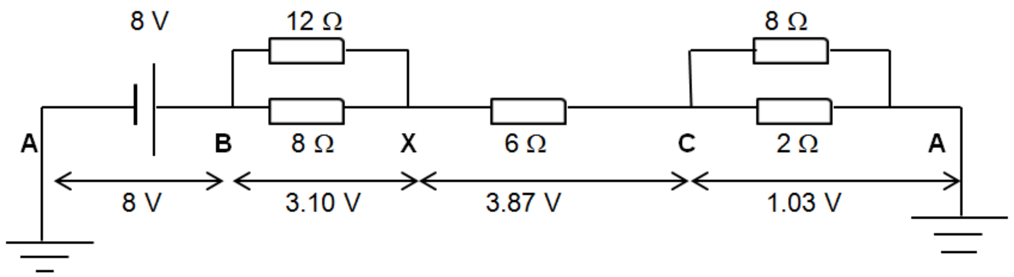
51 A network of resistors is connected across an 8 V battery of negligible internal resistance.



What is the potential at point **X**?

A 3.87 V **B** 4.13 V **C** 4.90 V **D** 11.1 V

[HCI 2012]



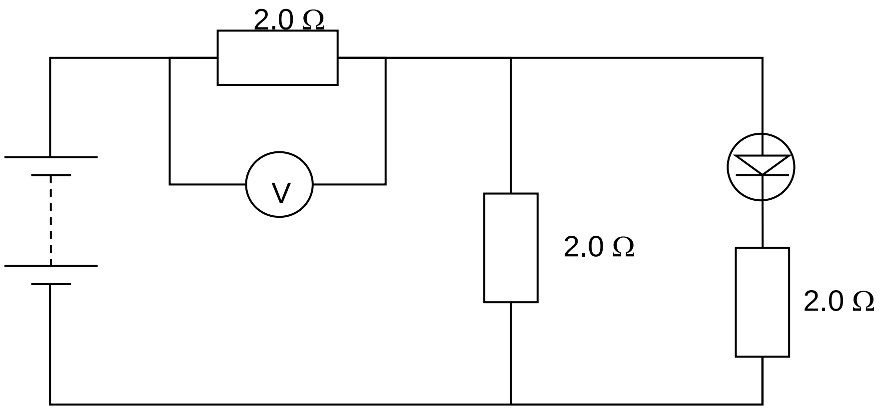
$R_{BX} = \left(\frac{1}{12}+\frac{1}{8}\right)^{-1} = 4.8\ \Omega$ $R_{CA} = \left(\frac{1}{8}+\frac{1}{2}\right)^{-1} = 1.6\ \Omega$

$R = 4.8 + 6 + 1.6 = 12.4\ \Omega$

$$V_{BX} = \left(\frac{R_{BX}}{R}\right)E = \left(\frac{4.8}{12.4}\right)(8) = 3.10\text{ V}$$

$$V_X = 8 - 3.10 = 4.90\text{ V}$$

52 In the circuit diagram below, the voltage supply has negligible internal resistance and the voltmeter reads 12 V.



If the connections to the terminals of the voltage supply are reversed, the voltmeter reading would be

A 6.0 V **B** 8.0 V **C** 9.0 V **D** 18 V

[MJC 2012]

Before voltage supply is reversed, diode is forward-bias.

$$I_T = \frac{V}{R} = \frac{12}{2.0} = 6.0 \text{ A}$$

Since diode is ideal, current in each of the resistors arranged in parallel across resistor, *R*

$$I = \frac{I_T}{2} = \frac{6.0}{2} = 3.0 \text{ A}$$

$$V_R = IR = 3.0(2.0) = 6.0 \text{ V}$$

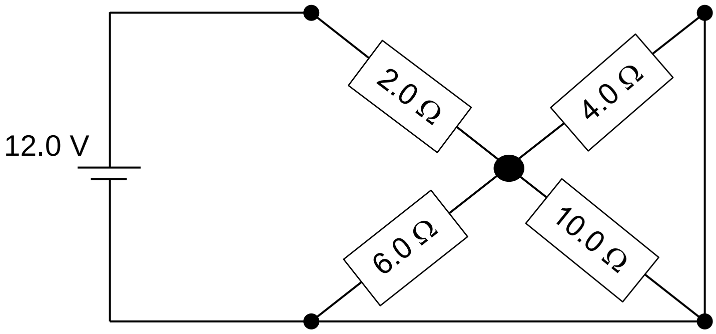
$$E = V + V_R = 12 + 6.0 = 18 \text{ V}$$

After voltage supply is reversed, diode is reverse-bias, no current will flow through the diode.

$$R_{eff} = 2.0 + 2.0 = 4.0\ \Omega$$

$$V = \left(\frac{R}{R_{eff}}\right)E = \left(\frac{2.0}{4.0}\right)(18) = 9.0 \text{ V}$$

53 A cell of e.m.f. 12.0 V with negligible internal resistance is connected to 4 resistors as shown below.

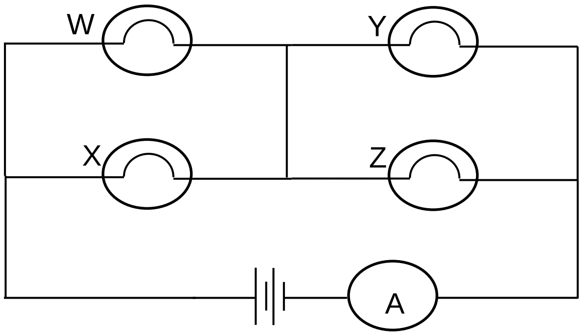


What is the current flowing through the 10.0 Ω resistor in diagram above?

A 0.59 A **B** 1.0 A **C** 5.3 A **D** 11.0 A

[NJC 2013]

54 Four similar bulbs are connected to a constant-voltage d.c. supply as shown below. Each bulb operates at normal brightness and the ammeter registers a steady current.

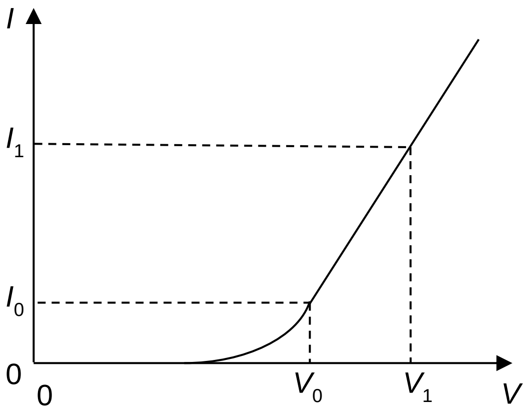


The filament of bulb X breaks. What happens to the brightness of the remaining bulbs?

	bulb W	bulb Y	bulb Z
A	brighter	less bright	less bright
B	less bright	less bright	less bright
C	brighter	brighter	brighter
D	less bright	brighter	brighter

[NJC 2013]

55 The graph shows the current-voltage (I–V) characteristic of an electrical component.



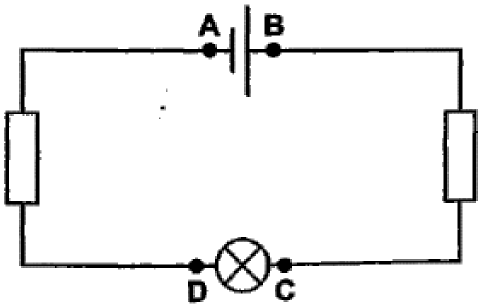
What is the resistance of the component at potential difference V_1 and how does the resistance change, if at all, when the potential difference increases from V_0 to V_1?

	resistance at V_1	resistance change from V_0 to V_1
A	$\frac{V_1 - V_0}{I_1 - I_0}$	no change
B	$\frac{V_1 - V_0}{I_1 - I_0}$	decreases
C	$\frac{V_1}{I_1}$	no change
D	$\frac{V_1}{I_1}$	decreases

[RVHS 2013]

The power delivered to a resistor by the rms current of an ac supply is equivalent to the power delivered by the dc current of a dc supply.

56 An electron travels around the circuit shown in the diagram. The cell has negligible internal resistance.
At which point in the circuit does the electron have its maximum electrical potential energy?



[SAJC 2013]

57 The potential difference between points A and B is 25 V. The time taken for charge carriers to move from A to B is 20 s, and in this time, the energy of the charge carriers changes by 12 J. What is the current flowing through AB?

A 0.024 A **B** 0.60 A **C** 2.1 A **D** 42 A

[YJC 2012]

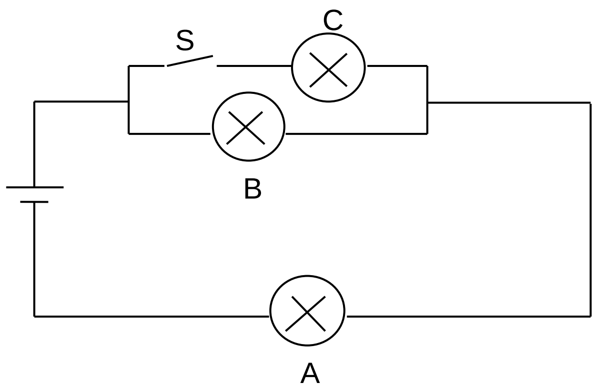
$W = QV$

$Q = \frac{W}{V} = \frac{12}{25} = 0.48 \text{ C}$

$Q = It$

$I = \frac{Q}{t} = \frac{0.48}{20} = 0.024 \text{ A}$

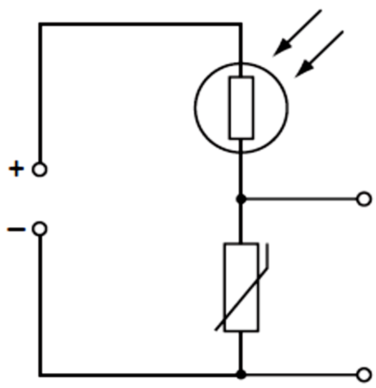
58 Three bulbs A, B and C, each of equal resistance, are connected as shown. Initially, switch S is closed and all bulbs lit up. What happens to the brightness of A and B when S is opened?



	bulb A	bulb B
A	increase	increase
B	decrease	increase
C	decrease	decrease
D	increase	decrease

[YJC 2012]

59 The diagram shows a light-dependent resistor (LDR) and a thermistor forming a potential divider.

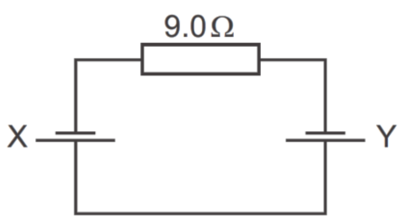


Under which set of conditions will the potential difference across the thermistor have the greatest value?

	illumination	temperature
A	low	low
B	high	low
C	low	high
D	high	high

[YJC 2012]

60 Two cells X and Y are connected in series with a resistor of resistance 9.0 Ω, as shown.

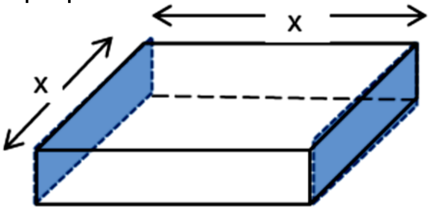


Cell X has an electromotive force (e.m.f.) of 1.0 V and an internal resistance of 1.0 Ω. Cell Y has an e.m.f. of 2.0 V and an internal resistance of 2.0 Ω.
What is the current in the circuit?

A 0.25 A **B** 0.17 A **C** 0.10 A **D** 0.083 A

[AJC 2013]

61 A sample of resistive material is prepared in the form of a thin square slab of side x.

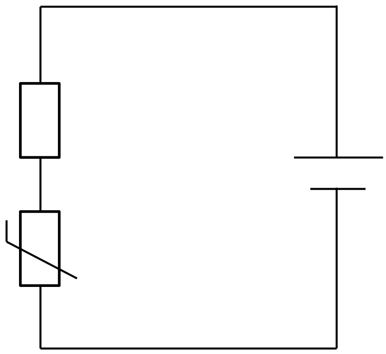


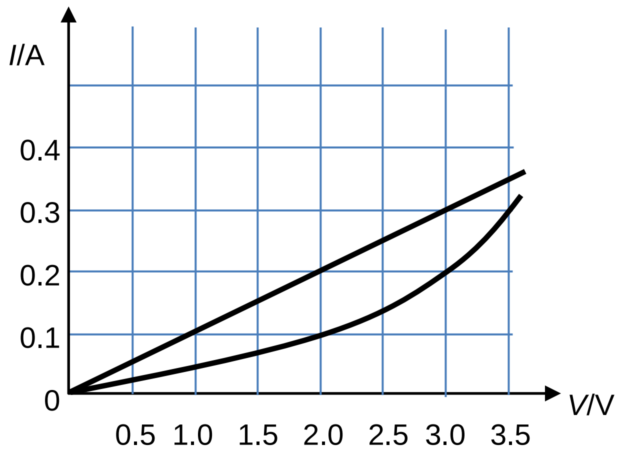
For a given thickness, the resistance between opposite edge faces of the sample is

A proportional to x^2 **B** proportional to x
C independent of x **D** inversely proportional to x

[CJC 2013]

62 A 10 Ω resistor and a thermistor are connected in series to a battery of e.m.f. 3.0 V and negligible internal resistance. The table shows the voltage of both thermistor and resistor corresponding to the current flowing in them.



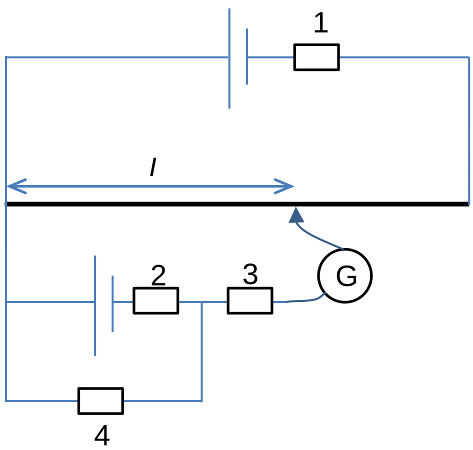


If the resistance of the resistor is doubled, what is the e.m.f. of the new battery assuming negligible internal resistance required for current flowing in the circuit to remain the same?

A 4.0 V **B** 4.5 V **C** 5.0 V **D** 6.0 V

[ACJC 2015]

63 The diagram shows a potentiometer setup with four resistors in place.



The jockey is at the null point. Which of the following statements is **not** true?

A Increasing the resistance of resistor 4 will increase the balance length *l*.
B Increasing the resistance of resistor 3 will decrease the balance length *l*.
C Decreasing the resistance of resistor 2 will increase the balance length *l*.
D Increasing the resistance of resistor 1 will decrease the fractional uncertainty of the balance length *l*.

[ACJC 2015]

64 The Large Hadron Collider is designed to accelerate groups of protons around a large circular ring. At any moment, there will be 3000 groups in the ring and each group will contain about 10^{11} protons. All the protons go around the ring 10^4 times per second.
What is the best estimate of the current in the ring?

A 50 μA **B** 160 μA **C** 500 mA **D** 160 A

[AJC 2015]

$Q = It$

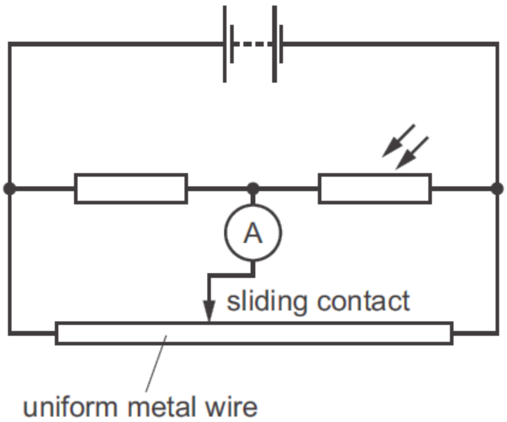
$$I = \frac{ne}{t}$$

$$= \frac{3000(10^{11})(10^4)(1.60 \times 10^{-19})}{1}$$

$$= 0.48 \text{ A}$$

$$\approx 500 \text{ mA}$$

65 In the potentiometer circuit shown, the reading on the ammeter is zero.

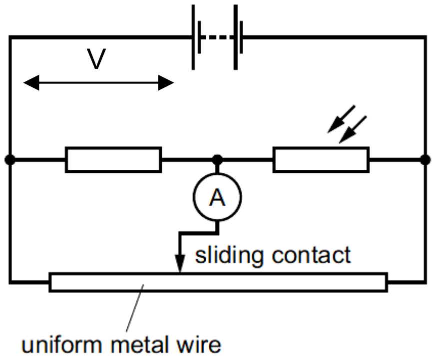


The light-dependent resistor (LDR) is then covered up and the ammeter gives a non-zero reading.
Which change could return the ammeter reading to zero?

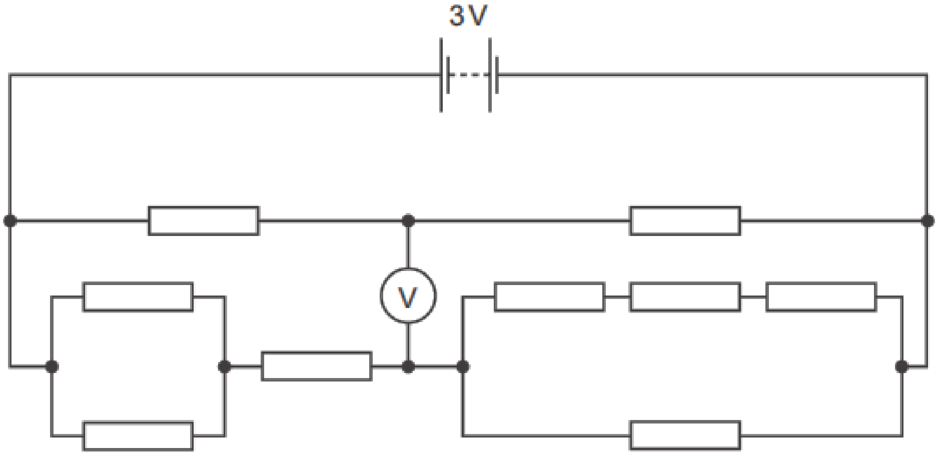
A decrease the supply voltage **B** increase the supply voltage
C move the sliding contact to the left **D** move the sliding contact to the right

[AJC 2015]

When LDR is covered, its resistance increases leading to a drop in the potential difference across it. To restore the balance, the sliding contact has to be shifted left. Changing the supply voltage affects V and $V_{\text{metal wire}}$ at the same time so it does not restore balance.



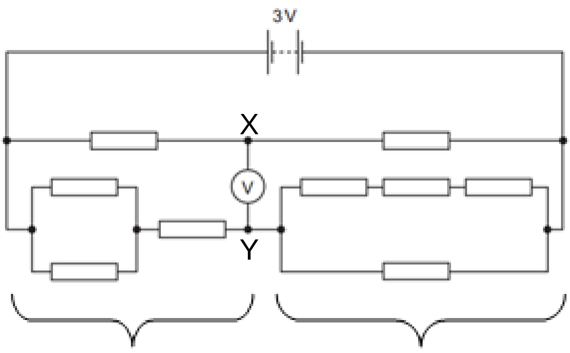
66 A circuit is set up as shown, supplied by a 3 V battery. All resistances are 1 kΩ.



What will be the reading on the voltmeter?

A 0 **B** 0.5 V **C** 1.0 V **D** 1.5 V

[AJC 2015]



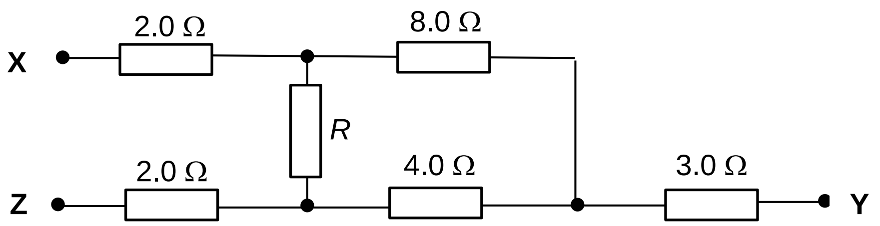
$1.5R$ $\quad$ $\left(\frac{1}{3R}+\frac{1}{R}\right)^{-1}=0.75R$

$V_X = 1.5\text{ V}$ $\qquad$ $V_Y = \left(\frac{0.75}{1.5+0.75}\right)(3)$

$= 1.0\text{ V}$

Hence voltmeter reading is 0.5 V

67 The diagram shows a network of six resistors. A multi-meter measures the resistance between X and Z as 8.0 Ω. What is the value of resistance R?



A 2.0 Ω **B** 4.0 Ω **C** 6.0 Ω **D** 8.0 Ω

[CJC 2015]

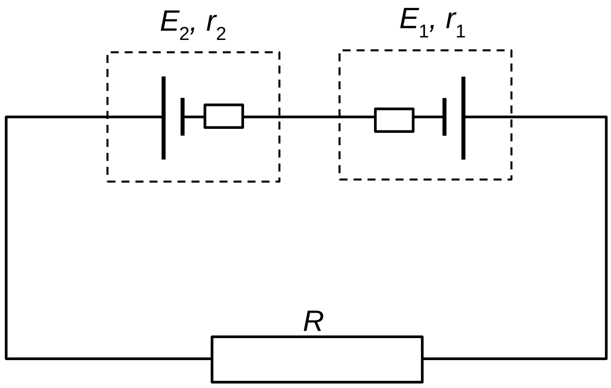
When the multi-meter measures the effective resistance between X and Z, it can be assumed that a small current is sent from terminal X to the circuit and return to terminal Z. The 3.0 Ω resistance will not be part of the circuit of the effective resistance since the current will not flow to terminal Y. Thus,

$$R_{eff} = 8.0$$

$$\left(\frac{1}{R}+\frac{1}{12.0}\right)^{-1} + 2.0 + 2.0 = 8.0$$

$$R = 6.0\ \Omega$$

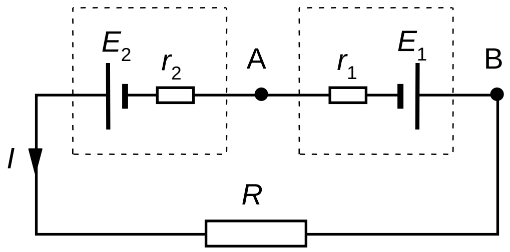
68 Two cells of electromotive forces E_1 and E_2, and internal resistances r_1 and r_2, are connected to a load resistance R in the circuit shown.



If the current flowing in the circuit is I and $E_1 < E_2$, what is the magnitude of the terminal potential difference across the cell E_1?

A $E_1 - Ir_1$ **B** $E_1 + Ir_1$ **C** $E_2 - I(r_1 + r_2 + R)$ **D** $E_2 + Ir_2 - IR$

[CJC 2015]

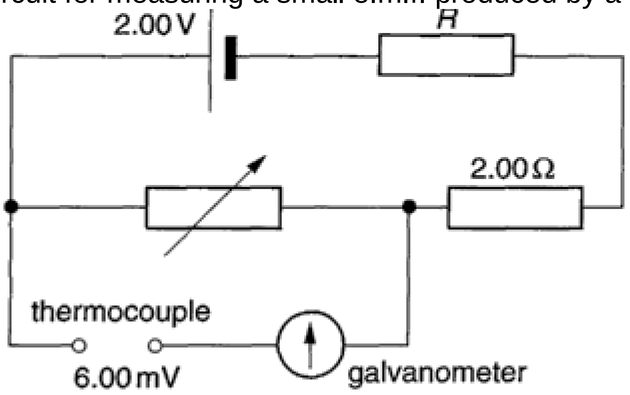


$V_X = 1.5$ V

Since $E_1 < E_2$, E_2 is charging E_1

$$V = IR$$
$$E_1 - E_2 = I\left(r_1 + r_2 + R\right)$$
$$= Ir_1 + I\left(r_2 + R\right)$$
$$E_2 - I\left(r_2 + R\right) = Ir_1 + E_1$$
$$V_{T,1} = V_{BA}$$
$$= Ir_1 + E_1$$

69 The diagram shows a circuit for measuring a small e.m.f. produced by a thermocouple.

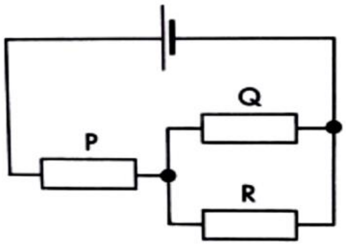


There is zero current in the galvanometer when the variable resistor is set at 3.00 Ω.
What is the value of *R*?

A 195 Ω **B** 495 Ω **C** 995 Ω **D** 1995 Ω

[DHS 2015]

70 In the circuit shown below, P, Q and R are identical resistors.



The ratio $\dfrac{\text{rate of production of heat in Q}}{\text{rate of production of heat in P}}$ is

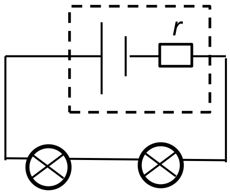
A 0.25 **B** 0.50 **C** 2 **D** 4

[HCI 2015]

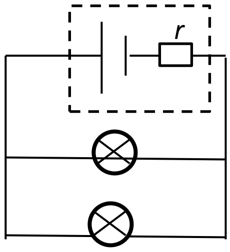
The current through Q is half that of the current through P.
Let the current through P be *I*.

$$P_P = I^2R$$
$$P_Q = \left(\frac{I}{2}\right)^2 R$$
$$\frac{P_Q}{P_P} = \frac{1}{4}$$

71 A battery with internal resistance *r* is connected to two identical light bulbs each of resistance *R*. Which of the following expressions gives the efficiency η of each of the circuit?



circuit 1



circuit 2

	circuit 1	circuit 2
A	$\eta = \dfrac{R}{R+2r} \times 100\%$	$\eta = \dfrac{R+2r}{R} \times 100\%$
B	$\eta = \dfrac{2R}{2R+r} \times 100\%$	$\eta = \dfrac{R}{2R+2r} \times 100\%$
C	$\eta = \dfrac{2R}{2R+r} \times 100\%$	$\eta = \dfrac{R}{R+2r} \times 100\%$
D	$\eta = \dfrac{R}{R+2r} \times 100\%$	$\eta = \dfrac{2R}{2R+r} \times 100\%$

[HCI 2015]

Calculate the useful power generated across the light bulbs and divide by total power dissipated in the entire circuit (including internal resistance of the battery)

For circuit 1:

$$\eta = \frac{I_1^2(2R)}{I_1^2(2R+r)} \times 100\%$$
$$= \frac{2R}{2R+r} \times 100\%$$

For circuit 2:

$$\eta = \frac{I_2^2\left(\frac{R}{2}\right)}{I_2^2\left(\frac{R}{2}+r\right)} \times 100\%$$
$$= \frac{R}{R+2r} \times 100\%$$

72 A lamp rated at 12 V and 24 W is used with a 10 V supply for 2 s. What is the energy transferred in the lamp?

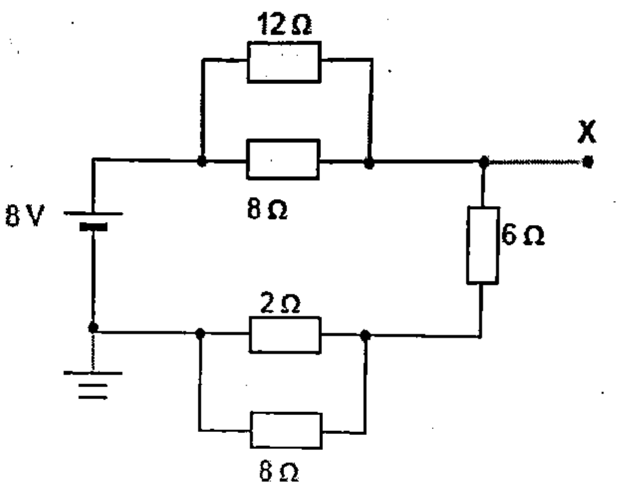
A 20 J **B** 24 J **C** 33 J **D** 40 J

[NJC 2015]

$$P = \frac{V^2}{R}$$
$$R = \frac{V^2}{P}$$
$$= \frac{12^2}{24}$$
$$= 6.0\ \Omega$$

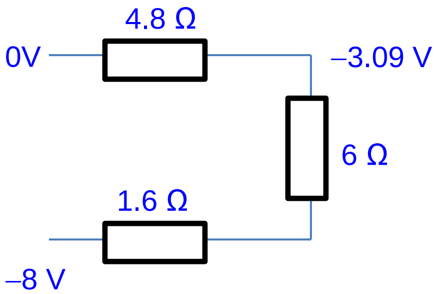
$$P = \frac{E}{t}$$
$$E = Pt$$
$$= \left(\frac{V^2}{R}\right)t$$
$$= \left(\frac{10^2}{6.0}\right)(2)$$
$$= 33\ \text{J}$$

73 A circuit is set up as shown below. What is the potential at point **X**?



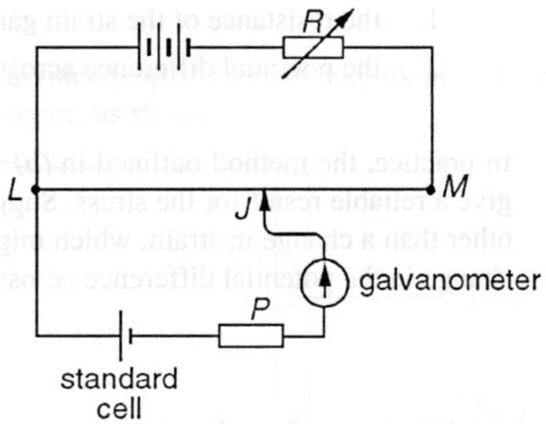
A –3.1 V **B** 3.1 V **C** –4.9 V **D** 4.9 V

[NJC 2015]



$$V = \left(\frac{R}{R_{eff}}\right)E$$
$$= \left(\frac{4.8}{4.8+6+1.6}\right)(8)$$
$$= 3.1\text{ V}$$

74 In the potentiometer circuit below, the moveable contact is placed at *J* on the bare wire *LM*, such that galvanometer shows zero deflection.



The resistance of the variable resistor *R* is now increased.
What is the effect of this increase on the potential difference across the wire *LM* and on the position of the moveable contact for zero deflection?

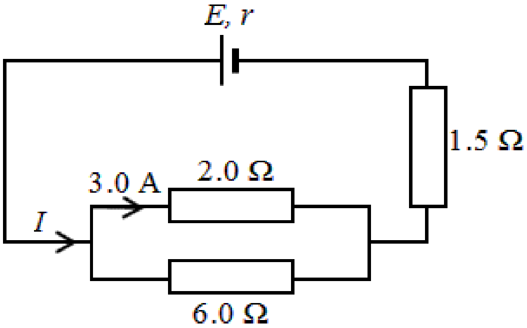
	p.d. across *LM*	position of moveable contact
A	increase	nearer to *L*

B	increase	nearer to *M*
C	decrease	nearer to *L*
D	decrease	nearer to *M*

[TJC 2015]

By potential divider method, as *R* increases, p.d. across LM decreases. The potential gradient of wire LM decreases. For zero deflection, contact J has to shift to the right so that p.d. across LJ is equal to e.m.f. of standard cell.

75 In the circuit shown, there is a current of 3.0 A in the 2.0 Ω resistor.



It is known that the source of e.m.f. *E* with internal resistance *r* has an output efficiency of 90% in its power delivery to the external circuit. What are the values of the current *I* delivered by the source and its e.m.f. *E*?

	I/A	*E*/V
A	3.0	12.0
B	4.0	10.8
C	4.0	13.3
D	12	18.0

[VJC 2015]

$$I = 3.0 + \frac{3.0(2.0)}{6.0}$$
$$= 4.0 \text{ A}$$
$$R = \left(\frac{1}{2.0} + \frac{1}{6.0}\right)^{-1} + 1.5$$
$$= 3.0\ \Omega$$

$$\eta = \frac{P_{out}}{P_{in}}$$
$$= \frac{IV}{IE}$$
$$= \frac{V}{E}$$
$$= \frac{IR}{E}$$
$$E = \frac{4.0(3.0)}{0.90}$$
$$= 13.3 \text{ V}$$

Short Structured Questions

1 **(a)** Define specific latent heat of fusion.

Specific latent heat is the quantity of heat required to change the state of a substance per unit mass from solid to liquid (or liquid to solid) w/o a change in temperature [1]

(b) Use the following physical data for ice, water and steam when necessary in answering the following questions given that standard pressure is 1.01×10^5 Pa.

	ice	water	water	steam
temperature	0 °C	0 °C	100 °C	100 °C
volume occupied by 1 kg at standard pressure/m^3	0.00109	0.00100	0.00104	1.67
kinetic energy of all the molecules in 1 kg/10^5 J	1.89	1.89	2.58	2.58
potential energy of all the molecules in 1 kg (referred to ice at 0 °C)/10^5 J	0	3.36	3.41	24.3
internal energy of 1 kg/10^5 J	1.89	5.25	5.99	26.9

(i) Explain why there is no change in *kinetic energy of the molecules* when ice at 0 °C changes to water at 0 °C.

The heat supplied was mainly used to break the bonds/overcome intermolecular forces of the molecules, which increases the molecular potential energy slightly due to the slight change in separation between molecules and not to increase the kinetic energy of the molecules (since temp remains the same) [1]

(ii) Explain why there is a significant increase in the *potential energy of the molecules* when water at 100 °C changes to steam at 100 °C.

Change in separation between the molecules from liquid to gaseous state is very large, about 10 times, hence the large increase in molecular potential energy. [1]

(iii) The first law of thermodynamics may be expressed in the form

$$\Delta U = q + w$$

where ΔU is the increase in internal energy of the system, q is the thermal energy supplied to the system, w is the work done on the system

1. Complete the table below for the processes indicated by writing down the symbol '+' for an increase, the symbol '–' for a decrease and the symbol '0' for no change, as appropriate.

	ΔU	q	w
water at 0 °C changes to ice at 0 °C	–	–	–
water at 100 °C changes to steam at 100 °C	+	+	–

[2]

2. Determine the specific latent heat of fusion of ice.

$$
\begin{aligned}
U &= Q + W \\
&= Q - p\Delta V \\
&= mL - p\Delta V \\
3.36\times10^5 &= 1.00L - 1.01\times10^5(0.00100 - 0.00109) \\
L &= 3.36\times10^5 \text{ J kg}^{-1}
\end{aligned}
$$

specific latent heat of fusion = ... J kg^{-1} [2]

[ACJC 2012]

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

The specific heat capacity of a substance is the quantity of heat required to produce a unit change in temperature per unit mass of that substance. [1]

(b) Fig. 6.1 shows an experimental set up by Ben to find out the specific heat capacity of water. Mr Haagen, his teacher, pointed out that without a lid for the calorimeter, heat will be lost through evaporation therefore causing inaccuracy to the specific heat capacity obtained.

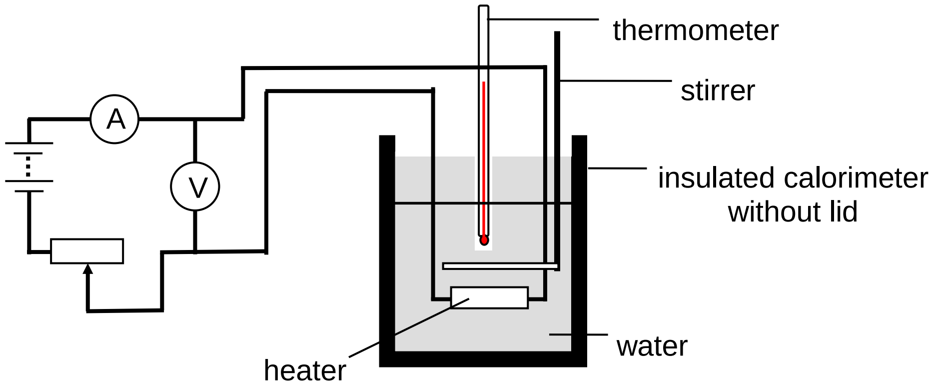


Fig. 6.1

Using the kinetic model for matter, explain how heat is lost through evaporation. Hence explain how adding a lid will prevent this loss.

Some molecules of the liquid have higher kinetic energy (KE) than others. A very fast moving molecule (i.e. with large KE) near the surface of the liquid may have enough energy to overcome the attractive forces of the neighbouring molecules and leave the liquid. As the more energetic molecules escape from the surface of the liquid, the remaining molecules in the liquid will have smaller kinetic energy. The overall K.E. of the remaining liquid molecules decreases and cooling occurs. By adding a lid, the energetic molecules that have escaped from the liquid will be confined to the space above the liquid. Some of these energetic molecules will enter the liquid as other molecules escape from the liquid. The net change in KE is zero and hence cooling does not occur [3]

(c) Jerry prepared a similar set up to Fig. 6.1, but **with a lid** for the insulated calorimeter. Starting at room temperature of 30.0 °C, the heater is turned on for 6.50 minutes until the water rises to a temperature of 50.0 °C. During heating, current is adjusted so that readings on the ammeter and voltmeter are constant at 1.97 A and 12.0 V respectively. Other useful information he found is as follows:

Mass of water = 100 g
Heat capacity of material of calorimeter and stirrer (made of same material) = 38.6 J K^{-1}
Calculate the specific heat capacity of water based on information found by Jerry.
Let subscript *l* denotes liquid and subscript *c* denotes calorimeter.
Assuming no heat loss to surrounding.
energy supplied by heater = energy absorbed by liquid and calorimeter

$$VIt = m_l c_l (T_f - T_i) + C_c (T_f - T_i)$$
$$= (m_l c_l - C_c)(T_f - T_i)$$
$$12.0(1.97)(6.5 \times 60) = (0.100 c_l + 38.6)(50 - 30)$$
$$c_l = 4220 \text{ J kg}^{-1} \text{ K}^{-1}$$

specific heat capacity of the water = ... J kg^{-1} K^{-1} [2]

(d) Mr Haagen used the continuous flow method as shown in Fig. 6.2 to determine the specific heat capacity of the water.

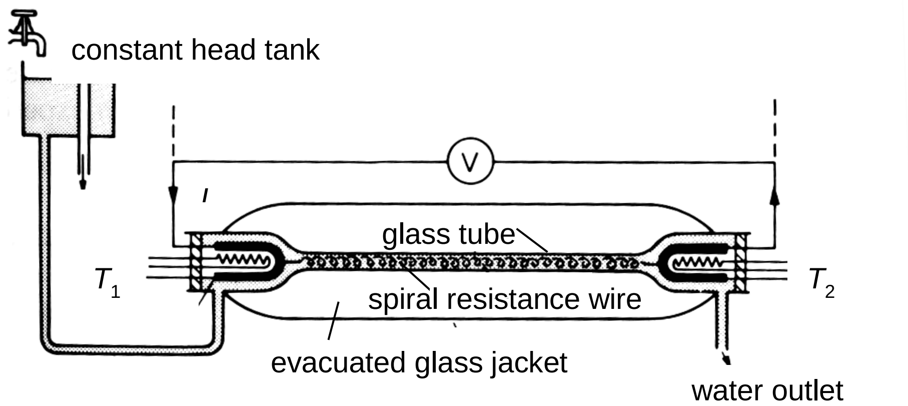


Fig. 6.2

Water of temperature T_1 from the constant head tank enters the glass tube at a constant rate of *M*. The water gets heated by a heating coil as it flows through the glass tube. The heating coil, which carries a steady electric current *I*, has a constant potential difference *V* applied across it. Water leaves the glass tube at temperature T_2.

The experiment was conducted twice and the measurements obtained are as follows.

experiment	M/g s^{-1}	T_1/°C	T_2/°C	*I*/A	*V*/V
1	2.33	30.0	35.0	1.83	30.0
2	4.61	30.0	35.0	2.05	50.0

(i) State two advantages of using the continuous flow method as compared to the method used by Jerry in the determination of specific heat capacity of water.

1. At steady state, none of the electrical energy supplied is used to warm the apparatus. As such heat capacity of the apparatus is not required in the determination of the specific heat capacity of the liquid.

2. As the temperature of the apparatus in excess of the surrounding when obtaining the two sets of data remains the same, by Newton's Law of Cooling, the rate of heat loss to the surrounding is the same for both cases. Since power supplied by heater = power used to heat liquid + rate of heat loss for both cases, rate of heat loss can be easily eliminated by algebraic manipulation (in the calculation). Therefore the rate of overall heat loss need not be known. [2]

(ii) Determine the specific heat capacity of water based on the measurements obtained from the continuous flow method.

$$IV = Mc(T_f - T_i) + \frac{h}{t} \quad \ldots \quad (1) \qquad\qquad I'V' = M'c(T_f - T_i) + \frac{h}{t} \quad \ldots \quad (2)$$

where $\frac{h}{t}$ is the rate of heat lost which is the same for both experiments

(2) – (1):

$$I'V' - IV = (M' - M)c(T_f - T_i)$$

$$50(2.05) - 30(1.83) = (4.61 - 2.33)c(35.0 - 30.0)$$

$$c = 4.175 \text{ J g}^{-1}\text{ K}^{-1}$$

$$= 4180 \text{ J kg}^{-1}\text{ K}^{-1}$$

specific heat capacity of the water = ... J kg^{-1} K^{-1} [2]

[MJC 2012]

3 Use the following physical data in answering this question.

Standard pressure = 1.01×10^5 Pa

Molar mass of water = 18.0 g mol^{-1}

Density of water at 100 °C and standard pressure = 962 kg m^{-3}

Density of steam at 100 °C and standard pressure = 0.599 kg m^{-3}

Specific latent heat of vaporization of water at 100 °C = 2.26×10^6 J kg^{-1}

(a) Show that the number of molecules in 1.00 kg of water is 3.34×10^{25}.

$$N = \left(\frac{m}{M}\right) N_A$$

$$= \left(\frac{1.00}{18.0 \times 10^{-3}}\right)\left(6.02 \times 10^{23}\right)$$

$$= 3.34 \times 10^{25} \ \text{(shown)}$$

[1]

(b) Assuming that steam behaves as an ideal gas, calculate the kinetic energy of all the molecules in 1.00 kg of steam at 100 °C.

$$\text{kinetic energy of molecules} = \frac{3}{2}NkT$$

$$= \frac{3}{2}\left(3.34 \times 10^{25}\right)\left(1.38 \times 10^{-23}\right)\left(100 + 273.15\right)$$

$$= 2.58 \times 10^5 \text{ J}$$

kinetic energy of all the molecules = ... J [2]

(c) 1.00 kg of water changes to steam at 100 °C and standard pressure.

(i) Calculate the work done by the system during this change in phase.

$$W = p\Delta V$$

$$= \left(1.01 \times 10^5\right)\left(\frac{1.00}{0.599} - \frac{1.00}{962}\right)$$

$$= 1.69 \times 10^5 \text{ J}$$

work done by the system = ... J [2]

(ii) Use the First Law of Thermodynamics to calculate the increase in internal energy of the molecules in this process.

$$\begin{aligned}\Delta U &= Q + W \\ &= mL + W \\ &= 1.00\left(2.26\times10^{6}\right)+\left(-1.69\times10^{5}\right) \\ &= 2.09\times10^{6}\ \text{J}\end{aligned}$$

increase in internal energy = ... J [2]

(iii) State the increase in the potential energy of the molecules during this change of phase. Explain how you arrive at your answer.

2.09×10^{6} J

increase in *potential* energy = ... J

Explanation:

Increase in potential energy is 2.09×10^{6} J, since the change occurs at constant temperature, the average kinetic energy and hence the total kinetic energy of the molecules remains constant and the increase in internal energy is due entirely to the increase in potential energy of the molecules. [2]

[DHS 2012]

4 0.050 moles of helium gas (assume ideal gas) is contained in a cylinder fitted with a piston. The piston moves slowly outwards, resulting in the variation of pressure shown in Fig. 2.1.

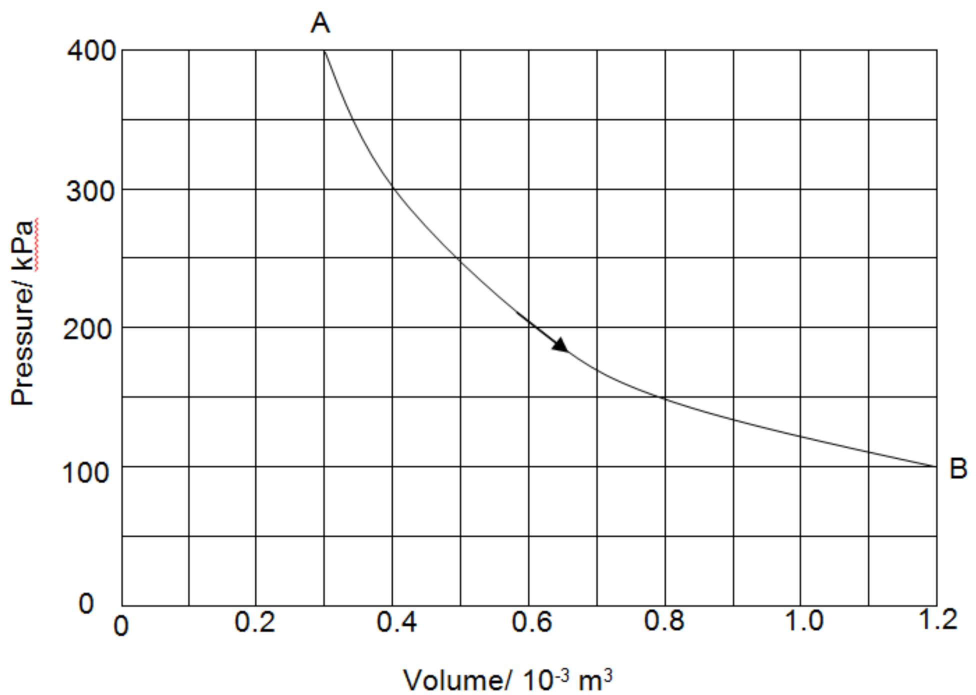


Fig. 2.1

(a) Show that the temperature of the gas does not change from A to B and calculate this temperature.

For a fixed mass of ideal gas, $pV \propto T$. If pV is the same/equal along path AB, T is constant.

$(pV)_A = (400)(0.3)$ $\qquad$ $(pV)_B = (100)(1.2)$

$= 120 \text{ Pa m}^{-3}$ $\qquad$ $= 120 \text{ Pa m}^{-3}$

Hence $T_A = T_B$

$pV = nRT$

$$T = \frac{pV}{nR}$$
$$= \frac{400(0.3)}{0.050(8.31)}$$
$$= 289 \text{ K}$$

temperature = ... K [2]

(b) Calculate the kinetic energy as a result of the random motion of the gas molecules in the cylinder.

$$E = \frac{3}{2}nRT$$
$$= \frac{3}{2}(0.050)(8.31)(289)$$
$$= 180 \text{ J}$$

kinetic energy = ... J [2]

(c) Estimate the amount of work done by the gas as it expands from A to B.

work done by gas = area under $p - V$ graph

$$= 34\left(50\times10^{3}\right)\left(0.10\times10^{-3}\right)$$
$$= 170 \text{ J}$$

Allow 165 – 175 J.

work done = ... J [2]

(d) A student claims that heat flows into the gas during the process from A to B. Use the First Law of Thermodynamics to verify if his claim is true.

Since the temperature is constant, $\Delta U = 0$. As gas expands from A to B, work done on gas is negative. From First Law of Thermodynamics,

$$\Delta U = Q + W$$
$$Q = -W$$

Hence q is positive, hence heat flows into the gas during expansion [2]

[TJC 2012]

5 **(a)** An object X, which has a mass of 3.0 kg and temperature of 373 K, is placed in thermal contact with object Y of mass 1.8 kg and an unknown initial temperature θ.
The two bodies eventually reach thermal equilibrium and the equilibrium temperature is measured to be 457 K. Given that the specific heat capacity of object X is 2200 J kg^{-1} K^{-1} and the specific heat capacity of object Y is 1800 J kg^{-1} K^{-1}, calculate the initial temperature θ, assuming there is no heat loss to surroundings.

heat gained by X = heat lost by Y

$$3.0(2200)(457-373) = 1.8(1800)(\theta - 457)$$
$$\theta = 628 \text{ K}$$

initial temperature = ... K [2]

(b) A fixed mass of monoatomic ideal gas occupies a volume of 300 cm^3 at a pressure of 1.5×10^5 Pa and a temperature of 320 K. The ideal gas undergoes heating at constant volume to a pressure of 2.5×10^5 Pa.

(i) State the first law of thermodynamics.

The first law of thermodynamics states that the internal energy is a function of state and that the increase in internal energy of a system is equal to the sum of the heat supplied to system and work done on system. [2]

(ii) Determine the temperature of the gas after heating.

$$p \propto T$$

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

$$T_2 = \left(\frac{p_2}{p_1}\right)T_1 = \left(\frac{1.5\times10^5}{2.5\times10^5}\right)(320) = 533 \text{ K}$$

temperature = ... K [2]

(iii) Given that the initial internal energy of the gas is 67.4 J, calculate the quantity of heat supplied to the gas.

$$U \propto T$$

$$\frac{U_2}{U_1} = \frac{T_2}{T_1}$$

$$U_2 = \left(\frac{533}{320}\right)(67.4) = 112 \text{ J}$$

$$\Delta U = U_2 - U_1 = 44.9 \text{ J}$$

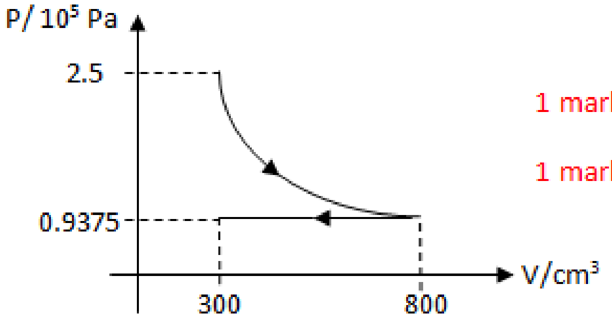
$$\Delta U = Q + W$$

$$Q = 44.9 \text{ J } (\because W = 0 \text{ J})$$

heat supplied = ... J [3]

(iv) The gas then undergoes isothermal expansion to a volume of 800 cm^3, followed by a contraction to its original volume at constant pressure.
Sketch, using the axes provided, a pressure-volume graph to illustrate the thermodynamic processes that the gas underwent. Indicate all values clearly.

[2]



1 mark for shape

1 mark for values

[TPJC 2012]

6 **(a)** Explain what is meant by an *ideal gas*.

An ideal gas is a hypothetical gas which obeys the ideal gas equation $pV = nRT$ for all pressures, temperatures and volumes. [1]

(b) State in words how the temperature of an ideal gas is related to the energy of the molecules of the gas.

The mean kinetic energy of the molecules in an ideal gas is directly proportional to the thermodynamic temperature. [1]

(c) A plasma is a mixture of gas atoms, gas ions and electrons, all in thermal equilibrium. In a certain hydrogen plasma, the hydrogen atoms, hydrogen ions (protons) and electrons can be assumed to behave like the molecules of a mixture of three ideal gases. The root-mean-square speed of the hydrogen ions in the plasma is found to be 6.0×10^4 m s^{-1}.

(i) Determine the root-mean-square speeds of

1. the hydrogen atoms,

2. the electrons,

in the plasma.

Since all three are in thermal equilibrium,

$$\frac{1}{2}m_{H^+}c_{H^+}^2 = \frac{1}{2}m_H c_H^2 = \frac{1}{2}m_e c_e^2 = \frac{3}{2}kT$$

$$m_{H^+} \approx m_H \quad \therefore c_H = 6.0 \times 10^4 \text{ m s}^{-1}$$

$$E_H = \frac{1}{2}\left(1.67 \times 10^{-27}\right)\left(6.0 \times 10^4\right)^2$$

$$= 3.006 \times 10^{-18} \text{ J}$$

$$3.006 \times 10^{-18} = \frac{1}{2}\left(9.11 \times 10^{-31}\right)\left(c_e^2\right)$$

$$c_e = 2.6 \times 10^6 \text{ m s}^{-1}$$

r.m.s. speed of hydrogen atoms = ... m s^{-1}

r.m.s. speed of electrons = ... m s^{-1} [3]

(ii) Determine the temperature of the plasma.

$$E = \frac{3}{2}kT$$

$$T = \frac{2E}{3k}$$

$$= \frac{2\left(3.006 \times 10^{-18}\right)}{3\left(1.38 \times 10^{-23}\right)}$$

$$= 1.5 \times 10^5 \text{ K}$$

temperature of plasma = ... K [2]

[RI 2013]

7 **(a)** Define the term *electric field strength*.

The electric force per unit positive charge placed at a point [2]

(b) Two oppositely-charged parallel metal plates are situated in a vacuum, as shown in Fig. 2.1.

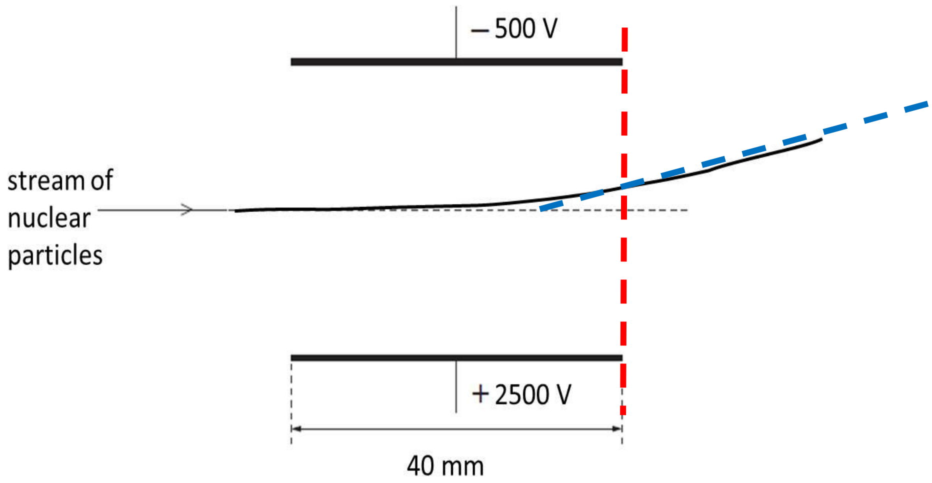


Fig. 2.1 (not to scale)

Between plates: reasonable curve upwards
Beyond the plates: Straight and at a tangent to the curve

The parallel plates have a length of 40 mm and their separation is 6.0 mm. The electric field can be assumed to be zero outside the plates.
A stream of positively-charged nuclear particles is directed horizontally at a speed of 4.0×10^6 m s^{-1} towards the plates. The nuclear particles pass between the plates and into the region beyond them.

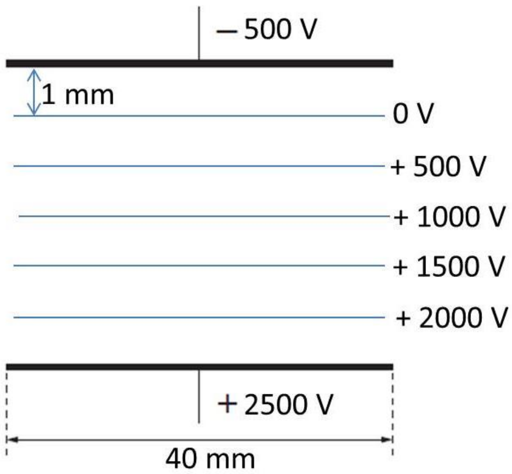
(i) On Fig. 2.1, draw the path of the nuclear particles between and beyond the plates. [2]

(ii) Determine the electric field strength halfway between the plates.

$$E = \frac{V}{d}$$
$$= \frac{2500 - (-500)}{6.0 \times 10^{-3}}$$
$$= 5.0 \times 10^5 \text{ V m}^{-1}$$

electric field strength = ... V m^{-1} [1]

(iii) Draw the equipotential lines for the region within the parallel plates on Fig. 2.2 below.



[1]
[CJC 2012]

8 **(a)** Define electric field strength at a point in an electric field.

Electric field strength at a point is defined as the (electrostatic) force per unit positive charge. [2]

(b) The electric potential, V, in a region varies with the distance, x, from a chosen reference point, as shown in Fig. 3.1.

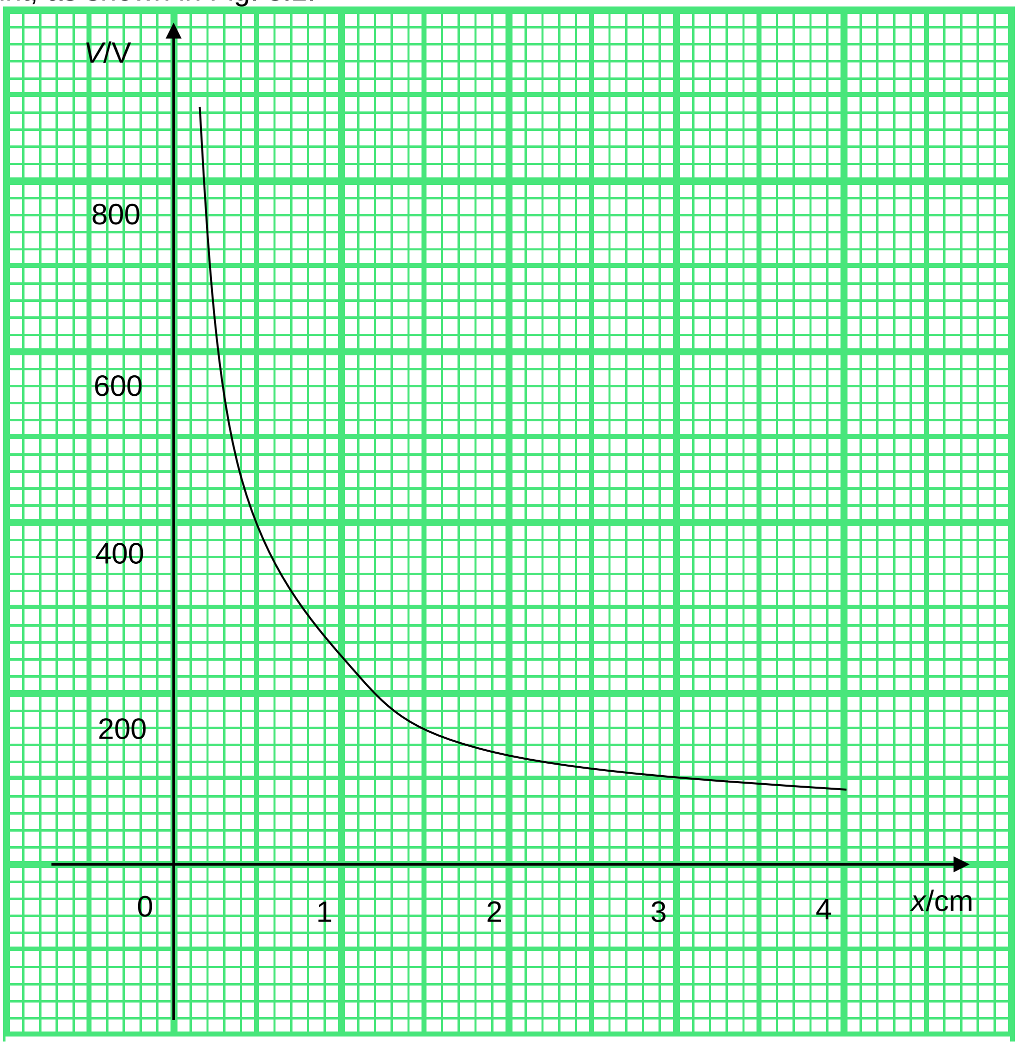


Fig. 3.1

A charged particle of $+2.0 \times 10^{-12}$ C moves from $x = 0.50$ cm to $x = 3.00$ cm in this region.

(i) Using the graph in Fig. 3.1, calculate the change in potential energy of the charged particle. State the assumption you made in your calculation.

At $x = 0.50$ cm, $V = 400$ V, at $x = 3.00$ cm, $V = 100$ V,

$$\Delta U = q\Delta V$$

$$= \left(2.0 \times 10^{-12}\right)\left(100 - 300\right)$$

$$= -6.0 \times 10^{-10} \text{ J}$$

Assumption: potential in the region is unaffected by the charged particle.

change in potential energy = ... J [3]

(ii) Calculate the increase in electric potential which the $+2.0 \times 10^{-12}$ C charge particle would cause at a point 1.00 cm away from itself.

$$V = \frac{q}{4\pi\varepsilon_0 r}$$
$$= \frac{2.0\times10^{-12}}{4\pi\left(8.85\times10^{-12}\right)\left(1.00\times10^{-2}\right)}$$
$$= 1.79 \text{ V}$$

increase in electric potential = ... V [1]

(iii) From your answer in part (ii), explain if the assumption you stated in part **(i)** is reasonable.

The assumption is part (i) is reasonable as the increase in the potential by the charged particle is insignificant compared to change in potential in the region [1]

(iv) Using the graph in Fig. 3.1, calculate the electric field strength at the point $x = 0.50$ cm.

electric field strength $= -$gradient of $V - x$ graph

$$= -\frac{600-200}{0.10\times10^{-2} - 0.90\times10^{-2}}$$
$$= 50000 \text{ V m}^{-1}$$

electric field strength = ... V m^{-1} [2]

(v) Hence or otherwise, calculate the electric force experienced by the charged particle at $x = 0.50$ cm. State if it is in the direction of increasing or decreasing x.

$$F = qE$$
$$= \left(2.0\times10^{-12}\right)\left(50000\right)$$
$$= 1.0\times10^{-7} \text{ N}$$

The force is in the direction of increasing x.

electric force = ... N [1]

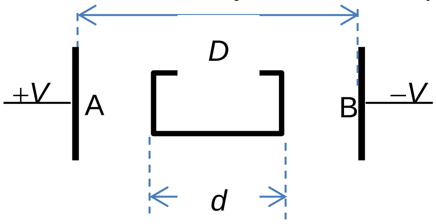
direction of force = ... [1]

[SAJC 2012]

9 **(a)** Define electric field strength E and electric potential V at a point. State the relationship between E and V.

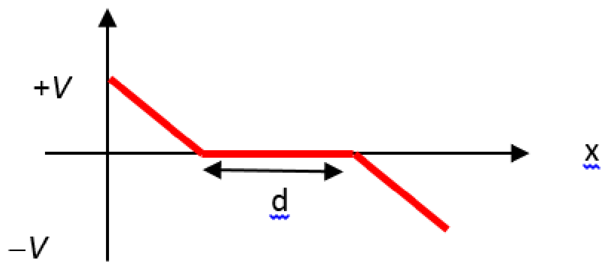
Electric field strength is defined as the force per unit positive charge. Electric potential at a point is defined as the work done per unit charge in bringing a test positive charge from infinity to the point. $E = -(dV/dr)$ [3]

(b) Two large metal plates are oppositely charged and placed a distance D apart. A conductor of thickness d is situated centrally between the plates.



Sketch graphs, one in each case, to show the variation from A to B of

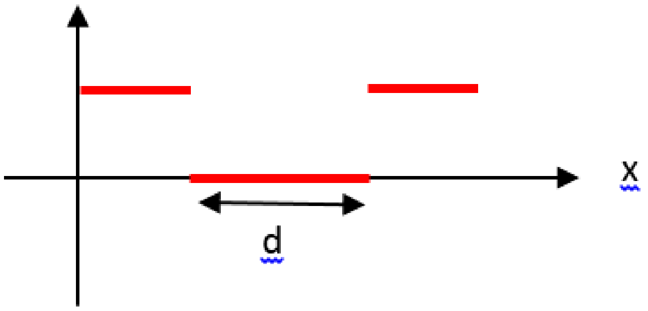
(i) the electric potential,



Slope must be the same.

[2]

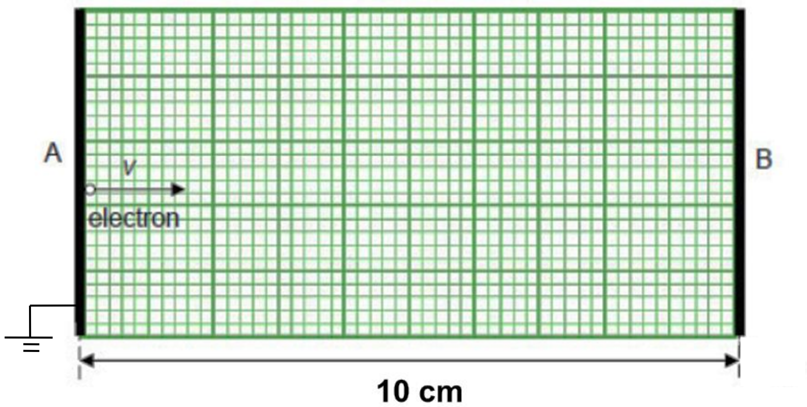
(ii) the electric field strength.



Taking (–) into consideration.

[2]
[CJC 2012]

10 The following diagram shows two large vertical plates A and B. Plate A is connected to earth. An electron is emitted perpendicularly from plate A with an initial velocity of 4.3×10^{6} m s^{-1} towards the right. In the region between the two plates, the electron experiences an electric force of 1.1×10^{-16} N towards the left.



(a) Define the electric potential at a point.

The electrical potential at a point is defined as the work done per unit charge by an external force in bringing a positive charge from infinity to that point [1]

(b) Determine the potential of plate B.

$$F = qE$$
$$= \frac{qV}{d}$$
$$V = \frac{dF}{q}$$
$$= \frac{(10\times10^{-2})(1.1\times10^{-16})}{1.60\times10^{-19}}$$
$$= 69 \text{ V}$$

Therefore potential of plate B is –69 V

potential = ... V [3]

(c) The electron comes to a stop momentarily at point P. Determine the distance between point P and plate A.

By conservation of energy,

loss in KE = work done against electron

$$\frac{1}{2}mu^2 = Fs$$
$$s = \frac{mu^2}{2F}$$
$$= \frac{(9.11\times10^{-31})(4.3\times10^{6})^2}{2(1.1\times10^{-16})}$$
$$= 0.077 \text{ m}$$

distance = ... m [2]

(d) Determine the potential at point P.

$$V_P = \left(\frac{s}{d}\right)\Delta V$$
$$= \left(\frac{0.077}{10\times10^{-2}}\right)(-69)$$
$$= -53 \text{ V}$$

potential = ... V [2]

[TPJC 2013]

11 Two small spherical charged particles P and Q may be assumed to be fixed point charges located at their centres. The particles are in a vacuum separated by 5.0 cm. An electron is moved along the line joining the two charges, as illustrated in Fig. 3.1.

Fig. 3.1

The variation with the displacement of electron from P, x of the electric potential energy E_p of the electron is shown in Fig. 3.2.

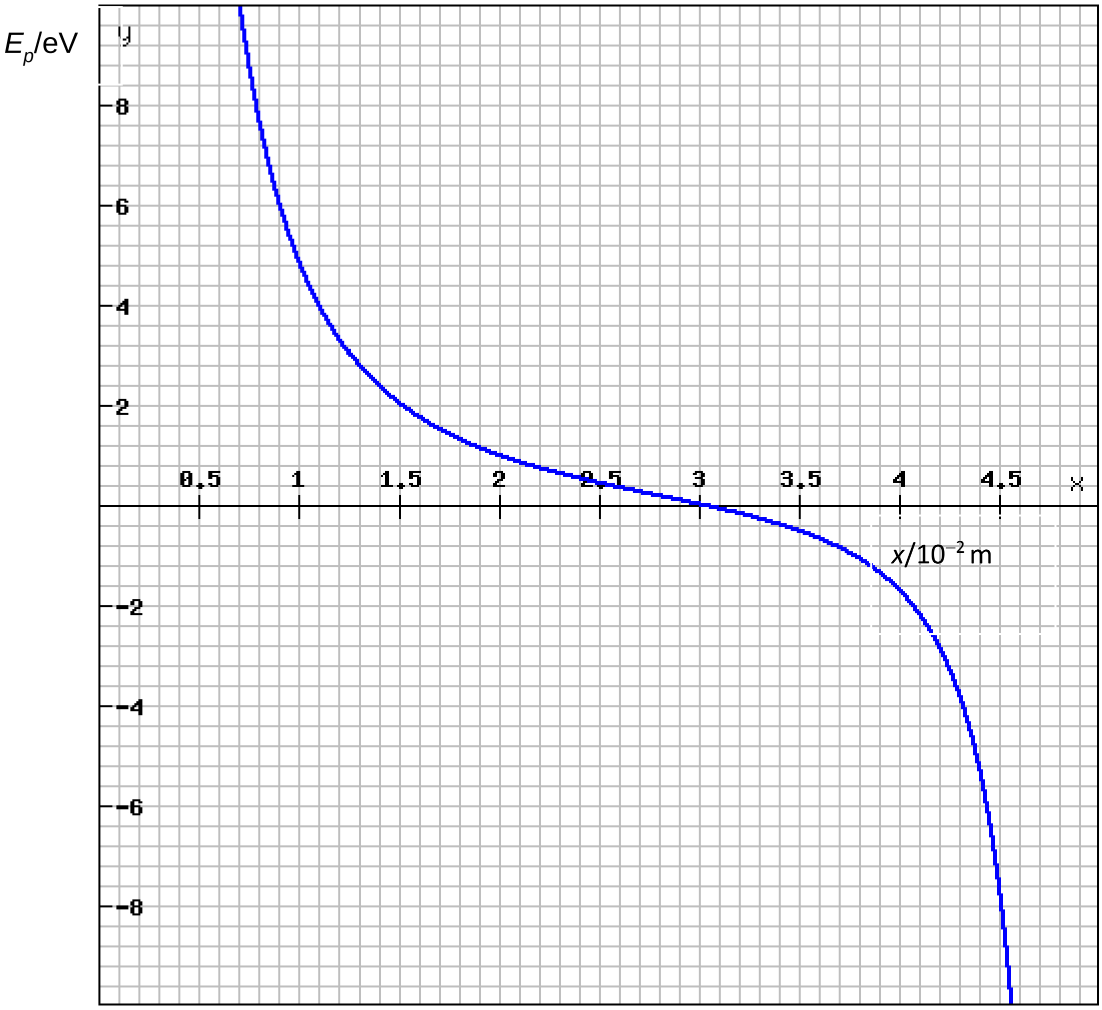


Fig. 3.2

(a) State and explain the sign of charge P and Q.

P is negatively charged and Q is positively charged. Potential energy $E_p = \dfrac{Qq}{4\pi\varepsilon_0 r}$. Since the charge of electron is negative, and the graph shows that E_p is positive when the electron is near to P, the potential of P must also be negative near P. [2]

(b) Calculate the magnitude of the force acting on the electron when it is at the point $x = 3.0$ cm.

electric force = −gradient of $E_p - x$ graph

$$= -\frac{\left[3.0-(-1.8)\right]\left(1.60\times10^{-19}\right)}{0-5.00\times10^{-2}}$$

$$= 1.5\times10^{-17} \text{ N}$$

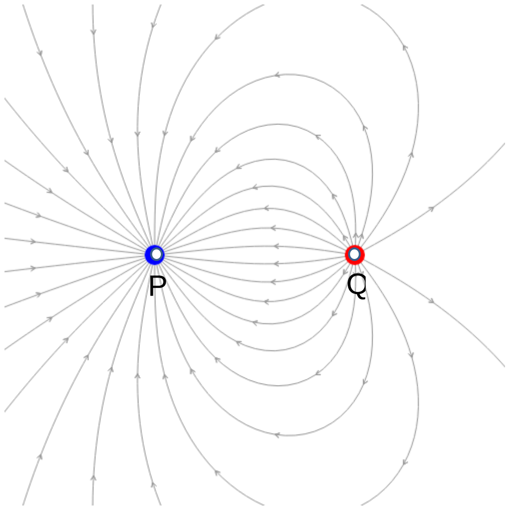
force = ... N [2]

(c) Calculate the work done to remove the electron from the point $x = 3.0$ cm to infinity.

Since at that point the potential energy is zero, the work done is zero.

work done = ... J [1]

(d) Sketch the electric field pattern in the space around P and Q.



P is larger in magnitude, with more field lines (as the field strength is not symmetrical, turning point nearer to Q). Arrows are pointing correctly.

[2]

(e) State the effect on the shape of the graph of doubling the charge on particle Q.

Values of potential near Q will be more negative for the same *x*. OR the zero potential energy point will shift towards P, occur at a smaller *x* OR the value of the gradient near Q will become steeper. [1]

[SAJC 2013]

12 Two spheres Q and R, carrying charges of −3.8 nC and +7.6 nC respectively, are placed 0.060 m apart from each other, as shown in Fig. 3.1. The diameter of the spheres is negligible compared to the distance between them.

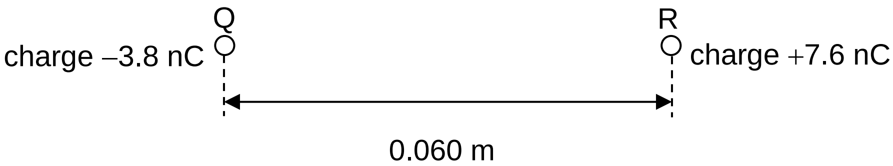
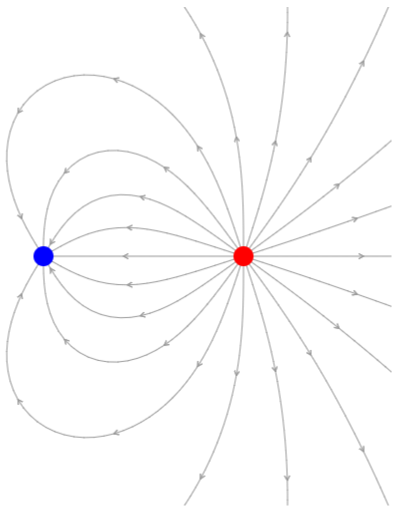


Fig. 3.1 (not drawn to scale)

(a) On Fig. 3.1, draw electric field lines to represent the electric field in the region between Q and R. [2]



(b) Deduce an expression for the potential V at an arbitrary point a distance x from Q along the horizontal line joining Q and R.

$$V = -\frac{3.8\times10^{-9}}{4\pi\varepsilon_o x} + \frac{7.6\times10^{-9}}{4\pi\varepsilon_o (0.060 - x)}$$

[1]

(c) On Fig. 3.2, sketch the variation with x of the potential V.

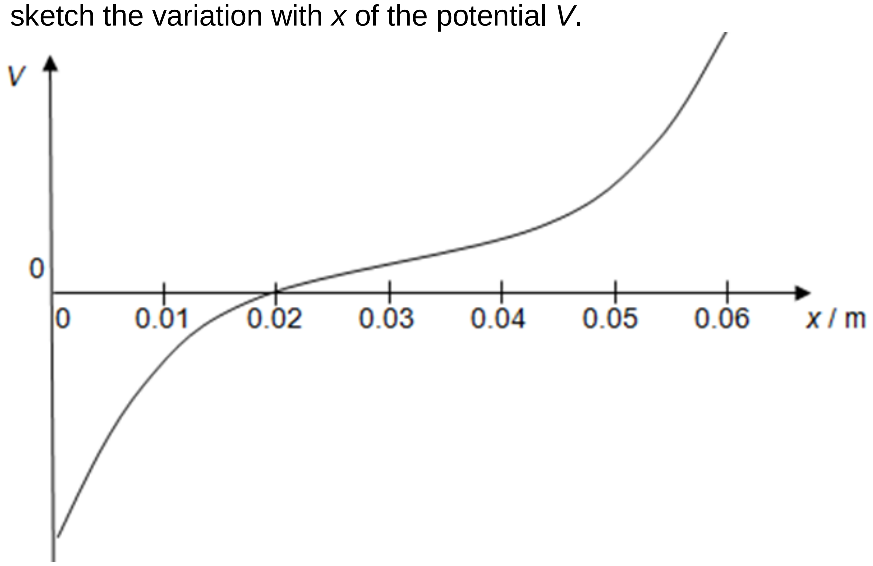


Fig. 3.2

[2]

(d) A model for the hydrogen atom consists of a proton, considered to be a point charge $+e$, at the centre of a spherical electron cloud of radius R. The charge density of the cloud is uniform, and its total charge is $-e$. The charge density is the charge divided by the volume of the space occupied by the charge.

(i) On Fig. 3.3 below, sketch graphs to show the variation with distance r from the proton, the electric fields

1. E_p due to the proton,

2. E_e due to the electron cloud.

Indicate R on the horizontal axis. Label your graphs.

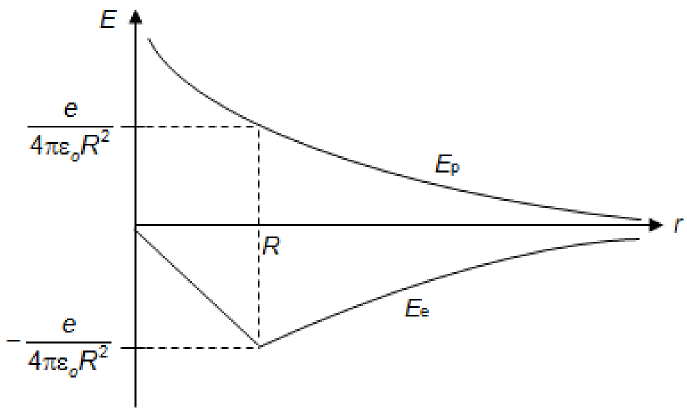


Fig. 3.3

[3]

(ii) Explain why a point charge outside the hydrogen atom experiences no electric force.

The hydrogen atom is electrically neutral hence it does not exert any electric force on an external point charge. OR Outside of the hydrogen atom, the electric fields due to the proton and electron cloud cancel each other, as they are equal in magnitude and opposite in directions. [1]

[RI 2013]

13 Fig. 2.1 is a map of equipotential lines. The potentials in the region mapped are set up by a system of small stationary charged bodies in a plane, three of which carrying charge of q_1, q_2 and q_3 are shown. All the charged bodies are fixed in their locations.
Potential values are given in volts (V). Note the signs (+/–).

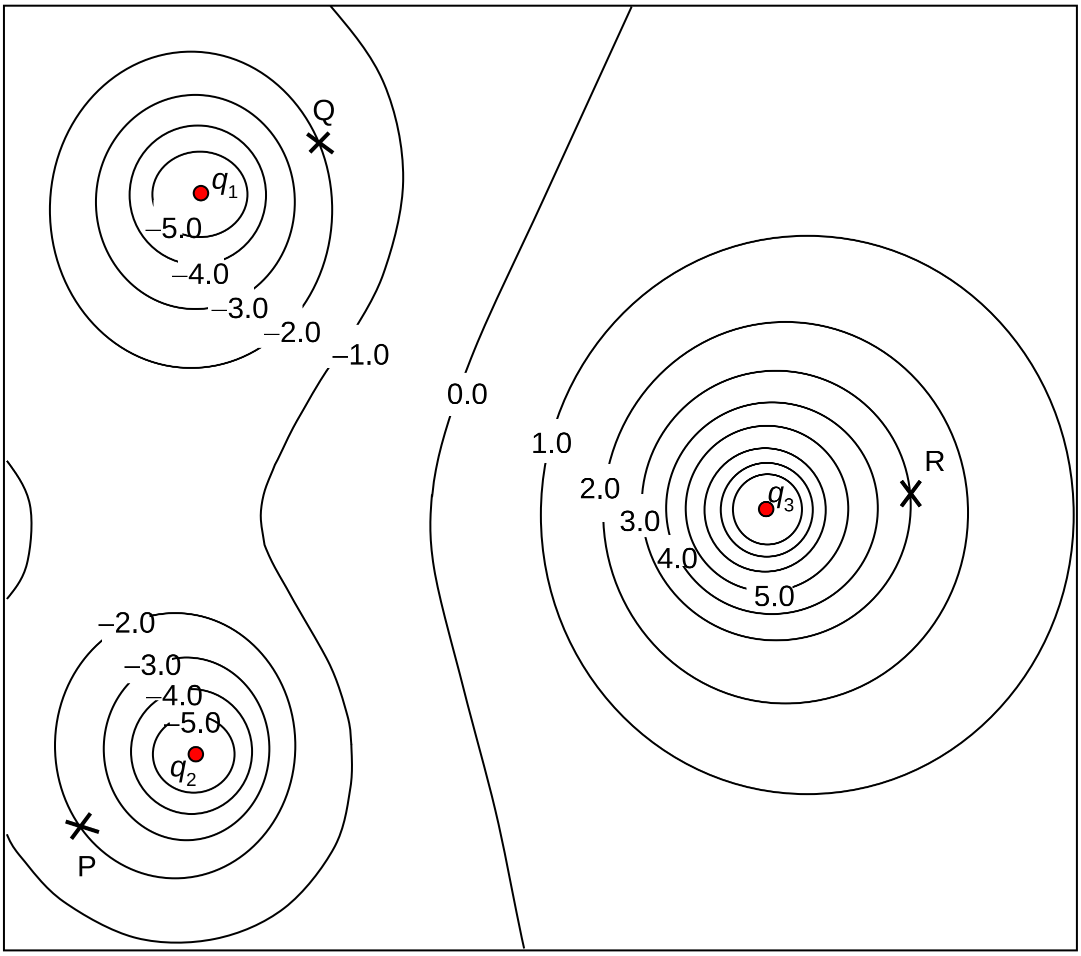


Fig. 2.1

(a) **(i)** Define the term *electric potential*.

Electric potential is the work done per unit positive charge by an external force in bringing a small charge from infinity to that point in question without a change in kinetic energy. [2]

(ii) Write down the relationship between electric field strength and electric potential.

Electric field strength at a point in the electric field is numerically equal to the potential gradient at that point, and directed towards lower potential. (no marks if direction not stated). or $E = -\frac{dV}{dr}$ .... [1]

(b) Based on Fig. 2.1, state with reasons whether the charge q_1, q_2 and q_3 are positive or negative.

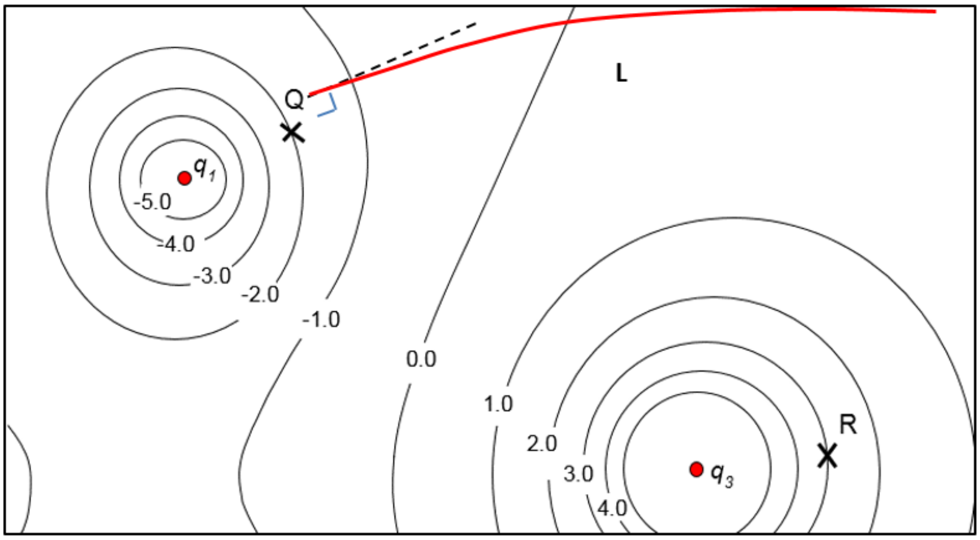
q_1, q_2 negative. Potential around them is negative and increases (gets less and less negative) with distance as one moves away from them. q_3 positive. The potential around it is positive and decreases (gets less and less positive) with distance as one moves away from it. .... [2]

(c) Calculate the net work required to move an electron from point P to point R without a gain in kinetic energy.

$$\begin{aligned} W &= \Delta U \\ &= q\Delta V \\ &= \left(-1.60\times10^{-19}\right)\left[3.0-(-2.0)\right] \\ &= -8.0\times10^{-19}\ \text{J} \end{aligned}$$

work = ... J [2]

(d) If the electron in part **(c)** is released at point Q instead, it would move under the influence of the electric force. Sketch on Fig. 2.1 a possible path that the electron could have taken. Label the path as *L*. [2]



(e) In Fig. 2.2 sketch a graph to show how the electric field strength *E* would vary along a straight line drawn between the body carrying charge q_1 to the body carrying charge q_3.

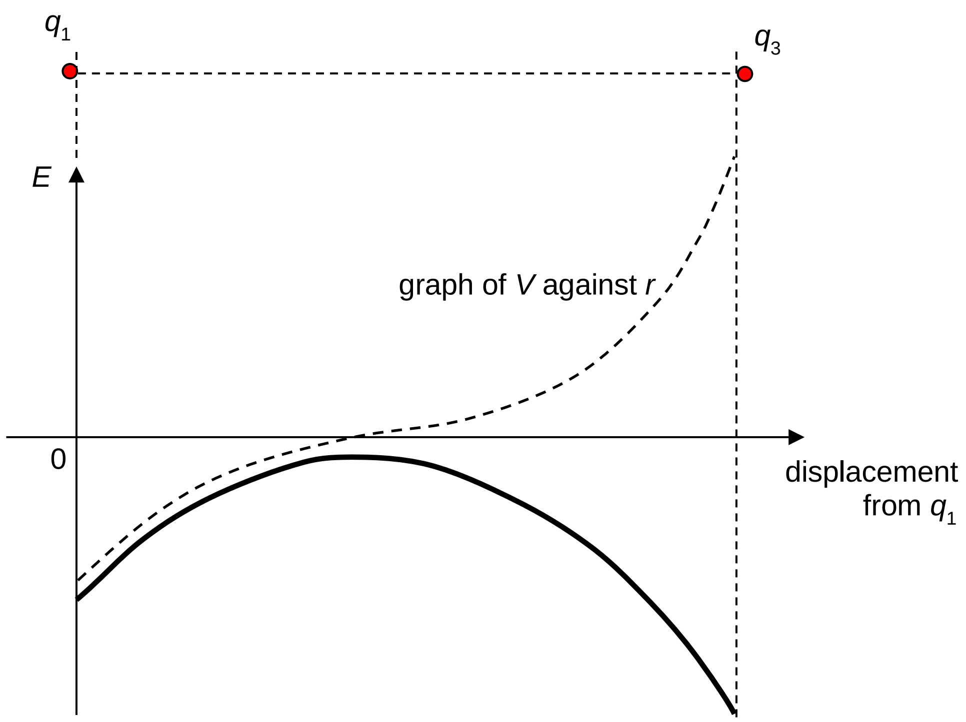


Fig. 2.2

Correct shape (having the turning point vs. the inflexion point). Negative and not touching the x-axis. Larger magnitude of E at q_3 than at q_1.

[3]
[HCI 2013]

14 The graph in Fig. 3.1 shows how the resistance of a resistor, R_1, and the resistance of a thermistor, T, change with temperature.

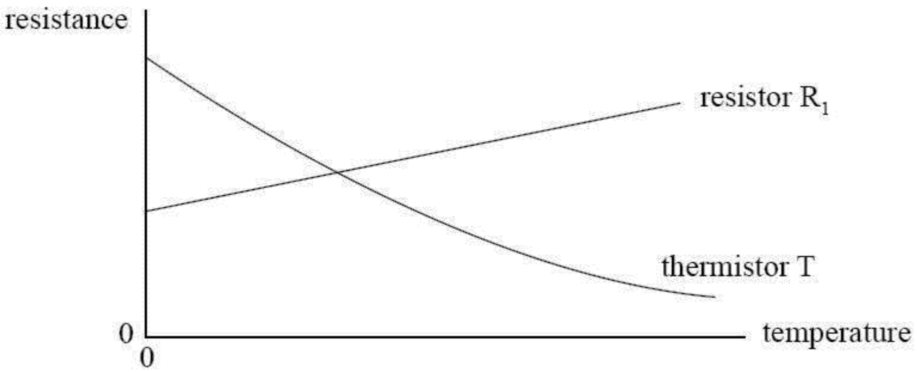


Fig. 3.1

(a) The circuit in Fig. 3.2 shows R_1 and T connected in series to a 12 V battery of negligible internal resistance.

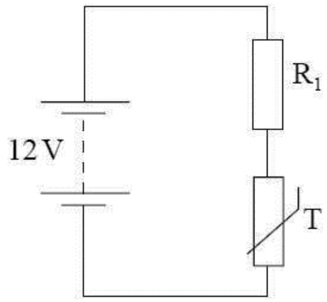


Fig. 3.2

At a certain temperature the resistance of R_1 is equal to the resistance of T. State the potential difference across R_1 and the voltage across T at this temperature.

6 V for both.

potential difference across R_1 = ... V

potential difference across T = ... V [1]

(b) A second resistor, R_2, having the same resistance as R_1 is connected in series with a switch across the thermistor, as shown in Fig. 3.3. The temperature of R_1 and T is the same as that in part (a).

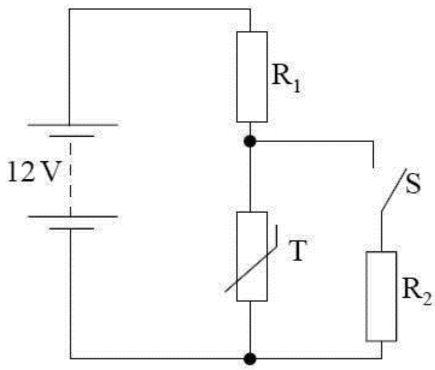


Fig. 3.3

(i) The switch S is now closed. Deduce, without calculation, whether the separate potential difference across R_1 and T will increase or decrease.

R_2 in parallel with T will result in lower resistance than T alone. Total resistance in circuit decreases. Current increases. Hence V across R_1 increases (> 6 V) and V across T decreases (< 6 V) [4]

(ii) The effect of the resistor R_2 on the potential difference across R_1 and the potential difference across T could have been obtained by changing the temperature of R_1 and T in the circuit of Fig. 3.2. State, with a reason, whether the temperature should have been decreased or increased.
Assume that the temperatures of R_1 and T are always equal to each other.

Mention that resistance of R_1 must increase and that of T decreases. Hence from Fig. 3.1, temperature increases. [2]

[ACJC 2012]

15 A network of resistors *R* is connected between the terminals of a battery of e.m.f. *E* and internal resistance *r*, as shown in Fig. 3.1.

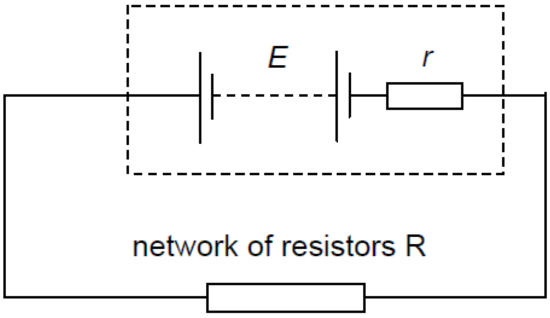


Fig. 3.1

The potential difference across *R* is *V* and the current in *R* is *I*.
The variation with potential difference *V* of the current *I* is shown in Fig. 3.2.

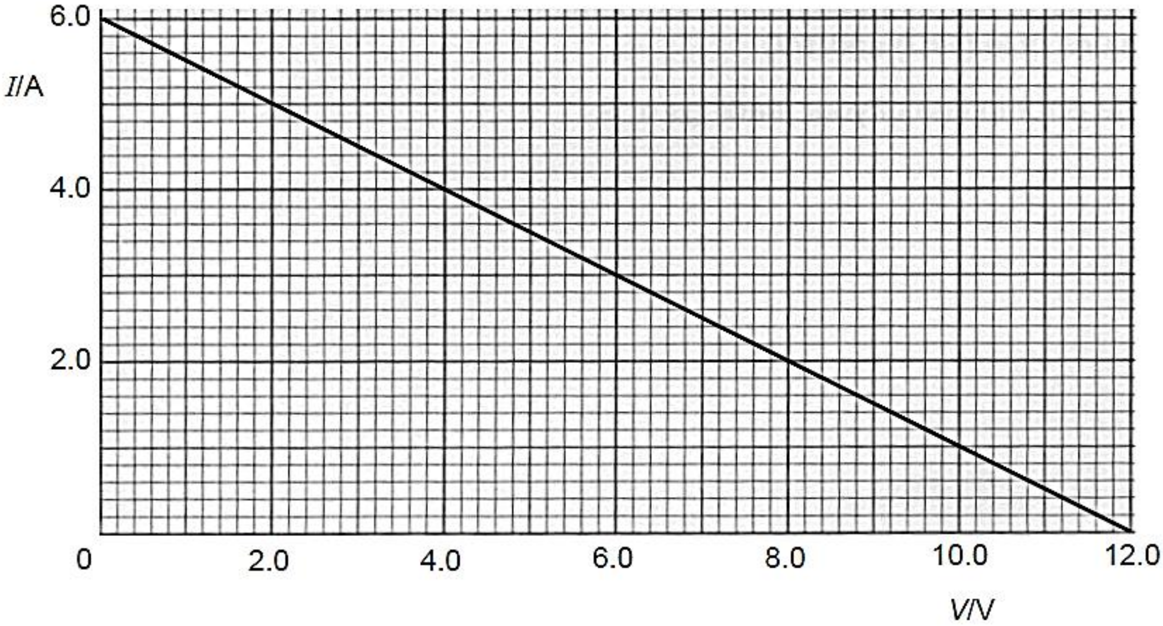


Fig. 3.2

(a) Use Fig. 3.2 to find

(i) the internal resistance of the battery

$$V = E - Ir$$

$$I = \frac{E}{r} - \frac{V}{r}$$

$$-\frac{1}{r} = m$$

$$= -\frac{6.0}{12.0}$$

$$r = 2.0\ \Omega$$

internal resistance = ... Ω [3]

(ii) the e.m.f. of the battery

$$\frac{E}{r} = y - \text{intercept}$$

$$E = 6.0(2.0)$$

$$= 12.0\ \text{V}$$

e.m.f. = ... V [1]

(b) Suppose the network of resistors *R* comprises of three resistors of resistances 2 Ω, 3 Ω and 5 Ω, and these resistors are all connected in series. Mark with an **S** on Fig. 3.2**,** the point that corresponds to the *V* and *I* values for this *R.* Show all working clearly in the space provided.

$R = 2 + 3 + 5$

$\quad = 10\ \Omega$

By potential divider rule,

$$V = \left(\frac{R}{R+r}\right)E$$

$$= \left(\frac{10}{10+2.0}\right)(12.0)$$

$$= 10\ \text{V}$$

$$V = IR$$

$$I = \frac{V}{R}$$

$$= \frac{10}{10}$$

$$= 1.0\ \text{A}$$

Label **S** at (10.0, 1.0) on graph.

Alternatively,

$V = IR$

$$I = \frac{1}{10}V$$

Draw the above line and find the intersection.

[2]

(c) If *R* is a network of resistors in parallel with each other, with the smallest resistor in the network being 1 Ω, mark with a **P** on Fig. 3.2, a possible point that represents this *R.* Explain your answer.

For resistors in parallel, the equivalent resistance is smaller than the smallest resistance in the network and should be less than 1.0 Ω. So the point should be one that gives a ratio of *V/I* less than 1.0 Ω (or equal to 1.0 Ω). Strategy: Draw a line of resistance 1.0 Ω on the graph and it intersects the original graph at (4.0, 4.0). Any point above this point will yield a resistance less than 1.0 Ω. [2]

(d) Fig. 3.3 shows two possible experimental setups that can be used to measure the resistance of a resistor *R*.

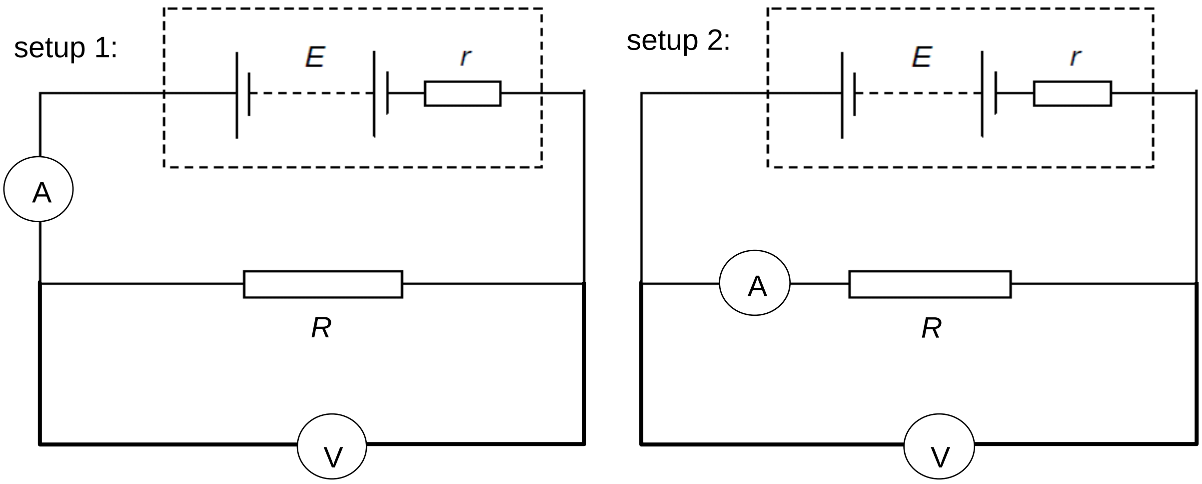


Fig. 3.3

Explain why setup 2 is preferred to setup 1 in determining *R*, if it is known that the resistance of *R* is comparable to the resistance of the voltmeter and much larger than the resistance of the ammeter.

In setup 1, the voltmeter V having a resistance comparable to R will draw a comparable current as compared to the current through R. Since, the ammeter measures both the current of through voltmeter and R, this current will be significantly different from the current through R. For setup 2, although the voltmeter is measuring the potential difference for both the ammeter and resistor, the potential difference across the ammeter is small compared to the potential difference across R, as its resistance is very small compared to R. Hence, the voltmeter reading will be close to p.d. across R and hence the results will have less error. [2]

[HCI 2012]

16 The variation with temperature of the resistance R_T of a thermistor is shown in Fig. 4.1.

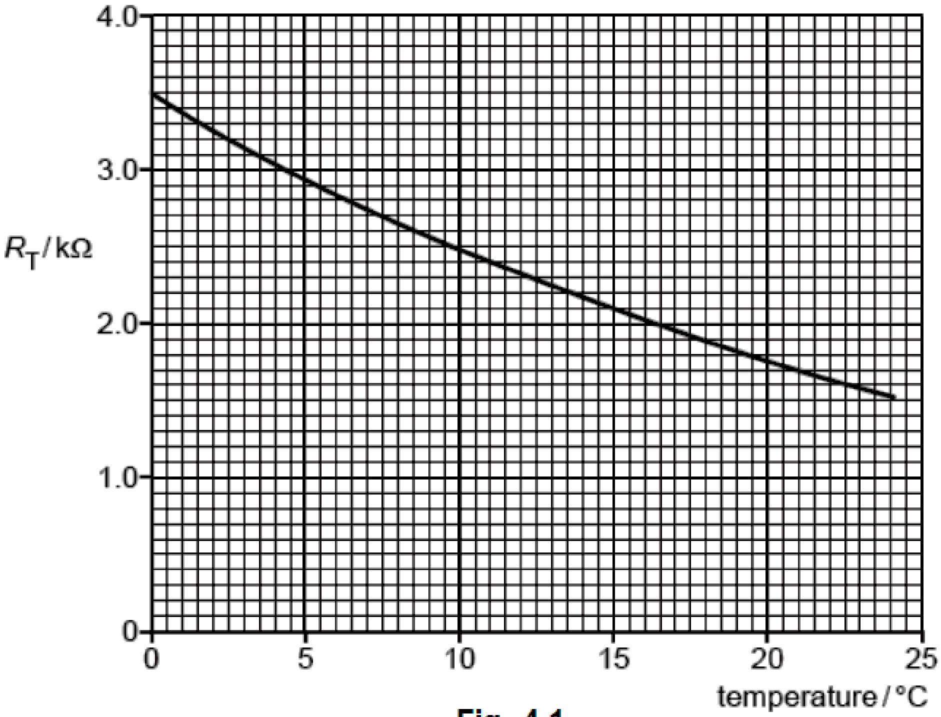


Fig. 4.1

The thermistor is connected in series with a resistor *R* as shown in the circuit in Fig. 4.2.

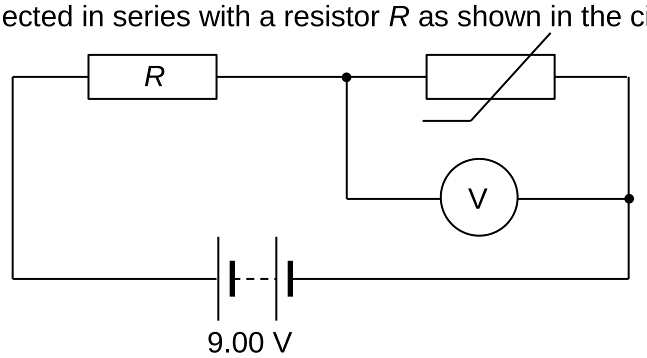


Fig. 4.2

The battery has e.m.f. 9.00 V and negligible internal resistance. The voltmeter has infinite resistance.

(a) For the thermistor at 22.5 °C, the voltmeter reading is 2.70 V. Determine the resistance of resistor *R*.

At 22.5 °C, R_T =1600 Ω, by potential divider rule,

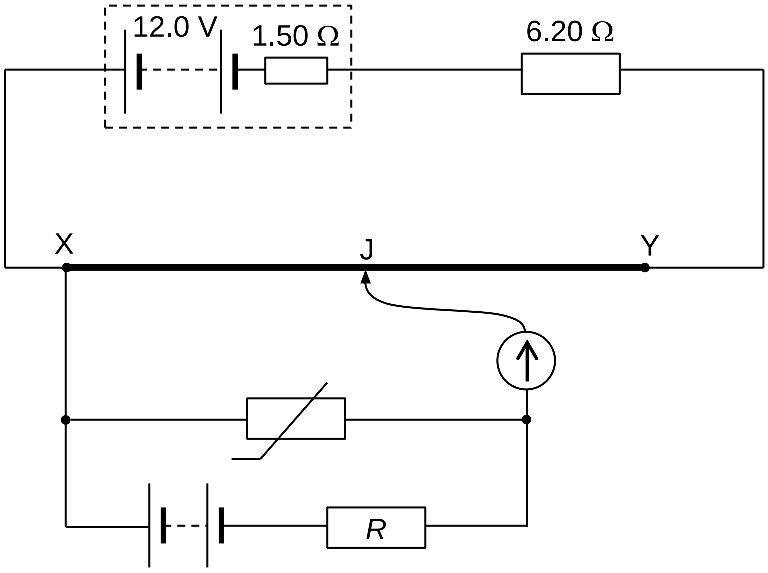
$$V = \left(\frac{R_T}{R + R_T}\right)E$$

$$2.70 = \left(\frac{1600}{R + 1600}\right)(9.00)$$

$$R = 3730\ \Omega$$

resistance of *R* = ... Ω [3]

(b) The voltmeter is now removed from the original circuit and the rest of the circuit is connected to a potentiometer as shown in Fig. 4.3.



The potentiometer has a driver cell of e.m.f. 12.0 V with internal resistance of 1.50 Ω. It is connected in series with a resistor of resistance 6.20 Ω and a uniform resistance wire XY, of length 120 cm and radius 0.250 mm. The resistivity of the wire is 1.10×10^{-6} Ω m.

(i) Determine the resistance of the wire XY.

$$R_{XY} = \frac{\rho l}{A}$$

$$= \frac{(1.10\times10^{-6})(120\times10^{-2})}{\pi(0.250\times10^{-3})^2}$$

$$= 6.72\ \Omega$$

resistance of wire XY = ... Ω [2]

(ii) For the thermistor at 22.5 °C, determine the balance length XJ where there is no deflection in the galvanometer.

$$V_{XY} = \left(\frac{R_{XY}}{R_{XY} + R + r}\right)E$$
$$= \left(\frac{6.72}{6.72 + 6.20 + 1.50}\right)(12.0)$$
$$= 5.59 \text{ V}$$

$$V_{XJ} = \left(\frac{l_{XJ}}{l_{XY}}\right)V_{XY}$$
$$l_{XJ} = \left(\frac{V_{XJ}}{V_{XY}}\right)l_{XY}$$
$$= \left(\frac{2.70}{5.59}\right)(120 \times 10^{-2})$$
$$= 0.579 \text{ m}$$

balance length XJ = ... m [2]

(iii) Explain what will happen to the position of the balance point J if the thermistor is at a temperature of 0 °C.

When the thermistor is placed at a temperature of 0 °C, the resistance of thermistor increases and hence the p.d. across thermistor will increase. As such, the balance point J will be closer to Y. [1]

[AJC 2012]

17 **(a)** Define *potential difference*.

Potential difference is the amount of electrical energy changed to other forms of energy per unit charge flowing between two points/through an electrical component. [1]

(b) A thermistor is connected in a potential divider circuit as shown in Fig. 2.1. This circuit is used to activate an alarm system whenever the ambient temperature rises to a certain value. The alarm bell will sound if the potential difference across it increases beyond the pre-set value.

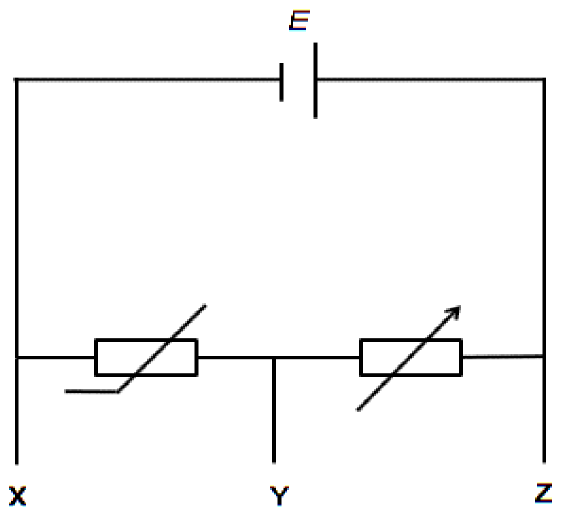


Fig. 2.1

(i) State and explain how the alarm bell should be connected to the circuit in Fig. 2.1.

As the temperature increases, the resistance of the thermistor decreases and hence, the potential difference XY across the thermistor decreases. This leads to the potential difference across YZ to increase and hence the alarm bell should be connected across YZ, i.e. connected in parallel to the variable resistor. [3]

(ii) Explain the purpose of the variable resistor in the circuit.

As the temperature increases, the resistance of the thermistor decreases and hence, the potential difference XY across the thermistor decreases. This leads to the potential difference across YZ to increase and hence the alarm bell should be connected across YZ, i.e. connected in parallel to the variable resistor. [2]

(c) Fig. 2.2 shows a potentiometer circuit. The length of the potentiometer wire AB is 100 cm and the e.m.f. of the driver cell is E_1. The internal resistance r of the cell in the lower circuit is 0.5 Ω. The balance length AC is found to be 60 cm when the resistance of the rheostat, $R_{variable}$, is set to 10.0 Ω.

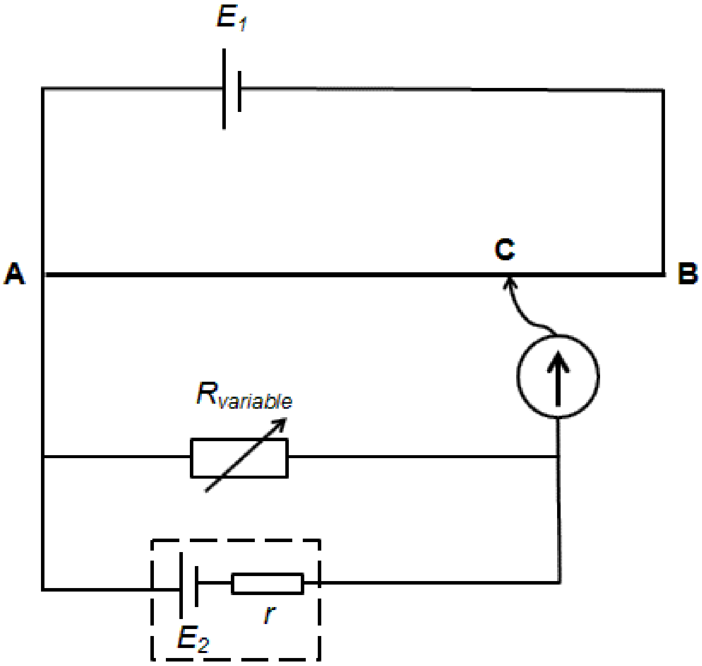


Fig. 2.2

(i) Show that the ratio $\dfrac{E_1}{E_2} = 1.59$.

$$\frac{V_{AC}}{V_{AB}} = \frac{l_{AC}}{l_{AB}}$$

$$\frac{V_{AC}}{E_1} = \frac{60}{100}$$

$$V_{AC} = \frac{3}{5}E_1 \quad \ldots \quad (1)$$

$$V_{AC} = \left(\frac{R}{R+r}\right)E_2$$

$$= \left(\frac{10.0}{10.0+0.5}\right)E_2$$

$$= \frac{20}{21}E_2 \quad \ldots \quad (2)$$

Equating (1) and (2),

$$\frac{3}{5}E_1 = \frac{20}{21}E_2$$

$$\frac{E_1}{E_2} = \frac{100}{63}$$

$$= 1.59 \ (\text{shown})$$

[3]

(ii) Find the new balance length when the resistance of the rheostat is decreased to 3.0 Ω.

$$V_{AC}' = \left(\frac{R'}{R'+r}\right)E_2$$
$$= \left(\frac{3.0}{3.0+0.5}\right)E_2$$
$$= \frac{6}{7}E_2 \quad ... \quad (3)$$

$$\frac{V_{AC}'}{V_{AB}} = \frac{I_{AC}'}{I_{AB}}$$
$$V_{AC}' = \left(\frac{I_{AC}'}{I_{AB}}\right)V_{AB}$$
$$= \left(\frac{I_{AC}'}{100}\right)E_1 \quad ... \quad (4)$$

Equating (3) and (4),

$$\frac{6}{7}E_2 = \left(\frac{I_{AC}'}{100}\right)E_1$$
$$I_{AC}' = \frac{600E_2}{7E_1}$$
$$= \left(\frac{600}{7}\right)\left(\frac{63}{100}\right)$$
$$= 54 \text{ cm}$$

new balance length = ... cm [2]

[CJC 2012]

18 **(a)** Explain what is meant by the *ohm*.

The ohm is the SI unit for resistance and one ohm is defined as the resistance of a conductor through which a current of one ampere flows when the potential difference across it is one volt. [1]

(b) Fig. 3.1 shows a circuit connecting a cable wire, a resistor *r* and 2 switches.

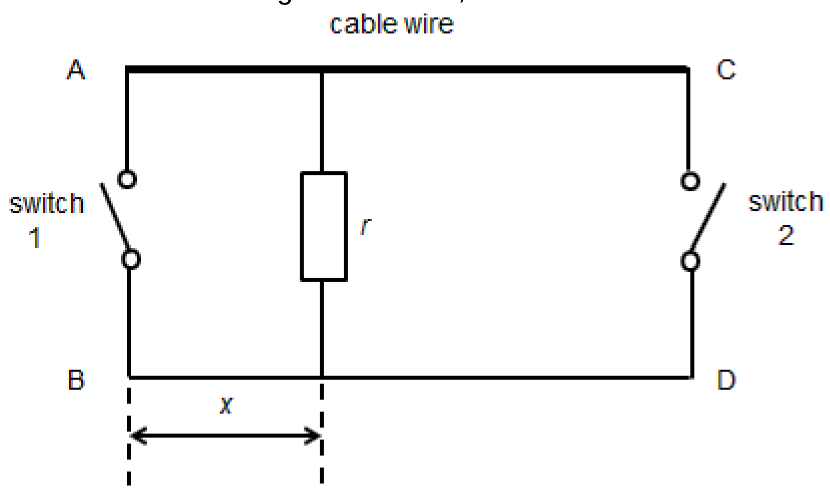


Fig. 3.1 (not to scale)

The cable wire is 7 km long and has a uniform resistance *R* across its entire length. A resistor *r* is placed *x* km away from switch 1.

Fig. 3.2 shows a table of the resistance measured across the points in different situations.

resistance across AB/Ω	resistance across CD/Ω	switch 1	switch 2
–	70	open	closed
64	–	closed	open

Fig. 3.2

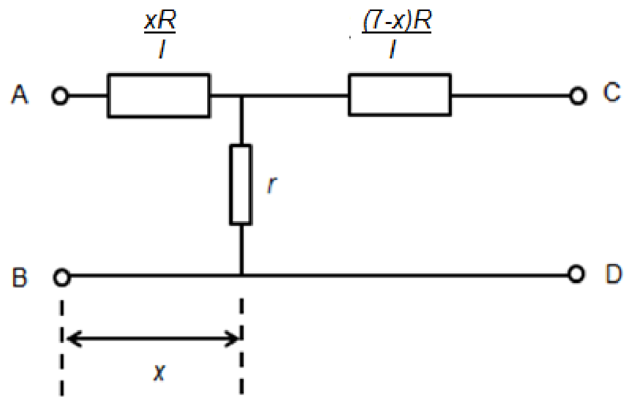
With both switches 1 and 2 opened, an e.m.f. source of 16 V is connected across AB and the potential difference across the resistor *r* is measured to be 15 V.

Assume that the resistance of the connecting wires is negligible.

(i) Determine the resistance of the resistor *r*.

Let *l* be the entire length of wire AC.

Redrawing the circuit (with switch 1 and 2 opened):



Now with switch 1 closed and switch 2 opened:

$$R_{AB} = \frac{xR}{l} + r$$

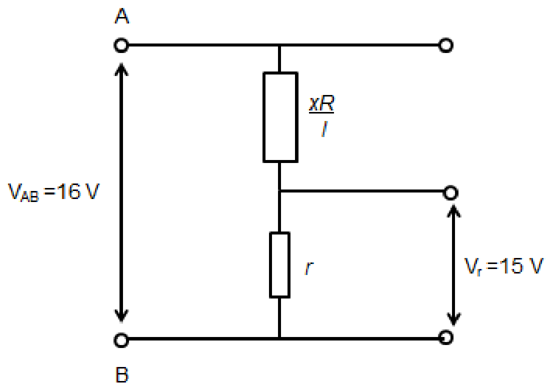
$$64l = xR + rl \quad ... \quad (1)$$

With switch 1 opened and switch 2 closed:

$$R_{CD} = \frac{(7-x)R}{l} + r$$

$$70l = (7-x)R + rl \quad ... \quad (2)$$

When an e.m.f. source of 16 V is connected across AB with both switch 1 and 2 opened:



Using potential divider principle,

$$V_r = \left(\frac{r}{r + \frac{xR}{l}} \right) V_{AB}$$

$$15 = \left(\frac{r}{r + \frac{xR}{l}} \right) (16)$$

$$15rl + 15xR = 16rl$$

$$15xR = rl \quad ... \quad (3)$$

Substitute (3) into (1),

$$64I = xR + 15xR$$
$$= 16xR$$
$$4I = xR \quad ... \quad (4)$$

Substitute (4) into (3),

$$15(4I) = rI$$
$$r = 60.0\ \Omega$$

resistance r = ... Ω [5]

(ii) Determine the distance x where the resistor is being connected to the cable wire.

Substitute $r = 60.0\ \Omega$ and (4) into equation (2),

$$70I = 7R - 4I + 60I$$
$$\frac{R}{I} = 2$$

From (4),

$$x = \frac{4I}{R}$$
$$= \frac{4}{2}$$
$$= 2.00 \text{ km}$$

x = ... km [3]

(iii) Determine the power dissipated by resistor r when 16 V is applied across AB.

$$P = \frac{V_r^{\,2}}{r}$$
$$= \frac{15^2}{60.0}$$
$$= 3.75 \text{ W}$$

power dissipated = ... W [1]

[CJC 2012]

19 A circuit contains three identical lamps A, B and C and three switches, S_1, S_2 and S_3, as shown in Fig. 3.1.

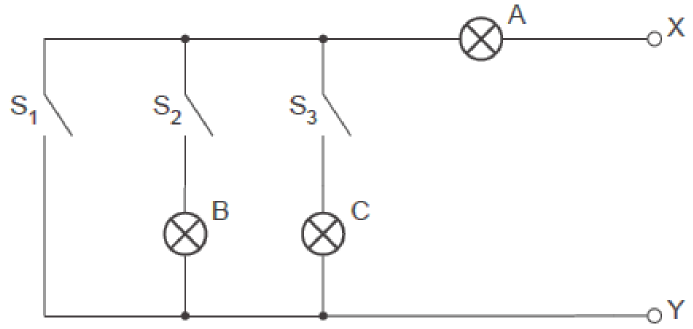


Fig. 3.1

One of the lamps is faulty. In order to detect the fault, an ohm-meter is connected between terminals X and Y. When measuring resistance, the ohm-meter causes negligible current in the circuit. Fig. 3.2 shows the readings of the ohm-meter for different switch positions.

switch			meter reading/Ω
S_1	S_2	S_3	
open	open	open	∞
closed	open	open	15
open	closed	open	30
open	closed	closed	15

Fig. 3.2

(a) Identify the faulty lamp, and the nature of the fault.

faulty lamp: lamp C

nature of fault: lamp is shorted/fused [2]

(b) Suggest why it is advisable to test the circuit using an ohm-meter that causes negligible current rather than with a power supply.

Shorted lamp A would cause damage to the supply/lamps/blow fuse in supply [1]

(c) Determine the resistance of one of the non-faulty lamps.

15 Ω

resistance = ... Ω [1]

(d) Each lamp is marked 6.0 V, 0.20 A. Calculate the resistance for one of the lamps operating at normal brightness.

$V = IR$

$R = \dfrac{V}{I}$

$= 30\ \Omega$

resistance = ... Ω [1]

(e) Explain why the resistance values in **(c)** and **(d)** are different.

Resistance of metal filament increases with temperature. When operating at normal brightness, filament is hot so resistance is higher [2]

[TJC 2012]

20 (a) A light dependent resistor (LDR) is one whose resistance varies with light intensity.

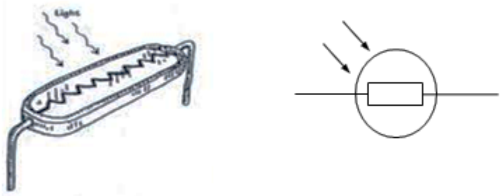


Fig. 2.1 shows a simple circuit with an LDR. The LDR is connected in series with a fixed e.m.f source *V* and fixed resistor *R*.

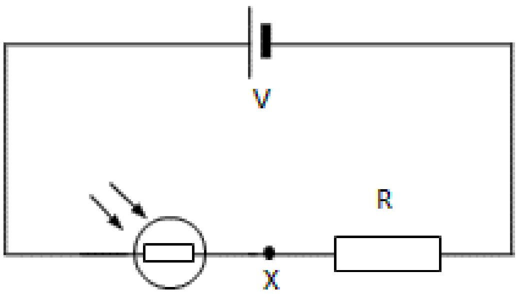


Fig. 2.1

When the intensity of incident light on the LDR increases, the potential at point X increases. State how the resistance of an LDR changes with brightness

Resistance of an LDR decreases with increasing brightness [1]

(b) Fig. 2.2 shows a circuit in which an LDR is used as a sensor. Point Y is connected to a lighting system. When the potential at Y is greater or equal to 11.5 V, the lighting system is switched on.

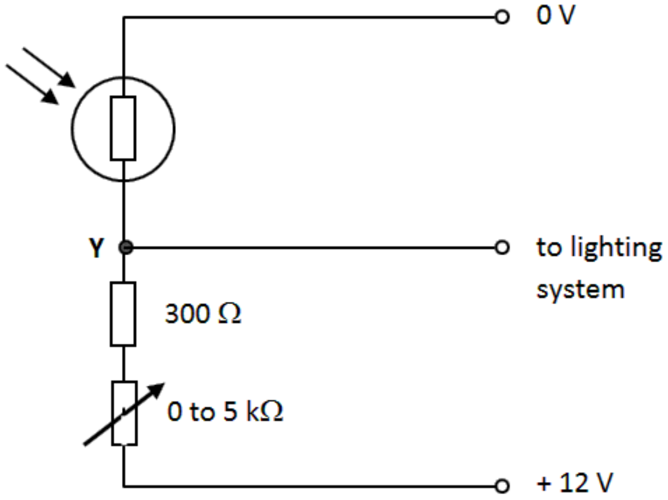


Fig. 2.2

(i) On a dull day, the resistance of the LDR is 500 kΩ, and the variable resistor is set to maximum resistance. Determine, with calculations, whether the lighting system will be switched on.

$$V_Y = \left(\frac{500000}{500000+300+5000}\right)(12)$$

$$= 11.9 \text{ V}$$

So lighting system will be switched on.

[3]

(ii) Calculate the resistance of the LDR when the lighting system first switches on, assuming that the variable resistor is set to maximum resistance.

$$V = \left(\frac{R_L}{R_L + r + R}\right)E$$

$$11.5 = \left(\frac{R_L}{R_L + 300 + 5000}\right)(12)$$

$$R_L = 122 \text{ k}\Omega$$

resistance = ... Ω [2]

(iii) Suggest why the variable resistor is included in the circuit.

The variable resistor allows for manual adjustment of the potential at Y, allowing for manual activation of the lighting system. [1]

(d) A modification can be made to the circuit in Fig. 2.2 so that it could be used to activate an air-cooling system, when the temperature gets too high. Suggest the modification that needs to be made.

Changing the LDR with a thermistor / thermostat [1]

[TPJC 2012]

21 In a metallic conductor, conduction electrons do not travel in a straight line through the conductor.

Fig. 5.1 shows some of the conduction electrons in a copper wire. The arrows represent the velocities of these electrons.

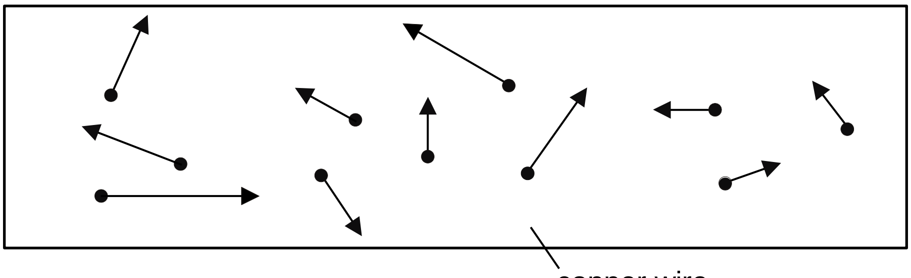


Fig. 5.1

Fig. 5.1 shows some of the conduction electrons in a copper wire. The arrows represent the velocities of these electrons.

(a) Explain, by reference to the motion of the electrons, why there is no current in the wire.

On the average as much mobile electrons move in one direction as in the opposite direction. Thus there is no net transfer of electric charge in any direction. OR The velocities of electrons are in random directions, which implies no net motion in any direction, hence no transfer of charge. [2]

(b) An electric field is established inside the copper wire directed as shown in Fig. 5.2. The dots represent electrons. The velocities of the electrons are not shown.
The average velocity that an electron travels along the conductor is called the drift velocity. Draw on Fig. 5.2 an arrow to indicate the direction of the drift velocity of the electrons.

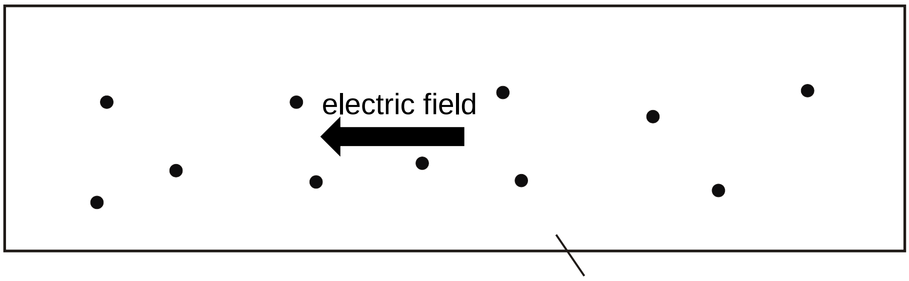


Fig. 5.2

[1]

(c) Electric current is related to drift velocity by the equation $I = nevA$ where
I : current
v : drift velocity
A : cross-sectional area of the conductor
n : charge density (the number of mobile electrons per unit volume)
e : electronic charge
In the circuit in Fig. 5.3, the length of the copper wire joining the negative terminal of the battery to the lamp is 0.50 m and has a radius of 0.40 mm. There are 8.5×10^{28} mobile electrons per cubic metre in copper.

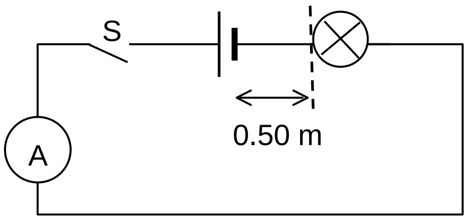


Fig. 5.3

(i) When the switch S is closed, the ammeter reads 2.0 A. Calculate the average time it would take for an electron to move from the negative terminal of the battery to the lamp.

$I = nevA$

$$v = \frac{I}{neA}$$

$$= \frac{2.0}{(8.5\times10^{28})(1.60\times10^{-19})\pi(0.40\times10^{-3})^2}$$

$$= 2.9\times10^{-4}\ \text{m s}^{-1}$$

$$t = \frac{d}{v}$$

$$= \frac{0.50}{2.9\times10^{-4}}$$

$$= 1700\ \text{s}$$

average time = ... s [2]

(ii) The lamp lights up in a time much less than that calculated in **(c)(i)**. Explain this observation.

All mobile electrons in the circuit start drifting at the same time/the electric field is established in the wire almost instantaneously. The lamp will light as soon as the mobile electrons already in the lamp filament begin to move [2]

(iii) The circuit is now connected with two copper wires of different thickness as shown in Fig. 5.4.

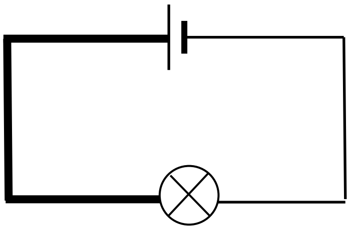


Fig. 5.4

Suggest and explain whether the drift velocity of electrons in the thicker wire is smaller than, equal to, or larger than that in the thinner wire.

Current, charge density and charge are the same in both wires. Cross-sectional area is larger for thicker wire. Hence drift velocity is smaller in the thicker wire. Alternatively, since the current in the circuit is the same, the thicker wire having a larger cross-sectional area, has greater number of electrons per unit length, since the charge density is the same for the same metal. Thus it should have a lower drift velocity to keep the number of electrons passing through a point per unit time (i.e. the current) constant. [3]

[HC1 2013]

22 **(a)** Define electrical resistance.

The electrical resistance of a circuit component or device is defined as the ratio of the potential difference across it to the current flowing through it [1]

(b) Fig. 2.1 shows a circuit designed to monitor the speed of rotation of a small fan.

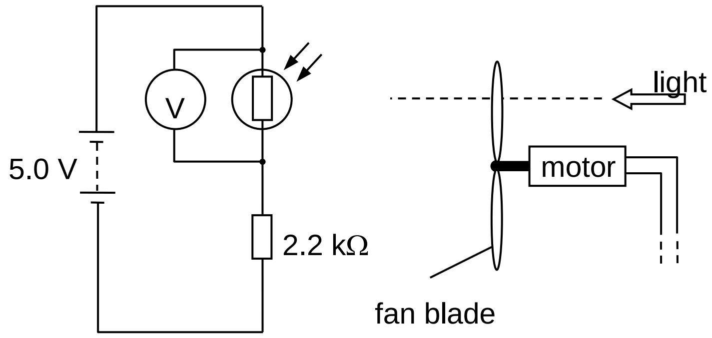


Fig. 2.1

The battery has negligible internal resistance. The output voltage *V* from the circuit is equal to the potential difference across the light-dependent resistor (LDR). Fig. 2.2 shows the variation of the output voltage *V* with the time *t*.

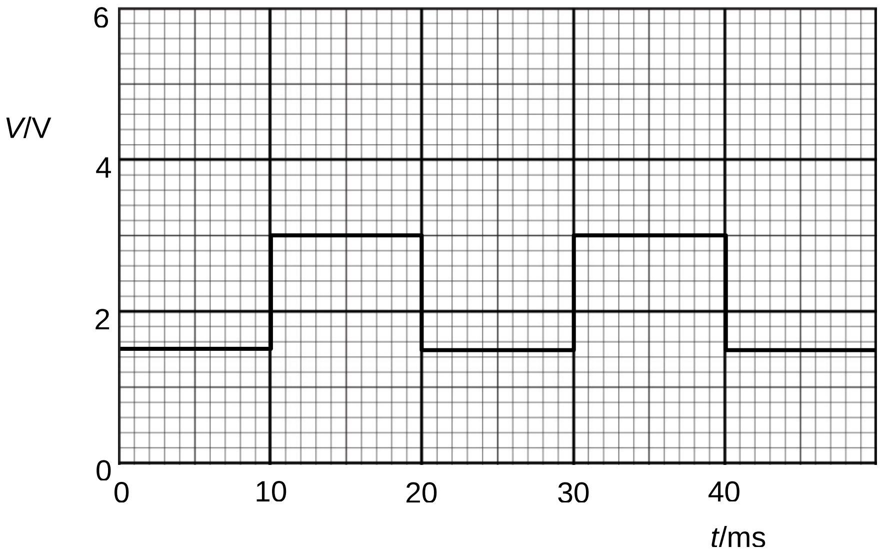


Fig. 2.2

(i) Explain why the graph of Fig. 2.2 shows two levels of output voltage.

Resistance of LDR changes as light intensity changes The resistance of LDR increases to a high value when blade blocks light, and the resistance decreases to a low value when light is not blocked. The resistance of LDR alternates between two values. Hence, the p.d. across the LDR will alternate (between two values).[3]

(ii) For the **maximum** value for the output voltage *V*, calculate

1. potential difference across the 2.2 kΩ resistor.

From graph, maximum p.d. across LDR is 3 .0 V.

$V = E - V_{LDR}$

$= 5.0 - 3.0$

$= 2.0$ V

potential difference = ... V [1]

2. resistance of the LDR.

$$V_{LDR} = \left(\frac{R_{LDR}}{R_{LDR} + R}\right)E$$

$$3.0 = \left(\frac{R_{LDR}}{R + 2.2 \times 10^3}\right)(5.0)$$

$$R_{LDR} = 3300\ \Omega$$

resistance = ... Ω [2]

[AJC 2013]

23 (a) (i) Define *internal energy* of a thermodynamic system.

It is the sum of random distribution of kinetic energy and potential energy of all the molecules that made up the system. [2]

(ii) Fig. 8.1 below shows a container containing two ideal gas atoms each of mass *m* and travelling at a speed v_i relative to the container and in opposite directions. The container is in an aircraft travelling at speed *u*.

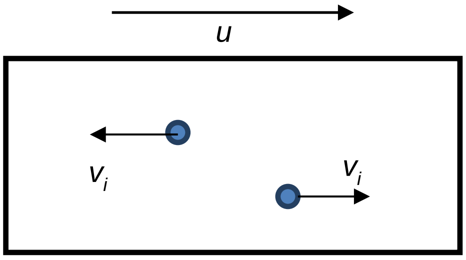


Fig. 8.1

1. Show that the total kinetic energy, E_K of the two gas atoms, taking into account the motion of the container, in terms of *m, u and* v_i is given by the expression $E_K = mu^2 + mv_i^2$.

$$E_K = \frac{1}{2}m(v_i - u)^2 + \frac{1}{2}m(v_i + u)^2$$

$$= \left(\frac{1}{2}mv_i^2 - muv_i + \frac{1}{2}mu^2\right) - \left(\frac{1}{2}mv_i^2 + muv_i + \frac{1}{2}mu^2\right)$$

$$= mu^2 + mv_i^2 \quad (\text{shown})$$

[2]

2. Hence or otherwise, write down an expression for the internal energy of the gas (assuming that the gas consists of only 2 atoms) in terms of *m*, v_i and/or *u*.

$$U = mv_i^2$$

[1]

(b) Fig. 8.2 below shows a helium atom of mass 6.8×10^{-27} kg about to strike the wall of a container. It rebounds with the same speed and in the opposite direction.

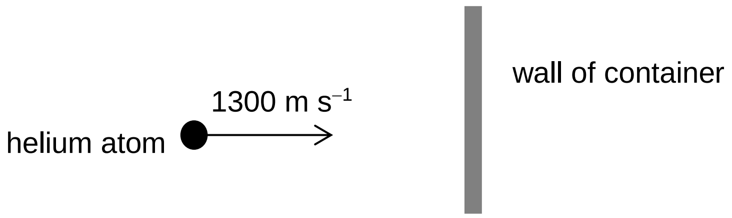


Fig. 8.2

(i) Calculate the change in momentum of the helium atom.

$\Delta p = m\Delta v$

$= (6.8\times10^{-27})[1300-(-1300)]$

$= 1.77\times10^{-23}$ N s

change in momentum = ... N s [2]

(ii) Calculate the number of collisions per second on each cm^2 of the container wall that will produce a pressure of 1.5×10^5 Pa

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

$F = pA$

$= (1.5\times10^5)(10^{-4})$

$= 15$ N

$F = \dfrac{N\Delta p}{t}$

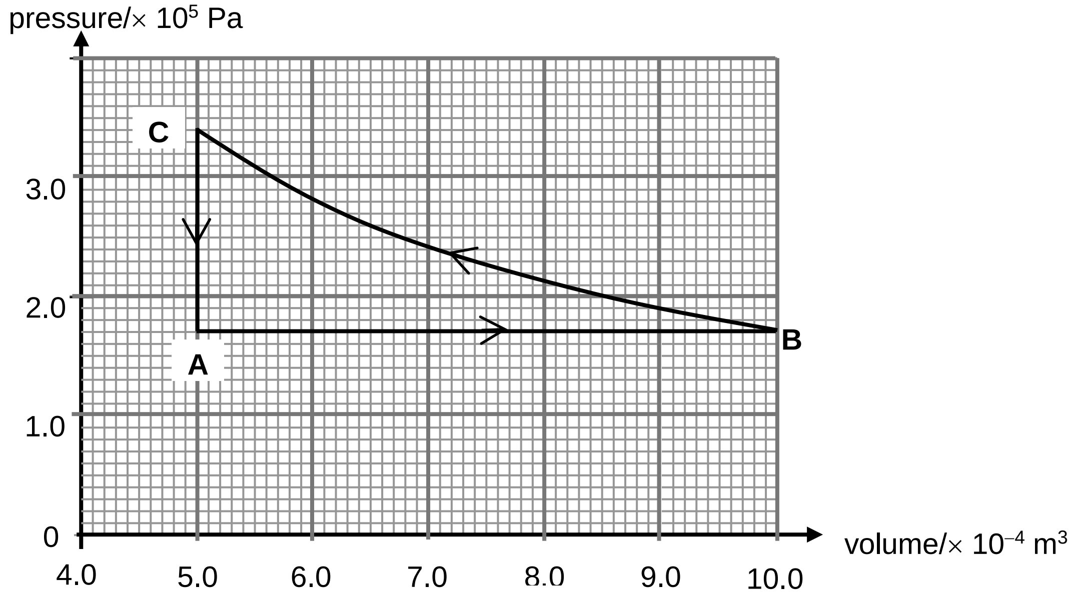
$\dfrac{N}{t} = \dfrac{F}{\Delta p}$

$= \dfrac{15}{1.77\times10^{-23}}$

$= 8.48\times10^{23}$ s^{-1}

number of collisions per second = ... s^{-1} [3]

(c) A fixed mass of ideal gas is made to undergo the following processes as shown in Fig. 8.3 below:



(i) Use data from Fig. 8.3 to confirm that process **BC** is isothermal. Show your working.

$pV = 170$ J evaluated correctly for 3 readings taken correctly from graph. Conclude that since pV values are the same (or some slight variation) hence it is isothermal (or not isothermal).

[3]

(ii) State and explain how you would attempt to ensure experimentally that the process **BC** is isothermal.

Process must be carried out (infinitely) slowly OR container must be a good conductor of heat so as to allow time for heat to enter into/exit from the system.[2]

(iii) The temperature of the gas at **C** is 385 K. Calculate the temperature of the gas at **A**.

$$\frac{p_A}{T_A} = \frac{p_C}{T_C}$$

$$T_A = \left(\frac{p_A}{p_C}\right)T_C$$

$$= \left(\frac{1.70}{3.40}\right)(385)$$

$$= 193 \text{ K}$$

temperature at A = ... K [2]

(iv) During the process **AB**, 213 J of energy is supplied by heating the gas. Calculate the increase in internal energy of the gas.

$$\Delta U = \frac{3}{2}nR\Delta T$$

$$= \frac{3}{2}p\Delta V$$

$$= \frac{3}{2}(1.70\times10^5)\left[(10.00-5.00)10^{-4}\right]$$

$$= 128 \text{ J}$$

Alternatively,

$$\Delta U = Q + W$$

$$= Q - p\Delta V$$

$$= 213 - (1.70\times10^5)\left[(10.00-5.00)10^{-4}\right]$$

$$= 128 \text{ J}$$

increase in internal energy = ... J [3]

[NJC 2013]

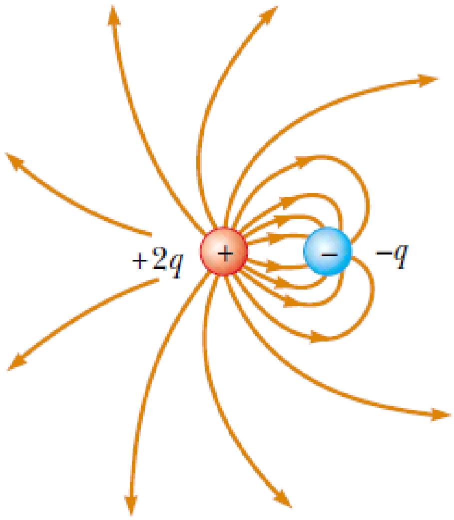
24 (a) Two charged spheres (with excess charges +2q and –q) are placed near each other as shown in Fig. 7.1.

Fig. 7.1

(i) Draw the electric field lines that should exist around them, paying special attention to

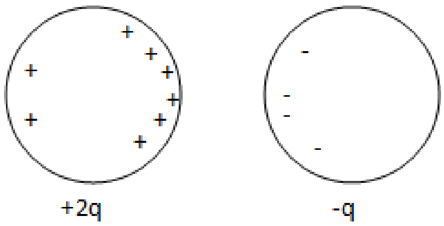
1. the number of field lines relative to the charge of conductor.

2. how close the field lines should be relative to the strength of the field at a point. [4]



1. Field lines start perpendicular to surface of sphere.
2. Twice the number of field lines coming out of 2q charge.
3. Field direction is from positive to negative charge (field lines in between two conductors must be a connected line).
4. Field lines closer nearer in between the two charges and further apart away from the middle. Required to have at least one field line on the left of the –ve change and on the right of the +charge for mark to be awarded.

(ii) Draw a possible distribution of the excess charges (using '+' and '–') on the two conductors. [2]



Note: Charge on the conducting sphere will reside on the surface and not inside the sphere.
Number of charges is twice for 2q over q and must be at the surface of conductor
Show excess charges inclined towards each other due to attraction

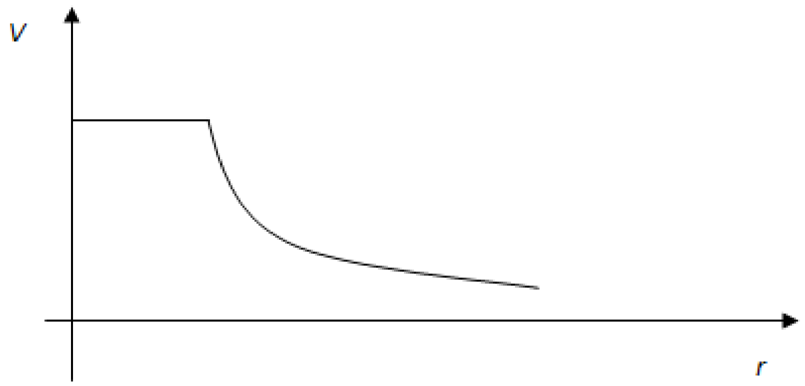
(b) **(i)** Define electric potential at a point.

The electric potential at a point is defined as the work done per unit charge by an external force in bringing a positive charge from infinity to that point. [2]

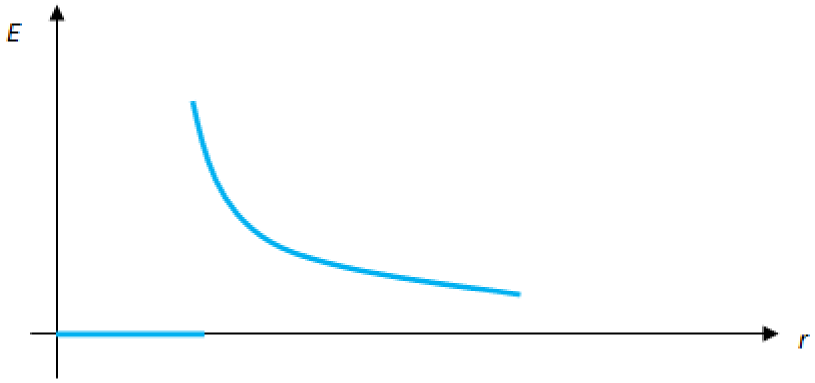
(ii) State whether electric potential is a vector or scalar quantity.

Scalar. [1]

(iii) An **isolated** charged sphere has a radius *a*. The graph below shows the variation of the electric potential *V* and the distance *r* from the center of the sphere.



Using the space provided, draw the corresponding electric field strength E against r graph for the same range of r. [2]



Electric field is zero inside conductor. $1/r^2$ decay outside conductor.

(c) An electron travels with a **constant** velocity through a magnetic field of flux density 0.0076 T and an electric field of electric field strength 5.6×10^4 V m^{-1}.

(i) Show on a diagram how this is possible, indicating clearly the forces and the direction of the fields involved.

Correct vector magnitude $F_B = F_E$

For correct magnetic field orientation for F_B and E-field orientation for F_E. [3]

(ii) Calculate the speed of the electron.

$$F_B = F_E$$
$$qE = Bqv$$
$$v = \frac{E}{B}$$
$$= \frac{5.6 \times 10^4}{0.0076}$$
$$= 7.4 \times 10^6 \text{ m s}^{-1}$$

speed = ... m s^{-1} [2]

(iii) Explain why this setup is called a velocity selector.

This is because only one velocity of electron will pass straight through, given a fixed E/B field. [1]

(d) **(i)** If the electron in **(c)** emerges from the electric field while still in the magnetic field, calculate the radius of curvature of the path of the electron, R.

$$F_B = ma$$

$$Bqv = \frac{mv^2}{R}$$

$$R = \frac{mv}{Bq}$$

$$= \frac{(9.11\times10^{-31})(7.4\times10^{6})}{0.0076(1.60\times10^{-19})}$$

$$= 5.5\times10^{-3} \text{ m}$$

radius = ... m [3]

(ii) When the electron is replaced by an alpha particle moving at the same velocity, explain if the radius of curvature is bigger or smaller.

Radius will increase since according to equation *m*/*q* increases. [1]

[TPJC 2012]

25 **(a)** Define *electric potential* at a point.

It is the work done per unit positive charge in moving a charge from infinity to the point.

.... [2]

(b) Two point charges **A** and **B** each have a charge of $+3.6\times10^{-9}$ C. They are separated in a vacuum by a distance of 30 cm, as shown in Fig. 7.1.

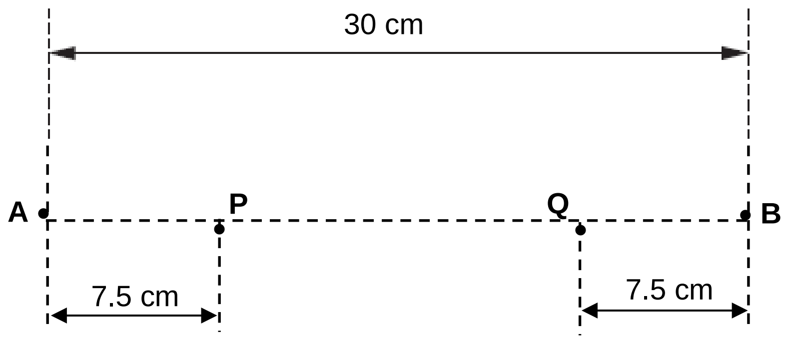


Fig. 7.1

Points **P** and **Q** are situated on the line **AB**. Points **P** and **Q** are 7.5 cm from charges **A** and **B** respectively.

(i) Calculate the force of repulsion between the charges **A** and **B**.

$$F = \frac{Q_A Q_B}{4\pi\varepsilon_0 r^2}$$

$$= \frac{(3.6\times10^{-9})^2}{4\pi(8.85\times10^{-12})(30\times10^{-2})^2}$$

$$= 1.3\times10^{-6} \text{ N}$$

force = ... N [2]

(ii) Explain why, without any calculation, when a small test charge is moved from point **P** to point **Q**, the net work done is zero.

The total potentials at P and Q are the same. Work done is the product of charge and potential difference between P and Q. [2]

(iii) Calculate the electrical potential at point **P** due to the charges at **A** and **B**.

$$V_P = \frac{Q_A}{4\pi\varepsilon_0 r_A} + \frac{Q_B}{4\pi\varepsilon_0 r_B}$$
$$= \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_A} + \frac{1}{r_B}\right)$$
$$= \frac{3.6\times10^{-9}}{4\pi\left(8.85\times10^{-12}\right)}\left[\frac{1}{7.5\times10^{-2}} + \frac{1}{(30-7.5)10^{-2}}\right]$$
$$= 580 \text{ V}$$

electrical potential = ... V [2]

(iv) Hence, calculate the work done in moving an electron from the midpoint of the line **AB** to point **P**.

$$V_M = \frac{Q_A}{4\pi\varepsilon_0 r_A} + \frac{Q_B}{4\pi\varepsilon_0 r_B}$$
$$= \frac{Q}{2\pi\varepsilon_0 r}$$
$$= \frac{3.6\times10^{-9}}{2\pi\left(8.85\times10^{-12}\right)\left(15\times10^{-2}\right)}$$
$$= 430 \text{ V}$$

$$W = \Delta U$$
$$= q\Delta V$$
$$= \left(-1.60\times10^{-19}\right)(580-432)$$
$$= -2.3\times10^{-17} \text{ J}$$

work done = ... J [3]

(c) The point charge at **B** is removed and replaced by charges of unknown value q as shown in Fig. 7.2.

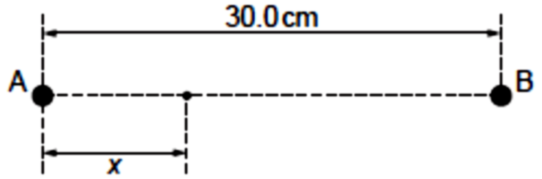


Fig. 7.2

The variation with distance x from **A** along **AB** of the potential V is shown in Fig. 7.3.

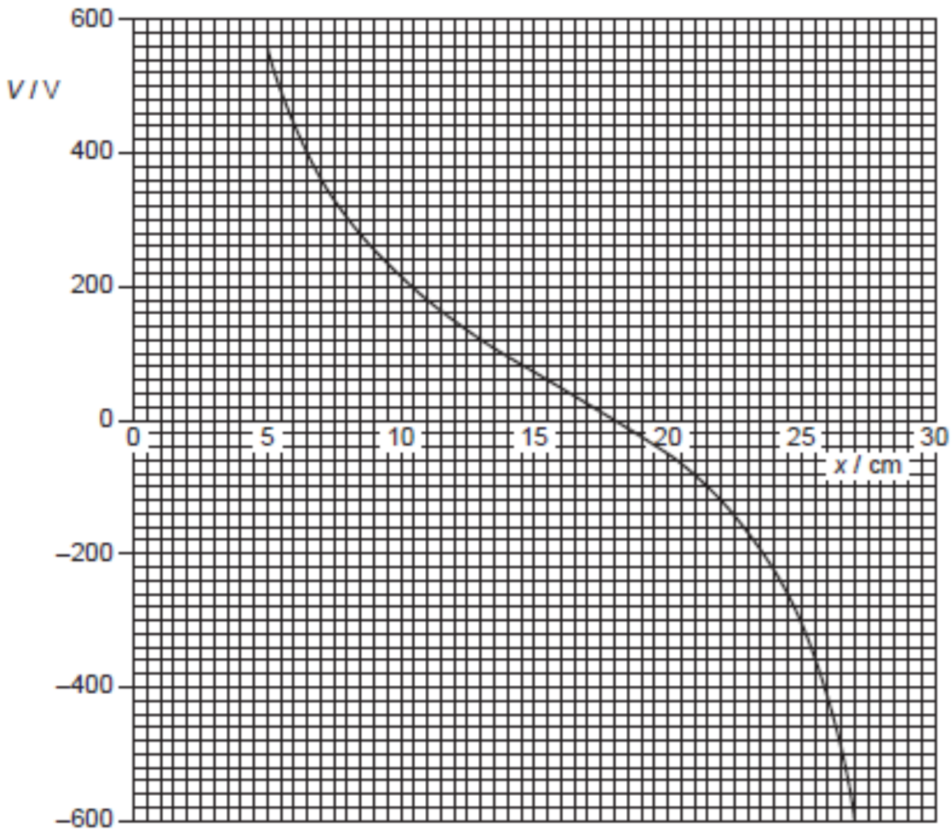


Fig. 7.3

(i) State the value of x at which the potential is zero.

$x = 18.0$ cm

$x =$ .... cm [1]

(ii) State and explain the direction of the electric field between **A** and **B** at this point where the potential is zero.

The direction of the electric field is the negative potential gradient. It is in the direction from positive to negative charge. OR direction of field points towards direction of decreasing potential. The electric field is directed from A to B. [2]

(iii) Use your answer in **(i)** to determine the charge q.

At $x = 18$ cm, $V = 0$,

$$V_A + V_B = 0$$

$$\frac{Q_A}{4\pi\varepsilon_0 r_A} + \frac{Q_B}{4\pi\varepsilon_0 r_B} = 0$$

$$\frac{Q_A}{r_A} + \frac{Q_B}{r_B} = 0$$

$$Q_B = -\left(\frac{r_B}{r_A}\right)Q_A$$

$$= -\left(\frac{30.0-18.0}{18.0}\right)(3.6\times10^{-9})$$

$$= -2.4\times10^{-9}\ \text{C}$$

charge $q =$ .... C [3]

(iv) A small test charge is now moved along the line AB from $x = 5.0$ cm to $x = 27$ cm. State and explain the value of x at which the force on the test charge will be a maximum.

The field strength is the negative potential gradient or the gradient of the graph. Field strength is the highest at the steepest gradient at point $x = 27$ cm. The electric force is the product of the charge and the gradient of the graph. Hence, the force is maximum at $x = 27$ cm. [3]

[IJC 2013]

26 **(a)** The new Galaxy SIII uses a battery of capacity 2100 mAh, and e.m.f. of 3.7 V. It has been tested that when the phone is in its standby mode, the current is only 7 mA.

(i) Define *current*.

The rate of flow of charged particles through a cross-section of a conductor. [1]

(ii) Define the *volt*.

One volt is the potential difference between two points in a circuit if one joule of electrical energy is converted to other forms of energy when one coulomb of charge passes through it. [1]

(iii) Calculate the duration in hours that the SIII can be in the standby mode.

$$t = \frac{2100}{7}$$
$$= 300 \text{ hours}$$

duration = ... h [2]

(iv) State and explain in practice, if the answer calculated in **(iii)** is an overestimation or underestimation of the actual value.

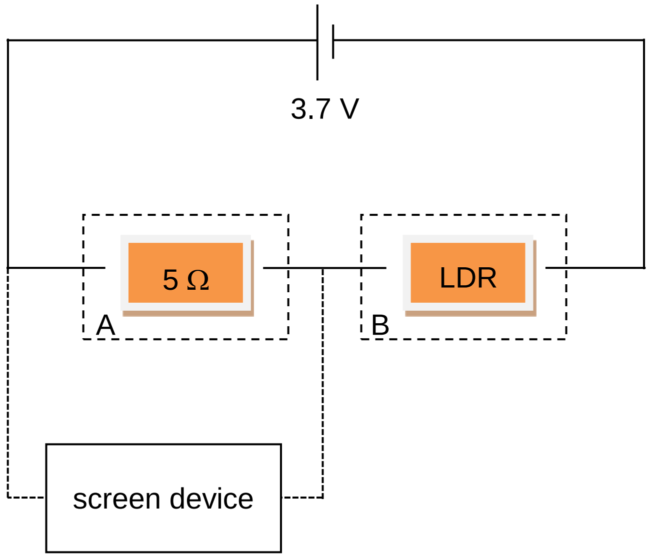
Overestimate. There may be other means where the energy is being used, e.g. internal resistance, apps which is running, Wi-Fi which is not turned off. [2]

(v) If the battery is connected to a heater that is immersed in water (in liquid form) at 0 °C, estimate the mass of this water that the temperature can be raised to 100 °C. Specific heat capacity of water = 4200 J kg^{-1} K^{-1}.

$$Q = mc\theta$$
$$Pt = mc\theta$$
$$IVt = mc\theta$$
$$m = \frac{IVt}{c\theta}$$
$$= \frac{(2100 \times 10^{-3})(3.7)(60 \times 60)}{4200(100)}$$
$$= 0.0666 \text{ kg}$$

mass = ... kg [2]

(b) LDR is used to control the brightness of the phone screen such that when it is in the dark, the brightness of the screen should decrease. The brightness of the screen increases with voltage supplied to it.



(i) In boxes A and B, draw appropriately a LDR and a 5 Ω resistor so that the screen works normally. [1]

(ii) The range of resistance of the LDR is between 12 Ω and 20 Ω. Calculate the potential difference that the screen device receives when the phone is in a very dark environment.

When dark, $R_{LDR} = 20\ \Omega$. By the Potential Divider Principle,

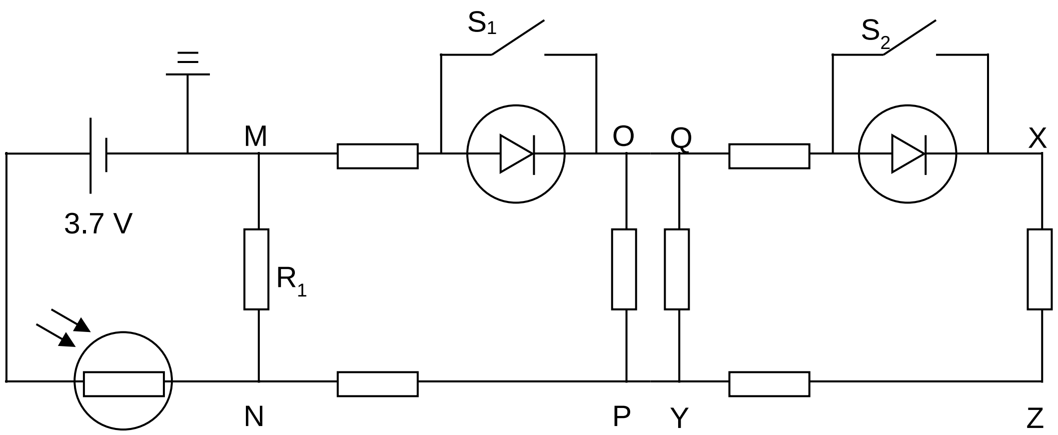
$$V = \left(\frac{R}{R+R_{LDR}}\right)E$$

$$= \left(\frac{5}{5+20}\right)(3.7)$$

$$= 0.74\ \text{V}$$

potential difference = ... V [2]

(c) Some application programs (Apps) of the phone also require the relative brightness of the phone to be adjusted. This can be done by turning On/Off various switches on the circuit board.



(i) Assuming that all the resistors shown above are 2 Ω, calculate the effective resistance across MN when both switches are closed.

When both switches are closed, the diode will be bypassed.

$$R_{OP}=\left(\frac{1}{2}+\frac{1}{2}+\frac{1}{6}\right)^{-1}=\frac{6}{7}\ \Omega$$

$$R_{MN}=\left[\frac{1}{2}+\frac{1}{\left(\frac{34}{7}\right)}\right]^{-1}=1.4\ \Omega$$

effective resistance = ... Ω [2]

(ii) S_1 is closed while S_2 opened, in a bright environment, the current flowing through R_1 is 0.197 A. In the table below, determine the potential at M, N, O and P. In the table below, determine the potential values at M, N, O and P.
Working must be clearly shown in the space below.

	potential/V
M	0
N	0.394
O	0.157
P	0.236

$$V_M=0\ (\because \text{grounded})$$

$$R_{eff}=\left(\frac{1}{5}+\frac{1}{2}\right)^{-1}+12=13.4\ \Omega$$

$$V=IR_{eff}$$
$$I=\frac{V}{R_{eff}}=\frac{3.7}{13.4}=0.276\text{ A}$$

$$V_N=V-IR_{LDR}=3.7-0.276(12)=0.394\text{ V}$$

$$V_P=\left(\frac{3}{3+2}\right)V_{NM}=\left(\frac{3}{5}\right)(0.394)=0.236\text{ V}$$

$$V_O=\left(\frac{2}{3+2}\right)V_{NM}=\left(\frac{2}{5}\right)(0.394)=0.157\text{ V}$$

[5]
[SRJC 2012]

27 **(a)** A cell of electromotive force (e.m.f.) *E* and internal resistance *r* is connected in series with a resistor *R*, as shown in Fig. 8.1 below.

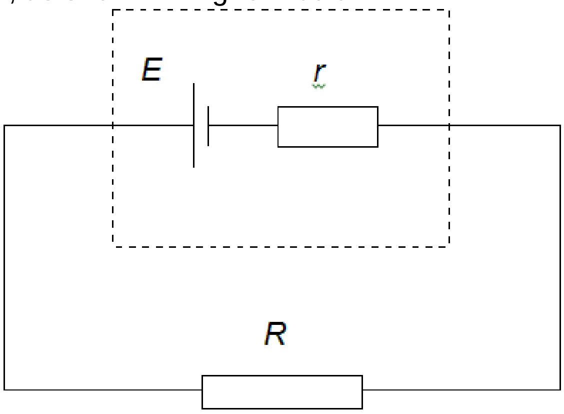


Fig. 8.1

The cell supplies 8.1 × 10^3 J of energy when 5.8 × 10^3 C of charge moves completely round the circuit. The current in the circuit is constant.

(i) Show that E is 1.4 V.

$$W = QE$$

$$E = \frac{W}{Q} = \frac{8.1\times10^3}{5.8\times10^3} = 1.4\text{ V (shown)}$$

[1]

(ii) The resistor R has resistance 6.0 Ω. The potential difference between its terminals is 1.2 V. Determine the internal resistance r of the cell.

$$V = IR \qquad\qquad V = E - Ir$$

$$I = \frac{V}{R} = \frac{1.2}{6.0} = 0.20\text{ A} \qquad\qquad r = \frac{E-V}{I} = \frac{1.4-1.2}{0.20} = 0.98\ \Omega$$

r = ... Ω [2]

(iii) Calculate the total energy transfer in the resistor R.

$$P \propto R$$

$$E = \left(\frac{R}{R+r}\right)W = \left(\frac{6.0}{6.0+0.98}\right)\left(8.1\times10^3\right) = 7.0\times10^3\text{ J}$$

energy transfer = ... J [2]

(iv) Describe, in terms of a simple model of electrical conduction, the mechanism by which the energy transfer in the resistor R takes place.

The charge carriers (mobile electrons with KE) collides with the lattice ions this collisions result in increase in the vibrational energy of the lattice and the higher energy translate to higher temperature (or work done on the resistor). [3]

(b) The graph Fig. 8.2 below shows the V–I characteristic for two 12 V filament lamps A and B.

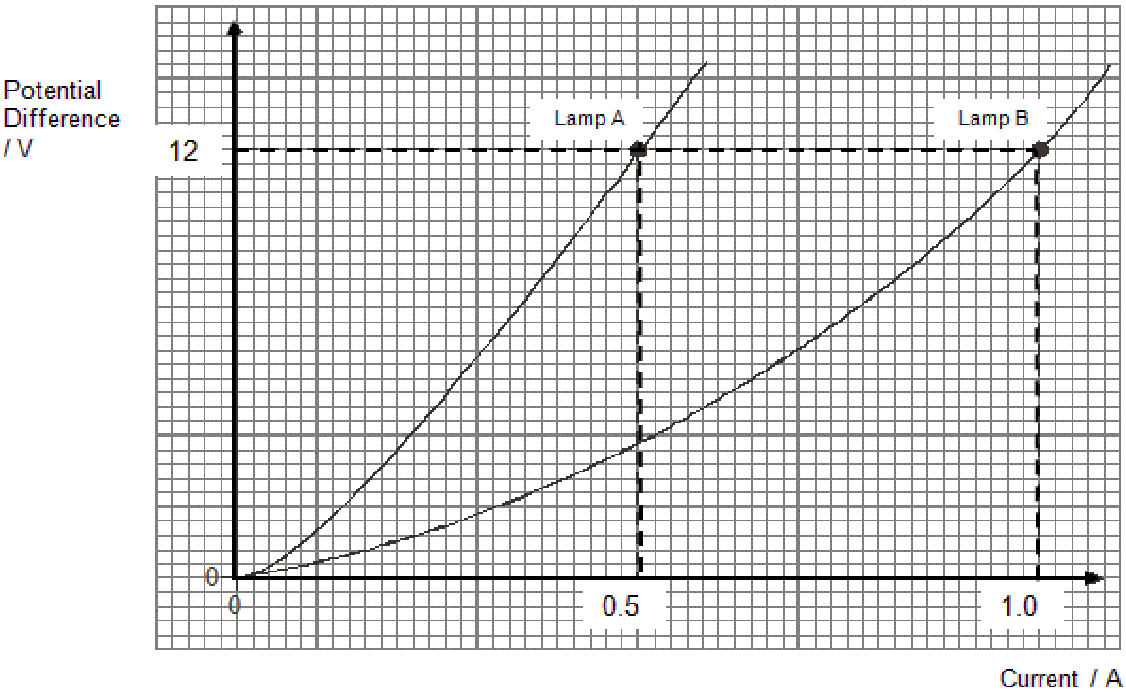


Fig. 8.2

(i) Based on the features of Fig. 8.2, explain why these lamps do not obey Ohm's law.

Ohm's law: The current in a component is proportional to the potential difference across it provided physical conditions (e.g. temperature) stay constant. The higher the potential difference applied, the brighter the bulb, the greater the temperature. Because of temperature changes, the conditions of Ohm's Law are not met, hence Ohm's Law is not obeyed. [2]

(ii) State and explain which lamp has the greater power dissipation for a potential difference of 12 V.

Lamp B must have greater power dissipation since $P = IV$ and for a similar V of 12 V, lamp B has a higher current. [2]

(c) The two lamps in **(b)** are now connected in series with a 12 V battery as shown in Fig. 8.3 below.

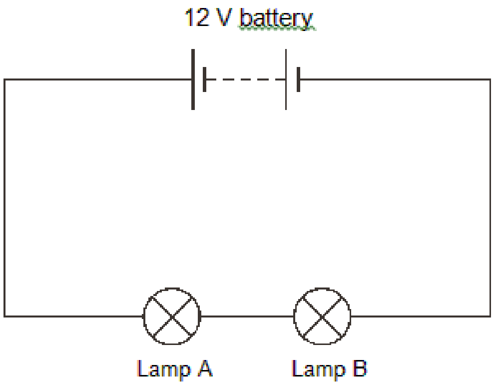


Fig. 8.3

(i) State how the current in lamp A compares with that in lamp B.

Current lamp A equals the current in lamp B. [1]

(ii) Use the *V–I* characteristics of the lamps in Fig. 8.2 to deduce the total current from the battery.

$V_A = 12$ V i.e. $V_A + V_B = 12$ V. From graph, current = 0.40 A.

current = ... A [2]

(iii) State and explain which lamp will be brighter under its operating conditions.

For constant (similar) current, power is proportional to potential difference (i.e. $P = IV$). Lamp A will be brighter as there is higher power dissipation. [2]

(d) Six resistors are connected to an e.m.f. source and ammeter as shown in Fig. 8.4 below.

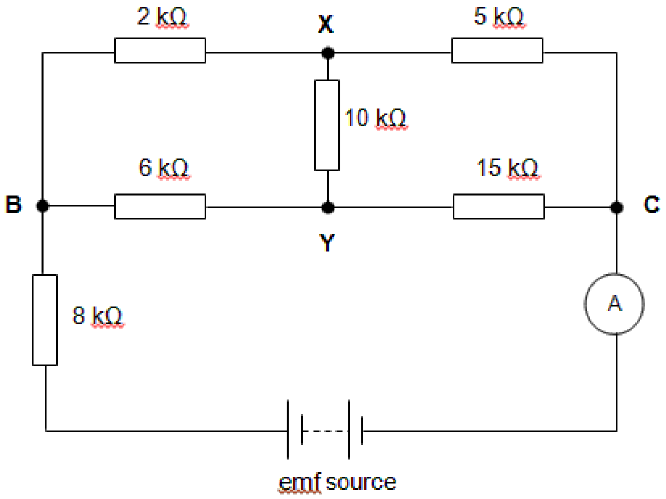


Fig. 8.4

State and explain which of the six resistors can be removed and yet the ammeter reading will remain unchanged.

There will always be no current through the branch XY as potential at X = potential at Y because $V_{BX} = V_{BY}$ and $V_{CX} = V_{CY}$ due to $\frac{R_{2k\Omega}}{R_{5k\Omega}} = \frac{R_{6k\Omega}}{R_{15k\Omega}}$. Thus, the 10 kΩ resistor will have no effect on the overall effective resistance of the circuit and the current through the ammeter will be unchanged even when this resistor is removed. [3]

[SAJC 2013]

28 (a) (i) List all the quantities that determine the state of an ideal gas.

Amount of gas; temperature; pressure and volume [1]

(ii) State what is meant by an *ideal* gas.

No intermolecular forces or obeys the equation $PV = nRT$. [1]

(b) A rigid storage cylinder contains 6.1 moles of an ideal gas. The gas is at a temperature of 23 °C and a pressure of 5.0×10^7 Pa.

(i) Show that the number of gas atoms in the storage cylinder is 3.67×10^{24}.

$$n = \frac{N}{N_A}$$
$$N = nN_A$$
$$= 6.1\left(6.02 \times 10^{23}\right)$$
$$= 3.67 \times 10^{24} \ \text{(shown)}$$

[1]

(ii) The gas leaks slowly from the cylinder such that, after a time of 35 days, the pressure has reduced by 3.0%. The temperature remains constant.

1. Determine the number of gas atoms that remains in the cylinder.

$$p \propto N$$
$$\frac{p'}{p} = \frac{N'}{N}$$
$$N' = \left(\frac{p'}{p}\right)N$$
$$= 0.97\left(3.67 \times 10^{24}\right)$$
$$= 3.56 \times 10^{24}$$

number of gas atoms = ... [2]

2. Calculate the average rate, in atom per second, at which the gas atoms escape from the cylinder.

$$\text{rate of escape} = \frac{N - N'}{t}$$
$$= \frac{(3.67 - 3.56)10^{24}}{35 \times 24 \times 60 \times 60}$$
$$= 3.64 \times 10^{16} \ \text{s}^{-1}$$

average rate of escape = ... s^{-1} [2]

3. Explain why the rate of escape obtained in **(b)(ii)2.** is an average rate.

Pressure is higher initially therefore molecules escapes faster initially. [1]

[ACJC 2015]

29 A variable resistor of resistance *R* is connected between the terminals of a battery of e.m.f. *E* and internal resistance *r* as shown in Fig. 3.1.

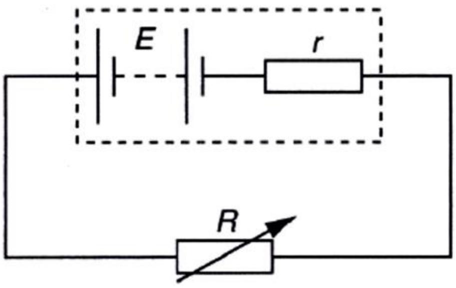


Fig. 3.1

(a) **(i)** Show that the current *I* in the circuit is given by $I = \dfrac{E}{R + r}$.

$$P = I^2(R+r)$$
$$IE = I^2(R+r)$$
$$I = \frac{E}{R+r} \quad \text{(shown)}$$

[1]

(ii) According to the Maximum Power Theorem, the power dissipated in the variable resistor reaches a maximum value of $\dfrac{E^2}{4r}$.

Determine the value of R in terms of r when this occurs.

$$P = I^2 R$$
$$= \left(\frac{E}{R+r}\right)^2 R$$
$$\frac{E^2}{4r} = \left(\frac{E}{R+r}\right)^2 R$$
$$R = r$$

R = ... Ω [2]

(b) **(i)** Write down an expression of the efficiency η of the transfer of power from the battery to the variable resistor in terms of R and r.

$$\eta = \frac{P_{out}}{P_{in}}$$
$$= \frac{I^2 R}{I^2(R+r)}$$
$$= \frac{R}{R+r}$$

[1]

(ii) The resistance of the variable resistor is varied such that the energy is transferred to it at maximum efficiency. State and explain the choice of R compared to r.

$$\eta = \frac{R}{R+r}$$
$$= \frac{1}{1+\frac{r}{R}}$$

Efficiency is maximum when R is at its maximum. The higher the external load's resistance compared to the internal resistance r, the lower the percentage of power wasted in the internal resistance and hence the higher efficiency. [2]

[ACJC 2015]

30 **(a)** State what is meant by a line of force in

(i) a gravitational field,

(tangent to line gives) direction of force on a (small test) mass [1]

(ii) an electric field.

(tangent to line gives) direction of force on a (small test) positive charge. [1]

(b) A charged metal sphere is isolated in space.
State one similarity and one difference between the gravitational force field and the electric force field around the sphere.

similarity: radial fields/lines normal to surface/greater separation of lines with increased distance from sphere/field strength inversely proportional to square of distance to centre of sphere.

difference: gravitational force (always) towards sphere while electric force direction depends on sign of charge on sphere; can be towards or away from sphere/gravitational field or force is attractive but electric field or force is attractive or repulsive. [3]

(c) Two horizontal metal plates are separated by a distance of 1.8 cm in a vacuum. A potential difference of 270 V is maintained between the plates, as shown in Fig. 5.1.

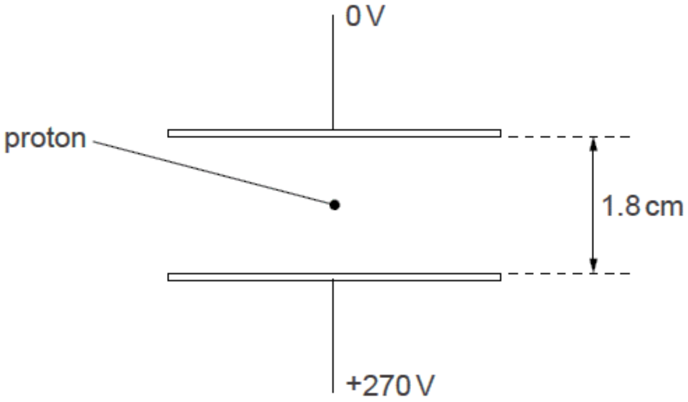


Fig. 5.1

A proton is in the space between the plates. Explain quantitatively why, when predicting the motion of the proton between the plates, the gravitational field is not taken into consideration.

$$F_G = mg = (1.67\times10^{-27})(9.81) = 1.6\times10^{-28}\text{ N}$$

$$F_E = qE = \frac{qV}{d} = \frac{(1.60\times10^{-19})(270)}{1.8\times10^{-2}} = 2.4\times10^{-15}\text{ N}$$

Electric force very much greater than gravitational force. [3]

(d) Define *electric potential* at a point.

Work done per unit positive charge in moving a point charge from infinity to the point. [1]

(e) Two point charges A and B are separated by a distance of 20 nm in a vacuum, as illustrated in Fig. 5.2.

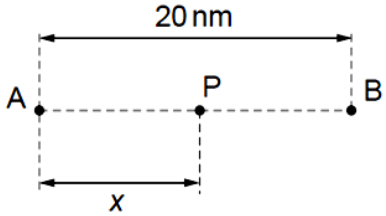


Fig. 5.2

A point P is a distance x from A along the line AB.
The variation with distance x of the electric potential V_A due to charge A alone is shown in Fig. 5.3.

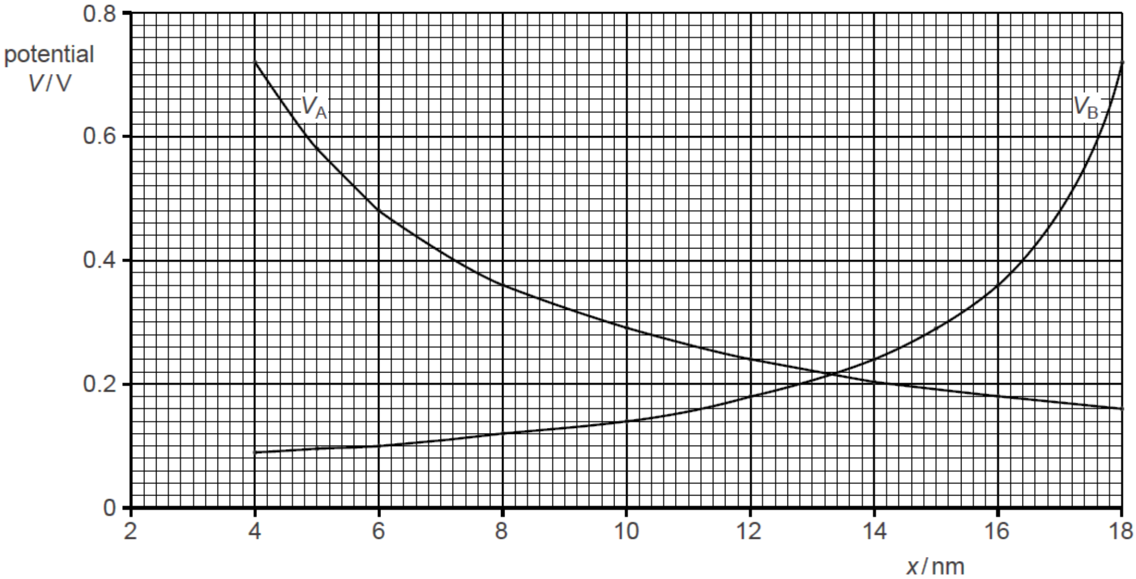


Fig. 5.3

The variation with distance x of the electric potential V_B due to charge B alone is also shown in Fig. 5.3.

(i) State and explain whether the charges A and B are of the same, or opposite, sign.

Either both potentials are positive or same sign so same sign or gradients are positive and negative so fields in opposite directions so same sign .... [2]

(ii) Use Fig. 5.3 to determine the charge on A.

$V_A = 0.36$ V when $x = 8.0$ nm (any value from graph of V_A)

$$V_A = \frac{Q_A}{4\pi\varepsilon_0 x}$$

$$Q_A = 4\pi\varepsilon_0 V_A x$$
$$= 4\pi\left(8.85\times10^{-12}\right)(0.36)\left(8.0\times10^{9}\right)$$
$$= 3.2\times10^{-19}\text{ C}$$

charge = ... C [2]

(iii) By reference to Fig. 5.3, state how the combined electric potential due to both charges may be determined.

The individual potentials are summed .... [1]

(iv) Without any calculation, use Fig. 5.3 to estimate the distance x at which the combined electric potential of the two charges is a minimum.

$x = 11$ nm (allow value of x between 10 nm and 13 nm)

x = ... nm [1]

(v) The point P is a distance $x = 10$ nm from A.
An α particle has kinetic energy E_K when at infinity. Use Fig. 5.3 to determine the minimum value of E_K such that the α particle may travel from infinity to point P.

$V = 0.14 + 0.29$

$= 0.43$ (allow 0.42 V to 0.44 V)

loss in kinetic energy = gain in electric potential energy

$= q\Delta V$

$= 2(1.60\times10^{-19})(0.43-0) \quad (\because V_\infty = 0)$

$= 1.4\times10^{-19}$ J

E_K at infinity is min if E_K at P is zero. Hence min E_K is 1.4×10^{-19} J

E_K = ... J [3]

(vi) On Fig.5.4, sketch the variation with x of the combined electric field strength E due to the two point charges A and B for values of x from 6 nm to 14 nm.

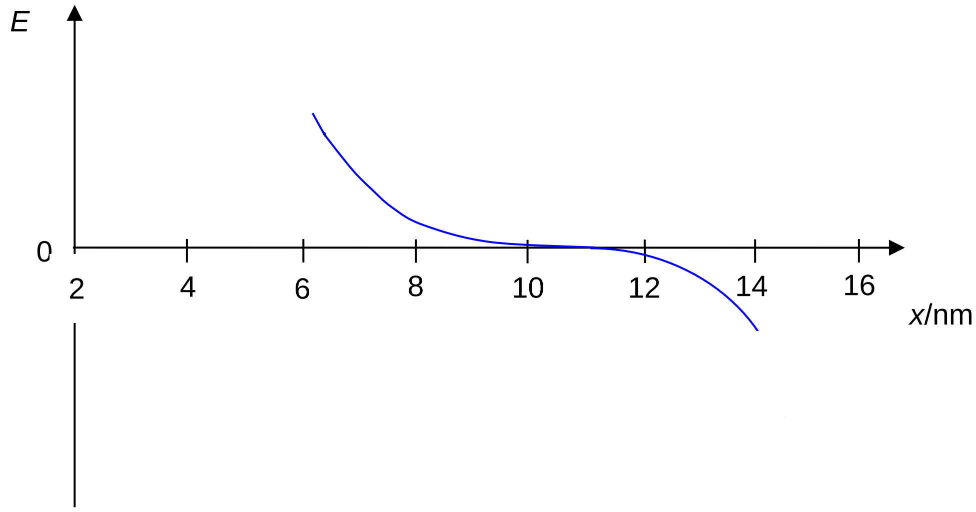


Fig. 5.4

[2]

[AJC 2015]

31 **(a)** A student states, quite wrongly, that temperature measures the amount of thermal energy in a body.
State and explain two observations that show why this statement is incorrect.

1. two objects of different masses of same material require different amount of thermal energy to raise the temperature by 1 kelvin OR

2. temperature shows direction of thermal energy transfer, from high to low regardless of objects OR

3. when substance melts/boils, thermal energy is supplied but no temperature change. [2]

(b) **(i)** Define *specific latent heat*.

Specific latent heat is the thermal energy required to change the state of unit mass of a substance without any change of temperature. [1]

(ii) A beaker containing a liquid is placed on a balance, as shown in Fig. 6.1.

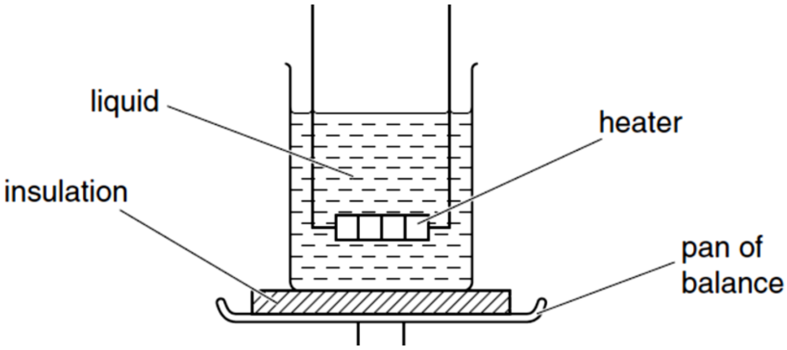


Fig. 6.1

A heater of power 110 W is immersed in the liquid. The heater is switched on and, when the liquid is boiling, balance readings *m* are taken at corresponding times *t*. A graph of the variation with time *t* of the balance reading *m* is shown in Fig. 6.2.

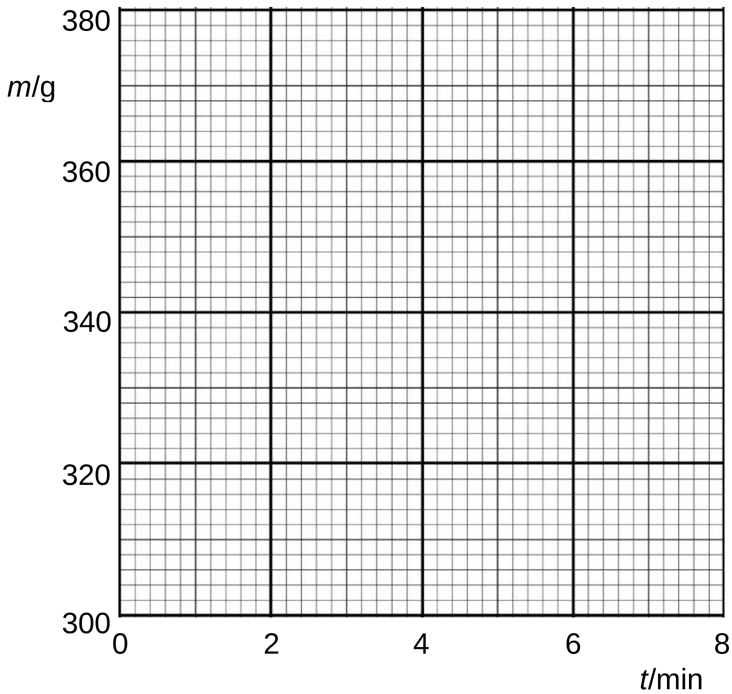


Fig. 6.2

1. State the feature of Fig. 6.2 which suggests that the liquid is boiling at a steady rate.

Constant gradient/straight line (allow constant slope) .... [1]

2. Use data from Fig. 6.2 to determine a value for the specific latent heat L of vaporisation of the liquid.

$$Pt = mL$$

$$110(7.0-0)(60) = \left[(372-325)10^{-3}\right]L$$

$$L = 9.80 \times 10^{5}\ \text{J kg}^{-1}\ \text{(allow 9.8 to 9.9 rounded to 2 s.f.)}$$

L = ... J kg^{-1} [2]

(iii) State, with a reason, whether the value determined in **(b)(ii)2.** is likely to be an overestimate or an underestimate of the normally accepted value for the specific latent heat of vaporisation of the liquid.

Some energy/heat is lost to surroundings or vapour condenses on sides, so value is an overestimate [2]

(c) **(i)** State what is meant by the *internal energy* of a gas.

The internal energy is the sum of the random kinetic and potential energies of all the molecules of a gas. [1]

(ii) The equation $pV = \text{constant} \times T$ relates the pressure p and volume V of a gas to its thermodynamic temperature T. State two conditions for the equation to be valid.

1. fixed mass/amount of gas

2. ideal gas [2]

(iii) A container has a volume of 2.1×10^{-3} m^3. On a day when the temperature is 15 °C, the pressure of the air in the container is 280 kPa.
Based on the conditions stated in **(c)(ii)**, calculate

1. number of moles n of air in the container,

$$pV = nRT$$

$$n = \frac{pV}{RT} = \frac{(280 \times 10^3)(2.1 \times 10^{-3})}{8.31(288)} = 0.25 \text{ mol}$$

n = ... mol [2]

2. the new temperature of the air in the container when the container is heated until the pressure rises to 290 kPa. Assume that no air has leaked from the container and that the volume is constant.

$$\frac{p'}{T'} = \frac{p}{T}$$

$$T' = \left(\frac{p'}{p}\right)T = \left(\frac{290}{280}\right)(288) = 298 \text{ K} = 25 \text{ °C}$$

$$pV = nRT$$

$$T = \frac{pV}{nR} = \frac{(290 \times 10^3)(2.1 \times 10^{-3})}{0.25(8.31)} = 293 \text{ K} = 20 \text{ °C (accepted)}$$

temperature = ... °C [1]

(d) **(i)** Write down an equation representing the first law of thermodynamics, defining your symbols carefully.

$\Delta U = Q + W$ where ΔU is the increase in internal energy of the system, Q is the energy (heat) supplied to the system and W is the work done on the system. [1]

(ii) The volume occupied by 1.00 mol of liquid water at 100 °C is 1.87×10^{-5} m^3. When the water is vaporised at an atmospheric pressure of 1.01×10^5 Pa, the water

vapour has a volume of 2.96 × 10^{-2} m^3. The latent heat required to vaporise 1.00 mol of water at 100 °C and 1.01 × 10^5 Pa is 4.05 × 10^4 J.
Determine, for this change of state, the change in internal energy of the system.

$$W = -p\Delta V$$
$$= -(1.01\times10^5)(2.96\times10^{-2} - 1.87\times10^{-5})$$
$$= -2990 \text{ J}$$

$$\Delta U = Q + W$$
$$= 4.05\times10^4 - 2990$$
$$= 3.75\times10^4 \text{ J}$$

change in internal energy = ... J [3]

(iii) Using your answer to **(d)(ii)**, estimate the binding energy per molecule in liquid water.

$$\text{binding energy per molecule} = \frac{3.75\times10^4}{6.02\times10^{23}}$$
$$= 6.23\times10^{-20} \text{ J}$$

binding energy per molecule = ... J [2]

32 **(a)** Define the *volt*.

The volt is the SI unit of potential difference and of electromotive force. It is defined as joule per coulomb. [1]

(b) Fig. 2.1 shows the variation of current *I* with potential difference *V* for three components: two diodes (D_1 and D_2) and a resistor (*R*).

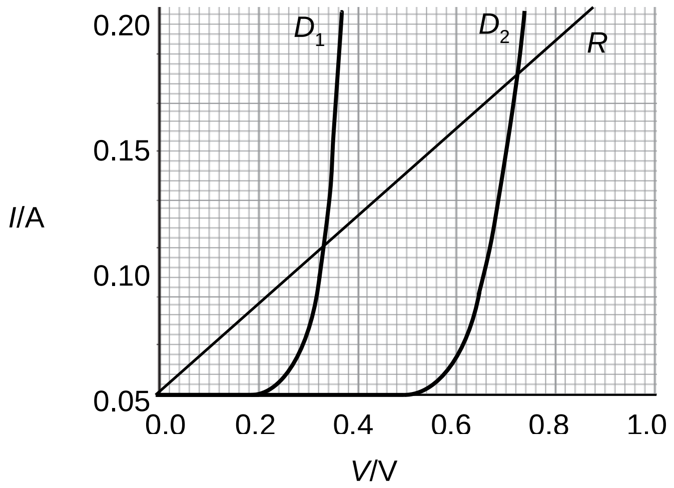


Fig. 2.1

(i) State the range of values of *V* where the resistance of *R* is the lowest among the three components. Briefly explain how you deduced this from the graph.

From 0 V to 0.33 V. This is where the ratio of *V* to *I* for *R* is the lowest compared to D_1 and D_2. [2]

(ii) Fig. 2.1 shows that a current flows through D_1 and D_2 only above a minimum voltage. Explain why.

The applied voltage must overcome the junction barrier potential difference of the respective p-n junctions from which D_1 and D_2 are made of, so as to collapse the depletion regions. [1]

(iii) D_1, D_2 and R are connected across a metre-long wire with a resistance of 5.0 Ω in the circuit shown in Fig. 2.2.

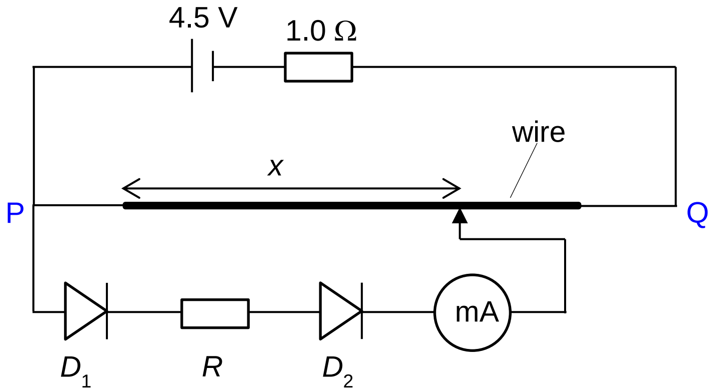
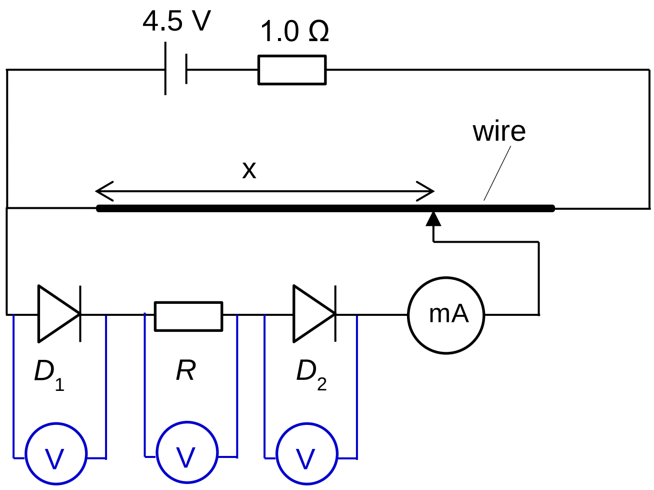


Fig. 2.2

Use Fig. 2.1 to explain why a minimum length x is required for a current to flow through D_1, D_2 and R in the circuit shown in Fig. 2.2.

A minimum voltage is required across P and Q to cause current to flow through D_1, D_2 and R. This is given by the sum of the applied voltages required to overcome the junction barrier potential difference of diodes D_1 and D_2 respectively. Thus, minimum voltage is required across P and Q is $V_{PQ} = 0.20 + 0.55 = 0.75$ V (read off from Fig. 2.1) where the voltage across R is zero when no current flows, hence it does not contribute to V_{PQ}. V_{PQ} is equal to the voltage across length x, which increases with length x. Hence length x must be adjusted such that the voltage across it exceeds 0.75 V for a current to flow. [3]

(iv) Draw in Fig. 2.2 to show how voltmeters may be connected to obtain the I–V graphs in Fig. 2.1. [1]



Vary x, and record the ammeter and voltmeters readings.

[CJC 2015]

33 Fig. 3.1 below shows the variation with volume of the pressure of an ideal gas contained within a cylinder. The gas is initially at state X.

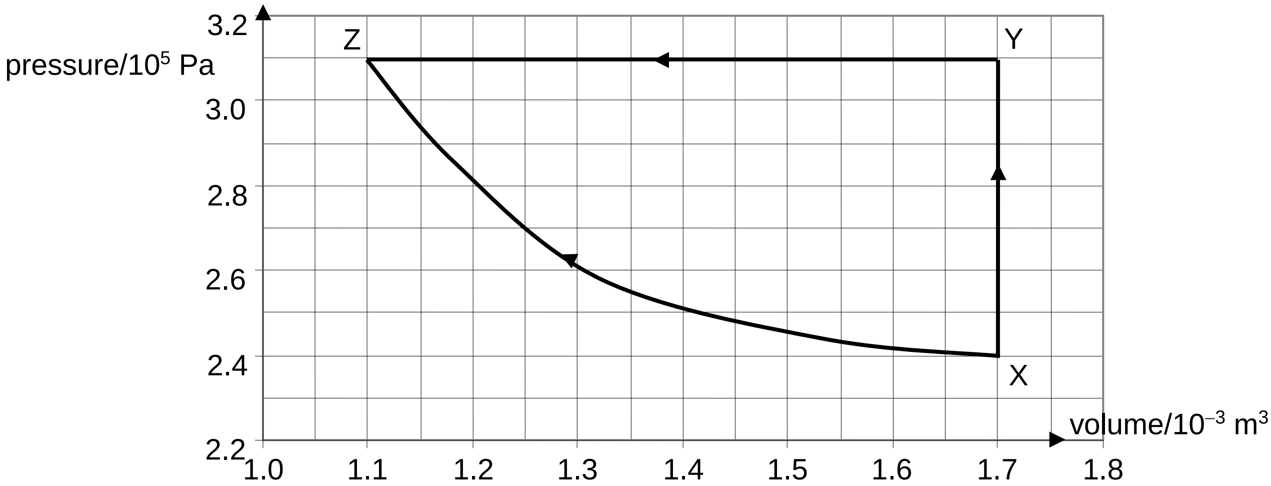


Fig. 3.1

(a) When the gas is compressed from X to Z along the curved path, 25.5 J of heat energy goes out of the gas and 15.6 J of work is done on the gas. Using Fig. 3.1,

(i) determine whether the change is isothermal.

$$p_xV_x = (2.4\times10^4)(1.7\times10^{-3}) = 40.8 \text{ Pa m}^3$$

$$p_zV_z = (3.1\times10^4)(1.1\times10^{-3}) = 34.1 \text{ Pa m}^3$$

Since $pV = nRT$ and nR is a constant, hence the product of pressure, p and volume, V must remain the same if T is constant. From the working steps as shown above, since the pV values at points X and Z are not equal, we can conclude that the process XZ is not isothermal.

[2]

(ii) determine the quantity of heat supplied to the gas when the gas increases pressure from X to Z along the paths XY and YZ.

The change in internal energies between points X and Z is the same for both paths since the starting and ending states are the same.

$$\Delta U_{XZ} = \Delta U_{XYZ}$$
$$Q_{XZ} + W_{XZ} = \Delta U_{XYZ}$$
$$\Delta U_{XYZ} = -25.5 + 15.6 = -9.9 \text{ J}$$

$$W_{XYZ} = \text{area under XYZ} = (3.1\times10^4)\left[(1.7-1.1)10^{-3}\right] = 18.6 \text{ J}$$

$$\Delta U_{XYZ} = Q_{XYZ} + W_{XYZ}$$
$$Q_{XYZ} = \Delta U_{XYZ} - W_{XYZ} = -9.9 - 18.6 = -28.5 \text{ J}$$

heat supplied = ... J [3]

(b) A car tyre of volume 1.60×10^{-2} m^3 contains air at a temperature of 30.0 °C and a pressure of 2.6×10^5 Pa. A foot pump is used to pump air into the tyre to increase the pressure to 3.1×10^5 Pa. Each stroke of the pump pushes 3.0×10^{-4} m^3 of air at 1.0×10^5 Pa into the tyre. The temperature of the air stays constant at 30.0 °C throughout the whole process. You may assume that air behaves like an ideal gas in this situation.

(i) State what is meant by an *ideal gas.*

An ideal gas is a gas that obeys the gas laws or the ideal gas law, $pV = nRT$, at all values of volume, pressure and temperature. [1]

(ii) The initial number of moles of air in the tyre is 1.65 moles. Calculate the number of strokes needed to raise the pressure of the car tyre to 3.1 × 10^5 Pa.

$$pV = nRT$$

$$n = \frac{pV}{RT}$$

$$= \frac{(3.0\times10^{-4})(1.0\times10^{5})}{8.31(30.0+273.15)}$$

$$= 0.0119 \text{ mol}$$

Assuming V and T remain constant, from the ideal gas equation, n is proportional to p

$$\frac{n'}{n} = \frac{p'}{p}$$

$$n' = \left(\frac{p'}{p}\right)n$$

$$= \left(\frac{3.1\times10^{5}}{2.6\times10^{5}}\right)(1.65)$$

$$= 1.97 \text{ mol}$$

Thus, the number of moles of air required to fill the car tyre is:

$$\Delta n = n' - n$$

$$= 1.97 - 1.65$$

$$= 0.317 \text{ mol}$$

where n' and p' are the number of moles of air and pressure of the tyre after the pumping action and n and p are the number of moles of air and pressure of the tyre before the pumping action.

$$\text{no of strokes required} = \frac{0.317}{0.0119}$$

$$= 26.7$$

$$= 27$$

number of strokes required = ... [4]

[CJC 2015]

34 **(a)** Distinguish between *electric potential* and *electric potential energy*.

Electric potential is the work done per unit positive charge in moving a small test charge from infinity to that point while electric potential energy is the work done in moving a charge from infinity to that point. .... [2]

(b) A cable used for the transmission in an electrical distribution system has a circular cross-section of radius 0.012 m. Fig. 2.1 is a full-scale drawing showing the electric field surrounding the cable together with lines of equal potential at an instant when the potential of the cable is +564000V.

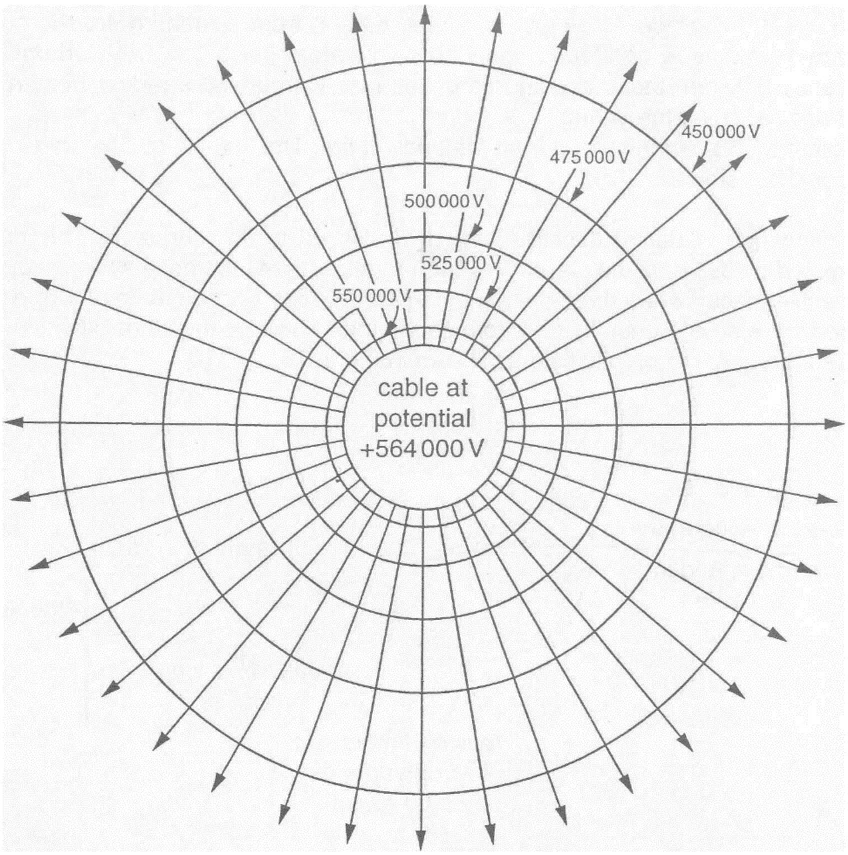


Fig. 2.1 (to scale)

(i) State the relation between electric field strength and potential gradient.

Electric field strength is the negative of the potential gradient. [1]

(ii) Use Fig. 2.1 to estimate the potential gradient near the surface of the cable.

$$\frac{dV}{dr} = \frac{564000 - 550000}{3 \times 10^{-3}}$$

$$= 4.7 \times 10^{6} \text{ V m}^{-1}$$

potential gradient = ... V m^{-1} [3]

(iii) Explain why a cable of a larger radius, but at the same potential, will have a smaller electric field at its surface.

Larger radius, the charges on the cable are less concentrated. Or same potential larger radius, so field lines more spaced out [1]

(iv) On Fig. 2.2, sketch the electric field lines near a cable of square cross-section.

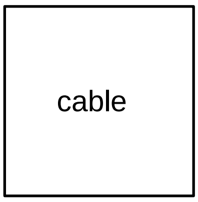


Fig. 2.2

Field lines are at right angle to conducting surface. Field lines concentrating at the corners of the square cross section.

Note: The shape of the cable would not make much difference to the pattern a long way from the cable.

[3]
[DHS 2015]

35 An ideal gas is enclosed in a cylinder by means of a movable frictionless piston as shown in Fig. 3.1. Any collision between the gas atoms and the piston or the walls can be assumed to be elastic.

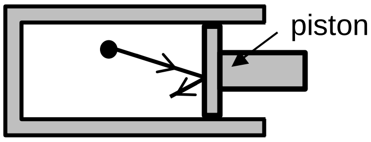


Fig. 3.1

(a) With reference to the gas atom shown in Fig. 3.1, state and explain whether the momentum of the gas atom is conserved when it collides with the stationary piston.

Not conserved, because the direction of motion changes (and momentum is a vector quantity). [1]

(b) The piston is moved outward *rapidly* so that the volume of the cylinder increases. Use kinetic theory to explain what happens to the temperature of the gas immediately after the piston motion.

Speed of gas atoms decreases on rebound as impact force by piston is smaller. Average kinetic energy of particles decreases. Since average kinetic energy is proportional to (thermodynamic) temperature, temperature decreases. [2]

(c) The cylinder is now turned upright, as shown in Fig. 3.2. The 8.0 kg piston has a cross-sectional area of 60 cm^2. Atmospheric pressure is 100 kPa. The gas is then taken through two stages:

stage 1: The gas is heated from 30 °C to 100 °C. The piston rises 20 cm.
stage 2: The piston is fastened in place and the gas is cooled back to 30 °C.

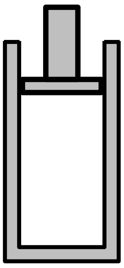


Fig. 3.2

(i) Calculate the work done on the gas in stage 1.

$$W = -p\Delta V$$
$$= -\left[100\times10^{3} + \frac{8.0(9.81)}{60\times10^{-4}}\right](20\times10^{-2})(60\times10^{-4})$$
$$= -136 \text{ J}$$

work done on gas = ... J [3]

(ii) Determine the net heat gain after the gas is put through stage 1 and 2.

For stage 2, $W = 0$ J.

$$\Delta U = Q + W$$
$$0 = W + (-136)$$
$$Q = 136 \text{ J}$$

net heat gain = ... J [2]

[HCI 2015]

36 **(a)** Define electric potential.

Electric potential is the work done per unit positive charge by an external force in bringing a small test charge from infinity to that point. [2]

(b) A solid, charged metal sphere holding a positive charge of 8.85 pC is situated in a vacuum as shown in Fig. 1.1.

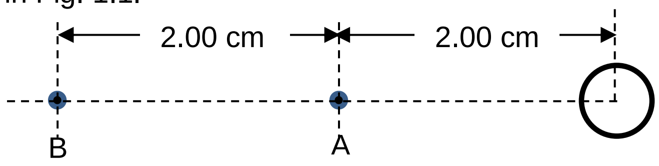


Fig. 1.1

(i) What is the electric potential at point A?

$$V_A = \frac{Q}{4\pi\varepsilon_0 r_A}$$
$$= \frac{8.85\times10^{-12}}{4\pi\left(8.85\times10^{-12}\right)\left(2.00\times10^{-2}\right)}$$
$$= 3.98 \text{ V}$$

potential = ... V [1]

(ii) What is the potential difference between points A and B?

$$V \propto \frac{1}{r}$$
$$\frac{V_B}{V_A} = \frac{r_A}{r_B}$$
$$V_B = \left(\frac{r_A}{r_B}\right)V_A$$

$$V_A - V_B = \left(1 - \frac{r_A}{r_B}\right)V_A$$
$$= \left(1 - \frac{1}{2}\right)(3.98)$$
$$= 1.99 \text{ V}$$

potential difference = ... V [1]

(iii) Within the dotted region in Fig. 1.2, draw

1. lines of equipotential passing through A and passing through B.

2. one electric field line (label as E) originating from the charged metal sphere.

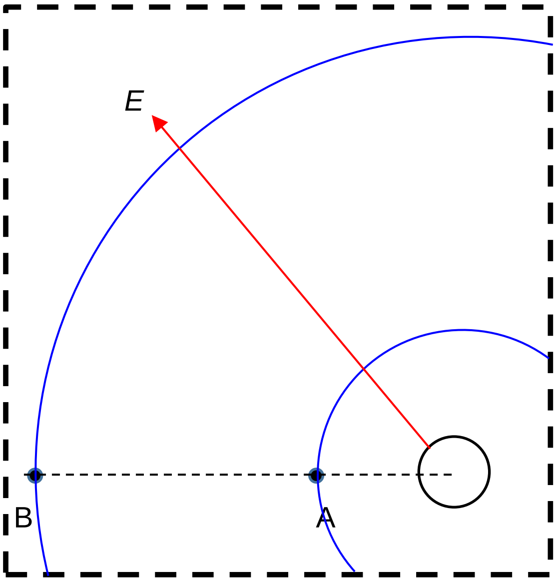


Fig. 1.2

Equipotential lines must be circular and centred with sphere. Field line must be straight, arrowed and begins from surface of sphere.

[2]

(iv) At what speed must a proton, positioned at B, be launched so that it follows a path from B to A and then returning to B with the same speed with which it was initially launched.

loss in kinetic energy = gain in electric potential energy

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

$$v = \sqrt{\frac{2qV}{m}}$$

$$= \sqrt{\frac{2\left(1.60\times10^{-19}\right)(1.99)}{1.67\times10^{-27}}}$$

$$= 1.95\times10^{4}\ \text{m s}^{-1}$$

speed = ... m s^{-1} [2]

(v) At what speed must an electron, positioned at B, be launched so that it travels along the line of equipotential passing through point B.

Electron move in a circular arc, centripetal force is provided by the electric force. This force acts perpendicular to direction of motion. By Newton's Second Law,

$$F = ma$$

$$\frac{Qq}{4\pi\varepsilon_0 r^2} = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{Qq}{4\pi\varepsilon_0 mr}}$$

$$= \sqrt{\frac{\left(8.85\times10^{-12}\right)\left(1.60\times10^{-19}\right)}{4\pi\left(8.85\times10^{-12}\right)\left(9.11\times10^{-31}\right)\left(4.0\times10^{-2}\right)}}$$

$$= 5.91\times10^{5}\ \text{m s}^{-1}$$

speed = ... m s^{-1} [2]

[HCI 2015]

Answers

MCQ

1	D	**2**	D	**3**	A	**4**	B	**5**	D
6	C	**7**	D	**8**	B	**9**	B	**10**	A
11	D	**12**	C	**13**	A	**14**	A	**15**	C
16	D	**17**	C	**18**	B	**19**	A	**20**	D
21	B	**22**	A	**23**	B	**24**	D	**25**	C
26	B	**27**	A	**28**	B	**29**	D	**30**	C
31	D	**32**	D	**33**	D	**34**	B	**35**	D
36	B	**37**	B	**38**	B	**39**	A	**40**	A
41	C	**42**	C	**43**	C	**44**	D	**45**	B
46	C	**47**	C	**48**	C	**49**	B	**50**	A
51	C	**52**	C	**53**	A	**54**	A	**55**	D
56	A	**57**	A	**58**	B	**59**	B	**60**	D
61	C	**62**	A	**63**	B	**64**	C	**65**	C
66	B	**67**	C	**68**	B	**69**	C	**70**	A
71	C	**72**	C	**73**	A	**74**	D	**75**	C

Short Structured Questions

1(b)(iii)2.	3.36×10^5 J kg^{-1}	**2(c)**	4220 J kg^{-1} K^{-1}	**2(d)(ii)**	4180 J kg^{-1} K^{-1}
3(b)	2.58×10^5 J	**3(c)(i)**	1.69×10^5 J	**3(c)(ii)**	2.09×10^6 J
3(c)(iii)	2.09×10^6 J	**4(a)**	289 K	**4(b)**	180 J
4(c)	170 J	**5(a)**	628 K	**5(b)(ii)**	533 K
5(b)(iii)	44.9 J	**6(c)(i)1.**	6.0×10^4 m s^{-1}	**6(c)(i)2.**	2.6×10^6 m s^{-1}
6(c)(ii)	1.5×10^5 K	**7(b)(ii)**	5.0×10^5 V m^{-1}	**8(b)(i)**	-6.0×10^{-10} J
8(b)(ii)	1.8 V	**8(b)(iv)**	50000 V m^{-1}	**8(b)(v)**	1.0×10^{-7} N
10(b)	–69 V	**10(c)**	0.077 m	**10(d)**	–53 V
11(b)	1.5×10^{-17} N	**11(c)**	0 J		
12(b)	$V = -\dfrac{3.8\times10^{-9}}{4\pi\varepsilon_o x} + \dfrac{7.6\times10^{-9}}{4\pi\varepsilon_o (0.060 - x)}$			**13(c)**	-8.0×10^{-19} J
14(a)	6 V for both	**15(a)(i)**	2.0 Ω	**15(a)(ii)**	12.0 V
15(b)	10 V	**16(a)**	3730 Ω	**16(b)(i)**	6.72 Ω
16(b)(ii)	0.579 m	**17(c)(ii)**	54 cm	**18(b)(i)**	60 Ω
18(b)(ii)	2.0 km	**18(b)(iii)**	3.75 W	**19(c)**	15 Ω
19(d)	30 Ω	**20(b)(ii)**	1.22×10^5 Ω	**21(c)**	1700 s
22(b)(ii)1.	2.0 V	**22(b)(ii)2.**	3300 Ω	**23(b)(i)**	1.8×10^{-23} N s
23(b)(ii)	8.5×10^{23} s^{-1}	**23(c)(iii)**	193 K	**23(c)(iv)**	128 J
24(c)(ii)	7.4×10^6 m s^{-1}	**24(d)(i)**	5.5×10^{-3} m	**25(b)(i)**	1.3×10^{-6} N
25(b)(iii)	580 V	**25(b)(iv)**	-2.3×10^{-17} J	**25(c)(i)**	18.0 cm
25(c)(iii)	-2.4×10^{-9} C	**26(a)(iii)**	300 h	**26(a)(v)**	0.0666 kg

26(b)(ii)	0.74 V	**26(c)(i)**	1.4 Ω	**26(c)(ii)**	0, 0.394, 0.157, 0.236
27(a)(ii)	0.98 Ω	**27(a)(iii)**	7.0×10^{3} J	**27(c)(ii)**	0.40 A
28(b)(ii)1.	3.56×10^{24}	**28(b)(ii)2.**	3.64×10^{16} s^{-1}	**29(a)(ii)**	r
29(b)(i)	$\dfrac{R}{R+r}$	**30(e)(ii)**	3.2×10^{-19} C	**30(e)(iv)**	11 nm
30(e)(v)	1.4×10^{-19} J	**31(b)(ii)2.**	9.8×10^{5} J kg^{-1}	**31(c)(iii)1.**	0.25 mol
31(c)(iii)2.	20 °C	**31(d)(ii)**	3.75×10^{4} J	**31(d)(iii)**	6.23×10^{-20} J
32(b)	0 V to 0.33 V	**33(a)(ii)**	–28.5 J	**33(b)(ii)**	27
34(b)(ii)	4.7×10^{6} V m^{-1}	**35(c)(i)**	–136 J	**35(c)(ii)**	136 J
36(b)(i)	3.98 V	**36(b)(ii)**	1.99 V	**36(b)(iv)**	1.95×10^{4} m s^{-1}
36(b)(v)	5.91×10^{4} m s^{-1}				