PART A (100 MARKS)

QUESTION 1

a) Write down the factors that control the capacitance of a parallel-plate capacitor.

Answer: Capacitance $C = \frac{\varepsilon A}{d}$; hence the dielectric constant of the material between the plates, ε, the area of the plates, A, and the separation of the plates, A.

(3 marks)

b) Experiments have shown that the amount of charge q, deposited on capacitors is directly proportional to the potential difference V, across the plates, or q = CV. In addition, the electric potential energy stored in a parallel-plate capacitor can be shown to be, $Energy = \frac{q}{2V}$.

i) Show that the electrical potential energy can also be written as $Energy = \frac{q^2}{2C}$.

Answer: Since average energy stored is $Energy = \frac{qV}{2}$ and the charge stored is $q = CV$, then, $Energy = q\frac{q}{2C} = \frac{q^2}{2C}$

(3 marks)

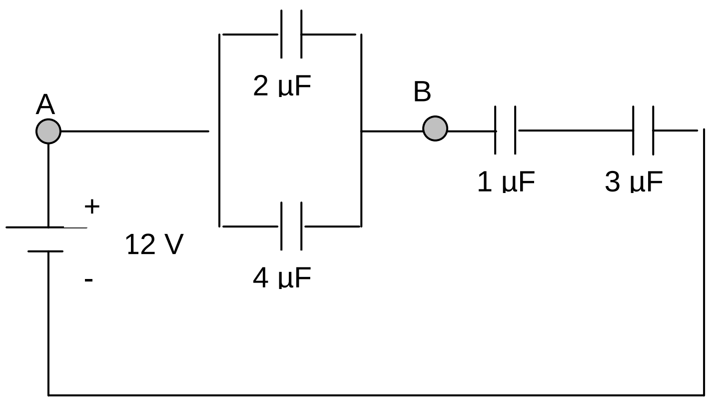
ii) A parallel plate capacitor is charged up by a battery and then the connection to the battery is broken. Explain how capacitance changes if the separation of the plates is reduced by a factor of 2.

Answer: Since the capacitance is inversely proportional to the plate separation d, then doubling the separation reduce the capacitance by 2. Mathematically,

$$\frac{C_2}{C_1} = \frac{d_1}{d_2} = \frac{d_1}{2d_1} = \frac{1}{2}.$$

(4 marks)

c) The figure below shows capacitors connected together in a circuit with a 12 volts battery.

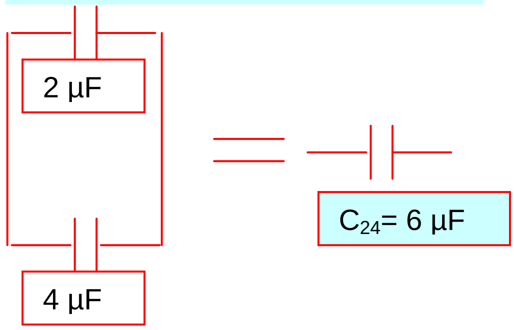


i) Obtain the total capacitance for the configuration in the figure.

Answer:

Since in parallel,

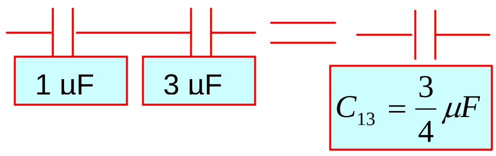
$$C_{24} = C_2 + C_4 = 2\mu F + 4\mu F = 6\mu F$$



(1 marks)

Since in series,

$$\frac{1}{C_{13}} = \frac{1}{C_1} + \frac{1}{C_3} = \frac{1}{1} + \frac{1}{3} = \frac{4}{3\mu F}$$



$$\frac{1}{1} + \frac{1}{3} = \frac{3}{3} + \frac{1}{3} = \frac{4}{3}$$

$$C_{13} = \frac{3}{4}\mu F$$

(2 marks)

Since the capacitances are in series,

then, $\frac{1}{6} + \frac{4}{3} = \frac{1}{6} + \frac{8}{6} = \frac{9}{6} = \frac{3}{2\mu F}$

(2 marks)

Hence the total capacitance is $C_{2413} = \frac{2}{3}\mu F$

(1 mark)

ii) Determine the total charge stored and the total electrical potential energy stored by the capacitance configuration above.

Answer: Since $q = CV$, then, $q = \frac{2}{3}\mu F \times 12V = 6\mu C$

(2 marks)

iii) Determine the potential difference between points A and B.

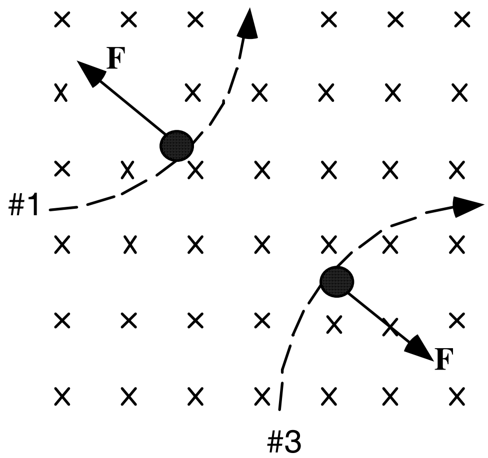
Answer: Since C_{24}= 6 µF, and the total charge is the same, then

$$V = \frac{q}{C} = \frac{6\mu C}{6\mu F} = 1V$$.

(2 marks)

QUESTION 2

a) Three particles move through a constant magnetic field and follow the paths shown in the drawing. Determine whether each particle is positively charged, negatively charged, or neutral. Give a reason for each answer.



Answer:
Using right hand rule #1, since v & B is perpendicular, then F_B points perpendicular to the path shown. Then F is as indicated for a charged particle, F_B is zero for a neutral particle. Hence particle 1 is +ve, particle 2 is neutral and particle 3 is –ve.

(2+3 = 5 marks)

b) The drawing shows an end-on view of three parallel wires that are perpendicular to the plane of the paper. All carries current I and the wires are separated from each other by a distance *d*. In two of the wires the current is directed into the paper, while in the remaining wire the current is directed out of the paper. The two outermost wires are held rigidly in place.

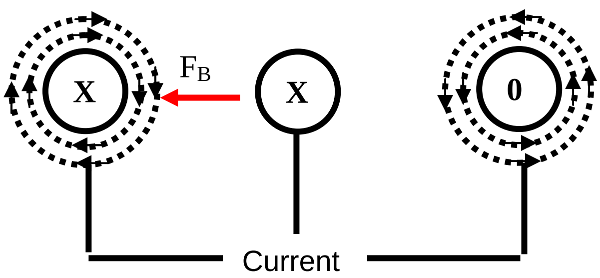
i) Draw the magnetic field lines for the rigid wires.

ii) Write the magnitude of the magnetic field at the position of the middle wire.

Answer: $B = 2\dfrac{\mu_0 I}{2\pi d}$

iii) Indicate the direction of the force acting on the middle wire.

Answer: To the left or the F_B shown.



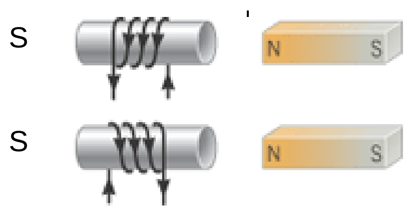
(2+1+1= 5 marks)

c) For each electromagnet at the left of the drawing,

i) label the polarity of the induced magnetic field

ii) explain whether it will be attracted to or repelled from the permanent magnet at the right.

Answer:
Top picture: Repelled because of same poles
Bottom picture: Repelled because of the same poles.



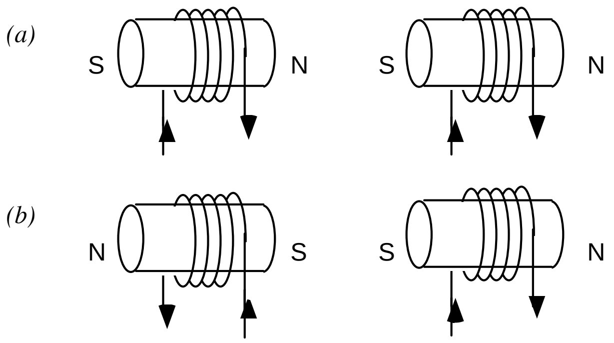
(2+2 = 4 marks)

d) For each electromagnet in the drawing on the right,

i) label the polarity of the induced magnetic fields.

ii) explain whether the left electromagnets in the drawing will be attracted to or repelled from the adjacent electromagnet on the right.

Answer:
Top picture: Attracted because of opposite poles
Bottom picture: Repelled because of the same poles.



(4+2 = 6 marks)

QUESTION 3

a) Write some scientific response about the following:

i) induced electromotive force (emf) and induced current.
Answer: Induced current is produced whenever there is a flux change in a circuit. As a result of the induced current, an emf will exist between points in that circuit.

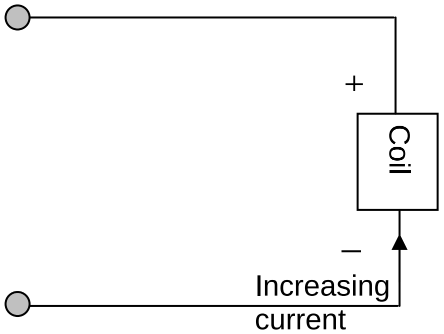
ii) magnetic flux
Answer: Magnetic flux is a measure of the number of magnetic lines through a surface area in space.

iii) Faraday's and Lenz's law of electromagnetic induction.
Answer: Faraday's law of magnetic induction states that the emf induced in a cicuit is proportional to the change in magnetic flux in one second.
Lenz's law states that the induced current will be in a direction opposing the the direction of current that induces the change.

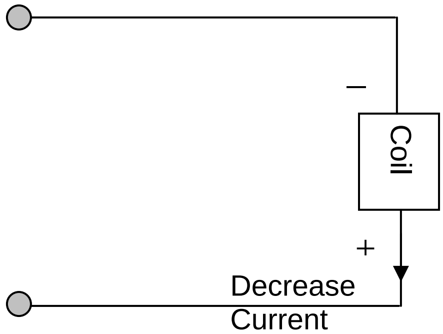
(2+2+6 = 10 marks)

b) In the diagrams below, label the high and low potential points of the coil by the usual symbol '**+**" and '**-**' and indicate the direction of the induced electromotive force (emf).

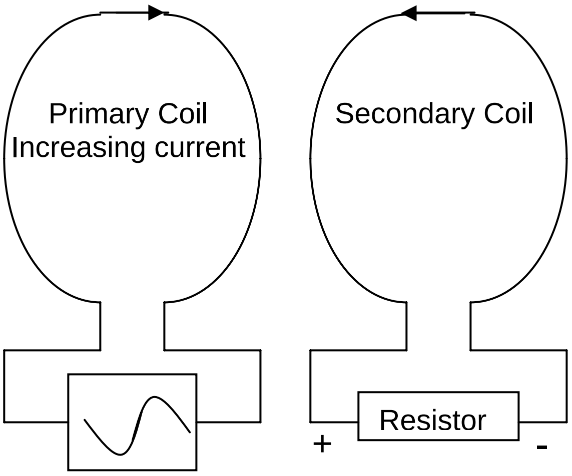
i)



ii)



iii)



(2+2+2 = 6 marks)

c) During a 72-ms interval, a change in the current in a primary coil occurs. This change leads to the appearance of a 6.0 mA current in a nearby secondary coil. The secondary coil is part of a circuit in which the resistance is 12 Ω. The mutual inductance between the two coils is 3.2 mH. Remembering Ohm's law and the fact that the induced emf in the secondary coil is because of the change in current in the primary coil, determine the change in the primary current, Δi_p.

Answer: The rate of change $\Delta I_p / \Delta t$, in the primary current is related to the emf ξ_S induced in the secondary coil according to $\xi_S = -M \Delta I_P / \Delta t$ (Equation 22.7), where *M* is the mutual inductance between the coils. We can use this expression to determine ΔI_p directly. However, in doing so, we will omit the minus sign, since the direction of the current is unspecified. A value for the induced emf can be obtained from the induced current I_S and the resistance *R* in the secondary circuit, according to $\xi_S = I_S R$, which is Ohm's law.

Substituting the induced emf from Ohm's law into Equation 22.7 (without the minus sign), and solving for ΔI_p gives

$$\xi_S = I_S R = M \frac{\Delta I_P}{\Delta t} \quad \text{or} \quad \Delta I_P = \frac{I_S R(\Delta t)}{M} = \frac{(6.0\times10^{-3}\ \text{A})(12\ \Omega)(72\times10^{-3}\ \text{s})}{3.2\times10^{-3}\ \text{H}} = \boxed{1.6\ \text{A}}$$

(4 marks)

QUESTION 4

a) Write some scientific response about the following:

i) the wave-particle-duality

Answer: A particle can behave or exhibit wave-like properties and a wave can exhibit particle-like properties.

iii) blackbody radiation

Answer: The intensity per unit wavelength of the radiation produced by a blackbody at any given temperature varies with wavelength and the maximum intensity occurs at a shorter wavelength.

iv) Photons.

Answer: Photons are particle-like quanta or packets of energy of electromagnetic waves

v) Heisenberg uncertainty principle.

Answer: Heisenberg uncertainty principle states that product of the uncertainty in position that an electron wave on a screen after passing thru a slit and its momentum change along the y-axis is probabilistic and has a minimum accuracy of $\frac{h}{4\pi}$;

$\Delta p_y \Delta y \geq \frac{h}{4\pi}$ or $\Delta E \Delta t \geq \frac{h}{4\pi}$

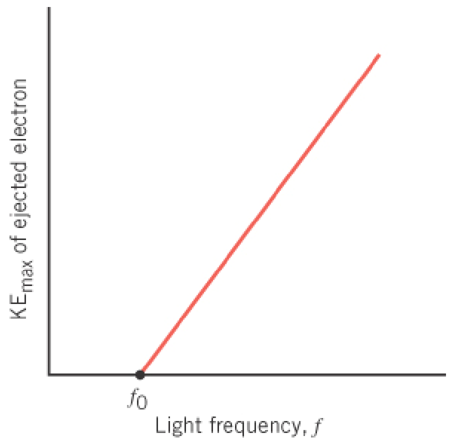
(10 marks)

b) i) Explain the photoelectric effect.

Answer: The process of emission of photoelectrons (photons) from the surface of a metal when light with energy higher than the work function of the metal shines on the surface.

(4 marks)

i) Draw an energy-frequency graph representing the phenomenon. Label all the axis.



(4 marks)

ii) A silver surface has a work function of 4.73 eV (1 eV = 1.6 x 10^{-19} J). Find the minimum frequency that light must have to eject electrons from this. (Planck's constant, h = 6.63 x 10^{-34} Js).

Answer: $W = hf_0 = 4.73eV \times 1.6 \times 10^{-19} \frac{J}{eV}$. Then

$$f_0 = \frac{W}{h} = \frac{4.73eV \times 1.6 \times 10^{-19} \frac{J}{eV}}{6.63 \times 10^{-34}\ Js} = 1.14 \times 10^{15}\ Hz.$$

(2 marks)

QUESTION 5

a) Write some scientific response about the following:

i) Rutherford's scattering

Answer: The deflection and back scattering of heavy alpha particles when bombarded onto a thin layer of gold led Rutherford to propose that the positive charge in an atom is confined to a small space and is now called the nucleus.

ii) Bohr's model of the hydrogen atom.

Answer: In a hydrogen atom there can only be certain allowed energies that the electron can have when orbiting around the nucleus, larger orbits correspond to larger energies.

iii) Balmer series

Answer: A group of lines belonging to the visible region of the electromagnetic spectrum representing photons emitted whenever there is a transition in an atom.

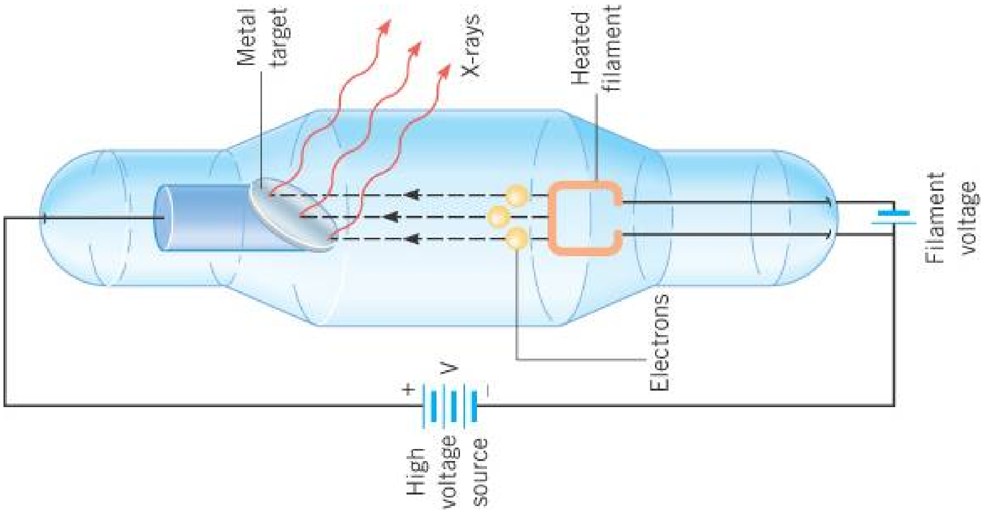
iv) ground state

Answer: The lowest energy state in an atom

(10 marks)

b) i) Describe, with the help of a picture, how x-rays are produced.

Answer:



Electrons are emitted from a heated filament and accelerated through a large voltage. When they strike the target, X-rays are emitted.

(7+3 = 10 marks)

PART B (100 MARKS)

QUESTION 1

a) Write some scientific response about the following:

i) the law of electrical charge conservation

Answer: Total amount of charges must be conserved in any process and the amount before and after must remain constant.

ii) charging by contact and induction

Answer: Charging by contact involves transfer of charges between objects whereas charging by induction involves bringing a charges object near an uncharged object to induce charges in the uncharged object to rearrange without any transfer of charges.

iii) Electric field lines

Answer: Electric field lines are lines in an area where a charged test charge will experience an acceleration if placed in this area due to the electrical forces exerted onto the test charge.

iv) Electric flux

Answer: Electric flux is the product of the parallel component of the electric field lines that pass through the surface area and the magnitude of the surface area.

(10 marks)

b) Consider three identical metal spheres, A, B, and C. Sphere A carries a charge of $+5q$. Sphere B carries a charge of $-q$. Sphere C carries no net charge. The following process were performed on the spheres:

1. Spheres A and B are touched together and then separated.
2. Sphere C is then touched to sphere A, and then separated from it.
3. Lastly, sphere C is touched to sphere B and separated from it.

i) What is the total charge on the three spheres before they are allowed to touch each other? Explain your answer.

Answer: Total charge is the sum of all the charges. So, $Q = q_1+q_2+q_3 = 5q-q+0 = 4q$.

ii) What is the total charge on the three spheres after they have touched? Explain your answer.

Answer: Using charge conservation, the total charge must remain the same before and after the process. Hence total charge after must be $+4q$.

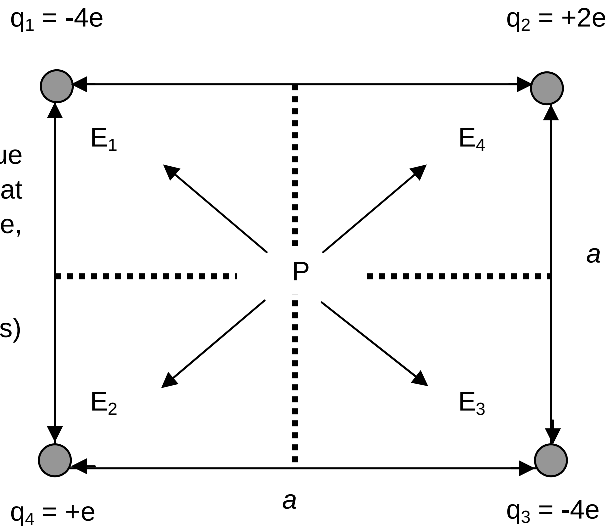
iii) Determine the amount of charges on each sphere after each of the process. Explain your answer.

Answer: When spheres A and B touch, an amount of charge $+q$, flows from A and instantaneously neutralizes the charge $-q$ on B leaving B momentarily neutral. Then, the remaining amount of charge, equal to $+4q$, is equally split between A and B, leaving A and B each with equal amounts of charge $+2q$. Sphere C is initially neutral, so when A and C touch, the $+2q$ on A splits equally to give $+q$ on A and $+q$ on C.

When B and C touch, the +2*q* on B and the +*q* on C combine to give a total charge of +3*q*, which is then equally divided between the spheres B and C; thus, B and C are each left with an amount of charge +1.5*q*

(2+2+6 = 10 marks)

c) The figure below shows a configuration of charged particles placed at the corners of a square measuring *a* by *a*



i) Draw and label the electric field due to each of the four charges at position P, the center of the square, E_1, E_2, E_3, and E_4.

(4 marks)

ii) Using Pythagoras theorem, determine the distance from P to the charge at the corners.

Answer: Use Pythagoras theorem: $r^2 = a^2 + b^2$. So, $r^2 = \left(\frac{a}{2}\right)^2 + \left(\frac{a}{2}\right)^2 = \frac{a^2}{2}$. Then $r = \frac{a}{\sqrt{2}}$

(2 marks)

iii) Write down the electric field strength for each of the charges at position P, E_1, E_2, E_3, and E_4.

Answer: Since $E = k\frac{q}{r^2}$, then, $E_1 = 2k\frac{4e}{a^2}$, $E_2 = 2k\frac{2e}{a^2}$, $E_3 = 2k\frac{4e}{a^2}$, $E_4 = 2k\frac{e}{a^2}$

(4 marks)

iv) Obtain the electric field along the x-axis and the electric field along the y-axis, respectively, for E_2 and E_4 at position P.

Answer: $E_{2x} = -2k\frac{2e}{a^2}\cos 45^\circ = -2k\frac{2e}{a^2}\frac{1}{\sqrt{2}}$, $E_{4x} = 2k\frac{e}{a^2}\cos 45^\circ = 2k\frac{e}{a^2}\frac{1}{\sqrt{2}}$

$$E_{2y} = -2k\frac{2e}{a^2}\sin 45^{\circ} = -2k\frac{2e}{a^2}\frac{1}{\sqrt{2}}, \quad E_{4x} = 2k\frac{e}{a^2}\sin 45^{\circ} = 2k\frac{e}{a^2}\frac{1}{\sqrt{2}}$$

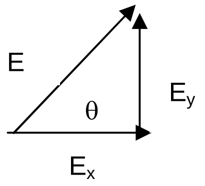
(8 marks)

v) Use the results of part (iv) and the symmetry of the problem to obtain the total electric field acting at position P.

Answer: By symmetry, E_1 and E_3 add up to zero in both the x and the y directions since they have the same magnitudes but act in opposite directions.

$$E_x = -E_{2x} + E_{4x} = -2k\frac{2e}{a^2}\frac{1}{\sqrt{2}} + 2k\frac{4e}{a^2}\frac{1}{\sqrt{2}} = \frac{4ke}{a^2}\frac{1}{\sqrt{2}},$$

$$E_y = -E_{2y} + E_{4y} = -2k\frac{2e}{a^2}\frac{1}{\sqrt{2}} + 2k\frac{4e}{a^2}\frac{1}{\sqrt{2}} = \frac{4ke}{a^2}\frac{1}{\sqrt{2}}$$



Then the total E is

$$E = \sqrt{E_x{}^2 + E_y{}^2} = \sqrt{\left(\frac{4ke}{a^2}\frac{1}{\sqrt{2}}\right)^2 + \left(\frac{4ke}{a^2}\frac{1}{\sqrt{2}}\right)^2} = \frac{4ke}{a^2}.$$

$$\tan\theta = \frac{E_y}{E_x} = \frac{\frac{4ke}{a^2}\frac{1}{\sqrt{2}}}{\frac{4ke}{a^2}\frac{1}{\sqrt{2}}} = 1. \; So\ \theta\ is\ 45^{\circ}$$

(8 marks)

vi) Explain what would happen to a positive test charge, q_0, if it was placed at position P.

Answer: A positive test charge will feel a force in the direction of the electric filed line and hence will accelerate in that direction with a magnitude of $a = \frac{F}{m} = \frac{q_0 E}{m} = \frac{q_0 4ke}{ma^2}$.

(4 marks)

QUESTION 2

a) Write some scientific response about the following:

i) alternating current
Answer: Current that changes direction after every cycle.

ii) parallel wiring
Answer: A type of wiring where the potential drop in each branch is the same.

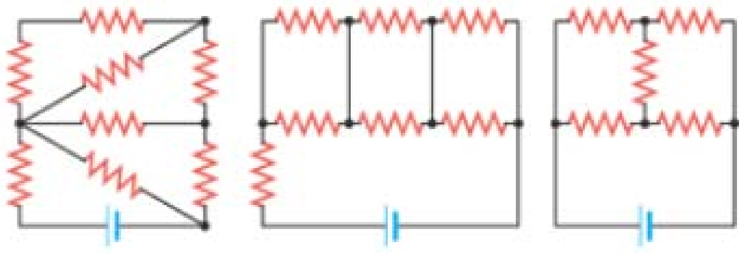
iii) Resistance
Answer: the opposing factor to the flow of current in a circuit.

iv) electrical power
Answer: Power is the amount of energy dissipated (lost) in a resistor in one second.

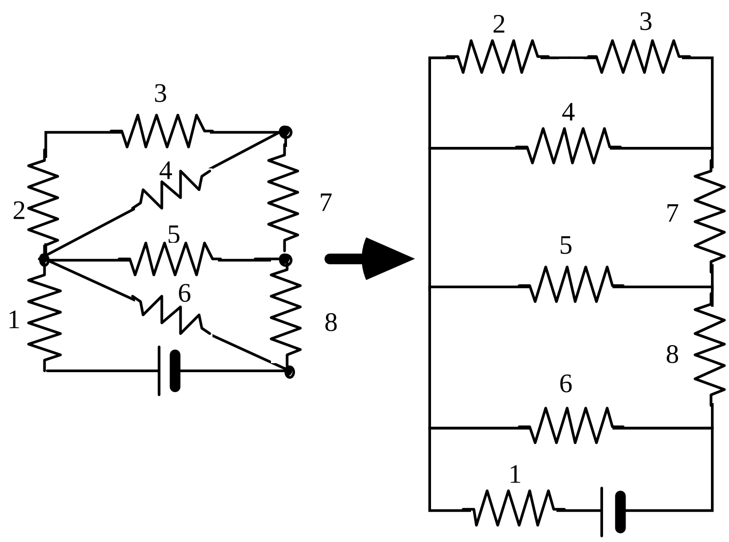
v) ammeter
Answer: Ammeter is a device (instrument) that is connected in series in a circuit and used to measure current through that circuit..

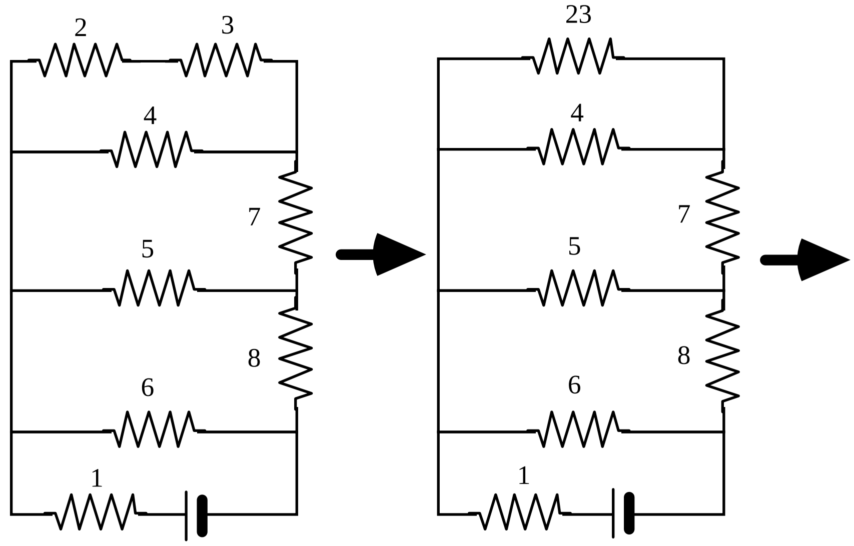
(10 marks)

b) Redraw each of the circuits on the right and identify which circuit is connected neither in series nor in parallel.

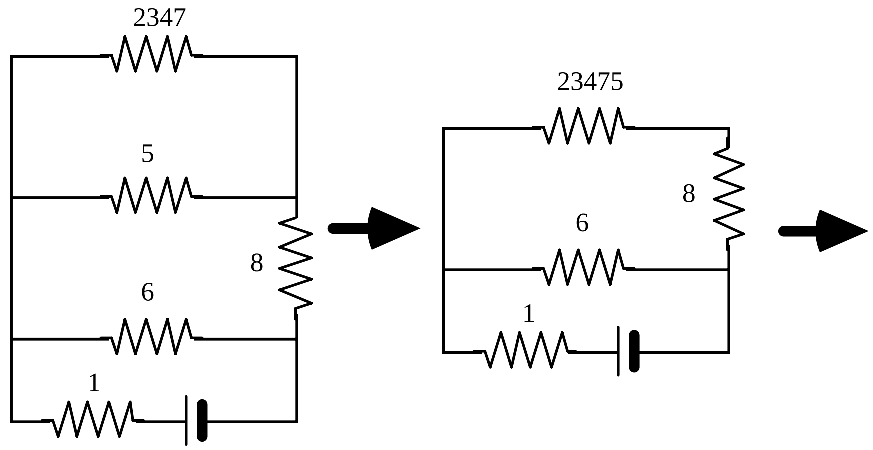


For the first circuit,

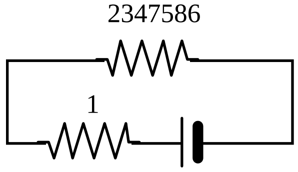




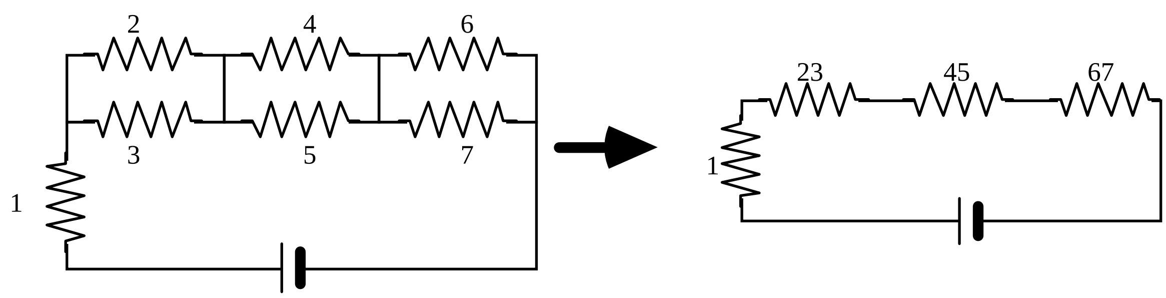
The resistors can further be rearranged as shown below:



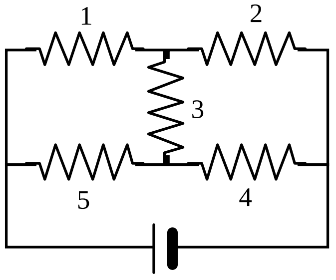
Finally, the resistors can be represented as,



For the second circuit, redrawing can be done as shown below:

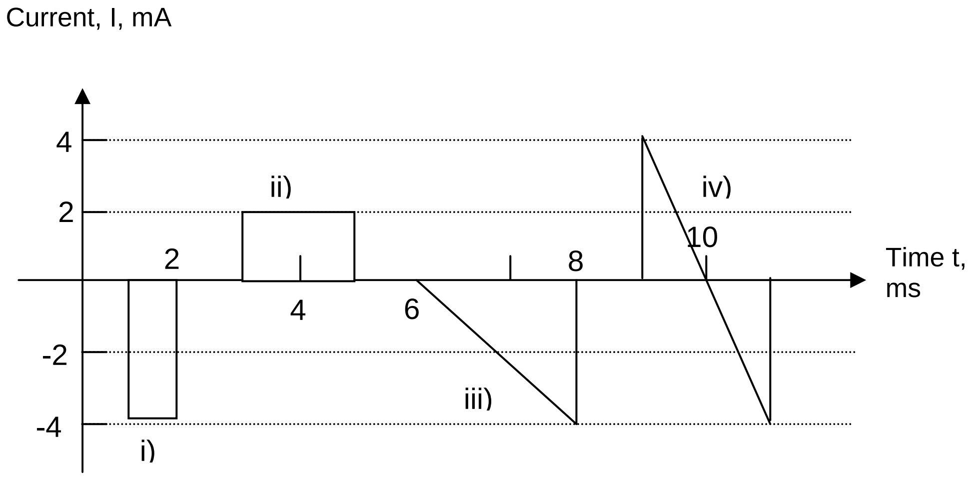


The last circuit could not be redrawn as was done for the first 2 circuits. Hence, this circuit does not have any resistors connected in series and in parallel.



(6+2+1+1 = 10 marks)

c) The figure below show plots of the electric current I through a certain cross section of a conducting wire over four different time periods. Determine the amount of net charge that pass through each cross section.



(2+2+2+2+2 = 10 marks)

Answer: The amount of charge is just the area since current is the amount of charge passing through in one second.

Section (i): $area = I\Delta t = -4mA \times 1ms = -4\mu C$

Section (ii): $area = I\Delta t = 2mA \times 2ms = 4\mu C$

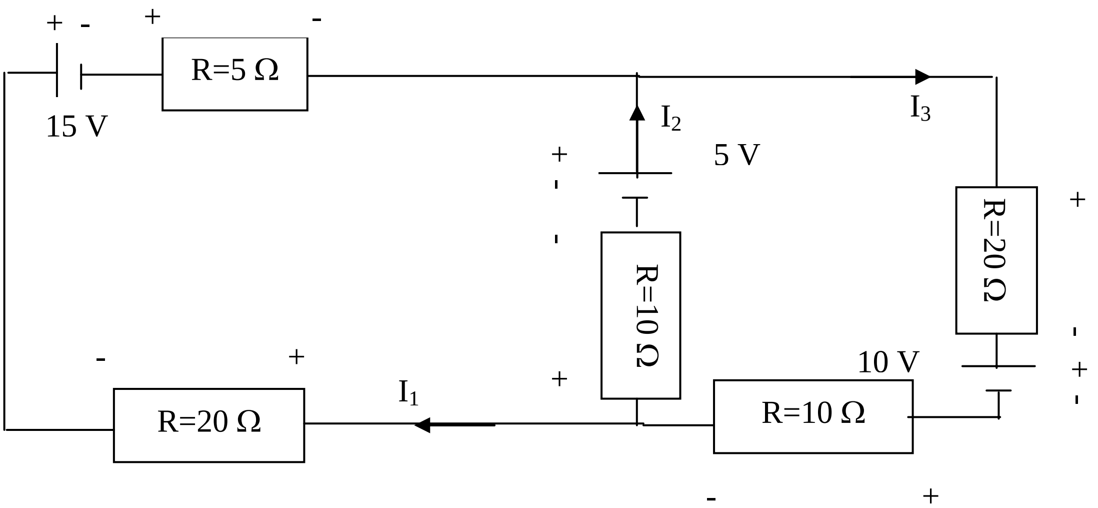
Section (iii): $area = I\Delta t = \frac{1}{2}\left(-4mA \times 2ms\right) = -4\mu C$

Section (iv): By symmetry, since the amount of charge above and the axis is the same then it adds up to zero.

d) Given the circuit below,

i) Label the '**+**' and '**–**' signs at the ends of each resistor and battery to indicate the high and low potential.

ii) Using Kirchoff's laws, and the results of part (i), determine the currents I_1, I_2, and I_3.



Show ALL your work.

<u>Answer</u>:

Kirchoff's current rule: Sum of currents into a junction must equal sum of current leaving.

$I_1 + I_2 = I_3$

Kirchoff's voltage rule: In a loop, Sum of potential drop must equal sum of potential rise.

Using clockwise motion:

Left loop $20I_1 + 15 + 5I_1 + 5 = 10I_2$. Rewrite: $25I_1 + 20 - 10I_2 = 0$

Right loop $20I_3 + 10 + 10I_3 + 10I_2 = 5$. Rewrite: $30I_3 + 10I_2 + 5 = 0$

Replace I_3 by I_1+I_2. $30I_1 + 40I_2 + 5 = 0$; $25I_1 + 20 - 10I_2 = 0$. Multiply by 4.

$100I_1 + 80 - 40I_2 = 0$. Add up to remove I_2. $130I_1 = -85$. So, $I_1 = -\frac{85}{130}A = -0.65A$.

Substitute I_1 into $25I_1 + 20 - 10I_2 = 0$. $-25\frac{85}{130} + 20 = 10I_2$. Then,

$I_2 = -25\frac{85}{1300} + 10 = 8.37A$. Finally, $I_3 = -0.65 + 8.35 = 7.7A$

(20 marks)

END OF QUESTION PAPER

