Physics (Theory)

[*Time allowed: 3 hours*] [*Maximum marks:70*]

General Instructions:

(i) **All** questions are compulsory.

(ii) There are **30** questions in total.
Questions **1** to **8** carry **one** mark each.
Questions **9** to **18** carry **two** marks each.
Question **19** to **27** carry **three** marks each.
Question **28** to **30** carry **five** marks each.

(iii) There is no overall choice. However, an internal choice has been provided in **one** question of **two** marks; **one** question of **three** marks and all **three** questions of **five** marks each. You have to attempt only one of the choices in such questions.

(iv) Use of calculators is **not** permitted.

(v) You may use the following values of physical constants wherever necessary:
$C = 3 \times 108\ ms^{-1}$
$H = 6.626 \times 10^{-34}$ Js
$e = 1.602 \times 10^{-19}$ C
$\mu_0 = 4\pi \times 10^{-7}$ Tm A^{-1}
$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ Nm^2C^{-2}$$
Mass of electron $m_e = 9.1 \times 10^{-31}$ kg
Mass of neutron $m_n \cong 1.675 \times 10^{-27}$ kg
Boltzmann's constant $k = 1.381 \times 10^{-23}\ JK^{-1}$
Avogadro's number $N_A = 6.022 \times 10^{23}\ mol^{-1}$
Radius of earth = 6400 km

9. (i) Net capacitance of three identical capacitors in series is 2 μF. What will be their net capacitance if connected in parallel?
(ii) Find the ratio of energy stored in the two configurations if they are both connected to the same source.

Solution:
(i) When connected in series, the net capacitance is 2 μF.

$$\Rightarrow \frac{1}{C}+\frac{1}{C}+\frac{1}{C}=\frac{1}{2}$$
$$\Rightarrow C = 6\ \mu\text{F}$$

When connected in parallel,

$C_{eq} = C_1 + C_2 + C_3 = 6\ \mu\text{F} + 6\ \mu\text{F} + 6\ \mu\text{F} = 18\ \mu\text{F}$.

(ii) Energy for series combination

$$E_s = \frac{1}{2}C_{\text{eq, s}}V^2 = \frac{1}{2}\times 2\times 10^{-6}\times V \qquad (1)$$

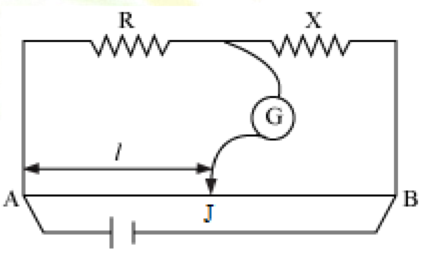
Energy for parallel combination

$$E_p = \frac{1}{2}C_{\text{eq, p}}V^2 = \frac{1}{2}\times 18\times 10^{-6}\times V \qquad (2)$$

As both are connected to the same source

Hence, $\dfrac{E_s}{E_p} = \dfrac{\frac{1}{2}\times 2\times 10^{-6}\times V}{\frac{1}{2}\times 18\times 10^{-6}\times V} = \dfrac{1}{9}$

10. In the meter bridge experiment, balance point was observed at J with AJ = *l*.
(i) The values of R and X were doubled and then interchanged. What would be the new position of balance point?
(ii) If the galvanometer and battery are interchanged at the balance position, how will the balance point get affected?

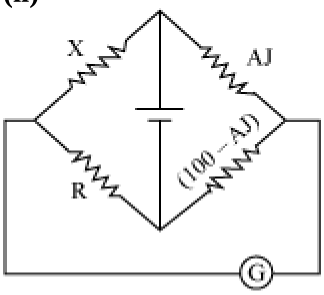


Solution:

(i) As the ratio of $\dfrac{R}{X}$ is now interchanged by $\dfrac{2X}{2R}=\dfrac{X}{R}$, the new balance point will be

$= 100 - l = 100 - AJ \left(\text{as } \dfrac{R}{X} = \dfrac{l}{100-l}\right)$

(ii)



At the balance position there is no current flowing through the galvanometer. Hence, interchanging the battery and the galvanometer will have no effect on the balance point.

11. Write the expression for Lorentz magnetic force on a particle of charge 'q' moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$. Show that no work is done by this force on the charged particle.

OR

A steady current (I_1) flows through a long straight wire. Another wire carrying steady current (I_2) in the same direction is kept close and parallel to the first wire. Show with the help of a diagram how the magnetic field due to the current I_1 exerts a magnetic force on the second wire. Write the expression for this force.

Solution:

Lorentz magnetic force, $\vec{F} = q\left(\vec{v} \times \vec{B}\right)$

Work done due to Lorentz force

$$W = \vec{F} \cdot \vec{r}$$

$$= q\left(\vec{v} \times \vec{B}\right) \cdot \vec{r}$$

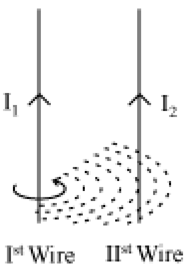
$$= q\left[\vec{B} \cdot \vec{r} - \vec{v} \cdot \vec{r}\right]$$

$$= q\left[0 - 0\right] = 0$$

$as\, \vec{r} \perp \vec{B}$ and $\vec{r} \perp \vec{v}$

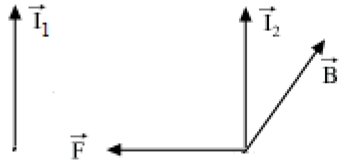
Hence, work done by the force on the charged particle will be zero.

OR



Magnetic field $\vec{B}$, will be moving into the page and I_2 is moving upward on the plane of the page.

Hence,



For a length L of the wire carrying the current I_2,
The force can be expressed as

$$F_{21} = I_2 L B_1$$

$$= \frac{\mu_0 I_1 I_2}{2\pi d} L$$

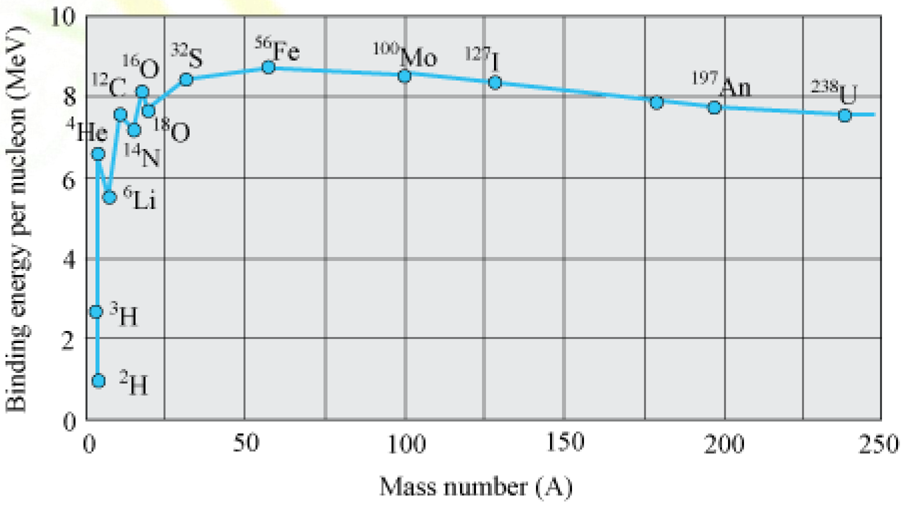
Where, d is the separation of the two wires. This force F_{21} will be directed towards the wire I_1 from the wire I_2.

12. State the principle of working of a transformer. Can a transformer be used to step up or step down a d.c. voltage? Justify your answer.

Solution:
The working principle of the transformer is the mutual induction. The magnetic flux linked with the primary winding of the transformer must change, to produce an induced emf in the secondary coil.
Transformers cannot work on DC voltages. If a DC supply is given to the primary coil of a transformer, it produces a **steady magnetic flux.** So, no emf will be induced in the secondary coil.

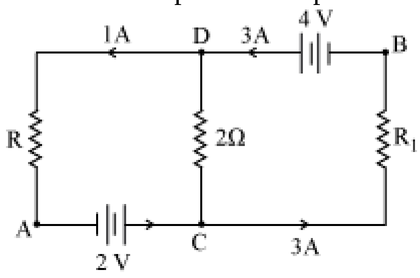
13. Using the curve for the binding energy per nucleon as a function of mass number A, state clearly how the release in energy in the processes of nuclear fission and nuclear fusion can be explained.

Solution:

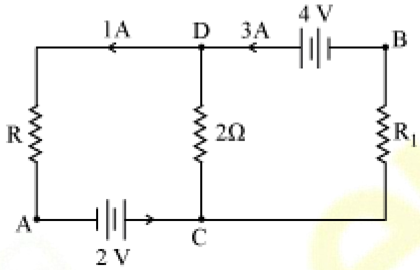


The rising of the binding energy curve at low mass numbers, indicates that energy will be released if two nuclides of small mass number combine to form a single middle-mass nuclide. This process is called nuclear fusion.
Highest peak (Fe) represents the most stable nucleus and all the other nuclei tend to achieve this state by undergoing nuclear reaction.
The eventual dropping of the binding energy curve at high mass numbers indicates that nucleons are more tightly bound when they are assembled into two middle-mass nuclides rather than into a single high-mass nuclide. Hence energy can be released by the nuclear fission, or splitting, of a single massive nucleus into two smaller fragments.

14. In the given circuit, assuming point A to be at zero potential, use Kirchhoff's rules to determine the potential at point B.



Solution:



According to Kirchhoff's Junction Law, when applied at junction D:
Incoming current = outgoing current
So, 3A = 1A + current through 2Ω.
Hence, current through 2Ω is 2A from D to C. Applying Kirchhoff's law to the loop containing R_1, 2Ω and 4V.
3A is the current through R1 as the current coming out from the 4V battery is 3A.

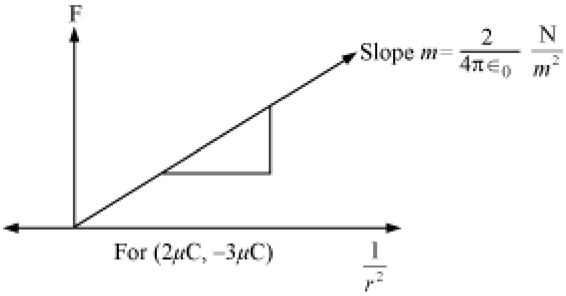
$4 = 3 \times R_1 + 2 \times 2$
$\Rightarrow R_1 = 0\ \Omega$

So, no potential drop between B and C.
Now lets analyse the bigger loop containing 4V, R and 2V (R_1 can be omitted now); here the 4V and 2V are connected in series with B as a point between the two batteries. So we finally have the potential at B to be 2V.

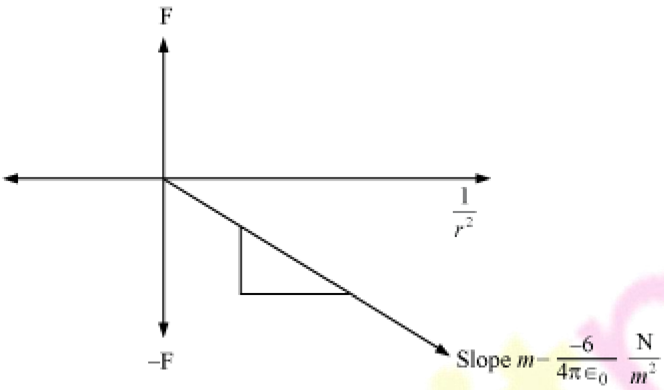
15. Plot a graph showing the variation of coulomb force (F) versus $\left(\frac{1}{r^2}\right)$, where r is the distance between the two charges of each pair of charges: (1 μC, 2 μC) and (2 μC, – 3 μC). Interpret the graphs obtained.

Solution:

I am answering it as Graph between F vs $\frac{1}{r^2}$ for (1μC, 2μC)



For (2μC, –3μC)

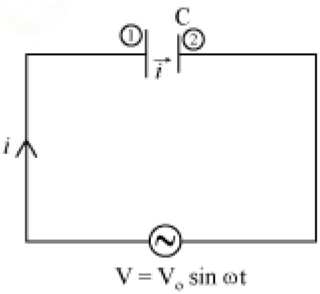


Interpretation

- Graphs show that $F \propto \frac{1}{r^2}$
- Slope gives a constant value and depends only on nature of charges and medium.
- Ist graph is for repulsive force in Ist quadrant and IInd graph is for attractive force in IVth quadrant i.e., F > 0 and F < 0 respectively.

16. A parallel plate capacitor is being charged by a time varying current. Explain briefly how Ampere's circuital law is generalized to incorporate the effect due to the displacement current.

Solution:



When a capacitor is connected to an alternating current, it offers a resistance $X_c\left(=\frac{1}{\omega c}\right)$ and allows the current to pass through.

As the current is moving from plate (1) to plate (2) there should be a magnetic field associated with this current as explained by Ampere circuital law, but as there can't be movement of actual electrons from plate (2) to plate (1), there will be no physical current, and still there will be a magnetic field.
To solve this paradox Maxwell altered the form of Ampere's law as followed.
Original form

$$\int_c \vec{B}\cdot\vec{dl} = \mu_0 i$$

Changed form

$$\int_c \vec{B}\cdot\vec{dl} = \mu_0 i + \mu_0 \in_0 \frac{d\phi_E}{dt}$$

$$= \mu_0 \left(i + i_D\right)$$

$i_D = \in_0 \dfrac{d\phi_E}{dt}$ (Displacement current)

ϕ_E = Electric flux

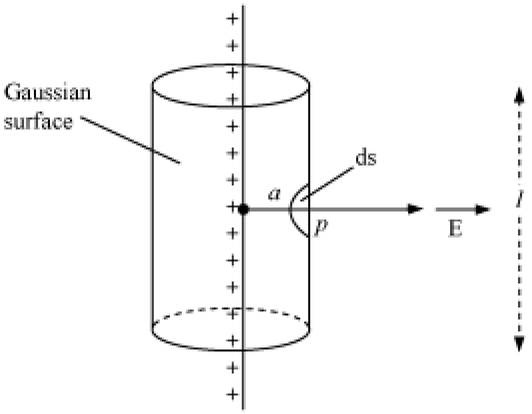
By introducing displacement current, Maxwell argued that due to change in electric field associated with alternating voltage, there will be a time dependent electric flux. This flux will cause a displacement current and hence there will be a magnetic field.

17. What is ground wave communication? On what factors does the maximum range of propagation in this mode depend?

Solution:
When the radio waves from the transmitting antenna propagate along the surface of the earth to reach the receiving antenna, it is called ground wave communication. For this type of communication, the frequency range is less than a few MHz. The maximum range depends on the absorption of energy by the earth and also on the initial transmitting power.

18. A thin straight infinitely long conducting wire having charge density λ is enclosed by a cylindrical surface of radius *r* and length *l*, its axis coinciding with the length of the wire. Find the expression for the electric flux through the surface of the cylinder.

Solution:



The thin infinitely long straight line has a linear charge density λ.
Since the electric field for this kind of configuration will be radial and perpendicular to the wire, there will be no flux through the flat surfaces of the cylinder. Also, the electric field (E) will be constant at every point on the curved surface of the cylinder (as all points on it are equidistant from the wire) and perpendicular to it.
We shall us Gauss's law to find the electric flux through the cylinder. The charge enclosed by the cylinder is $\lambda \times l$, as l is the length of the cylinder and it is also the length of the charged wire within the cylinder.
We know,

$$\text{Electric flux} = \frac{\text{Charge enclosed}}{\varepsilon_0} = \frac{\lambda l}{\varepsilon_0}$$