PART – I

1. (c)
2. (d)
3. (a)
4. (d)
5. (b)
6. (c)
7. (b)
8. (b)
9. (d)
10. (c)
11. (b)
12. (d)
13. (d)
14. (d)
15. (d)

PART – II

16. In the context of semiconductors, doping refers to the intentional introduction of a small amount of impurity atoms into a pure (intrinsic) semiconductor to change its electrical properties. This is done to increase the number of free charge carriers—electrons or holes—so the material can conduct electricity more efficiently.

There are two main types of doping: -

(i). n-type doping: -

- A pentavalent element (with 5 valence electrons) like Phosphorus (P), Arsenic (As), or Antimony (Sb) is added to a semiconductor like silicon (Si).
- Four electrons of the dopant form covalent bonds with silicon atoms, leaving one extra free electron.
- Result: The semiconductor has more electrons as charge carriers (negative carriers), hence "n-type."

(ii). p-type doping: -

- A trivalent element (with 3 valence electrons) like Boron (B), Aluminum (Al), or Gallium (Ga) is added.
- These form bonds with silicon, but one bond is incomplete, creating a "hole" (a positive charge carrier).
- Result: The semiconductor has more holes as charge carriers, hence "p-type."

Key point: Doping does not change the crystal structure, only the number of charge carriers.

17. X-rays are a form of high-energy electromagnetic radiation, and they have many important applications in medicine, industry, and science because they can pass through materials that are opaque to visible light. Here's a clear breakdown of their uses:

(i). Medical Uses: -

- X-ray Radiography (Imaging bones):
- Used to view broken bones, fractures, and dental cavities.
- Fluoroscopy:
- Real-time X-ray imaging to see internal organs in motion, e.g, digestive system.
- Computed Tomography (CT scan):
- Produces detailed 3D images of internal organs and tissues.
- Cancer Treatment (Radiotherapy):
- High doses of X-rays are used to kill cancerous cells.

(ii). Industrial Uses: -

- Non-destructive Testing (NDT):
- Detect cracks, flaws, or defects in metals, welds, or pipelines.
- Security:
- Used in airport scanners to inspect luggage for dangerous items.

(iii). Scientific Uses: -

- Crystallography (X-ray diffraction):
- Determine structures of crystals and molecules, e.g., DNA structure was discovered using X-ray crystallography.
- Material Analysis:
- Identify elements and compounds in substances.

(iv). Miscellaneous Uses: -
- Art Authentication:
- Reveal underlying layers in paintings or detect forgeries.
- Astronomy:
- Observing X-ray emission from stars, black ′ ↓ 35, and other cosmic sources.

18. Step (1): Identify given values and the relevant principle

The given values are:
- Primary turns, $N_p = 460$
- Secondary turns, $\mathrm{N_s} = 40{,}000$
- Primary voltage, $V_P = 230$ V

For an ideal transformer, the voltage per turn is constant in both the primary and secondary coils, which is described by the transformer equation:

$$\frac{V_p}{N_p} = \frac{V_s}{N_s}$$

The voltage per turn is $\frac{V}{N}$.

Step (2): Calculate the voltage per turn in the primary coil

The voltage developed per turn in the primary coil is calculated using the primary voltage and the number of primary turns:

$$\text{Voltage per turn } = \frac{V_p}{N_p} = \frac{230\text{ V}}{460\text{turns}} = 0.5\text{ V/tum}$$

Step (3): Determine the voltage per turn in the secondary coil

Since the transformer is ideal, the voltage developed per turn in the secondary coil is the same as that in the primary coil.

Voltage per turn of secondary = Voltage per turn of primary = 0.5 V /turn

19.

No.	Fresnel diffraction	Fraunhofer diffraction
(i).	The Source of light and screen is kept at a finite distance.	The Source of light and screen is at infinite distance.
(ii).	Spherical or cylindrical wavefronts are considered.	Only plane wavefronts are considered.
(iii).	It is observed in straight edge, narrow slit, etc.	It is observed in the single slit, double slit, etc.
(iv).	Lenses are not used.	Convex lenses are used.

20. Corona discharge is a phenomenon in high-voltage electricity where the air around a conductor becomes ionized and starts conducting electricity locally, without a complete breakdown (spark) between conductors.

Key Points:

(i). Definition: -

It is the ionization of air near sharp points or edges of a high-voltage conductor, resulting in a faint glow, hissing sound, and ozone production.

(ii). Conditions for Corona Discharge: -
- Occurs when the electric field intensity near the conductor exceeds the dielectric strength of air ($\sim$ 30kV/cm).
- More likely at sharp edges, points, or thin wires (because electric field is stronger there).
- Happens in high-voltage AC or DC transmission lines.

(iii). Characteristics: -
- Partial discharge: current does not flow fully between conductors.
- Produces a blue or violet glow.
- Hissing or crackling noise is audible.
- Generates ozone (O_3) and other nitrogen oxides.

(iv). Advantages: -
- Sometimes used deliberately in ozone generators for water purification.

(v). Disadvantages: -
- Power loss in high-voltage lines.
- Can damage insulation over time.
- Causes radio interference.

21. A skip area, or skip zone, is a region around a radio transmitter where signals can't be received, located between the range of the ground wave (following the Earth) and the first return of the sky wave (bouncing off the ionosphere). This "silent zone" occurs because signals don't effectively travel along the ground far enough, and the sky waves either pass through or are too weak to reflect back to that specific area, with its size depending on frequency, time of day, and ionospheric conditions.

How it Happens: -
(i) Ground Waves: Radio waves travel along the Earth's surface but weaken and get absorbed as distance increases.
(ii) Sky Waves: Other waves travel upwards to the ionosphere (a layer in the atmosphere).
(iii) Ionospheric Reflection: The ionosphere reflects some radio waves back to Earth, allowing for long-distance communication.
(iv) The Gap: The skip zone is the area where the ground wave signal dies out before the reflected sky wave signal arrives back on Earth.

Key Characteristics: -
- Location: An annular (ring-shaped) area around the transmitter.
- No Signal: No reception of either ground waves or reflected sky waves.
- Variable Size: Larger at night and smaller (or non-existent) during the day, depending on ionospheric density and working frequency.
- Frequency Dependent: Higher frequencies (like VHF/UHF) often pass through the ionosphere, making skywave communication rare and affecting the skip zone.3

22. Neutrinos are elusive, neutral elementary particles with nearly zero mass, spin 1/2 (fermions), and no strong or electromagnetic charge, meaning they interact primarily through the weak nuclear force and gravity, allowing them to pass through matter almost unimpeded; they come in three "flavors" (electron, muon, tau) and can oscillate between them, making them abundant "ghost particles" from the Sun and other sources, vital for understanding astrophysics and particle physics.

Key Properties: -
- No Electric Charge: Neutrinos are electrically neutral, hence the name "neutrino" (little neutral one).
- Very Small Mass: Once thought massless, experiments show they have tiny, but non-zero, masses, far less than other particles.
- Spin 1/2: They are fermions, following the rules for particles with half-integer spin.
- Weak & Gravitational Interaction: They only feel the weak nuclear force and gravity, not the strong or electromagnetic forces, making them extremely hard to detect.
- Three Flavors: There are three types: electron neutrino ($\boldsymbol{v_e}$), muon neutrino ($\boldsymbol{v_\mu}$), and tau neutrino ($\boldsymbol{v_\tau}$).
- Neutrino Oscillation: They can change from one flavor to another as they travel, a phenomenon that proved they have mass.
- Abundant "Ghost Particles": Billions pass through you every second from the Sun, yet you feel nothing.

23. Step (1): Calculate the susceptibility of each material

The magnetic susceptibility ($\mathcal{X}$) is defined as the ratio of the intensity of magnetization (I) to the magnetizing field (H), given by the formula $\chi = \frac{I}{H}$.

For material X, the susceptibility χ_X is calculated as:

$$\chi_X = \frac{I_X}{H} = \frac{500\text{Am}^{-1}}{1000\text{Am}^{-1}} = 0.5$$

For material Y, the susceptibility χ_Y is calculated as:

$$\chi_Y = \frac{I_Y}{H} = \frac{2000\text{Am}^{-1}}{1000\text{Am}^{-1}} = 2.0$$

Step (2): Determine the ratio between the susceptibilities

The ratio of the susceptibility of material X to material Y is found by dividing χ_X by $\chi_Y \dot{E}$

$$\frac{\chi_X}{\chi_Y} = \frac{0.5}{2.0} = \frac{1}{4}$$

24. Electrons are preferred over X-rays in high-resolution microscopy primarily because they interact much more strongly with matter, allowing for better focusing and detection, and their extremely short wavelengths (determined by their high momentum) provide vastly superior resolution compared to even X-rays for imaging nanoscale structures, enabling visualization of individual atoms. While X-rays have short wavelengths, they penetrate too deeply and scatter too weakly for efficient, focused imaging, making them less practical for the detailed, high-magnification microscopy electrons offer.

(i) Key Advantages of Electrons: -

- Stronger Interaction: Electrons (charged particles) interact powerfully with the electromagnetic fields of atoms, scattering significantly (high cross-section). X-rays (photons) interact weakly, making them harder to focus and detect efficiently for imaging.
- Superior Resolution: The de Broglie wavelength of an accelerated electron is incredibly short, much shorter than X-rays or visible light, directly translating to much higher resolving power, crucial for seeing tiny details like atoms.
- Focusing Capabilities: Magnetic lenses, used in electron microscopes, can effectively focus electron beams, which is difficult with X-rays.
- Lower Dose for Imaging: Electron microscopy can achieve high-resolution molecular imaging with significantly lower radiation doses compared to X-ray microscopy, protecting beam-sensitive samples.

(ii) Why X-rays are Less Ideal for High-Res Microscopy: -

- Weak Interaction: X-rays tend to pass through samples, interacting nondirectionally, making it difficult to form coherent, efficient images with high contrast.
- Focusing Challenges: Effectively focusing X-rays for microscopy is a major technical hurdle, limiting their practical resolution compared to electrons.

In essence, electrons offer a better balance of short wavelength, strong interaction, and focus ability, making them the tool of choice for resolving the finest details in materials science and biology, far surpassing X-rays for this purpose.

PART – III

25. A galvanometer is converted into a voltmeter by connecting a high resistance in series with it, which increases its total resistance and allows it to measure potential difference (voltage) without significantly affecting the circuit, with the scale then calibrated to read volts directly.

Here's a breakdown of the process: -

(i) Add a Series Resistor (R): A large resistor is placed in series with the galvanometer's coil.

(ii) Increase Total Resistance: The total resistance of the voltmeter becomes $G + R$ (where G is the galvanometer's internal resistance), making it very high, as seen in Vedantu's explanation.

(iii) Calibrate the Scale: The galvanometer's original current scale (e.g., milliamperes) is then relabeled (calibrated) to display voltage (volts), based on the known voltage drop across the series resistor and galvanometer.

(iv). Connection in Circuit: The resulting voltmeter is connected in parallel across the component whose voltage is to be measured, ensuring it draws minimal current from the circuit.

This modification allows the galvanometer to measure voltage accurately, protecting the sensitive coil and extending its measuring range.

26. Let's solve this step by step.

We are given: -

- Resistance at 0°C: $R_0 = 10\Omega$
- Temperature coefficient of resistance: $\alpha = 0.004/\,^\circ\text{C}$
- Temperature of boiling water: $T = 100^\circ\text{C}$

We are asked: Resistance at 100°C and comment.

Step (1): Formula for resistance at temperature T
The resistance of a conductor at temperature T is:
$R_T = R_0[1 + \alpha(T - 0)]$
$R_T = R_0(1 + \alpha T)$
Step (2): Substitute values
$R_{100} = 10[1 + 0.004 \cdot 100]$
$R_{100} = 10[1 + 0.4]$
$R_{100} = 10 \cdot 1.4 = 14\Omega$
Step (3): Comment on the result
- The resistance increased from 10Ω to 14Ω as the temperature rose from $0^\circ\mathrm{C}$ to $100^\circ\mathrm{C}$.
- This is expected because nichrome is a metal, and metals generally increase in resistance with temperature due to increased collisions of electrons with vibrating ions.

27. The average binding energy curve shows nuclei with mass numbers around Iron (A $= 56$) are most stable (peak), while lighter nuclei (A<20) and heavier ones (A>180) are less stable, explaining the energy release in nuclear fusion (light nuclei combining towards
the peak) and fission (heavy nuclei splitting towards the peak). Key inferences are the peak stability at Iron, the instability of extremes, and that energy is released when reactions move towards this peak, forming the basis for nuclear power.

Key Inferences: -
(i). Nuclear Stability: The curve's peak (around Iron-56) represents the most stable nuclei, as they have the highest binding energy per nucleon, meaning more energy is needed to break them apart.
(ii). Energy from Fusion: Light nuclei (left side of the curve, e.g., Hydrogen) are less stable; fusing them to form heavier nuclei up to Iron releases significant energy.
(iii). Energy from Fission: Heavy nuclei (right side of the curve, e.g., Uranium) are also less stable; splitting them (fission) into lighter, more stable nuclei releases energy.
(iv). Nuclear Reactions: The curve predicts that nuclear reactions (fusion and fission) release energy when they move towards the peak of stability ($A = 56$).
(v). Exceptional Stability: Small, distinct peaks for nuclei like Helium-4 ($^4_2 He), Carbon - 12(^{12}_6C), andOxygen - 16(^{16}_8$0) indicate they are more stable than their neighbors.
(vi). Instability of Extremes: Nuclei with very small (like Hydrogen) or very large (like Uranium) mass numbers are inherently less stable due to lower binding energy per nucleon.

28. To find the values of I_B, I_C, and β for the given transistor circuit, we apply Krchhoff's Voltage Law (KYL) to the input and output loope.
(i)Finding Base Current (I_B)
We apply KVL to the base-emitter (input) loop. Aseuming the transistor is a standard slicon NPN trancistor, the base-emitter voltage V_{BE} is approximately 0.7 V .
$V_i = I_B R_B + V_{BE}$
Substituting the given values:
- $V_i = 20$ V
- $R_B = 500\mathrm{k}\Omega = 500 \times 10^3\Omega$
-$V_{BE} = 0.7$ V
$20 = I_B(500 \times 10^5) + 0.7$
$19.3 = I_B(500 \times 10^5)$
$I_B = \frac{19.3}{500 \times 10^3} = 38.6 \times 10^{-6}$ A $= 38.6\mu$ A
(ii) Finding Collector Current (I_C)
We apply KVL to the collector-emitter (output) loop. The problem provides the collectoremitter voltage $V_{CE} =$ 0 V.
$V_{CC} = I_C R_C + V_{CE}$
Substituting the given values:
- $V\alpha c = 20$ V
- $R_c = 4\mathrm{k}\Omega = 4 \times 10^3\Omega$
- $V_{cz} = 0$ V

$20 = I_C(4 \times 10^5) + 0$

$I_C = \frac{20}{4 \times 10^8} = 5 \times 10^{-3}$ A = 5 mA

(iii) Finding Current Gain (β)

The DC current gain β is the ratio of the collector current to the base current:

$\beta = \frac{I_C}{I_B}$

$\beta = \frac{5 \times 10^{-\xi}}{38.6 \times 10^{-6}} \approx 129.5$

29. (i). Concept of Parallel Connection

- In a parallel connection, the capacitors are connected such that all their terminals are connected to the same two points.
- This means:

$V = V_1 = V_2 = V_3 = \cdots = V_n$

where V is the voltage across each capacitor.

(ii). Total Charge

- Let $C_1, C_2, C_3, \ldots, C_n$ be the capacitances connected in parallel.
- When a voltage V is applied:

$Q_1 = C_1 V, Q_2 = C_2 V, Q_3 = C_3 V, \ldots$

- The total charge stored by the combination is:

$Q_{\text{total}} = Q_1 + Q_2 + Q_3 + \cdots + Q_n$

$Q_{\text{tatal}} = C_1 V + C_2 V + C_3 V + \cdots + C_n V$

$Q_{\text{total}} = V(C_1 + C_2 + C_3 + \cdots + C_n)$

(iii) Define Equivalent Capacitance

- Let C_{eq} be the equivalent capacitance of the parallel combination.
- By definition:

$Q_{\text{total}} = C_{\text{eq}} \cdot V$

(iv). Compare and Solve

$C_{\text{eq}} \cdot V = V(C_1 + C_2 + C_3 + \cdots + C_n)$

$\boxed{C_{\text{eq}} = C_1 + C_2 + C_3 + \cdots + C_n}$

30. **(i).** Advantages of AC over DC: -

- Efficient Transmission: AC voltage can be easily stepped up (high voltage, low current) or down using transformers, allowing it to travel long distances with minimal energy loss, unlike DC.
- Voltage Versatility: Transformers make voltage changes simple and cheap, suiting various needs (e.g., high for transmission, low for homes).
- Easier Generation & Conversion: AC generators are simpler, and AC can be readily converted to DC for electronic devices.
- Motor Efficiency: AC motors often lack commutators (mechanical parts), leading to simpler design, lower maintenance, and better efficiency in high-speed applications.
- Simpler Circuit Breaking: Its periodic zero-crossing makes interrupting AC current easier for circuit breakers compared to DC.

(ii). Disadvantages of AC over DC: -

- Higher Danger at High Voltages: High-voltage AC poses greater shock risks and is more hazardous to work with than low-voltage DC.
- Electromagnetic Interference: AC produces EMI, which can disrupt sensitive electronics.
- Skin Effect: Current tends to flow near the conductor's surface, increasing resistance and energy loss at high frequencies.
- Not Ideal for All Processes: Processes like electroplating, refining, and battery charging require stable DC, necessitating conversion from AC.
- Storage Issues: AC needs conversion to DC for storage in batteries, adding complexity and cost.

When DC is Preferred: -

- Electronics: Laptops, smartphones, EVs (batteries, circuits).
- Energy Storage: Batteries, solar panels.
- Industrial: Electroplating, refining, electric railways (HVDC systems).

31. When two light sources of equal amplitude (A) interfere, the ratio of maximum to minimum intensity is infinite $(\omega: 0)$ because maximum intensity ($I_{\max}$) is $4A^2$ (constructive interference) and minimum intensity ($I_{\min}$) is 0 (destructive interference). This results from

$I_{\max} = (A + A)^2 = 4A^2$ and $I_{\min} = (A - A)^2 = 0$, making the ratio $4A^2/0$.

Here's the step-by-step breakdown:

(i) Intensity & Amplitude Relationship: Intensity (I) of light is proportional to the square of its amplitude (A), i.e., $I \propto A^2$.

(ii) Equal Amplitudes: Let the amplitude of each source be $A_1 = A_2 = A$.

(iii) Maximum Intensity ($I_{\max}$): Occurs during constructive interference, where waves add up (phase difference 0 or 2π).

(a)Resultant Amplitude: $A_{\max} = A_1 + A_2 = A + A = 2A$.

(b) $I_{\max} \propto (2A)^2 = 4A^2$.

(iv) Minimum Intensity (I_{min}) : Occurs during destructive interference, where waves cancel out (phase difference π).

(a) Resultant Amplitude: $A_{\min} = A_1 - A_2 = A - A = 0$.

(b) $I_{\min} \propto (0)^2 = 0$.

(v) Ratio: The ratio of maximum to minimum intensity is:

$\frac{I_{\max}}{I_{\min}} = \frac{4A^2}{0} = \infty(or\ 4A^2: 0)$.

32. (i). de-Broglie Hypothesis

- Louis de-Broglie proposed that all matter has wave properties.
- The wavelength λ associated with a particle of momentum p is:

$$\lambda = \frac{h}{p}$$

where: -

- h = Planck's constant $(6.626 \times 10^{-34}\text{Js})$
- p = momentum of the particle

(ii). Electron Accelerated Through a Potential Difference

- Let an electron be accelerated through a potential difference V.
- It gains kinetic energy:

$$K.E. = eV$$

where:

- e = charge of electron $(1.602 \times 10^{-19}\text{C})$
- V = accelerating voltage

(iii) Kinetic Energy and Momentum

- The kinetic energy of the electron is related to its momentum:

$$K.E. = \frac{1}{2}mv^2$$

where m = mass of electron, v = velocity.

- Momentum:

$$p = mv$$

- From kinetic energy:

$$v = \sqrt{\frac{2K.E.}{m}} = \sqrt{\frac{2eV}{m}}$$

$$p = mv = m\sqrt{\frac{2eV}{m}} = \sqrt{2meV}$$

33. Here's a clear explanation of why modulation helps reduce antenna size in wireless communication:

(i). Background: -

- In wireless communication, antennas are designed to be roughly of the order of the wavelength λ of the signal.
- The length of a practical antenna is typically:

$$L \approx \frac{\lambda}{2} \text{ or } \frac{\lambda}{4}$$

- Wavelength and frequency are related by:

$\lambda = \frac{c}{f}$

where: -

- c = speed of light (3×10^8 m/s)
- f = frequency of the wave

(ii). Problem with Low-Frequency Signals: -

- Suppose the signal is a voice signal with $f \sim 10^3$Hz(1kHz).
- Then the wavelength:

$$\lambda = \frac{3 \times 10^8}{10^3} = 3 \times 10^5 \text{ m} = 300 \text{ km}$$

- Clearly, building an antenna 300 km long is impossible!

(iii) Role of Modulation: -

- Solution: Use high-frequency carrier waves (radio frequency) to carry the low-frequency signal.
- Let the carrier frequency be $f_c \sim 10^6$ Hz(1MHz) :

$$\lambda_c = \frac{3 \times 10^5}{10^6} = 300 \text{ m}$$

- A 300 m wavelength allows a practical antenna.
- The information (voice, data) is still preserved because it is imprinted on the carrier via modulation (AM or FM).

PART – IV

34. (a) (i). Magnetic Flux through the Coil

- Consider a coil of N turns, each of area A, placed in a uniform magnetic field B.
- Let θ be the angle between the normal to the plane of the coil and the magnetic field.

The magnetic flux through the coil is:

$\Phi = N \cdot B \cdot A \cdot \cos\theta$

where: -

- N = number of turns
- B = magnetic field strength
- A = area of one turn of the coil

(ii) Coil Rotating in a Magnetic Field

- Suppose the coil rotates with angular velocity &).
- Then the angle changes with time

$\theta = \omega t$

So, the time-dependent flux is:

$\Phi(t) = NBA\cos(\omega t)$

(iii). Faraday's Law of Induction

- Induced EMF $\mathcal{E}$ is given by:

$$\mathcal{E} = -\frac{d\Psi}{dt}$$

Substitute $\Phi(t) =$

$$\varepsilon = -\frac{d}{dt}(\text{ NBAcos }(\omega t))$$

$$\varepsilon = -\text{ NBA } \cdot \frac{d}{dt}(\cos(\omega t))$$

(iv). Differentiate

$$\frac{d}{dt}\cos(\omega t) = -\omega\sin(\omega t)$$

So.

$$\varepsilon = -\text{ NBA } \cdot (-\omega\sin(\omega t))$$

$$\varepsilon = \text{ NBA } \omega\sin(\omega t)$$

(v). Final Expression

$\varepsilon(t) = \text{ NBA } \omega\sin(\omega t)$

- Maximum EMF accurs when $\text{sln}(\omega t) = 1$:

$\varepsilon_{\max} = \text{ NBAw}$

OR

(b) (i) Mirror Equation: -

Consider a concave mirror (derivation for corwex mirror is similar with sign convention).
Step 1: Set up the geometry
- Let:
$u =$ object distance from the mirror (pasitive if in front of mirror)
$t =$ image distance from the mirror (positive if in front of mirror)
$f =$ focal length of the mirror
C = center of curvature
$P =$ pole of the mirror
Using paraxial approximation (small angles), the triangles formed by the object, image, and mirror satisfy similar triangle rules.
Step (2): Use similar triangles
From the mirror diagram:

$$\frac{\text{height of lmage}}{\text{height of object}} = \frac{\text{Image dlstance from principel axis}}{\text{object dlstance from princlpal sxis}}$$

But using the mirror geometry, we gat

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

This is the mirror equation.
Mirror Equation:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{t}$$

- $f = \frac{R}{2}$, where R is the radtus of curvature.
- Sign conventions must be followed for concave and convex mirrors.
(ii) Lateral Magnification: -
- Lateral magnification m is the ratio of the height of image h_i to the height of object h_{ar} -

$$m = \frac{h_i}{h_s}$$

- Using similar triangles in the mirror deagram:

$$m = -\frac{v}{u}$$

- The negative sign indicates that a real image is inverted.
- For a virtual image, v is negative, so m becomes paxitive (upright imaga).
Lateral Magnification Equation:

$$m = \frac{h_i}{h_n} = -\frac{v}{u}$$

35. (a) force on a current-carrying wire in a magnetic field ($F = ILB$) to find the force per unit length $\left(FIL = \frac{\mu_0 I_1 I_2}{2\pi d}\right)$, where μ_0 is permeability, I_1, I_2 are currents, and d is the distance between wires, showing attraction for same direction currents and repulsion for opposite directions.
Derivation Steps
(1). Magnetic Field from Wire $1(B_1)$:
(i). Consider two long, parallel wires (1 and 2) separated by distance d. Wire 1 carries current I_1 and Wire 2 carries I_2.
(ii). Using Ampere's Law, the magnetic field (B_1) produced by Wire 1 at the location of Wire 2 is given by: $B_1 = \frac{\mu_0 I_1}{2\pi d}$ (where μ_0 is the permeability of free space).
(iii) Force on Wire $2(\bar{F}_2)$:
(iv) Wire 2, carrying current I_2 and having length L, experiences a force (F_2) in the magnetic field B_1.
(v) The formula for this force is $F_2 = I_2 L B_1$ (using the Lorentz force law $F = \vec{IL} \times \vec{B}$ and right-hand rule).
(vi). Substitute and Find Force per Unit Length: -
(vii). Substitute the expression for B_1 into the force equation:

$$F_2 = I_2 L \left(\frac{\mu_0 I_1}{2\pi d}\right).$$

Rearrange to find the force per unit length $(f_2 = F_2/L)$:-

$$f_2 = \frac{F_2}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

Final Expression & Interpretation

- Force per Unit Length: $f=\frac{\mu_0 I_1 I_2}{2\pi d}$.

OR

(b) (i) Electrodynamics can be summarized into four basic equations, known as Maxwell's Equations.

(ii) First equation is Gauss Law, it relates net electric flux and net charge

$$\oint \vec{E}\cdot d\vec{A}=\frac{Q_{enclosed}}{\epsilon_0}$$

(iii) Second equation has no name but can be called Gauss Law in magnetism. It states that the surface integral of the magnetic field over a closed surface is zero.

$$\vec{B}\cdot d\vec{A}=0$$

(iv) Third equation is Faraday's Laws of electromagnetic induction.

$$\oint \vec{E}\cdot d\vec{l}=-\frac{d}{dt}\Phi_B$$

(v) The line integral of the electric field ground any closed path is equal to the rate of change of magnetic flux through the closed path bounded by the surface.

(vi) Fourth Equation is modified Ampere's Circuital Law known as Ampere-Maxwell's Law

$$\oint \vec{B}\cdot d\vec{l}=\mu_0 I_{enclosed}+\mu_0\varepsilon_0\frac{d}{dt}\int \vec{SE}\cdot d\vec{A}$$

(vii) This law relates the magnetic field around any closed path to the conduction current and displacement current through the path. These four equations are known as Maxwell's Equation in electrodynamics.

36. (a) The Davisson-Germer experiment demonstrated the wave nature of electrons by firing a beam of accelerated electrons at a nickel crystal, observing that the scattered electrons produced a diffraction pattern, much like X - rays, confirming Louis de Broglie's hypothesis that particles possess wave-like properties, specifically showing constructive interference at specific angles for certain accelerating voltages (like 54 V).

Experimental Setup & Procedure: -

- Electron Source: A heated tungsten filament (electron gun) produced electrons via thermionic emission.
- Acceleration: A high voltage accelerated these electrons into a fine, collimated beam.
- Target: The beam struck a nickel crystal (initially polycrystalline, but heating created large single crystals).
- Detection: An electron detector (Faraday cup) was moved around the crystal on a circular scale to measure the intensity of scattered electrons at different angles (θ).
- Voltage Variation: The accelerating voltage $(40-68\text{ V})$ was varied to change the electron's momentum and wavelength.

Key Observations & Results: -

- Diffraction Pattern: Instead of scattering randomly, electrons scattered in specific directions, creating peaks (maxima) in intensity, similar to X -ray diffraction.
- Peak Intensity: A strong peak appeared at 50° when the accelerating voltage was 54V, indicating constructive interference.
- Bragg's Law: The observed diffraction matched predictions from Bragg's Law for waves scattering off crystal planes, with a known interatomic spacing ($d\approx 0.091$ nm for nickel).

OR

(b)(i)

(1). Force balance (centripetal = electrostatic)

The centripetal force requied for circular motion is provided by Coulomb's attraction

$$\frac{mv^2}{r}=\frac{1}{4\pi e_0}\frac{e^2}{r^2}$$

$$\Rightarrow mv^2=\frac{1}{4\pi e_0}\frac{e^2}{r}$$

(2). Bohr's angular momentum quantization

$$mvr=nh=\frac{nh}{2\pi}, n=1,2,3,\ldots$$

$$\Rightarrow v=\frac{nh}{mr}\ (2)$$

(3). Radius of the $\boldsymbol{n}$ th orbit

Substitute (2) into (1):

$$m\left(\frac{n^2\hbar^2}{m^2r^2}\right)=\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$\Rightarrow r_n=\frac{4\pi e_0 n^2 h^2}{me^2}$$

(4). Total energy of the electron

Total energy $E=$ kinetic energy + potential energy

- Kinetic energy:

$$K=\frac{1}{2}mv^2$$

From (1)

$$mv^2=\frac{1}{4\pi e_0}\frac{e^2}{r}\Rightarrow K=\frac{1}{2}\frac{1}{4\pi e_0}\frac{e^2}{r}$$

- Putential energy:

$$U=-\frac{1}{4\pi e_0}\frac{e^2}{r}$$

(5). Orbital energy

$$E=K+U=\frac{1}{2}\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}-\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$\Rightarrow E=-\frac{1}{2}\frac{1}{4\pi e_0}\frac{e^2}{r}$$

Substituter $r=r_{\mathrm{n}}$:

$$E_n=-\frac{me^4}{8edt^2}\frac{1}{n^2}$$

(6). Final result

$$\boxed{E_n=-\frac{13.6}{n^2}\text{ el }\downarrow n=1,2,3,....}$$

(ii) In Bohr's model, the energy of the electron in the nth orbit is

$$E_n=-\frac{13.6}{n^2}\text{eV}$$

Given:

$E_n=-3.4\text{eV}$

Step (1): Find the principal quantum number n

$$\frac{13.6}{n^2}=3.4$$

$$n^2=\frac{13.6}{3.4}=4\Rightarrow n=2$$

Step (2): Angular momentum of the electron

According to Bohr's quantization condition:

$$L=nh=\frac{nh}{2\pi}$$

For $n=2$

$$L=2\hbar=\frac{2h}{2z}=\frac{h}{z}$$

Final Answer

$$L=2\hbar=\frac{\hbar}{t}$$

37. **(a)** A transistor acts as an oscillator by using its amplification property with positive feedback, creating a self-sustaining electronic signal (AC) from DC power, typically with a tuned LC tank circuit to set the frequency, where energy oscillates between the inductor and capacitor, and the transistor continuously amplifies this signal to overcome losses, generating stable, continuous waves like sine or square waves.

Key Components: -

- Transistor: Acts as the active amplifier, boosting the weak oscillating signal.
- LC Tank Circuit: (Inductor & Capacitor in parallel) Stores and releases energy, determining the oscillation frequency ($f=1/(2\pi\sqrt{LC})$).

- Feedback Network: Connects output back to input, providing a portion of the amplified signal in phase (positive feedback) to sustain oscillations.
Working Principle (Simplified): -
(i) . Initial Oscillation: When power is applied, tiny fluctuations in the DC current excite the LC tank circuit, causing it to oscillate at its resonant frequency.
(ii). Amplification: The transistor, configured as an amplifier (e.g., common emitter), receives these weak oscillations at its base and amplifies them.
(iii). Positive Feedback: A part of this amplified output signal is fed back to the input (tank circuit) in phase with the original signal, making it stronger.
(iv). Sustained Waves: This continuous loop of amplification and positive feedback sustains the oscillations, turning the DC power into a steady AC waveform (sine, square, etc.). The transistor constantly switches between saturation (fully ON) and cut-off (fully OFF) states, driven by the tank circuit's energy.
Types of Oscillators: -
- LC Oscillators: Use LC circuits (Hartley, Colpitts) for high frequencies.
- RC Oscillators: Use resistors and capacitors (Wien Bridge, Phase Shift) for lower audio frequencies.

OR

(b) In a pure inductive circuit, the current lags behind the applied voltage by a phase angle of 90 degrees (or $\frac{\pi}{2}$ radians). This means the voltage reaches its peak value a quarter cycle before the current does, as the inductor opposes changes in current, causing a delay in the current's response to the voltage.
Key Points: -
- Voltage Leads Current: The voltage waveform appears first, leading the current waveform.
- Phase Angle: The separation is exactly 90° (or one-quarter of a full cycle).
- Why? An inductor creates a back-EMF (electromotive force) that opposes the change in current (Lenz's Law). The voltage across the inductor is proportional to the rate of change of current $\left(V = L\frac{dI}{dt}\right)$, which results in this 90° lag.
Visualizing the Relationship: -
- If the applied voltage is $V_m \sin(\omega t)$, the current will be $I_m \sin(\omega t - 90^\circ)$ or $I_m \cos(\omega t)$.
- In a phasor diagram, the voltage phasor leads the current phasor by 90°.

38. (a) Gauss's Law in Electrostatics
Statement:
The total electric flux through any closed surface is equal to $1/\varepsilon_0$ times the total charge enclosed by that surface.

$$\oint \vec{E} \cdot d\vec{S} = \frac{Q_{\text{enclosed}}}{\varepsilon_0}$$

where
$\vec{E}$ = electric field,
$d\vec{S}$ = outward area element,
ε_0 = permittivity of free space.
Electric Field due to an Infinitely Long Charged Wire
Let the wire have a uniform linear charge density λ (charge per unit length).
Step (1): Choose a Gaussian Surface
Select a cylindrical Gaussian surface of:
- radius r
- length l
The charged wire passes along the axis of the cylinder.
Step (2): Electric Flux through the Gaussian Surface
- Electric field is radially outward and same at all points on the curved surface.
- Flux through the flat ends = 0 (field is parallel to them).
So, total flux:
$\Phi = E \times (2\pi r l)$
Step (3): Charge Enclosed
$Q_{\text{enclosed}} = \lambda l$
Step (4): Apply Gauss's Law

$$E(2\pi r l) = \frac{\lambda l}{\varepsilon_0}$$

Cancel l :

$$E=\frac{\lambda}{2\pi\varepsilon_0 r}$$

Final Expression

$$E=\frac{\lambda}{2\pi\varepsilon_0 r}$$

OR

(b) Comparison of EMFs of Two Cells Using a Potentiometer

A potentiometer is a device used to compare the emfs of two cells accurately without drawing current from them.

Principle

The potential drop along a uniform potentiometer wire is directly proportional to its length, provided the current through the wire is constant.

$V \propto l$

Experimental Arrangement: -

- A long uniform potentiometer wire AB is connected in series with:
- a driver cell (battery),
- a rheostat,
- a key.
- The two cells whose emfs are to be compared, E_1 and E_2, are connected one by one through a twoway key, a galvanometer, and a jockey.

Procedure

(i). Primary Circuit ON

Adjust the rheostat so that the potential drop along the entire wire is greater than both emfs.

(ii). First Cell (E_1)

- Press the jockey on the wire.
- Find the null point (no deflection in galvanometer).
- Let the balancing length be l_1.

(iii). Second Cell (E_2)

- Using the two-way key, connect the second cell.
- Find its null point.
- Let the balancing length be l_2.

Theory

At balance condition: -

$E_1 = kl_1$

$E_2 = kl_2$

where k is the potential gradient (constant).

Comparison of EMFs

$$\frac{E_1}{E_2}=\frac{l_1}{l_2}$$

Advantages of Using Potentiometer: -

- Highly accurate method.
- No current drawn from the cells at null point.
- Internal resistance of cells does not affect the result.