Time: 60min	Physics Ch 7,10 and 14	Marks: 20

SECTION A

1. **Select and write the correct answer for the following multiple choice type of questions:** **3**

i. **The energy of photon of wavelength λ is _______.**
[h = Planck's constant, c = speed of light in vacuum]

- [ ] (A) hcλ
- [ ] (B) $\frac{h\lambda}{c}$
- [ ] (C) $\frac{\lambda}{hc}$
- [x] (D) $\frac{hc}{\lambda}$

ii. **Cylindrical wavefront can be obtained from**

- [ ] (A) point source of light.
- [x] (B) light source like slit.
- [ ] (C) light source like circle.
- [ ] (D) point source of light at infinity.

iii. **If Young's double slit experiment is done with white light, which of the following statements will be true?**

- [ ] (A) All the bright fringes will be coloured.
- [ ] (B) All the bright fringes will be white.
- [x] (C) The central fringe will be white.
- [ ] (D) No stable interference pattern will be visible.

Ans: Path difference for all wavelengths at the central point will be zero. Hence, central band will be white a few coloured bands are observed on either side of the central band.

2. **Answer the following questions:** **3**

i. **State Biot-Savart law.**

Statement:
The magnitude of magnetic induction (dB) at a point due to a small element of current carrying conductor is
i. directly proportional to the current (dB ∝ I).
ii. directly proportional to the length of the element (dB ∝ d*l*).
iii. directly proportional to the sine of the angle between the element and the line joining the centre of the element to the point (dB ∝ sin θ) and
iv. inversely proportional to the square of the distance of the point from the centre of the element $\left(dB \propto \frac{1}{r^2}\right)$.

ii. **Why was the wave theory of light accepted as a correct theory?**

Reason: Wave theory could explain all the visual effects exhibited by the light.

iii. **What is photoelectric effect?**

The phenomenon of emission of electrons from a metal surface, when radiation of appropriate frequency is incident on it, is known as photoelectric effect.

SECTION B

Attempt any TWO questions of the following: **4**

3. **Explain what you understand by the de-Broglie wavelength of an electron. Will an electron at rest have an associated de-Broglie wavelength? Justify your answer.**

i. According to de Broglie, every particle of matter has both particle as well as wave properties associated with it.

ii. The de Broglie, relation thus is given as,

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

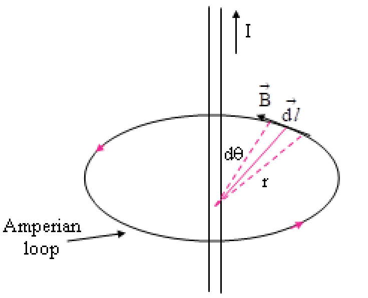
iii. For a charged particle, like electron, of charge q, accelerated from rest, through a potential difference V, de Broglie wavelength is given as,

$\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$

iv. For an electron at rest, as its momentum is zero, its de-Broglie wavelength would be infinite.

4. **Obtain expression for magnetic field at a distance r from straight current conducting wire using Ampere's law.**

i. Consider a long straight wire carrying a current I as shown in figure below.



Long straight current carrying wire

$\vec{B}$ and $\vec{dl}$ are tangential to the Amperian loop which in this case is a circle.

$\therefore \vec{B} \cdot \vec{dl}$ = B d*l*

= B r dθ

ii. The field $\vec{B}$ at a distance r from the wire is given by, $B = \frac{\mu_0}{2\pi} \frac{I}{r}$

Integrating over a closed loop,

$\therefore \oint_c \vec{B} \cdot \vec{dl} = \int_0^{2\pi} \frac{\mu_0 I}{2\pi r} r d\theta = \mu_0 I$

5. **Explain the inverse linear dependence of stopping potential on the incident wavelength in a photoelectric effect experiment.**

i. During photoelectric effect experiment, it was observed that, when the frequency of incident radiation was changed keeping the intensity and accelerating potential V constant, then the saturation current remained the same but the stopping potential V_0 changed.

ii. Consider photons with frequency ν are incident on the metal surface such that, the most energetic electrons come out at emitter surface with kinetic energy $K.E._{max}$.

iii. Let ($-V_0$) be the stopping potential. If the ejected electrons have kinetic energy more than eV_0, then electrons can reach the collector and the current flows. When the kinetic energy of the electron is less than or equal to eV_0, no current flows.

the electron is less than or equal to eV_0, no current flows.

iv. Photocurrent becomes zero when $KE_{max} = eV_0$.

But, $K.E._{max} = h\nu - \phi_0$

$\therefore\ eV_0 = h\nu - \phi_0$

$\therefore\ V_0 = \frac{h\nu}{e} - \frac{\phi_0}{e}$

Also, $\nu = \frac{c}{\lambda}$

$\therefore\ V_0 = \left(\frac{hc}{e}\right)\frac{1}{\lambda} - \frac{\phi_0}{e}$

Above equation tells us that stopping potential has inverse linear dependence with incident wavelength in a photoelectric effect experiment. i.e., with increase in wavelength of incident radiation, stopping potential decreases and it becomes zero when the radiation of threshold wavelength is incident.

6. A. **What is the shape of the wavefront at a point far away from the source of light?**

Plane

B.

Using the values of work function given in the following table, tell which metal will require the highest frequency of incident radiation to generate photocurrent.

Metal	**Work function**	**Metal**	**Work function**
Potassium	2.3	Aluminium	4.3
Sodium	2.4	Tungsten	4.5
Calcium	2.9	Copper	4.7
Zinc	3.6	Nickel	5.0
Silver	4.3	Gold	5.1

Gold will require the highest frequency of incident radiation to generate photocurrent.

SECTION C

Attempt any TWO questions of the following: **6**

7. What are the conditions for obtaining good interference pattern? Give reasons.

Conditions for obtaining sustaining and good interference pattern are:

i. **The two sources of light must be coherent:**

Only two coherent sources can maintain their phase relation necessary for sustained interference pattern. For incoherent sources, emitted waves undergo rapid and random changes and steady interference cannot be obtained.

ii. **The two sources of light must be monochromatic:**

a. The condition for bright and dark fringes, the position of these fringes as well as the width of the fringes depend on the wavelength of light.

b. Therefore, the fringes of different colours do not coincide.

c. The resultant pattern contains coloured, overlapping bands due to their different wavelength.

iii. **The two interfering waves must have the same amplitude:**

Only if the amplitudes are equal, the intensity of dark fringes (destructive interference) is zero and the contrast between bright and dark fringes will be maximum.

iv. **The separation between the two slits (d) must be small in comparison to the distance between the plane containing the slits and the observing screen (D):**

This is necessary as only in this case, the width of the fringes will be sufficiently large to be measurable and the fringes are well separated and can be clearly seen.

v. **The two slits should be narrow:**

If the slits are broad, the distances from different points along the slit to a given point on the screen are significantly different and therefore, the waves coming through the same slit will interfere among themselves, causing blurring of the interference pattern.

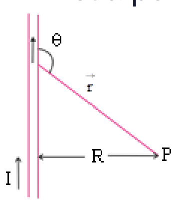
vi. **The two waves should be in the same state of polarization:**

This is necessary only if polarized light is used for the experiment.

8. Apply Biot-Savart law to infinitely long current carrying conductor.

i. Consider a straight wire of length *l* carrying current I.

ii. Let a point P situated at a perpendicular distance R from the wire as shown below.



iii. Consider infinitesimal length $\vec{dl}$ of wire carrying current I, then current element = I$\vec{dl}$.

iv. Current element is situated at distance r from point P making an angle θ, as shown in figure above.

v. Using Biot Savart law, magnetic field, produced $\vec{dB}$ at P due to current element I$\vec{dl}$ is,

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I\vec{dl}\sin\theta}{r^2} \qquad ....(1)$$

vi. According to properties of cross-product,

$\vec{dl} \times \vec{r}$ indicates direction of $\vec{dB}$, in this case, is into the plane of paper.

vii. Summing up all current elements upper half of infinitely long wire,

$$B_{upper} = \int_0^\infty dB = \frac{\mu_0}{4\pi} \int_0^\infty \frac{I\vec{dl}\sin\theta}{r^2} \qquad ....(2)$$

viii. Taking into account symmetry of wire, current elements in lower half of infinitely long wire will also contribute same as upper half.

i.e., $B_{lower} = B_{upper}$ ….(3)

ix. Adding contributions from lower and upper part, total magnetic field point P is

$$B = 2\int_0^\infty dB \quad \text{….[using equation (2)]}$$

$$= \frac{2\mu_0}{4\pi}\int_0^\infty \frac{I\,dl\,\sin\theta}{r^2} \quad \text{….[using equation (1)]}$$

But $r = \sqrt{l^2 + R^2}$ and

$\sin\theta = \sin(\pi - \theta) = \frac{R}{r} = \frac{R}{\sqrt{l^2 + R^2}}$

$$\therefore B = \frac{\mu_0 I}{2\pi}\int_0^\infty \frac{R\,dl}{(l^2 + R^2)\sqrt{l^2 + R^2}} = \frac{\mu_0 I}{2\pi} R \int_0^\infty \frac{dl}{(l^2 + R^2)^{\frac{3}{2}}}$$

Solving the integration,

$$B = \frac{\mu_0 I}{2\pi} R \times \frac{1}{R^2} = \frac{\mu_0 I}{2\pi R} \quad \text{….(4)}$$

This is the equation for magnetic field at a point situated at a perpendicular distance R from infinitely long wire carrying current I.

9. The magnetic field at the centre of a circular current carrying loop of radius 12.3 cm is 6.4×10^{-6} T. What will be the magnetic moment of the loop?

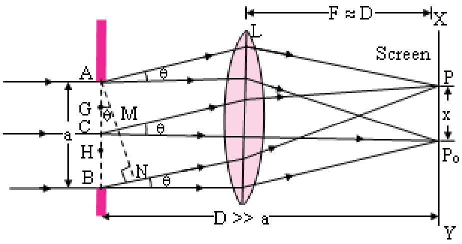
Magnetic moment of the loop is **5.954×10^{-2} Am^2.**

SECTION D

Attempt any ONE question of the following: **4**

10. Derive the conditions for bright and dark fringes produced due to diffraction by a single slit.

Fraunhofer diffraction due to single slit:



i. Consider a narrow slit AB of width ‘a’, kept perpendicular to the plane of the paper. The slit can be imagined to be divided into extremely thin slits or slit elements. It is illuminated by a parallel beam of monochromatic light of wavelength λ i.e., a plane wavefront is incident on AB.

ii. The diffracted light is focused by a converging lens L, on a screen XY.

iii. The screen is kept in the focal plane of the lens and is perpendicular to the plane of the paper.

iv. Let D be the distance between the slit and the screen.

v. According to Huygens’ principle, each and every point of the slit acts as a source of secondary wavelets, spreading in all directions.

Position of central maxima:

i. Let C be the centre of the slit AB. The secondary wavelets travelling parallel to CP_O come to a focus at P_O. The secondary wavelets from points equidistant from C in the upper and lower halves of the slit travel equal paths before reaching P_O.

ii. The optical path difference between all these wavelets is zero and hence they interfere in the same phase forming a bright image at P_O.

iii. The intensity of light is maximum at the point P_O. It is called the central or the principal maxima of the diffraction pattern.

iv. For the line CP_O, angle θ = 0°.

Position of secondary minima:

i. Consider a point P on the screen at which waves travelling in a direction making an angle θ with CP are brought to focus at P by the lens. This point P will be of maximum or minimum intensity because the waves reaching at P will cover unequal distance.

ii. Draw AN perpendicular to the direction of diffracted rays from point A. BN is the path difference between secondary waves coming from A and B.

iii. From ΔABN, sin θ = $\frac{BN}{AB}$

∴ BN = AB sin θ = a sin θ

Since θ is very small

∴ sin θ ≈ θ

∴ BN = aθ

In figure, suppose BN = λ and θ = θ_1 then

$\sin \theta_1 = \frac{\lambda}{a}$

iv. Such a point on the screen will be the position of first secondary minimum. It is because, if the slit is assumed to be divided into two equal halves AC and BC, then the waves from corresponding points of two halves of the slit will have a path difference of λ/2.

It gives rise to destructive interference at P which has minimum intensity.

v. If point P on the screen is such that BN = 2λ and angle θ = θ_2, then $\sin \theta_2 = \frac{2\lambda}{a}$ Such a point on the screen will be the position of the second secondary minimum.

In general for n^{th} minimum,

$\sin\theta_n = \frac{n\lambda}{a}$

where, n = ±1, ±2, ±3,…

vi. If y_{n_d} is the distance of n^{th} minimum from P_O, on the screen, then $(\tan\ \theta_{n_d}) = \frac{y_{n_d}}{D}$.

vii. If θ_{n_d} is very small,

$\tan \theta_{n_d} \approx \sin \theta_{n_d} = \frac{n\lambda}{a}$

∴ $\frac{y_{n_d}}{D} = \frac{n\lambda}{a}$

∴ $y_{n_d} = \frac{n\lambda D}{a}$ = nW ....(1)

where, W is fringe width.

Equation (1) gives distance of n^{th} secondary minima from central maxima.

Position of secondary maxima:

i. To obtain secondary maxima on the screen, path difference should be odd multiple of $\frac{\lambda}{2}$.

∴ BN = $(2n + 1)\frac{\lambda}{2}$

where n = 1, 2, 3,…….

$\sin \theta_{n_b} = (2n + 1)\frac{\lambda}{2a}$ ….(2)

ii. Since θ_{n_b} is very small,

$\therefore$ $\tan \theta_{n_b} \approx \sin \theta_{n_b}$

$= \frac{(2n+1)\ \lambda}{2a}$ ....[From equation (2)]

$\therefore$ $\frac{y_{n_b}}{D} = \frac{(2n+1)\ \lambda}{2a}$

$\therefore$ $y_{n_b} = \frac{(2n+1)\lambda D}{2a} = \left(n + \frac{1}{2}\right) W$ ....(3)

Equation (3) gives distance of n^{th} secondary maxima from the central maxima.

11. A. **Mention some applications of photocell.**

i. Photocell is used to operate control systems and in light measuring devices.

ii. Light meters in photographic cameras make use of photocell to measure the intensity of light.

iii. Photocell can also be used to switch on or off the street lights.

iv. It can be used to operate a counter in counting devices, or to set a burglar alarm.

v. Traffic law defaulters can be identified by setting an alarm using the photocell.

B. **A magnetic dipole of moment 40 mJ/T is free to rotate in a uniform magnetic field of induction 50 mT. When released from rest in the magnetic field, the dipole rotates to align with the field. At the instant the dipole moment is parallel to the field, its kinetic energy is 800 μJ. What was the initial angle between the dipole moment and the magnetic field?**

Given: $m = 40$ mJ/T $= 4 \times 10^{-2}$ J/T

$\Delta K = 800\ \mu J = 8 \times 10^{-4}$ J

Change in potential energy,

$\Delta U = U_0 - U_\theta$

$= mB \cos 0° - (- mB \cos \theta)$

$= mB (1 - \cos \theta)$

Applying the principle of conservation of energy,

$\Delta K + \Delta U = 0$

$\therefore$ $\Delta K = - \Delta U = mB (1 - \cos \theta)$

$\therefore$ $8 \times 10^{-4} = (4 \times 10^{-2}) (5 \times 10^{-2}) (1 - \cos \theta)$

$\therefore$ $(1 - \cos \theta) = \frac{2}{5}$

$\therefore$ $\cos \theta = \frac{3}{5}$

The initial angle between the dipole moment and the magnetic field,

$\theta = \cos^{-1} \left(\frac{3}{5}\right) =$ **53° 8'**