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.

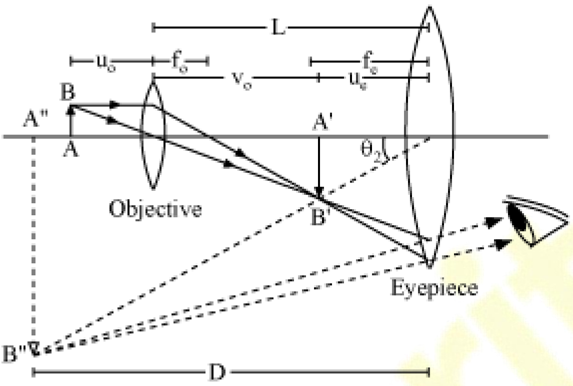
(v) You may use the following values of physical constants wherever necessary:
$C = 3 \times 108 \text{ ms}^{-1}$
$H = 6.626 \times 10^{-34}$ Js
$e = 1.602 \times 10^{-19}$ C
$\mu_0 = 4\pi \times 10^{-7}$ Tm A^{-1}
$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$
Mass of electron $m_e = 9.1 \times 10^{-31}$ 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

19. A compound microscope uses an objective lens of focal length 4 cm and eyepiece lens of focal length 10 cm. An object is placed at 6 cm from the objective lens. Calculate the magnifying power of the compound microscope. Also calculate the length of the microscope.

OR

A giant refracting telescope at an observatory has an objective lens of focal length 15 m. If an eyepiece lens of focal length 1.0 cm is used, find the angular magnification of the telescope.
If this telescope is used to view the moon, what is the diameter of the image of the moon formed by the objective lens? The diameter of the moon is 3.42×10^6 m and the radius of the lunar orbit is 3.8×10^8 m.

Solution:



First we shall find the image distance for the objective(v_o),

$$\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o};\ f_o = 4cm,\ u_o = -6cm$$

$\Rightarrow v_0 = 12cm$

Magnification of the microscope is,

$$m = m_o m_e = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right) = \left(\frac{12}{-6}\right)\left(1 + \frac{25}{10}\right)$$

$= -7,$ negative sign indicates that the image is inverted.

The length of the microscope is $v_o + u$, $u = |u_e|$ is the object distance for the eyepiece. And u_e can be found using,

$$\frac{1}{f_o} = \frac{1}{D} - \frac{1}{u_e};$$ as D is the image distance for the eyepiece.

$$\Rightarrow \frac{1}{10} = \frac{1}{-25} - \frac{1}{u_e} \Rightarrow u_e = -7.14cm$$

Hence, $u = |u_e| = 7.14cm.$

Length of the microscope = $v_o + u = 19.14cm$

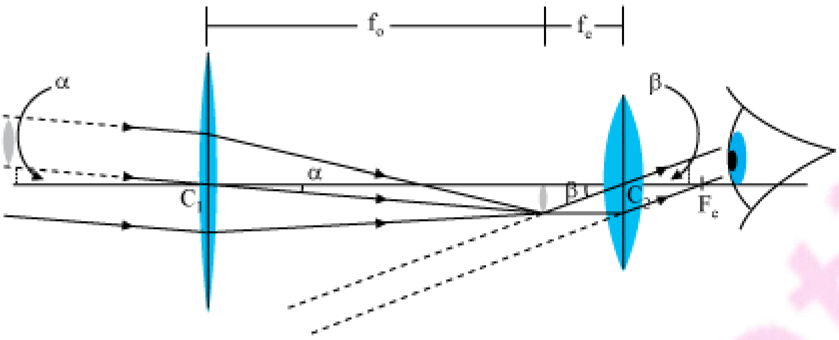
Length of the microscope is given as

$$L = \frac{mf_o f_e}{D} = \frac{7 \times 4 \times 10}{25} = 11.2 \text{ cm}$$

OR

Angular magnification = $-\frac{f_o}{f_e}\left(1+\frac{f_e}{D}\right) = -\frac{1500}{1}\left(1+\frac{1}{25}\right) = -1560$

Negative sign indicates that the image is inverted.



Diameter of the image of the moon formed by the objective lens = d (say)

$$\tan\alpha \approx \alpha = \frac{\text{diameter of the moon}}{\text{raidus of the orbit}} = \frac{d}{f_o}$$

or, $\frac{3.42 \times 10^6}{3.8 \times 10^8} = \frac{d}{15} \Rightarrow d = 0.135m$

20. (a) Using de Broglie's hypothesis, explain with the help of a suitable diagram, Bohr's second postulate of quantization of energy levels in a hydrogen atom.
(b) The ground state energy of hydrogen atom is –13.6 eV. What are the kinetic and potential energies of the electron in this state?

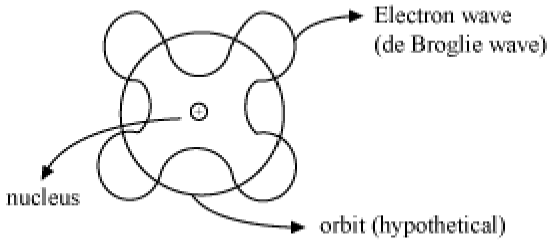
Solution:

(a) De Broglie's Explanation of Bohr's Second Postulate of Quantisation

- De-Broglie's hypothesis that electron has a wavelength $\lambda = h/mv$ gave an explanation for Bohr's quantised orbits by bringing in the wave particle duality.
- Orbits correspond to circular standing waves in which the circumference of the orbits equal whole number of wavelength.

According to de Broglie's hypothesis

$\lambda = \frac{h}{p}$ also for Bohr's model



It states,

$n\lambda = 2\pi r$

$\Rightarrow n\frac{h}{p} = 2\pi r$

$\Rightarrow rp = n\frac{h}{2\pi}$ $\quad$ $(\text{as } rp = L)$

$\Rightarrow L = n\frac{h}{2\pi}$ $\quad$ Bohr's IInd Postulate

(b) Potential energy of electron in ground state of H-atom

$V = -\frac{1}{4\pi\epsilon_0}\cdot\frac{qq}{r_a}$ $\quad$ $(r_a = \text{Bohr's radius})$

$= -27.2\,\text{eV}$ $\quad$ $(V = 2E_0)$

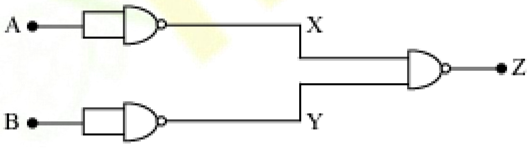
Kinetic energy of electron in this state

$K = \frac{1}{2}m_e v^2$ $\quad$ $v = $ Velocity of electron in ground state

$= 13.6 \text{ eV}$

$(K = E_0)$

21. You are given a circuit below. Write its truth table. Hence, identify the logic operation carried out by this circuit. Draw the logic symbol of the gate it corresponds to.



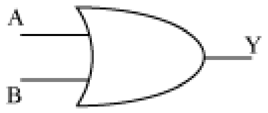
Solution:

A	B	Z
0	0	0
0	1	1
1	0	1
1	1	1

Hence, the gate is an **OR** gate.

The output is 1 when either of the input or both the inputs are 1.

Symbol:



22. A convex lens made up of glass of refractive index 1.5 is dipped, in turn, in (i) a medium of refractive index 1.6, (ii) a medium of refractive index 1.3.
(a) Will it behave as a converging or a diverging lens in the two cases?
(b) How will its focal length change in the two media?

Solution:
Given
Refractive index of glass, $\mu_a = 1.5$
Refractive index of I^st medium, $\mu_1 = 1.6$
Refractive index of II^nd medium, $\mu_2 = 1.3$

(a) For I^st medium

$$\mu_1 > \mu_a \Rightarrow \frac{\mu_a}{\mu_1} < 1$$

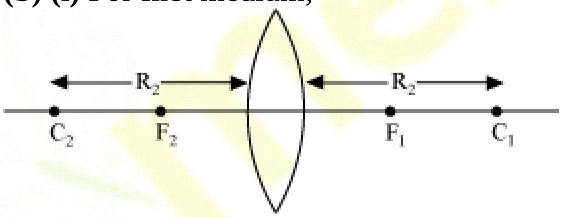
Hence, $f > 0$; concave lens or diverging lens

(ii) For II^nd medium

$$\mu_2 > \mu_a \Rightarrow \frac{\mu_a}{\mu_2} > 1$$

Hence, $f < 0$; convex lens or converging lens

(b) (i) For first medium,



$$\frac{1}{f_1} = \left(1 - \frac{\mu_a}{\mu_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \begin{matrix} R_1 > 0 \\ -R_2 > 0 \end{matrix}$$

$$= \left(1 - \frac{1.5}{1.6}\right) \qquad (\text{Positive number}) \text{ for convex lens}$$

$$= (1 - 0.9) \qquad (\text{Positive number})$$

$$= (0.1) \qquad (\text{Positive number})$$

Original focal length

$$\frac{1}{f} = (1-\mu_a)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f} = -0.5 \qquad \text{(Positive number)}$$

$$\Rightarrow \frac{f_1}{f} = -\frac{0.5}{0.1}$$

$$\Rightarrow f_1 = -5f$$

Hence, focal length will be 5 times the original focal length and its nature will become diverging.

(ii) For second medium

$$\frac{1}{f_2} = \left(1-\frac{\mu_a}{\mu_2}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= \left(1-\frac{1.5}{1.3}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= (1-1.15)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$= 0.2\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\Rightarrow \frac{f_2}{f} = \frac{0.2}{0.1}$$

$$\Rightarrow f_2 = 2f$$

Hence, focal length will be twice the original focal length and its nature (Converging nature) will remain same.

23. Write briefly any two factors which demonstrate the need for modulating a signal. Draw a suitable diagram to show amplitude modulation using a sinusoidal signal as the modulating signal.

Solution:

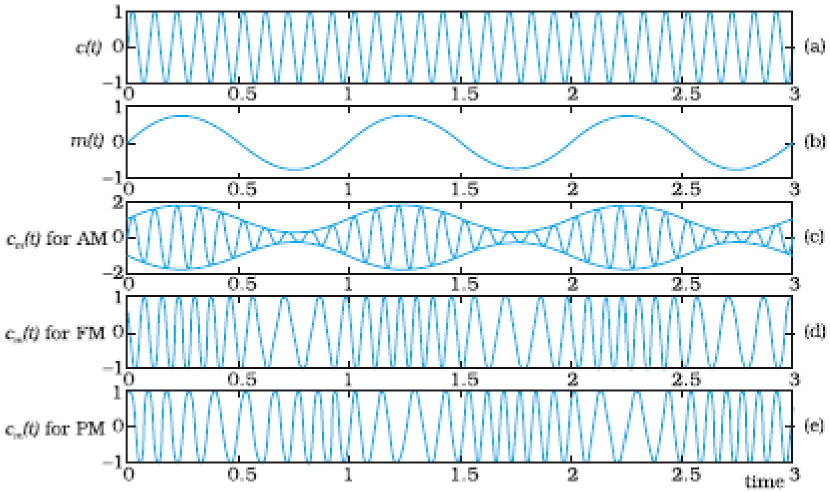
The need for modulation can be summarized as follows:

(1) The antenna needed for transmitting signals should have size at least λ/4, where, λ is the wavelength. The information signal, also known as baseband signal is of low frequency (and therefore the wavelength is high). If we need to transmit such a signal directly, the size of the antenna will be very large and impossible to build. Hence direct transmission is not practical.

(2) The radiated power by an antenna is inversely proportional to the square of the wavelength. So, if we use high frequency signals, the power radiated will be increased.

(3) If we transmit the baseband signals directly, the signals from different transmitters will get mixed up and the information will be lost.

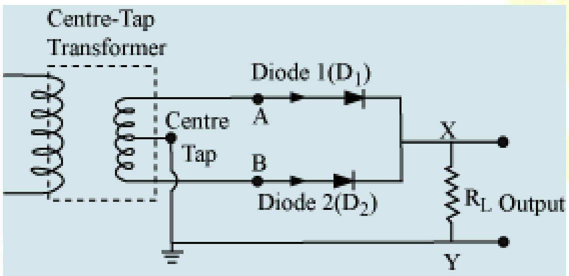
Because of these reasons, we use the technology of modulation, for transmitting message signals effectively for long distances.



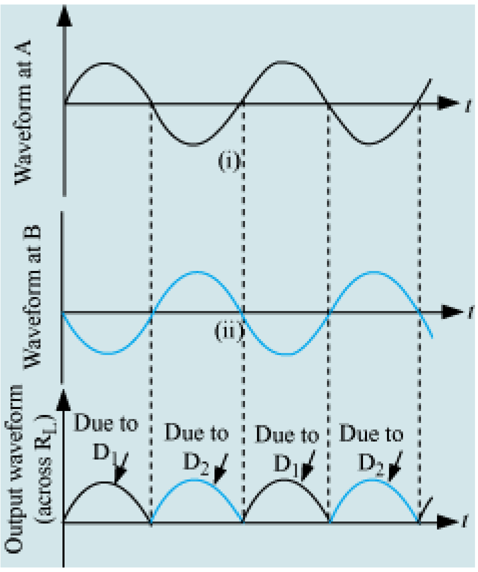
24. Draw a labeled diagram of a full wave rectifier circuit. State its working principle. Show the input-output waveforms.

Solution

To get an output voltage for both half cycles of the input signal, we use full wave rectifiers. The commonly used full wave rectifier circuits are center-tap rectifier and bridge rectifier. The figure below shows the center-tap rectifier circuit.



Now consider the circuit. The P-side of the diodes D_1 and D_2 are connected to the secondary terminals of the transformer. The N-sides of the diodes are connected together. The load is connected between this point and the midpoint of the transformer. When the input signal to diode D_1 is positive, it conducts and load current flows. During this time, the input to diode D_2 is negative with respect to the midpoint. During the negative half cycle of the input signal, the voltage at D_1 is negative and that at D_2 is positive. So D_2 conducts during this time period. Thus we get output voltage during both the half cycles. As the full wave rectifier rectifies both the half cycles, it is more efficient than the half wave rectifier. The waveforms are given below:



25. Two heating elements of resistances R_1 and R_2 when operated at a constant supply of voltage, V, consume powers P_1 and P_2 respectively. Deduce the expressions for the power of their combination whey they are, in turn, connected in (i) series and (ii) parallel across the same voltage supply.

Solution:

Given

$$P_1 = \frac{V^2}{R_1} \qquad \& \qquad P_2 = \frac{V^2}{R_2}$$

(i) Power when they are connected in series

$$P_{eq} = \frac{V^2}{R_{eq}} = \frac{V^2}{R_1 + R_2} \qquad \text{(From given information } R_1 = \frac{V^2}{P_1}; R_2 = \frac{V^2}{P_2}\text{)}$$

$$\Rightarrow P_{eq} = \frac{V^2}{\frac{V^2}{P_1} + \frac{V^2}{P_2}}$$

$$\boxed{P = \frac{P_1 P_2}{P_1 + P_2}}$$

(ii) Power when they are connected in parallel

$$P_{eq} = \frac{V^2}{R_{eq}}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\Rightarrow P_{eq} = V^2\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$= \frac{V^2}{R_1} + \frac{V^2}{R_2}$$

$$\boxed{P_{eq} = P_1 + P_2}$$

26. Use the mirror equation to show that
(a) an object placed between f and 2f of a concave mirror produces a real image beyond 2f.
(b) a convex mirror always produces a virtual image independent of the location of the object.
(c) an object placed between the pole and focus of a concave mirror produces a virtual and enlarged image.

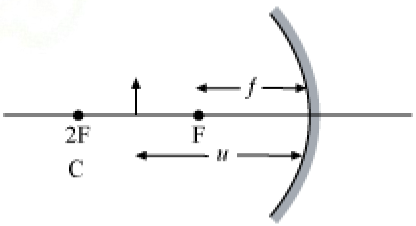
Solution:
(a) For concave mirror
$f < 0$ and $u < 0$ (always)
Given $|2f| > |u| > |f|$ (object placed between f and $2f$)
According to mirror equation,

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \Rightarrow v = \frac{fu}{u-f}$$

As $f < 0; u < 0 \Rightarrow fu < 0$

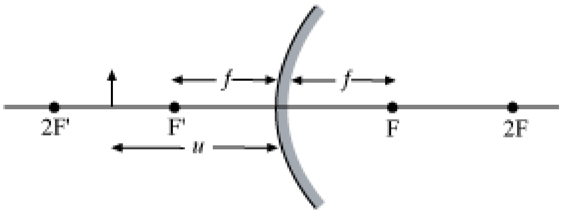
and $u - f > 0$

$\Rightarrow v < 0$



Hence, real image

(b) A convex mirror
$f > 0$; $u < 0$ (always)
Case I $|u| > |f|$



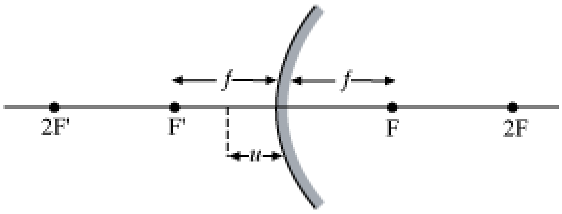
We know,

$$v = \frac{fu}{u-f}$$

$fu < 0$ and $f - u < 0$

$\Rightarrow v > 0$ virtual image

Case II $|u| < |f|$



$$v = \frac{fu}{u-f} \qquad fu < 0$$

$$u - f < 0$$

$\Rightarrow u > 0$

Hence, at all the positions convex mirror will form a virtual image.

(c) Given $|u| < |f|$ and $u < 0$

$f < 0$ concave mirror

According to mirror equation,

$$v = \frac{fu}{u-f}$$

$\Rightarrow fu > 0$

Also, As $|u| < |f|$

$u - f < 0$

$\Rightarrow v > 0$ virtual image

Also, $|fu| > 0$ and $|fu| > |u - f|$

Product of two Real numbers > the difference of same two numbers

$$\Rightarrow v = \frac{fu}{u-f} > 1 > u$$

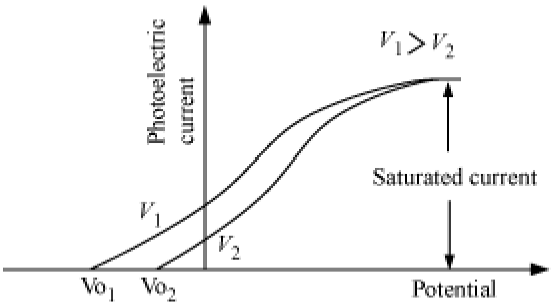
Hence, $\frac{v}{u} > 1$; Enlarged image.

27. Draw a plot showing the variation of photoelectric current with collector plate potential for two different frequencies, $\nu_1 > \nu_2$, of incident radiation having the same intensity. In which case will the stopping potential be higher? Justify your answer.

Solution:

Effect of frequency of the incident radiation:

Taking radiations of different frequencies but of same intensity, the variation between photoelectric current and potential of plate *A* is obtained and shown in graph given below:



From the graph, we note:
(i) The value of stopping potential is different for radiation of different frequency.
(ii) The value of stopping potential is more negative **for radiation of higher incident frequency**.
(iii) The value of saturation current depends on the intensity of incident radiation, but is independent of the frequency of the incident radiation.