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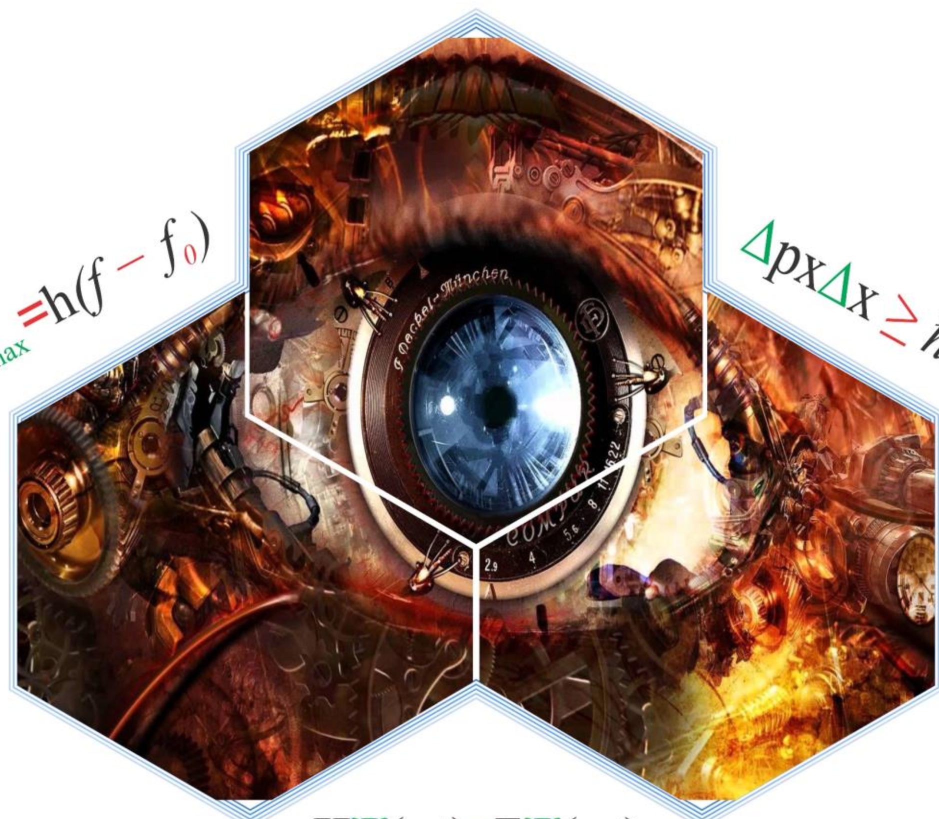
MODERN PHYSICS & ELECTRONICS

For BS Physics Programme

2nd Edition

$K_{max} = h(f - f_0)$

$\Delta p x \Delta x \geq \hbar/2$



$H\Psi(\mathbf{r},t) = E\Psi(\mathbf{r},t)$

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MODERN PHYSICS & ELECTRONICS

2nd Edition

For **BS Physics** students of all Pakistani Universities

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Contents

Chapter 1

Origins of Quantum Mechanics

SOLVED PROBLEMS

Problem: 1.1- Find surface temperature and radiation intensities of following:

1. A star with spectral radiancy 240 nm.
2. Sun with spectral radiancy 500 nm.

Solution

$$\lambda_{\max}\mathrm{T} = 2898\mu\ \mathrm{mK}$$
$$T = \frac{2898\mu\ \mathrm{mK}}{\lambda_{\max}}$$
$$\text{Surface temperature} = T = ?$$
$$\text{Radiant intensity} = I(T) = ?$$

1. For star:

$$\text{Wavelength} = \lambda_{\max} = 240 \times 10^{-9}\mathrm{m}$$

$$\mathrm{T} = \frac{2898\mathrm{mK}}{240 \times 10^{-9}\mathrm{m}}$$
$$\mathrm{T} = 12075\mathrm{K}$$

Radiant intensity for star is

$$
\begin{aligned}
I(T) &= \sigma T^4 \\
I(T) &= 5.678 \times 10^{-8} \times (12075K)^4 \\
I(T) &= 1.2 \times 10^{9} W/m^2
\end{aligned}
$$

2. For Sun

$$
\begin{aligned}
\text{Wavelength } \lambda_{max} &= 500 \times 10^{-9} m \\
\text{Surface temperature } &= T = ? \\
\text{Radiant intensity } &= I(T) = ?
\end{aligned}
$$

$$T = \frac{2898 \times 10^{-6} mK}{500 \times 10^{-9} m} = 5796K$$

Radiant intensity of sun is

$$
\begin{aligned}
I(T) &= \sigma T^4 \\
I(T) &= 5.678 \times 10^{-8} W/m^2K^4 \times (5796K)^4 \\
I(T) &= 6.4 \times 10^{7} W/m^2
\end{aligned}
$$

Problem: 1.2- By interaction plank's radiation law over all wavelengths, show that the power radiated per square meter of cavity surface is given by

$$I(T) = \left(\frac{2\pi^5 K_B^4}{15h^3c^2}\right) T^4 = \sigma T^4$$

OR, deduce Stefen Boltzmann law from plank's radiation law. Also find numerical value of σ and show that it comes out to be $5.678 \times 10^{-8} W/m^2K^4$.

Solution

From plank's law

$$R(\lambda) = \frac{2\pi c^2}{\lambda^5} \frac{1}{e^{hc/\lambda k_B T} - 1}$$

Radiant intensity is defined as,

$$\mathrm{I(T)} = \int_0^\infty \mathrm{R}(\lambda) d\lambda$$

$$\mathrm{I(T)} = \int_0^\infty \frac{2\pi \mathrm{c}^2}{\lambda^5} \frac{1}{\mathrm{e}^{\frac{\mathrm{hc}}{\lambda \mathrm{k_B T}}} - 1} \mathrm{d}\lambda$$

$$\mathrm{I(T)} = 2\pi \mathrm{c}^2 \int_0^\infty \frac{1}{\mathrm{e}^{\frac{\mathrm{hc}}{\lambda \mathrm{k_B T}}} - 1} \frac{\mathrm{d}\lambda}{\lambda^5}$$

By putting,

$$x = \frac{\mathrm{hc}}{\lambda \mathrm{k_B T}}$$

$$dx = \frac{\mathrm{hc}}{\lambda^2 \mathrm{k_B T}} \mathrm{d}\lambda$$

$$x^3 dx = \left(\frac{\mathrm{hc}}{\lambda \mathrm{k_B T}}\right)^3 \frac{\mathrm{hc}}{\lambda^2 \mathrm{k_B} T} d\lambda$$

$$x^3 dx = \frac{h^3 c^3}{\lambda^3 k_B^3 T^3} \frac{hc}{\lambda^2 k_B T} d\lambda$$

$$\frac{d\lambda}{\lambda^5} = \frac{k_B^4 T^4}{h^4 c^4} x^3 dx$$

So,

$$I(T) = 2\pi h c^2 \frac{k_B^4 T^4}{h^4 c^4} \int_0^\infty \frac{x^3 dx}{e^x - 1}$$

$$I(T) = 2\pi h c^2 \frac{k_B^4 T^4}{h^4 c^4} \frac{\pi^4}{15}$$

$$I(T) = \left(\frac{2\pi^5 K_B^4}{15 h^3 c^2}\right) T^4$$

$$I(T) = \sigma T^4$$

Which is Stefan-Boltzmann law for cavity radiator. Where

$$\sigma = \left(\frac{2\pi^5 K_B^4}{15 h^3 c^2}\right)$$

Putting values, we obtain

$$\sigma = \frac{2(3.14)^5(1.381\times 10^{-23}\frac{J}{K})^4}{15(6.63\times 10^{-34}Js)(3\times 10^8 m/s)^2}$$
$$\sigma = 5.678\times 10^8 W/m^2K^4$$

Problem: 1.3- A $2k$ block is attached to a massless spring that has a force constant of $k = 25N/m$. The spring is trenched $0.4m$ from its equilibrium position and released from rest.

1. Find the total energy of the system and frequency of oscillation according to classical calculations.
2. Assume the energy of oscillation is quantized; find the quantum number n for the system oscillation with this amplitude.

Solution

$$k = 25N/m$$
$$A = 0.4m$$
$$m = 2kg$$

$$E = ? \quad \text{and} \quad \nu = ?$$

1. Total energy of system is,

$$E = \frac{1}{2}kA^2$$
$$E = \frac{1}{2}25N/m\times(0.4m)^2 = 2J$$

For frequency,

$$\nu = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$
$$\nu = \frac{1}{2\times 3.14}\sqrt{\frac{25N/m}{2kg}}$$
$$\nu = 0.563\ Hz$$

2. Using,

$$
\begin{aligned}
E &= nh\nu \\
n &= \frac{E}{h\nu} \\
n &= \frac{2J}{6.63\times10^{-34}Js\times0.563Hz} \\
n &= 5.63\times10^{33}
\end{aligned}
$$

Problem: 1.4- A simple pendulum has a length of 1 m and a mass if 1 kg. The maximum horizontal displacement of the pendulum bob from equilibrium is 3 cm. Calculate the quantum number n for the pendulum.

Solution

$$\text{Height of bob} = L-\sqrt{L^2-x^2}$$

Energy of bob is,

$$
\begin{aligned}
E &= U = mg\left(L-\sqrt{L^2-x^2}\right) \\
E &= 1\times9.8\times(1-\sqrt{(1)^2-(3\times10^{-2})^2} \\
E &= 4.41\times10^{-3}J
\end{aligned}
$$

According to quantization of energy,

$$
\begin{aligned}
E &= nh\nu \\
n &= \frac{E}{h\nu} \\
n &= \frac{E}{h}\times2\pi\sqrt{\frac{L}{g}} \\
n &= \frac{4.41\times10^{-3}}{6.63\times10^{-34}}\times2\pi\sqrt{\frac{1}{9.8}} \\
n &= 1.34\times10^{31}
\end{aligned}
$$

Problem: 1.5- An atom absorb photon having wavelength 375 nm and emidiatly emits another photon having a wavelength of 580 nm. What was net energy absorb by atom in this process.

Solution

$$\lambda = 375 \times 10^{-9}\ m \quad \text{Incident photon}$$
$$\lambda' = 580 \times 10^{-9}\ m \quad \text{Emitted photon}$$
$$\text{Net energy} = \frac{hc}{\lambda} - \frac{hc}{\lambda'}$$
$$= hc\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right)$$
$$= 6.63 \times 10^{-34} \times 3 \times 10^{8}$$
$$\left(\frac{1}{375 \times 10^{-9}} - \frac{1}{580 \times 10^{-9}}\right)$$
$$= 1.875 \times 10^{-19}\ J$$
$$= \frac{1.875 \times 10^{-19}}{1.6 \times 10^{-19}}\ eV\ = 1.17\ eV$$

Chapter 2

Wave Particle Duality

SOLVED PROBLEMS

Problem: 2.1- Calculate the de Broglie wavelength of an electron whose $K.E$ is 1 KeV.

Solution

Given data:

$$\begin{aligned}
\text{Mass of electron} &= m = 9.1\times10^{-31}\ Kg\\
\text{Kinetic energy} &= K.E = 1\ KeV\\
&= 1\times10^{3}\times1.6\times10^{-19}\ J\\
\text{Wavelength} &= \lambda = ?
\end{aligned}$$

We know that

$$\begin{aligned}
K.E &= \frac{1}{2}mv^2\\
v &= \sqrt{\frac{2K.E}{m}}\\
v &= \sqrt{\frac{2(1\times10^{3}\times1.6\times10^{-19})}{9.1\times10^{-31}}}\\
&= 1.87\times10^{7}\ m/s
\end{aligned}$$

Thus,

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$
$$\lambda = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.87 \times 10^{7}}$$
$$\lambda = 3.89 \times 10^{-11}\ m$$

Problem: 2.2- If de Broglie wavelength of electron is $1.1 \times 10^{-10}\ m$. What is the speed of electron?

Solution

Given data:

$$m = 9.1 \times 10^{-31}\ Kg$$
$$\lambda = 1.1 \times 10^{-10}\ m$$
$$v = ?$$

Using the formula of de Broglie wavelength

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$
$$v = \frac{h}{m\lambda}$$
$$v = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.1 \times 10^{-10}}$$
$$v = 6.62 \times 10^{6}\ m/s$$

Problem: 2.3- A microscope, using photons, is employed to locate an electron in an atom to within a distance of $0.2\ A^{\circ}$. What is the uncertainty in the momentum of the electron located in this way?

Solution

Given data:

$$\Delta x = 0.2\ A^{\circ} = 0.2 \times 10^{-10}\ m$$

$$h = 6.63 \times 10^{-34} \ Js$$
$$\Delta p = ?$$

Using the formula for uncertainty principle,

$$\Delta x \Delta p = \frac{h}{2\pi}$$
$$\Delta p = \frac{h}{2\pi \Delta x}$$
$$\Delta p = \frac{h}{2 \times 3.14 \times 0.2 \times 10^{-10}}$$
$$\Delta p = 5.274 \times 10^{-24} \ Kgm/s$$

Problem: 2.4- Find the uncertainty in the location of a particle in terms if its de Broglie wavelength λ so that the uncertainty in its velocity is equal to its velocity?

Solution

$$\Delta x \Delta p_x \cong \frac{h}{2\pi}$$
$$\Delta x m \Delta v_x = \frac{h}{2\pi} \qquad \because \Delta p_x = m\Delta v_x$$

Put $\lambda = \Delta x$, where λ is de Broglie wavelength.

$$\lambda m \Delta v_x \cong \frac{h}{2\pi}$$
$$\frac{h}{p} m \Delta v_x \cong \frac{h}{2\pi} \qquad \because \lambda = \frac{h}{p}$$
$$\frac{h}{mv} m \Delta v_x \cong \frac{h}{2\pi}$$
$$\Delta v_x = \frac{v}{2\pi}$$

Since 2π is constant, so we can write

$$v = \Delta v_x$$

Problem: 2.5- If the de-Broglie wavelength of proton is 0.113 pm (a) What is the speed of proton. (b) Through what electrical potential would the proton have to be accelerated from rest to acquire this speed?

Solution

(a) For proton
Given data:

$$\begin{aligned} \lambda &= 0.113\ pm = 0.113 \times 10^{-12}\ m \\ m &= 1.67 \times 10^{-27}\ Kg \\ e &= 1.6 \times 10^{-19}\ C \\ v &= ? \end{aligned}$$

Since, we know that

$$\begin{aligned} \lambda &= \frac{h}{p} = \frac{h}{mv} \\ v &= \frac{h}{m\lambda} \\ v &= \frac{6.63 \times 10^{-34}}{1.67 \times 10^{-27} \times 0.113 \times 10^{-12}} \\ v &= 3.5 \times 10^{6}\ m/s \end{aligned}$$

(b)

$$\begin{aligned} K.E &= eV_\circ \\ \frac{1}{2}mv^2 &= eV_\circ \\ mv^2 &= 2eV_\circ \\ V_\circ &= \frac{mv^2}{2e} \\ V_\circ &= \frac{1.67 \times 10^{-27}(3.5 \times 10^{6})^2}{2 \times 1.6 \times 10^{-19}} \\ V_\circ &= 6.39 \times 10^{4}\ V \end{aligned}$$

Chapter 3

Introduction to Quantum Mechanics

SOLVED PROBLEMS

Problem: 3.1- Verify the operator equation

$$\frac{\partial}{\partial x}x^n = nx^{n-1} + x^n\frac{\partial}{\partial x}$$

Solution

Consider a wave function ψ , then

$$\frac{\partial}{\partial x}x^n\psi = nx^{n-1}\psi + x^n\frac{\partial}{\partial x}\psi$$

$$\frac{\partial}{\partial x}x^n\psi = \left(nx^{n1} + x^n\frac{\partial}{\partial x}\right)\psi$$

$$\frac{\partial}{\partial x}x^n\psi = \left(nx^{n-1} + x^n\frac{\partial}{\partial x}\right)\psi$$

Since ψ is arbitrary function, so

$$\frac{\partial}{\partial x}x^n = nx^{n-1} + x^n\frac{\partial}{\partial x}$$

Problem: 3.2- Check whether momentum operator $\hat{p}_x$ and position vector $\hat{x}$ commute ? What conclusion you draw from result.

Solution

Consider an arbitrary wave function ψ then

$$\begin{aligned}
[\hat{p}_x, \hat{x}]\,\psi &= (\hat{\rho}_x\hat{x} - \hat{x}\hat{p}_{\hat{x}})\,\psi \\
&= \left(-i\hbar\frac{\partial}{\partial x}x + xi\hbar\frac{\partial}{\partial x}\right)\psi \\
[\hat{p}_x, \hat{x}]\,\psi &= -\,i\hbar\frac{\partial}{\partial x}x\psi + xi\hbar\frac{\partial}{\partial x}\psi \\
&= -\,i\hbar\frac{\partial}{\partial x}x\psi - i\hbar\psi + xi\hbar\frac{\partial}{\partial x}\psi \\
[\hat{p}_x, \hat{x}]\,\psi &= -\,i\hbar\psi
\end{aligned}$$

As ψ is arbitrary function, so $[\hat{p}_x, \hat{x}]\,\psi = -i\hbar$ Conclusion: Since position and momentum operators do not commute, so position and momentum of a particle cannot be measured simultaneously.

Problem: 3.3- A proton is trapped in one dimensional box of length 0.1 nm. What is minimum energy of proton.

Solution

$$\begin{aligned}
L &= 0.1 \times 10^{-9} m \\
m &= 1.67 \times 10^{-27} kg \\
E_1 &= ?
\end{aligned}$$

We know that,

$$E = n^2\left(\frac{h^2}{8mL^2}\right)$$

Energy is minimum for $n = 1$

$$
\begin{aligned}
E &= 1^2 \left(\frac{\left(6.63 \times 10^{-34}\right)^2}{8 \times 1.67 \times 10^{-27} \times \left(0.1 \times 10^{-9}\right)^2} \right) \\
E &= \frac{3.28 \times 10^{-21}}{1.7 \times 10^{-19}} \\
E &= 2.05 \times 10^{-2} eV
\end{aligned}
$$

Problem: 3.4- Wave function of particle is confined to infinite well and in lowest energy state is,

$$
\psi\left(x\right) = A \sin \frac{\pi}{L} x
$$

Normalize the function i.e. find value of A ?

Solution

To find value of A we apply normalization condition,

$$
\begin{aligned}
\int_0^L \psi^*(x)\psi(x) &= 1 \\
\int_0^L A^* \sin \frac{\pi}{L} x A \sin \frac{\pi}{L} x dx &= 1 \\
|A|^2 \sin^2 \frac{\pi}{L} x dx &= 1 \\
|A|^2 \int_0^L \frac{1 - \cos(\frac{2\pi}{L})x}{2} dx &= 1 \\
\frac{|A|^2}{2} \left| x - \frac{\sin \frac{2\pi}{L} x}{\frac{2\pi}{L}} \right|_0^L &= 1 \\
\frac{|A|^2}{2} \left(L - 0 - 0 + 0\right) &= 1 \\
|A|^2 &= \frac{2}{L} \\
A &= \sqrt{\frac{2}{L}}
\end{aligned}
$$

So normalized function is,

$$\psi(x) = \sqrt{\frac{2}{L}} \sin \frac{\pi}{L} x$$

Problem: 3.5- A particle is confined with rigid walls by distance L.Find probability that it will be found within a distance $\frac{L}{3}$ from one wall ? coefficient occurs for a 1 % increase in barrier height ?

Solution

The normalized eigen function of particle are

$$\psi(x) = \sqrt{\frac{2}{L}} \sin \frac{n\pi}{L} x$$

Probability that a particle will be found within a distance $\frac{L}{3}$ from one wall is,

$$p = \int_0^{\frac{L}{3}} \psi^*(x)\psi(x)dx$$

$$p = \int_0^{\frac{L}{3}} \sqrt{\frac{2}{L}} \sin \frac{n\pi}{L} x \sqrt{\frac{2}{L}} \sin \frac{n\pi}{L} x dx$$

$$p = \int_0^{\frac{L}{3}} \frac{2}{L} \sin^2 \frac{n\pi}{L} x dx$$

$$p = \frac{2}{L} \int_0^{\frac{L}{3}} \frac{1 - \cos \frac{2n\pi}{L} x}{2} dx$$

$$p = \frac{2}{L} \frac{1}{2} \left| x - \frac{\sin \frac{2n\pi}{L} x}{\frac{2n\pi}{L}} \right|_0^{\frac{L}{3}}$$

$$p = \frac{1}{L} \left(\frac{L}{3} - \frac{L}{2n\ pi} \sin \frac{2n\pi}{3} - 0 \right)$$

$$p = \left(\frac{L}{3} - \frac{1}{2n\pi} \sin \frac{2n\pi}{3} \right)$$

Chapter 4

Atomic Physics

SOLVED PROBLEMS

Problem: 4.1- (a)-What is wavelength of least energetic photon in Balmer series. (b)-What is wavelength of series limit for the Balmer series.

Solution

(a) Least energetic photon is obtained when electron moves from 3rd orbit $n = 3$ into second orbit $p = 2$ in Balmer series. Thus,

$$\frac{1}{\lambda} = R\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$\frac{1}{\lambda} = 1.097 \times 10^7 \left(\frac{1}{4} - \frac{1}{9}\right)$$

$$\frac{1}{\lambda} = 1.097 \times 10^7 \times \frac{5}{36}$$

$$\lambda = \frac{36}{5} \times \frac{1}{1.097} \times 10^{-7}$$

$$\lambda = 7 \times 10^{-7}\ m$$

$$\lambda = 700\ nm$$

(b) For series limit, in Balmer series, transition of electron takes place from $n = \infty$ to $p = 2$, then

$$\frac{1}{\lambda} = R\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$
$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right)$$

$$\frac{1}{\lambda} = 1.097 \times 10^7 \left(\frac{1}{4} - \frac{1}{\infty}\right)$$
$$\frac{1}{\lambda} = 1.097 \times 10^7 \times \frac{1}{4}$$
$$\lambda = 4 \times \frac{1}{1.097} \times 10^{-7}$$
$$\lambda = 3.65 \times 10^{-7}\ m$$
$$\lambda = 365\ nm$$

Problem: 4.2- A He-Ne has light at a wavelength of $6328 \times 10^{-10}\ m$ and has an out put power of 2.3×10^{-3} watt. How many photons are emitted each minute by this laser.

Solution

Energy of one photon is E_{Photon}. As, we know that

$$E_{\text{Photon}} = \frac{hc}{\lambda}$$
$$E_{\text{Photon}} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{6328 \times 10^{-10}}$$
$$E_{\text{Photon}} = 3 \times 10^{-19}\ J$$

Since the number of photons are

$$\text{No. of photon} = N = \frac{P \times t}{E_{\text{Photon}}}$$
$$\text{No. of photon} = N = \frac{2.3 \times 10^{-3} \times 60}{3 \times 10^{-19}}$$
$$\text{No. of photon} = N = 46 \times 10^{16}$$

Problem: 4.3- A ruby laser emits light at wavelength 694.4 nm. If a laser pulse is emitted for 12 ps and the energy released per pulse is 150 mJ. What is the length of the pulse. How many photons are in each pulse.

Solution

$$\lambda = 694.4\ nm = 694.4 \times 10^{-9}\ m$$
$$t = 12\ ps = 12 \times 10^{-12}\ s$$
$$E = 150\ mJ = 150 \times 10^{-3}\ J$$
$$c = 3 \times 10^{8}\ m/s$$
$$S = ?$$
$$n = ?$$

Using the formula

$$S = ct = 3 \times 10^{8} \times 12 \times 10^{-12}$$
$$S = 0.0036\ m$$

Number of photons can be determined by

$$E = \frac{nhc}{\lambda}$$
$$n = \frac{E\lambda}{hc}$$
$$n = \frac{150 \times 10^{-3} \times 694.4 \times 10^{-9}}{6.63 \times 10^{-34} \times 3 \times 10^{8}}$$
$$n = 5.2 \times 10^{17}$$

Problem: 4.4- Determine the Planck's constant from the fact that the minimum X-rays wavelength produced by 40 KeV electrons is 31.1 pm?

Solution

$$\lambda_{\min} = 31.1\ pm = 31.1 \times 10^{-12}\ m$$
$$K.E = 40\ KeV = 40 \times 10^{3} \times 1.6 \times 10^{-19}\ J$$

$$c = 3 \times 10^8 \ m/s$$
$$h = ?$$

Using the formula, we get

$$\lambda_{\min} = \frac{hc}{K.E}$$
$$h = \frac{\lambda_{\min} K.E}{c}$$
$$h = \frac{31.1 \times 10^{-12} \times 40 \times 10^3 \times 1.6 \times 10^{-19}}{3 \times 10^8}$$
$$h = 6.63 \times 10^{-34} \ Js$$

Problem: 4.5- What are the wavelength, momentum and energy of the photon that is emitted when a hydrogen atom undergoes a transition from the state $n = 3$ to $n = 1$.

Solution

$$\frac{1}{\lambda} = R\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$
$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{3^2}\right)$$
$$\frac{1}{\lambda} = 1.097 \times 10^7 \left(1 - \frac{1}{9}\right)$$
$$\frac{1}{\lambda} = 1.097 \times 10^7 \times \frac{8}{9}$$
$$\lambda = \frac{9}{8} \times \frac{1}{1.097} \times 10^{-7}$$
$$\lambda = 1.032 \times 10^{-7} \ m$$

Also, we know that

$$E = \frac{hc}{\lambda}$$
$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.032 \times 10^{-7}}$$
$$E = 1.9 \times 10^{-18} \ J$$

Also,

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

$$p = \frac{6.63 \times 10^{-34}}{1.032 \times 10^{-7}}$$

$$p = 6.4 \times 10^{-27}\ Ns$$

Chapter 5

Nuclear Physics

SOLVED PROBLEMS

Problem: 5.1- What is the approximate density of the nuclear matter from which all the nuclei made?

Solution

The number of nucleons per unit volume is called density of nuclear matter.

$$\rho = \frac{A}{V}$$

Since, nucleus is spherical. Its volume is $\frac{4}{3}\pi R^3$, so

$$\rho = \frac{A}{\frac{4}{3}\pi R^3} = \frac{3A}{4\pi R^3}$$

$$\rho = \frac{3A}{4\pi (R_\circ A^{1/3})^3} \qquad \because R = R_\circ A^{1/3}$$

$$\rho = \frac{3A}{4\pi R_\circ^3 A} = \frac{3}{4\pi R_\circ^3}$$

$$\rho = \frac{3}{4 \times 3.14 (1.2 \times 10^{-15})^3}$$

$$\rho = 1.38 \times 10^{44} \ \frac{\text{nucleons}}{m^3}$$

$$\rho = 1.38 \times 10^{44} \times 1.67 \times 10^{-27}$$

$$\rho = 2.3046 \times 10^{17} \ kg/m^3$$

Problem: 5.2- Imagine that a typical middle-mass nucleus such that Sn_{50}^{120} is picked apart into its constituent protons and neutrons. Find the total energy required and the energy per nucleon. Atomic mass of Sn is 119.902199 u

Solution

$$\text{Mass of } Sn_{50}^{120} = 119.902199\ u$$
$$E_B = ? \quad \text{and} \quad \frac{B.E}{A} = ?$$

The nucleus of Sn contains 50 protons and 70 neutrons,

$$m_p = 1.007825\ u \quad ; \quad m_n = 1.008665\ u$$

So,

$$\Delta m = (50m_p + 70m_n) - m\left(Sn_{50}^{120}\right)$$
$$\Delta m = (50 \times 1.007825 + 70 \times 1.008665) - 119.902199$$
$$\Delta m = 1.095601\ u$$

The binding energy is

$$E_B = \Delta mc^2$$
$$E_B = 1.095601 \times 931.5 = 1020.6\ MeV$$

Also,

$$\frac{B.E}{A} = \frac{E_B}{A} = \frac{1020.6}{120}$$
$$\frac{B.E}{A} = 8.5\ MeV/\text{nucleon}$$

Problem: 5.3- Show that 1 $a.m.u = 931.5\ MeV$.

Solution

$$\begin{aligned} m &= 1.67 \times 10^{-27}\ kg \\ c &= 3 \times 10^{8}\ m/s \\ E &= ? \end{aligned}$$

We know that

$$\begin{aligned} E &= mc^2 = 1.67 \times 10^{-27} \times (3 \times 10^{8})^2 \\ E &= 15 \times 10^{-11}\ J = \frac{15 \times 10^{-11}}{1.6 \times 110^{-19}}\ eV \\ E &= 9.315 \times 10^{8}\ eV = 931.5 \times 10^{6}\ eV \\ E &= 931.5\ MeV \end{aligned}$$

Problem: 5.4- Calculate Q for the reaction $^{59}Co(p,n)$, ^{59}Ni needed atomic masses are $^{59}Co = 58.933198\ u, H_1^1 = 1.007825\ u,^{59} Ni = 58.934349\ u, n = 1.008665\ u.$

Solution

$$\begin{aligned} m(Co) &= 58.933198\ u \\ m(Ni) &= 58.934349\ u \\ m_p &= 1.007825\ u \\ m_n &= 1.008665\ u \\ Q &= ? \end{aligned}$$

The nuclear reaction is

$$\begin{array}{ccccccc} {}_1^1H & + & ^{59}Co & \longrightarrow & ^{59}Ni & + & {}_0^1n \\ 1.007825 & + & 58.933198 & \longrightarrow & 58.934349 & + & 1.008665 \end{array}$$

$$\Delta m = 59.941023 - 59.943014$$
$$\Delta m = -1.991 \times 10^{-3}\ u$$

The Q-value of nuclear reaction is

$$Q = \Delta mc^2$$
$$Q = -1.991 \times 10^{-3} \times 931.5$$
$$Q = -1.85\ MeV$$

Problem: 5.5- A carbon specimen found in a cave contained 1/8 as much ^{14}C as an equal amount of carbon in living matter. Calculate the approximate age of specimen. Half life period of ^{14}C is 5568 years.

Solution

$$T_{1/2} = 5568 \text{ years}$$

Using the formula of half life

$$T_{1/2} = \frac{0.6931}{\lambda}$$
$$\lambda = \frac{0.693}{5568}$$

Also,

$$N = N_{\circ} e^{-\lambda t}$$
$$\frac{N}{N_{\circ}} = e^{-\lambda t}$$
$$\frac{1}{8} = e^{-\lambda t}$$
$$\lambda t = \log_e 8$$

$$
\begin{aligned}
t &= \frac{\log_e 8}{\lambda} \\
t &= \frac{\log_e 8 \times 5568}{0.693} \\
t &= 16710 \text{ years}
\end{aligned}
$$

Chapter 6

Basic Electronics

SOLVED PROBLEMS

Problem: 6.1- A transformer has rated secondary voltage $V_{rms} = 24V$. Find average current, peak current, dc voltage across the load resistance of 50 *ohm*.

Solution

$$\text{Load resistance} = R = 50$$
$$\text{Root mean square voltage} = V_{rms} = 24V$$
$$\text{Average current} = I_{dc} = ?$$
$$\text{Peak current} = I_m = ?$$
$$\text{Dc voltage} = V_{dc} = ?$$

For half wave rectifier, we have ,

$$V_m = \sqrt{2V_{rms}}$$
$$= \sqrt{2 \times 24\ V} = \ 33.8\ V$$
$$I_m = \frac{V_m}{R} \ = \ \frac{33.8\ V}{50\ \Omega}$$
$$= 0.676\ A$$

$$I_{dc} = \frac{0.636\ V_m}{R} = \frac{0.636 \times 33.8}{50}$$
$$= 0.43\ A$$
$$V_{dc} = I_{dc}R$$
$$= 0.676\ A \times 50\ \Omega$$
$$= 21.5\ V$$

Problem: 6.2- determine the needed peak inverse voltage for a diode in bridge rectifier if $V_{dc} = 80\ volt$?

Solution

$$\text{dc voltage} = V_{dc} = 80\ V$$
$$\text{peak inverse voltage} = P.I.V = ?$$

For a bridge rectifier circuit,

$$V_{dc} = 0.636\ V_m$$
$$V_m = \frac{V_{dc}}{0.636}$$
$$= \frac{80\ V}{0.636}$$
$$= 125.79\ V$$
$$P.I.V = V_m = 125.79\ V$$

Problem: 6.3- The dc output voltage of full wave rectifier is 120 V .What is required $r.m.s$ voltage rating for each half of center tap transformer ? What is peak ac voltage rating for transformer?

Solution

$$\text{output voltage} = V_{dc} = 120\ V$$
$$\text{r.m.s voltage} = V_{rms} = ?$$
$$\text{Peak voltage} = V_m = ?$$

For full wave rectifier, We have

$$V_{dc} = 0.636\ V_m$$
$$V_m = \frac{V_{dc}}{0.636} = \frac{120\ V}{0.636} = 188.67\ V$$
$$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{188.67\ v}{\sqrt{2}} = 133.8\ V$$

Problem: 6.4- calculate barrier potential for Si junction at 100 $°C$ if its value at 25 $°C$ is 0.7 V ?

Solution

$$\Delta T = (100 - 25) = 75°C$$
$$\Delta V = -0.002\ \Delta T = 0.002 \times 75 = -0.15\ V$$

For Si junction,

$$\text{Barrier potential} = V_B = 0.7 + (-0.15) = 0.55\ V$$

Problem: 6.5- Current through a PN-junction silicon diode is 45 mA at a forward bias of 0.5 V. Find reverse saturation current?

Solution

$$\text{Absolute Temperature} = T = 27\ °C = 300K$$

For $Si, \eta = 2$

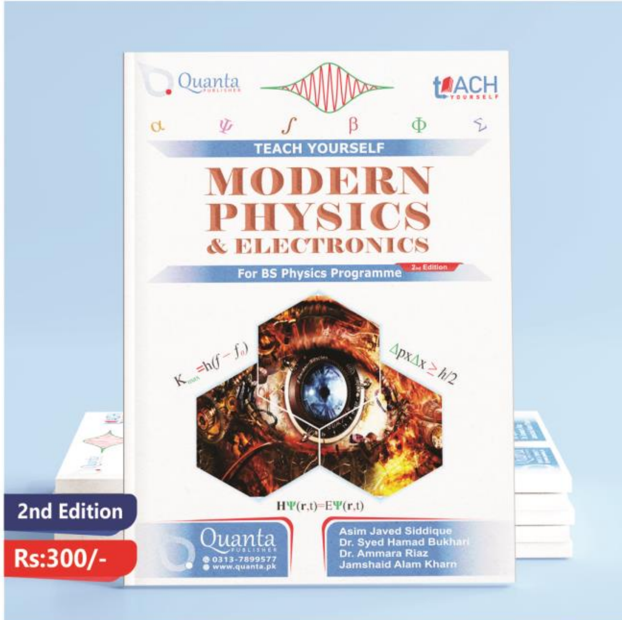
$$\frac{e}{\eta KT} = 1.6 \times 10^{-19} \frac{C}{2} \times 1.381 \times 10^{-23} \frac{J}{K} \times 300K = 9.66 \frac{C}{J}$$
$$I = 45 \times 10^{-3}\ A$$
$$I_S = ?$$
$$V = 0.4\ Volts$$

Diode voltage current equation is,

$$I = I_S\left(e^{\frac{eV}{\eta KT}} - 1\right)$$
$$I_S = \frac{I}{e^{\frac{eV}{\eta KT}} - 1} - 1$$

putting values

$$I_S = 3 \times 10^{-6}\ A$$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