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Internal Assessment Test 1 – May 2025

Sub:	Applied Physics for CSE stream					Sub Code:	BPHYS202	Branch:	CSE/CSE(AI&DS)
Date:	05/05/2025	Duration:	90 mins	Max Marks:	50	Sem/Sec:	II Sem / I,J,K & L		OBE

Answer any FIVE FULL Questions

Given: c = 3 × 10^8 m/s; h = 6.625 × 10^{-34}Js; k = 1.38 × 10^{-23} J/K; m_e = 9.1 × 10^{-31}kg; e = 1.6 × 10^{-19}C

		MARKS	CO	RBT
1 (a)	Find the eigen function and energy eigen values for a particle in a one-dimensional potential well of infinite height.	[07]	CO3	L2
(b)	The attenuation of light in an optical fiber is 0.925 dB/Km. What fraction of its initial intensity remains after 600 m.	[03]	CO1	L3
2 (a)	Obtain the expression for energy density using Einstein's A and B coefficients. Draw inference on the condition $B_{12}=B_{21}$.	[07]	CO1	L2
(b)	Calculate the energy of an electron if the de- Broglie wavelength associated with it is 1.8Å. Also calculate the group velocity of the de-Broglie wave.	[03]	CO1	L3
3 (a)	Describe the construction and working of a semiconductor diode laser.	[07]	CO1	L2
(b)	An electron has a speed of 9.6x 10^5 m/s accurate to 0.017%. With what accuracy can the position of electron be located?	[03]	CO1	L3

PTO

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PTO

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(b)	A He-Ne laser is generating laser beam of power 8 mW. Calculate the number of photons emitted by the laser. Given the wavelength of the emitted radiation is 650nm..	[3]	CO1	L3
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(b)	The first excited state energy of an electron in an infinite well is 150 eV. What will be its ground state energy when the width of the potential well is doubled?	[3]	CO3	L3
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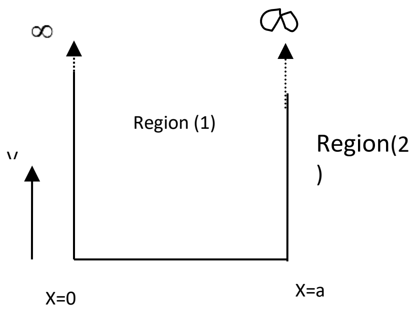
IAT -1 PHYSICS SOLUTION

1A

Particle in an infinite potential well problem:

Consider a particle of mass m moving along X-axis in the region from X= 0 to X = a in a one dimensional potential well as shown in the diagram. The potential energy is assumed to be zero inside the region and infinite outside the region.



Applying, Schrodingers equation for region (1) as particle is supposed to be present in region (1)

$\frac{d^2\Psi}{dx^2} + \frac{8\Pi^2 mE\psi}{h^2} = 0 \because V = 0$ for region (1)

But $k^2 = \frac{8\Pi^2 mE}{h^2}$

$\therefore \frac{d^2\Psi}{dx^2} + k^2\Psi = 0$

Auxiliary equation is $(D^2 + k^2)x = 0$

Roots are D = +ik and D = -ik

The general solution is

$$x = Ae^{ikx} + Be^{-ikx}$$

$$= A(\cos k\,x + i\,\sin k\,x) + B(\cos k\,x - i\,\sin k\,x)$$
$$= (A + B)\cos k\,x + i(A - B)\sin k\,x$$
$$= C\cos k\,x + D\sin k\,x$$

The boundary conditions are

1. At x=0, $\Psi = 0 \therefore C = 0$

2. At x=a, $\Psi = 0$

D sin ka = 0 ⇒ka = nΠ ………(2)

where n = 1, 2 3…

$$\therefore \Psi = D\,\sin\left(n\frac{\Pi}{a}\right)x$$

From (1) and (2) E = $\frac{n^2h^2}{8ma^2}$

To evaluate the constant D:

Normalisation: For one dimension

$$\int_0^a \Psi^2\,dx = 1$$

$$\int_0^a D^2\,\sin^2(\frac{n\Pi}{a})\,xdx = 1$$

But $\cos 2\,\theta = 1 - 2\,\sin^2\theta$

$$\int_0^a D^2\,\frac{1}{2}(1 - \cos 2\,(\frac{n\Pi}{a})x)dx = 1$$

$$\int_0^a \frac{D^2}{2}\,dx - \int_0^a \frac{1}{2}\cos 2\,(\frac{n\Pi}{a})x)dx = 1$$

$$\frac{D^2a}{2} - [\sin 2\left(\frac{n\Pi}{a}\right)\frac{x}{2}]_0^a = 1$$

$D^2\,\frac{a}{2}$ −0 =1

D = $\sqrt{\frac{2}{a}}$

$$\therefore \Psi_n = \sqrt{\frac{2}{a}}\, sin\left(n\frac{\Pi}{a}\right) x$$

1B

$$\alpha = \frac{10}{L} log_{10}\left(\frac{P_{in}}{P_{Out}}\right)$$
$$\left(\frac{P_{in}}{P_{out}}\right) = 10^{\frac{\alpha L}{10}} = 1.13$$
$$P_{out} = \frac{P_{in}}{1.13} = 0.88 P_{in}$$

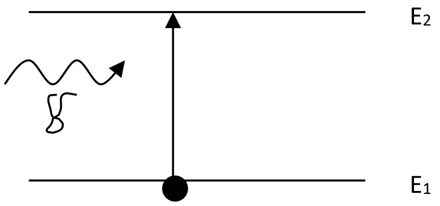
2A

Expression for energy density:

Induced absorption:

It is a process in which an atom at a lower level absorbs a photon to get excited to the higher level.

Let E_1 and E_2 be the energy levels in an atom and N1 and N_2 be the number density in these levels respectively. Let U_γ be the energy density of the radiation incident..



$$\gamma = \frac{E_2 - E_1}{h}$$

Rate of absorption is proportional to the number of atoms in lower state and also on the energy density U_γ.

Rate of absorption = $B_{12}\ N_1 U_\gamma$

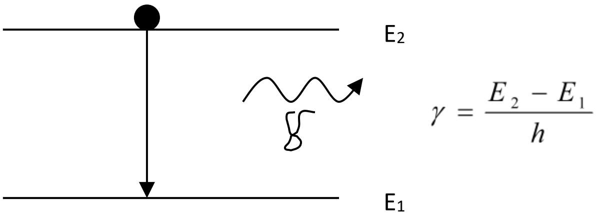
Here B_{12} is a constant known as Einsteins coefficient of spontaneous absorption.

Spontaneous emission:

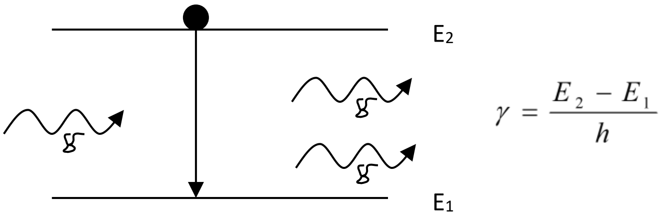
It is a process in which ,atoms at the higher level voluntarily get excited emitting a photon. The rate of spontaneous emission representing the number of such deexcitations is proportional to number of atoms in the excited state.

Rate of spontaneous emission = $A_{21}\ N_2$

Here B_{12} is a constant known as Einsteins coefficient of spontaneous emission.



Stimulated emission:
In this process, an atom at the excited state gets deexcited in the presence of a photon of same energy as that of difference between the two states.



The number of stimulated emissions is proportional to the number of atoms in higher state and also on the energy density U_γ.

Rate of stimulated emission = $B_{21}\ N_2U_\gamma$

Here B_{21} is the constant known as Einsteins coefficient of stimulated emission.

At thermal equilibrium,

Rate of absorption = Rate of spontaneous emission + Rate of stimulated emission

$$B_{12}\ N_1U_\gamma = A_{21}\ N_2 + B_{21}\ N_2\ U_\gamma$$

$$U_\gamma = \frac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$$

Rearranging this, we get

$$U_\gamma = \frac{A_{21}}{B_{21}}\left[\frac{1}{\frac{B_{12}N_1}{B_{21}N_2}-1}\right]$$

From Boltzmann's law ,$\frac{N_1}{N_2} = e^{\frac{h\gamma}{kT}}$

Hence

$$U_\gamma = \frac{A_{21}}{B_{21}}\left[\frac{1}{\frac{B_{12}}{B_{21}}e^{\frac{h\gamma}{kT}}-1}\right]$$

From Planck's radiation law,

$$U_\gamma = \frac{8\pi h\gamma^3}{c^3}\left[\frac{1}{e^{\left[\frac{h\gamma}{kT}\right]}-1}\right]$$

Comparing these expressions, we get

$\frac{A_{21}}{B_{21}} = \frac{8\pi h\gamma^3}{c^3}$ and $\frac{B_{12}}{B_{21}} = 1$

Conclusions

1.Rate of stimulated emission is directly proportional to wavelength

2. Rate of Induced absorption is equal to rate of Stimulated emission

2B

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

$$E = \frac{h^2}{2m\lambda^2} = 7.45x10^{-22}J$$

$$V_g = \frac{h}{m\lambda} = 4.05x10^4 m/s$$

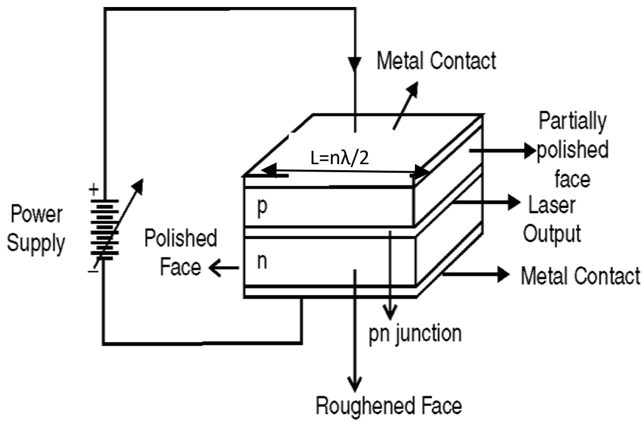
3A

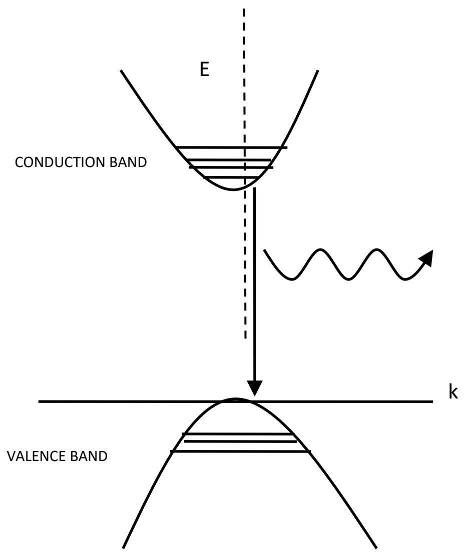
Gallium – Arsenide Semiconductor laser :

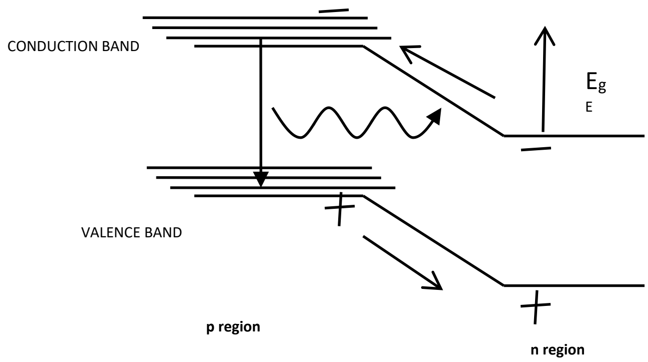
It is the only device which can be used for amplification in the infrared and optical ranges.

CONSTRUCTION

- Gallium Arsenide is heavily doped with Tellurium (n side) and Zinc (P side) to a concentration of 10^{19} atoms /cm^3.
- Resonant cavity is formed by polishing the end faces of Junction diode.
- Amplification is possible if the population of the valence and conduction bands could be inverted as shown in the diagram.
- Optical pumping is done by suitable forward bias voltage







WORKING

The first laser action was observed in a GaAs junction(8400Å) which is a direct gap semiconductor.

When a heavily doped junction is forward biased, electrons from n side are injected into p side causing population inversion. They combine with holes on the P side releasing photons. The junction region is the active region .The optical cavity is formed by the faces of the crystal itself which are taken on the cleavage plane and are then polished. The wavelength of the radiation depends on temperature. The wavelength of laser increases as the energy gap decreases. The frequency can be increased to the optical region by alloying with phosphor according to the relation $Ga(As)_{1-x}P_x$.

If E_g is the energy gap, then $E_g = eV_{forward} = \frac{hc}{\lambda}$

3B

$$\Delta x \times \Delta p = \frac{h}{4\pi}$$

$$\Delta x = \frac{h}{4\pi.\Delta P} = \frac{h}{4\pi.m\nabla v} = 3.54x10^{-7}m$$

4A

HEISENBERG'S UNCERTAINTY PRINCIPLE:

The position and momentum of a particle cannot be determined accurately and simultaneously. The product of uncertainty in the measurement of position (Δx) and momentum is always greater than or equal to $\frac{h}{2\Pi}$. (1 mark)

$$\boxed{(\Delta x).(\Delta p) \geq \frac{h}{4\Pi}}$$

TO SHOW THAT ELECTRON DOES NOT EXIST INSIDE THE NUCLEUS:

We know that the diameter of the nucleus is of the order of 10^{-15}m.If the electron is to exist inside the nucleus, then the uncertainty in its position Δx cannot exceed the size of the nucleus

$$\Delta x = 5x10^{-15}m$$

Now the uncertainty in momentum is

$$\Delta x = 5x10^{-15}m$$

$$\Delta P = \frac{h}{4\pi x \Delta x} = 0.1x10^{-19}kg.m/s$$

Then the momentum of the electron can atleast be equal to the uncertainty in momentum.

$P \approx \Delta P = 0.1x10^{-19} kg.m/s$

Now the energy of the electron with this momentum supposed to be present in the nucleus is given by (for small velocities -non-relativistic-case)

$$E = \frac{p^2}{2m} = 5.5x10^{-11} J = 343 MeV$$

The beta decay experiments have shown that the kinetic energy of the beta particles (electrons) is only a fraction of this energy. This indicates that electrons do not exist within the nucleus. They are produced at the instant of decay of nucleus ($n \rightarrow p + e + \bar{\nu}$ / $p \rightarrow n + \overset{+}{e} + \nu$).

4B

$$\frac{N_g}{N_e} = e^{\frac{hc}{\lambda kT}}$$

$$T = 300K$$

$$\frac{N_e}{N_g} = \frac{N_2}{N_1} 1.076x10^{-30} = e^{-\frac{hc}{\lambda kT}}$$

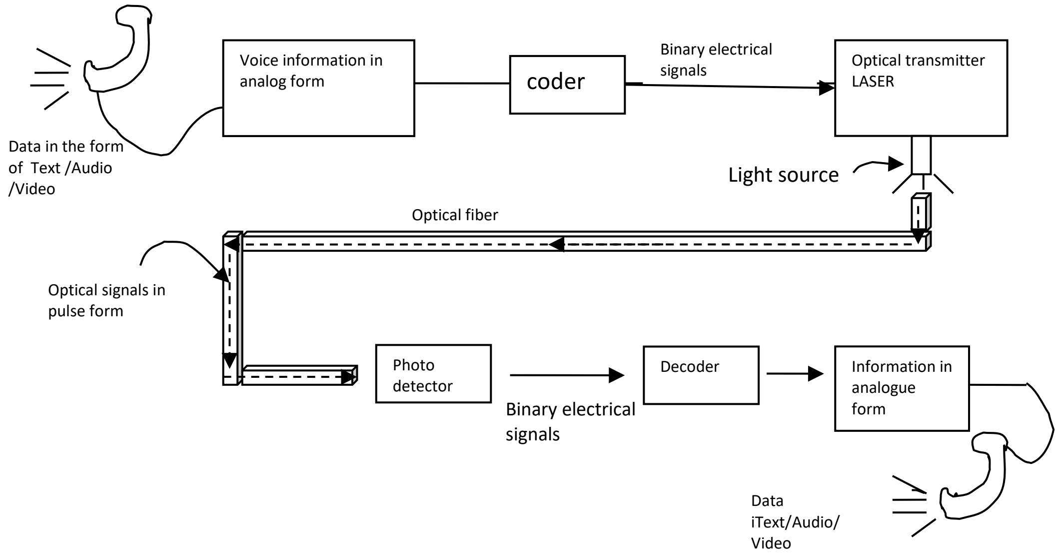
$$ln\left(\frac{N_e}{N_g}\right) = -\frac{hc}{\lambda kT} ln_e\, e$$

$$\lambda = -\frac{hc}{kT\, ln\left(\frac{N_e}{N_g}\right)} = 695x10^{-9} m$$

5A

<u>Point to point communication system using optical fibers</u>

This system is represented through a block diagram as follows.



The information in the form of voice/ picture/text is converted to electrical signals through the transducers such as microphone/video camera. The analog signal is converted in to binary data with the help of coder. The binary data in the form of electrical pulses are converted in to pulses of optical power using Semiconductor Laser. This optical power is fed to the optical fiber. Only those modes within the angle of acceptance cone will be sustained for propagation by means of total internal reflection. At the receiving end of the fiber, the optical signal is fed in to a photo detector where the signal is converted to pulses of current by a photo diode. Decoder converts the sequence of binary data stream in to an analog signal . Loudspeaker/CRT screen provide information such as voice/ picture.

Merits and Demerits of optical fiber communication

Merits –

Large bandwidth (1000GHz)
Data security
No Electrical Interference (No cross talk)
Low loss (0.01dB/km)
Portable
Cheaper

Demerits

Repair costs high

Light emitting sources are limited to low power

The distance between the transmitter and eceiver should keep short or repeaters are needed to boost the signal.

5B

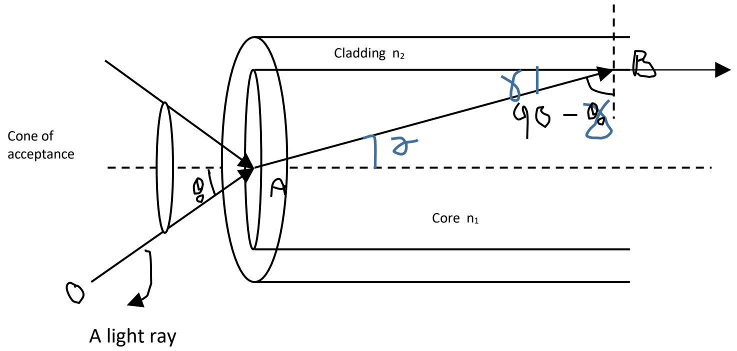
$$P = \frac{E}{t} = \frac{nhc}{\lambda t}$$

$$n = \frac{P\lambda t}{hc} = 2.6x10^{16}$$

6A

Sine of angle of acceptance is known as Numerical aperture.

<u>Expression for condition for propagation :</u>



Consider a light ray falling in to the optical fibre at an angle of incidence θ_o equal to acceptance angle. Let n_0 be the refractive index of the surrounding medium .

Let n_1 be the refractive index of the core.

Let n_2 be the refractive index of the cladding.

From Snell's Law:

For the ray OA $n_0 \sin\theta_0 = n_1 \sin r = n_1\left(\sqrt{1 - \cos^2 r}\right)$………… (1)

For the ray AB $n_1 \sin(90 - r) = n_2 \sin 90$

$$n_1 \cos r = n_2$$

$\cos r = \frac{n_2}{n_1}$

[here the angle of incidence is (90 - θ_1) for which angle of refraction is 90^0].

Substituting for cosr in equation (1)

$$n_0 \sin\theta_0 = n_1\sqrt{1 - \frac{n_2^2}{n_1^2}}$$

$$\sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

If the medium surrounding the fiber is air then $n_0 = 1$,

Numerical aperture = $\sin\theta_0 = \sqrt{n_1^2 - n_2^2}$

The total internal reflection will take place only if the angle of incidence $\theta_i < \theta_0$

$$\therefore \theta_i < \theta_0$$

$\boldsymbol{\sin\theta_i < \sqrt{n_1^2 - n_2^2}}$

This is the condition for propagation.

6B

Numerical aperture = $\sin\theta_0 = \sqrt{n_1^2 - n_2^2} = 0.32$

$n_2 = 1.51$

$$n_1 = 1.54$$

$$SINC = \frac{n_2}{n_1}$$

$$C = 78^0$$

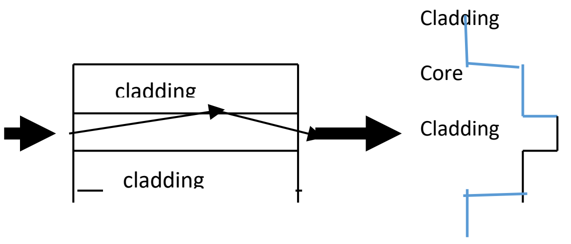
7A

Mode: It represents a specific electric field and magnetic field pattern propagating along specific path. Only a certain discrete number of modes are capable of propagating along the fiber. These are the electromagnetic waves that satisfy the homogeneous wave equation and the boundary conditions.

Types:

1. Single mode fiber:

Core diameter is around 5-10 µm. The core is narrow and hence it can guide just a single mode.



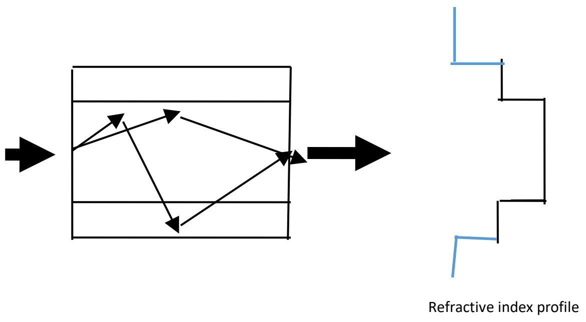
Refractive index profile

- No modal dispersion
- Difference between n_1& n_2 is less.Critical angle is high. Low numerical aperture.
- Low Attenuation -0.35db/km
- Bandwidth -100GHz
- Preferred for short range

Step index multimode fibre :

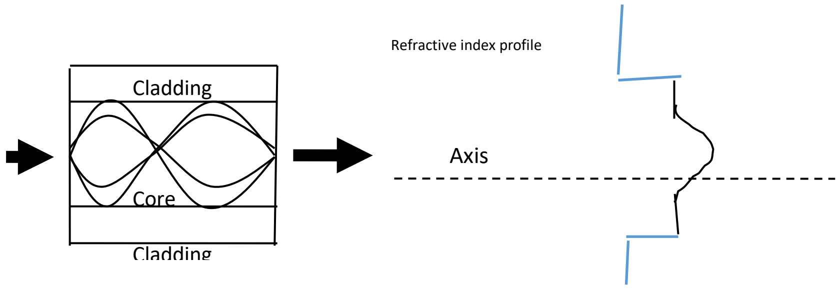
- Here the diameter of core is larger so that large number of rays can propagate. Core diameter is around 50. µm.
- High modal dispersion
- Difference between n_1& n_2 is high. Low Critical angle. Large numerical aperture.
- Losses high
- Bandwidth -500MHz
- Allows several modes to propagate
- Preferred for Long range

7B



Graded index multimode fiber:

In this type, the refractive index decreases in the radially outward direction from the axis and becomes equal to that of the cladding at the interface. Modes travelling close to the axis move slower where as the modes close to the cladding move faster.As a result the delay between the modes is reduced. This reduces modal dispersion.



- Low modal dispersion
- High data carrying capacity.
- High cost
- Many modes propagate
- Bandwidth -10GHz

7B

$$E = \frac{n^2h^2}{8ma^2}$$

$$E_1 = \frac{1^2h^2}{8ma^2}$$

$$E_2 = \frac{2^2h^2}{8ma^2} = 150eV$$

$$E_{1before} = \frac{E_2}{4} = 37.5eV = \frac{1^2h^2}{8ma^2}$$

When width ‘a’ is doubled

$$E_{1after\ doubling} = \frac{E_{1before}}{4} = 9.38eV$$

8A

Time independent Schrödinger equation

A matter wave can be represented in complex form as

$$\Psi = A\,sin\,k\,x(cos\,w\,t + i\,sin\,w\,t)$$

$$\Psi = A\,sin\,k\,xe^{iwt}$$

Differentiating wrt x

$$\frac{d\Psi}{dx} = kA\,cos\,k\,xe^{iwt}$$

$\frac{d^2\Psi}{dx^2} = -k^2A\,sin\,k\,xe^{iwt} = -k^2\Psi$ ………….. (1)

From Debroglie’s relation

$\frac{1}{\lambda} = \frac{h}{mv} = \frac{h}{p}$

k $= \frac{2\pi}{\lambda} = \frac{2\Pi p}{h}$

$k^2 = 4\Pi^2\frac{p^2}{h^2}$……………. (2)

Total energy of a particle

E = Kinetic energy + Potential Energy

E = $\frac{1}{2}$m v^2 + V$E = \frac{p^2}{2m} + V$

$$p^2 = (E - V)2m$$

Substituting in (2)

$$k^2 = \frac{4\Pi^2(E - V)2m}{h^2}$$

∴From (1)

$$\boxed{\begin{aligned} &\frac{d^2\Psi}{dx^2} + \frac{8\Pi^2 m(E - V)\Psi}{h^2} = 0 \\ &For \quad 3D \\ &\frac{d^2\Psi}{dx^2} + \frac{d^2\psi}{dy^2} + \frac{d^2\psi}{dx^2} + \frac{8\Pi^2 m(E - V)\Psi}{h^2} \\ &= 0 \end{aligned}}$$

8B

BAR CODE SCANNER

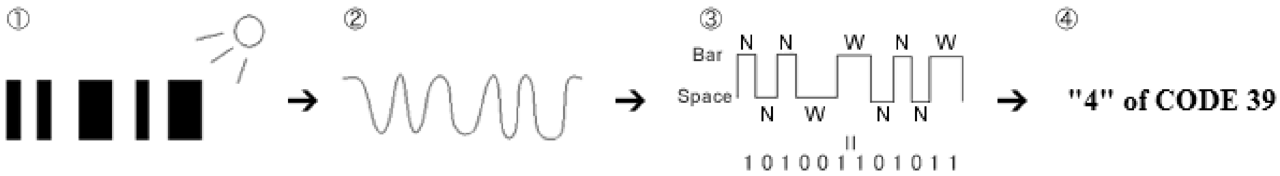
Barcodes are codes that contain data or information about a particular product. Different letters and numbers are encoded using bars of varying lengths and widths. These barcodes are significant for accurate inventory management.

Types Of Barcode Scanner

Based on the amount of data that you would like to store in the barcode, they are available in 2 categories:A linear black and white gaps of different widths, these codes have around 12 characters. They can carry only alphanumeric data. If you want to include more information, you will have to increase the length of the barcode. 90% of applications use the 1D Code.

2D Codes, like data matrix and QR Codes, use hexagons, squares, or other shapes to store data. Arranged in both horizontal as well as vertical patterns, as the name suggests, it facilitates 2-dimensional readability. Though much smaller in size than the 1D Code, it can hold up to 100 characters and thus store much more information.

WORKING



Barcode scanners utilize light-based technology to capture and decode the data encoded in barcodes. They emit light, capture the reflected light pattern from the barcode, and then convert this pattern into an electrical signal. This signal is then decoded by a decoder, which interprets the barcode symbology and sends the data to a computer or other device.

1. Light Emission and Capture:

- Barcode scanners use various light sources like lasers, LEDs, or even cameras to illuminate the barcode.
- The scanner then captures the reflected light from the barcode, with the sensor detecting variations in light intensity corresponding to the black bars and white spaces.

2. Signal Conversion and Decoding:

- The captured light is converted into an electrical signal by a light sensor within the scanner.
- This signal is then processed by a decoder, which analyzes the pattern of light and dark regions to determine the encoded data.
- The decoder interprets the barcode symbology (e.g., UPC, EAN, Code 128) to understand how the data is encoded.

3. Data Output:

- Once the data is decoded, the scanner sends it to a computer or other device via an output port.
- This data can be used for various applications like inventory management, point-of-sale transactions, or tracking assets.