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Schrodinger's Time independant wave equation

① As per DBH, particle of mass m moving with velocity v is associated with matter wave having wavelength (λ)

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad \text{--- (1)}$$

② Differential eq^n of matter waves with wave vel (u)

$$\frac{\partial^2 \psi}{\partial t^2} = u^2 \left[\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} \right]$$

$$\frac{\partial^2 \psi}{\partial t^2} = u^2 \nabla^2 \psi \quad \text{--- (2)}$$

as laplacian operator $= \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$

③ Solution of the above eq^n will give ψ as function of space and time

$$\psi_{(x,y,z,t)} = \psi_0 (x,y,z)\, e^{-i\omega t} \quad \text{--- (3)}$$

④ Here, ψ_0 is amplitude of wave at (x,y,z)

⑤ Above eq^n can be written as

$$\psi = \psi_0 e^{-i\omega t}$$

⑥ Differentiating above eq^n twice we get

$$\frac{\partial \psi}{\partial t} = -i\omega \psi_0 e^{-i\omega t}$$

$$\frac{\partial^2 \psi}{\partial t^2} = -\omega^2 \psi_0 e^{-i\omega t}$$

$$\frac{\partial^2 \psi}{\partial t^2} = -\omega^2 \psi \quad \text{--- (4)}$$

(7) Equating (2) and (4)

$$u^2 \nabla^2 \psi = -\omega^2 \psi$$

$$\nabla^2 \psi = -\frac{\omega^2}{u^2} \psi$$

$$\nabla^2 \psi + \frac{\omega^2}{u^2} \psi = 0 \quad \text{——— (5)}$$

(8) But we know $\omega = 2\pi\nu$ and $u = \lambda\nu$

$$\frac{\omega}{u} = \frac{2\pi\nu}{\lambda\nu} = \frac{2\pi}{\lambda} \quad \text{——— (6)}$$

(9) Substituting $\frac{\omega}{u} = \frac{2\pi}{\lambda}$ in eq^n (5)

$$\nabla^2 \psi + \frac{4\pi^2}{\lambda^2} \psi = 0$$

$$\nabla^2 \psi + \frac{4\pi^2 p^2}{h^2} \psi = 0 \quad \text{——— (7)} \quad \left[\because \lambda = \frac{h}{p} \right]$$

(10) Total Energy of particle = E = P.E + K.E

$$E = V + \frac{1}{2} mv^2$$

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

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

$$p^2 = 2m(E - V) \quad \text{——— (8)}$$

(11) Putting eq^n (8) in eq^n (7) we get

$$\nabla^2 \psi + \frac{4\pi^2 [2m(E-V)]}{h^2} \psi = 0$$

$$\nabla^2 \psi + \frac{8\pi^2 m(E-V)}{h^2} \psi = 0$$

This is Schroidinger's Time Independent Wave Equation.

η = efficiency

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Significance of Schroedinger Wave Equation. (SWE)

① SWE are the mathematical tools 4 cal energy of e^- and nature of wave functions, probability.

② This is done in active systems by applying proper boundary conditions to the system.

③ All these parameters regarding functioning of e^- helps engineers to modify the systems 2 ↑ese its η

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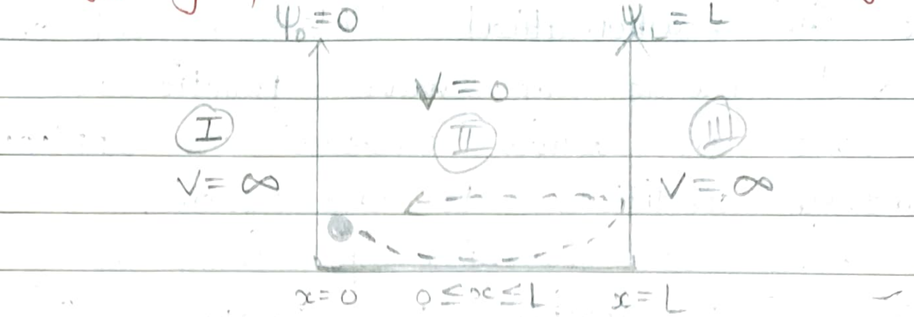
✓ Energy of particle enclosed in 1 D rigid box / ∞ Potential well



① Consider, particle of mass m moving with velocity v

② STIWE is $\nabla^2 \psi + \frac{8\pi^2 m (E - V)}{h^2} \psi = 0$ —— ①

③ As we know particle is inside box where V=0

eqⁿ ① becomes $\nabla^2 \psi + \frac{8\pi^2 m E}{h^2} \psi = 0$ —— k^2

$$\nabla^2 \psi + k^2 \psi = 0 \quad \text{—— ②}$$

④ Solution of eqⁿ ② can be sine function/cosine function

i.e $\psi(x) = A\cos kx + B\sin kx$

⑤ Since, $\psi_{(x)} = A e^{ikx} + B e^{-ikx}$

⑥ For boundary conditions

when $x = 0$: $\psi_{(0)} = A e^{0} + B e^{-0} = A + B$

$A + B = 0 \Rightarrow B = -A$

when $x = L$: $\psi_{(L)} = A e^{ikL} + B e^{-ikL}$

$\psi_{(L)} = A e^{ikL} + (-A) e^{-ikL} = 0$ $\quad \because B = -A$

$$\frac{2iA\left[e^{ikL} - e^{-ikL}\right]}{2i} = 0$$

$$\underline{2Ai \sin kL} = 0 \qquad \because \frac{e^{+ikL} - e^{-ikL}}{2i} = \sin kL$$

$$\sin kL = 0$$

$$kL \neq 0$$

$$kL = n\pi$$

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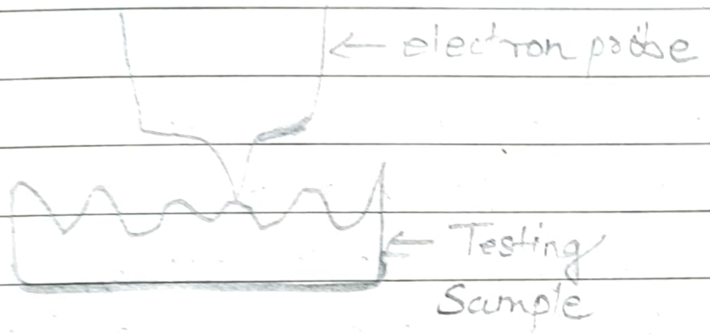
$$k = \frac{n\pi}{L}$$

$$k^2 = \frac{n^2\pi^2}{L^2}$$

$$\frac{8\cancel{\pi^2} m E}{h^2} = \frac{n^2 \cancel{\pi^2}}{L^2}$$

$$\boxed{E = \frac{n^2 h^2}{8 m L^2}}$$

Tunnelling Effect + STM + Applications



Tunnelling effect is phenomenon in which particle is present in ∞ Potential well. The Particle Energy is not enough to climb up the walls still it can penetrate the walls and leak out.

① STM is electron microscope ② STM shows 3D image of sample
③ STM helps 2 study structure of surface by scanning surface
④ It slowly scans across surface @ dist of atom's diameter.
⑤ Stylus is raised & lowered in order to keep signal constant
⑥ This enables it 2 follow even smallest details of surface
⑦ Profile pic of surface is created & from that computer generated contour map of surface is produced.

Applications

① STM is used in the study of DNA molecules
② STM is used in chemistry as surface reactions play imp role.
③ STM is used in phy as study of surfaces is an important part of Phy.

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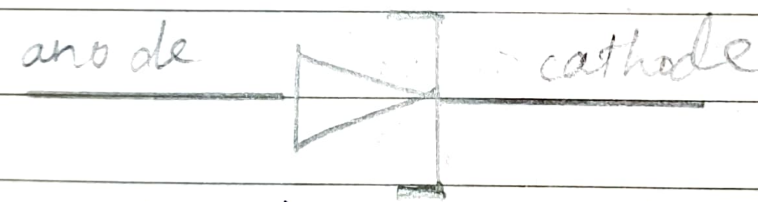
Tunnel diode

1. Tunnel diode is type of semiconductor diode which is capable of very fast operation
2. Symbollically it is represented



3. Diode has heavily doped p-n junction.
4. It is fast switching device used in computers
5. Used in frequency converter & detector, oscillators, amplifier, high frequency swite (10^9 Hz)
6. Tunnel diode usually made from Germanium.

State + Explain De Brogli's Hypothesis (DBH)
Any three properties of matter waves

1. DBH states that moving particle always has wave associated with it and the motion of particle is guided by that wave.
2. It says material particle has dual nature i.e particle nature & wave nature.
3. Light wave of frequency ν is associated with energy ϵ

$$\epsilon = h\nu \quad \text{———} \quad (1) \quad [h = \text{plank' constant}]$$

4. Particle of mass m equivalent to amt of energy ϵ

$$E = mc^2 \quad \text{———} \quad (2) \quad [\text{Einstein's Theory of relativity}]$$

5. Equate eq^n (1) and eq^n (2)

$$h\nu = mc^2$$

$$\frac{h\nu}{c} = mc$$

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

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

$$\lambda = \frac{h}{P} \quad \text{———} \quad (3)$$

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(6) Equation (6) shows relation betⁿ λ and P.

DBH in terms of K.E

- $E = \frac{1}{2} mv^2 = \frac{1}{2m} m^2v^2 = \frac{p^2}{2m}$

$p^2 = 2mE \Rightarrow p = \sqrt{2mE}$

But $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$ — (1)

- For electron with charge e accelerated with Potential V the K.E is given by

$E = eV$ — (2)

Substitute value of E in (1)

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

$\lambda = \frac{6.25 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} V}}$

$\lambda = \frac{12.27 \times 10^{-10}}{\sqrt{V}}$

$\lambda = \frac{12.27}{\sqrt{V}} \text{Å}$

Properties of Matter waves

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

(1) $\lambda \propto \frac{1}{m}$ hence lighter the particle greater is the wavelength

(2) $\lambda \propto \frac{1}{v}$ greater the vel smaller is the wavelength.

(3) The wave (v) vel inversely depends on λ. This is basic diff betⁿ Light waves & matter waves

(4) Vel of matter waves not constant like EMW it depends of particle generating them.

Heisenberg's Ucertainity Principle HUP

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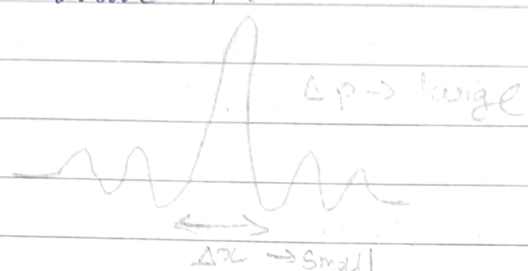
1. HUP states that in any simultaneous determination of Position and Momentum of particle of atomic size the product of uncertainities is equal to / greater than Plank's constant

2. $$\Delta x \cdot \Delta p \geq h$$

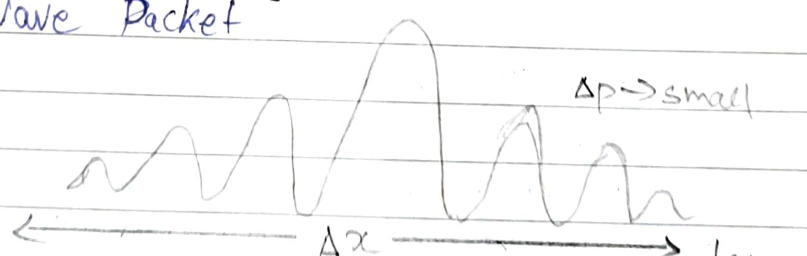
3. Narrow Wave Packet



Narrow Wave Packet (a)

1. In case of ∞^{ly} small wave packet, the Amplitude is large over small region of space & negligible elsewhere (a)
2. The small region of space can be associated with Pos^n of Part
3. Pos^n of Par can be fixed with min error.
4. At the same time λ and hence momentum P cannot be measured accurately.

4. Wide Wave Packet



Wide wave packet (b)

1. Wave Packes is wide so λ & P can be determined with more accuracy.
2. But at the same time Pos^n of particle becomes very uncertain.

5. Thus, it is impossible 2 det the Pos^n & P simultaneously.

What is wave function ψ
Explain physical significance of ψ^2

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1. Wave variable associated with matter wave is ψ & varies periodically
2. ψ may be real / complex.

3. ψ^2 denotes (probability of finding the particle at a point in space / medium at time t)
4. If ψ^2 is large, ☆ is max.
5. If ψ^2 is small, ☆ is min
6. If $\psi = 0$ then there is no particle. Hence ☆ is zero.
7. ψ may be complex funⁿ having real + imgʸ part
8. $\psi = A + iB$ & $\psi^* = A - iB$
   $\psi \psi^* = A^2 + B^2$ which is +ve quantity
9. Particle under consideration will always be found somewhere hence total probability is 1
   $\Rightarrow \iiint_{-\infty}^{+\infty} \psi \psi \, dv = 1$
10. Above conⁿ of ψ is normalisation condition.

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Phase Velocity (V_p)	Group Velocity (V_g)
① V_p or wave velocity of monochromatic ~~light~~ wave is vel with which a definite phase (crest/trough) of wave propogate in medium.	V_g is velocity with which hump/wave group travels ~~is called~~
② Expression for V_p is $\frac{\omega}{k}$	Exp^n for V_g is $\frac{d\omega}{dk}$
③ V_p always $> c$	V_g is always $< c$
④ V_p is not same for all the components, some of them propogate faster some slower	④ V_g represents the vel of wave packet
⑤ This leads 2 dispersion of wave packet	⑤ V_g is more significant

Quantum Computing

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① Quantum computing came into picture when it was identified that computers use so much energy & get so hot even though they appear 2 do very less work,

② Laundauer's showed how quatum computer can circunvent this pb by working in reversible way.

③ Quantum computer could carry massively complex computations without using massive amt of energy.

Applications ;

① Q. C could empower Machine Learning by enabling AI programs 2 search through In gigantic datasets

② In Q. C we could expect it to be able 2 handle almost innumerable Permutation & Combinations.