

Quantum Mechanics

1. Wave functions

2. Expt: A spherical wave traveling outwards from point is given by $\psi(r) = \frac{A}{r} e^{ikr}$ probability current density

$$J = \frac{\hbar k}{m} |A|^2 \quad J = \frac{\hbar k}{m} \left| \frac{A}{r} \right|^2 \quad J = \frac{\hbar k}{m r^2} |A|^2$$

4. Expt: $\frac{J_{+x}}{J_{-x}} = \frac{\frac{\hbar k}{m} 9|A|^2}{\frac{\hbar k}{m} 16|A|^2} = \frac{9}{16}$

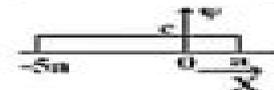
5. Expt: Use $\int_{-\pi}^{\pi} \frac{\sin^2 x}{r^2} dx = \pi$

6. Expt: $\int_{-\infty}^{\infty} |\psi|^2 dx = 1; \int_{-\infty}^{\infty} N^2 e^{-4|x|} dx = 1; N^2 \left[\int_{-\infty}^0 e^{-4|x|} dx + \int_0^{\infty} e^{-4|x|} dx \right] = 1; 1 + 1 = \left[\frac{x}{-4} + \frac{x}{4} \right]_{-\infty}^0 + \left[\frac{x}{4} + \frac{x}{-4} \right]_0^{\infty}$
 $N^2 \left[\frac{1}{4r} + \frac{1}{4r} \right] = 1; N^2 = 2r \Rightarrow N = \sqrt{2r}$

7. Expt: $p = \int \psi^* \hat{p} \psi dx; x=0 \& x=L/a; p = \frac{2}{L} \int_0^{L/a} \sin^2 \frac{2\pi x}{L} dx; p = \frac{2}{L} \left(\frac{1}{2} \right) \int_0^{L/a} (1 - \cos \frac{4\pi x}{L}) dx; p = \frac{1}{L} \left[\int_0^{L/a} dx - \int_0^{L/a} \cos \frac{4\pi x}{L} dx \right]$
 $p = \frac{1}{L} \left[\frac{L}{a} \right] - 0; p = \frac{1}{a}$

The state of a particle is described by the following wave function as shown.

$$\psi(x) = \begin{cases} 0 & \text{for } x < -5a \\ c & \text{for } -5a < x < a \\ 0 & \text{for } x > a \end{cases}$$



8. Expt: Normalization $\int_{-\infty}^{\infty} |\psi|^2 dx = 1; \int_{-5a}^a |c|^2 dx = 1; 1 + 1 + |c|^2 x \Big|_{-5a}^a = 1 + 1 + |c|^2 (6a) = 1 + 6a|c|^2$

9. Expt: $\int_0^L |\psi|^2 dx = 1 \Rightarrow \int_0^L A^2 \sin^2 \frac{\pi x}{L} dx = 1; A = \sqrt{\frac{2}{L}}; \int_0^L |\psi|^2 dx = \left(\sqrt{\frac{2}{L}} \right)^2 \frac{L}{4} = \frac{2}{L} \times \frac{L}{4} = \frac{1}{2}$

10. Expt: $\int_{-\infty}^{\infty} |A e^{-2|x|} \sin \theta|^2 dx = 1; \int_0^a \int_0^{2\pi} \int_0^\pi A^2 e^{-2|x|} \sin^2 \theta dx \sin \theta d\theta d\phi = 1; A^2 \int_0^a e^{-2|x|} dx (4\pi) = 1; A = \frac{1}{\sqrt{\pi a^2}}$

11. Expt: $\psi(x,0) = \frac{A}{\sqrt{a}} \sin \frac{\pi x}{a} + \frac{\sqrt{3}}{\sqrt{5a}} \sin \frac{3\pi x}{a} + \frac{1}{\sqrt{5a}} \sin \frac{5\pi x}{a} = \frac{1}{\sqrt{2}} \left[A \sqrt{\frac{2}{a}} \sin \frac{\pi x}{a} + \sqrt{\frac{3}{5}} \sqrt{\frac{2}{a}} \sin \frac{3\pi x}{a} + \frac{1}{\sqrt{5}} \sqrt{\frac{2}{a}} \sin \left(\frac{5\pi x}{a} \right) \right]$
 $= \frac{1}{\sqrt{2}} \left[A \psi_1(x) + \sqrt{\frac{3}{5}} \psi_3(x) + \frac{1}{\sqrt{5}} \psi_5(x) \right]; |\psi|^2 = 1; \psi(x,0) = \frac{1}{2} \left[A^2 + \frac{3}{5} + \frac{1}{5} \right] = 1; A^2 + \frac{4}{5} = 2; A^2 = 6/5 \Rightarrow A = \sqrt{6/5}$

12. Expt: $\psi(x,0) = A \sin \frac{5\pi x}{a} \cos \frac{2\pi x}{a} = \frac{A}{2} \left[\sin \frac{7\pi x}{a} + \sin \frac{3\pi x}{a} \right]; \int_0^a |\psi|^2 dx = 1$

$$= \frac{A^2}{4} \left[\int_0^a \left(\sin^2 \frac{7\pi x}{a} + \sin^2 \frac{3\pi x}{a} + 2 \sin \frac{7\pi x}{a} \sin \frac{3\pi x}{a} \right) dx \right] = \frac{A^2}{4} \left(\frac{a}{2} + \frac{a}{2} \right) = 1 \Rightarrow A = \frac{2}{\sqrt{a}} \therefore \psi(x,0) = \frac{1}{\sqrt{a}} \left[\sin \frac{7\pi x}{a} + \sin \frac{3\pi x}{a} \right]$$

13. Expt: Probability $\int_0^{2a} |\psi|^2 dx = \int_0^{2a} |c|^2 dx = |c|^2 x \Big|_0^{2a} = |c|^2 2a \Rightarrow p(x) = \frac{1}{6}$

14. Expt: $\Psi = \frac{2}{L} \sin \frac{\pi x}{2} \sin \frac{\pi y}{2}; p = \int_0^L \int_0^L |\Psi|^2 dx dy = 0.32$

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