Quantum Physics I Notes

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1 Lec 1: Superposition Intuition

- Physical processes in the lab are unpredictable, nondeterminate, random
- Probability forced by observation

Uncertainty Principle: For incompatible properties, you cannot have an object w/ defined values for both properties at the same time

- ex. position and momentum
- If one property is determined, the object is in superposition of values for the other property
- Quantum effects negligible for large objects
- Quantum effects only significant for small objects w/ small energies
- ex. atoms, electrons, molecules

2 Lec 2: Physical Effects explained by Quantum Mechanics but not Classical Mechanics

1. Atoms exist
2. Randomness exists
3. Atomic Spectra are discrete and have structure
4. Photoelectric effect
5. Electron Diffraction
6. Bell's Poor Inequality

2.1 Atoms exist

- e^- orbiting nucleus in Bohr atom is an accelerating charged particle and so emits light (loses energy)
- Thus Bohr atom doesn't work classically because it collapses as the electron spirals around nucleus while releasing energy by radiation

2.2 Randomness exists

- Self explanatory

2.3 Atomic Spectra

$$\frac{1}{\lambda} = R \cdot \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) \text{ for } n_i \in \mathbb{Z}, n_2 > n_1 \tag{1}$$

- R is the Rydberg constant which depends on the element but is independent of the emission series
- This eqn shows that the atomic spectra are discrete and have structure, but classical mechanics doesn't have discrete energy levels (no energy quantization)

2.4 Photoelectric Effect

V_0: Stopping voltage req to stop e^- from being released by photoelectric effect
I: Current generated in circuit

Prediction	Result
• More intense beam $\implies$ e^- w/ higher KE • $V_0 \propto I$ • V_0 indep of frequnecy ν	• Same KE regardless of intensity • V_0 indep of intensity • $V_0 \propto \nu$

- Rate of e^- release depends on intensity
- But for $\nu < \frac{W}{h}$ (less than critical frequency), no e^- released regardless of intensity (not enough energy)
- Einstein's explanation: Light comes in chunks with defined energy $E = h\nu$

$$KE = h\nu - W \tag{2}$$

  where W is the work required to remove the e^-
- Recall $E = pc$ and $c = \lambda\nu$

$$\therefore \quad p = \frac{h}{\lambda} \tag{3}$$

- This implies that the discrete packets of light w/ wavelength λ have momentum p by above eqn (wave-particle duality)

2.4.1 Waves vs Particles

- Waves can interfere with themselves (Young's Double Slit)
- Waves are **not localized**; particles are
- An interference pattern (wave) implies that **amplitudes** but intensities do not

- Classical particles can pass through either top or bottom slit
- Passing classical particles through double slit leads to 2 peaks near the 2 openings

- e^- can interfere with themselves (wave behaviour) in double slit
- Each e^- takes superposition of the possible paths; We don't know if it took the top or bottom bath
- An e^- is neither strictly a particle nor strictly a wave

2.4.2 Light comes in chunks

- Light has an energy and momentum

$$E = h\nu \tag{4}$$
$$p = \frac{h}{\lambda} \tag{5}$$

2.5 Electron Diffraction

- Bragg's Law

$$\frac{1}{\lambda} = \frac{n}{2dsin\theta} \tag{6}$$
$$p = \frac{h}{\lambda} \tag{7}$$

2.6 Bell's Inequality

- For 3 binary properties A, B, C, **Bell's Inequality** states

$$N(A, \overline{B}) + N(B, \overline{C}) \geq N(A, \overline{C}) \tag{8}$$

  where $N(X, Y)$ is the number of objects with properties X and Y
- e^- have 3 binary properties (angular momentum about x-, y-, and z-axes)
- However, it violates Bell's Inequality

$$N(\uparrow_0, \downarrow_\theta) + N(\uparrow_\theta, \downarrow_{2\theta}) \leq N(\uparrow_0, \downarrow_{2\theta}) \tag{9}$$

- Can't add probabilities classically with basic addition