Quantum Physics

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Lecture 1: Introduction

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Introduction

At the end of the 19th century, people classified things as either particles or waves (strings or electromagnetic waves). It is thought that we can have infinite precision if we have enough computing power and data.

In the early 20th century, there are experimental challenges.

1. Photoelectric effect
2. Black body radiation
3. Electron diffraction
4. Atomic structure etc.

0.1 Photoelectric Effect

When you shine a light to induce a photocurrent, the stopping voltage satisfies

$$\frac{1}{2}mv^2 = eV_0 = E - W.$$

By looking at the comparison between photocurrent and retarding voltage, we see that increasing light intensity gives the same stopping voltage, while increasing light frequency increases the stopping voltage. It would no make sense with waves, but considering the photons as packages makes sense. That is

$$eV_0 = h\nu - W, \quad V_0 = \frac{h\nu}{e} - \frac{W}{e}$$

where ν is a discrete amount. So we have

$$E = h\nu = \hbar\omega.$$

0.2 Black body

We have Energy Density = Density per mode × Energy per mode,

$$\rho(\lambda, T)d\lambda = \frac{8\pi}{\lambda^4} k_B T d\lambda.$$

It means that when the wavelength is short, the black body energy blows up, which does not match up with experimental data where the energy decreases as the wave length gets further smaller. It can be explained by Plank's radiation formula where the packages are considered instead.

$$\rho_E = \frac{8\pi\rho\gamma^3}{c^3} \frac{1}{e^{hv/k_B T} - 1}.$$

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0.3 Atoms

If the electrons rotate around the proton, it would create radiation. Thus, it would emit radiation and lose energy. So it cannot be the correct model. Bohr suggested that if the waves behave like particles, maybe particles behave like waves as well.

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

If there are stable orbits, $2\pi r_n = \mu\lambda$.

And we end up with

$$E_n = -\frac{hcR}{n^2}$$

where R is called *Rydberg constant*.

In sum, the angular momentum of an orbiting electron is quantized to fix the problem.

0.4 Electron Diffraction

By considering electrons as waves, it exhibits diffraction pattern as well.

$$\lambda = \frac{h}{p} = \frac{t}{\sqrt{2eVm}}.$$

The first maximum occurs at $\lambda = d\sin\theta$ theoretically, and it agrees well with experimental results.

0.5 Quantum Interference

Even when one photon is sent through the slit at a time, interference patterns are described. The photon seems to be interfering with itself.

1 Wave Functions

1.1 Introduction

Definition 1.1. We define a *wavefunction* as

$$\varphi(x,t) = Ae^{i(kx-\omega t)}, \quad (k = \frac{p}{t}, \omega = \frac{E}{t})$$
$$P(x,t)dx = |\varphi(x,t)|^2 dx \quad (\int Pdx = 1).$$

For a free particle, $E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$. To describe a localized wave function, we need to wave packet.