Lecture 35

Light as a probability wave

- let us return to double-slit experiment.

- we can place a photodetector D at some location on the screen C.

- result is that photodetector produces a series of clicks, randomly spaced in time, w/ each click signaling transfer of energy from light wave to screen via photon absorption.

- Moving the detector up & down increases or decreases the click rate, when going from minima & maxima that correspond to interference fringes

- Observation: Cannot predict when a photon will arrive @ a particular point on the screen.

- We can however predict the probability that it arrives - it is proportional to light intensity @ that point.

can think of light as a <u>probability wave</u> (to every point in a light wave, we can assign a probability that a photon is detected there)

A variation of the double-slit experiment is to perform it w/ single photons.

- Difference is that light source emits a single photon at a time.

Remarkably, we still see interference fringes in this case.

- explanation is that each photon travels from source to screen as a probability wave that fills up the space between source & screen & then vanishes in photon absorption @ the screen.

- cannot predict exactly where this transfer of energy will take place, but we can predict the probability.

- photons are more likely to be detected @ bright fringes & less likely @ dark fringes.

- go back to birth of quantum physics & blackbody radiation

- Consider thermal radiation emitted by a blackbody radiator (idealized opaque, non-reflective body)
- emitted radiation depends only on its temperature

- problem was that experimental results differed dramatically from theoretical predictions.

Setup of experiment

- form a cavity w/in a body & keep cavity walls @ uniform temperature

- atoms on inner wall oscillate, causing them to emit thermal EM radiation

- to sample the radiation, drill a small hole in cavity wall.

intensity distribution defined in terms of <u>spectral radiancy</u>

$$S(\lambda) = \frac{\text{intensity}}{\text{unit wavelength}}$$

$S(\lambda) \cdot d\lambda$ = intensity in wavelength range λ to $\lambda + d\lambda$

prediction of classical physics is

$$S(\lambda) = \frac{2\pi c k T}{\lambda^4}$$

where k is Boltzmann constant

agrees well for long wavelengths,
but very bad for short wavelengths
"ultraviolet catastrophe"

In 1900, Planck wrote down a function
consistent w/ experimental results

$$S(\lambda) = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

$$= \quad " \quad \frac{1}{e^{hf/kT} - 1}$$

No one understood why this worked for 17 years, but then Einstein explained it

1) energies of cavity-wall atoms are quantized.

2) energies of radiation in cavity are quantized & each photon has energy $E = hf$.

Electrons & Matter waves

Louis de Broglie ~~observed~~ speculated that if light is a wave & transfers energy to matter only @ points, why can't electrons have the same property?

This speculation was very insightful & correct.

Previously, we wrote the equation

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

momentum of a photon

Now we turn it around to define wavelength of a particle w/ momentum p:

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

This was demonstrated w/ a double-slit experiment using electrons

- electrons sent one-by-one through double-slit apparatus & fringes appear.

this kind of interference
- experiment has been demonstrated
w/ iodine molecules I_2 &
complex fullerenes C_{60} & C_{70}

- such small objects travel as
matter waves, but much larger
ones do not & classical
physics governs their behavior.

- Electron diffraction is now
a standard technique for
studying atomic structure.

Q: What is de Broglie wavelength of an electron w/ KE = 120 eV?

A: use $\lambda = h/p$ + find momentum p

Since given KE is much less than rest energy of electron, use classical approximation

$$p = mv \quad \& \quad KE = \frac{1}{2}mv^2$$

$$\Rightarrow \quad p = \sqrt{2m(KE)}$$

$$= \sqrt{2 \cdot 9.11 \times 10^{-31}\,kg \cdot 120\,eV \cdot (1.60 \times 10^{-19}\,J/eV)}$$

$$= 5.91 \times 10^{-24}\,kg \cdot m/s$$

$$\Rightarrow \quad \lambda = h/p = \frac{6.63 \times 10^{-34}\,J \cdot s}{5.91 \times 10^{-24}\,kg \cdot m/s}$$

$$= 1.12 \times 10^{-10}\,m$$

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What happens to electron wavelength after increasing KE?

decreases