Course Essay

• 500-750 word typed essay due Wed. May 2
• First deadline: Wed. next week (Mar. 28)
• Turn in Topic and Paragraph Description
• Topic ideas:
  - Nobel prize winner: work & importance
  - Big science project: mission & successes
  - Bogus or contentious science: any scientific support?
  - Science topic: achievements and outlook

See course web site for details and resources

Title / paragraph example

Topic: Quantum Computers

Paragraph:

Over the last decade, scientists have developed new approaches to computing using basic ideas of quantum mechanics. Individual atomic particles are used as ‘bits’ of a computer, but instead of representing only ‘0’ and ‘1’, the quantum-mechanical wavefunction is used to simultaneously represent an infinitely variable range of values.

Such systems have the potential to revolutionize computing, but only for specialized problems such as factoring large numbers. The scientific aspect I will discuss is the use of trapped atoms as quantum bits.

I will also discuss the background and operating principles of quantum computers, and the potential achievements of quantum computers.

Description of topic

Outlook

What else I will write

Science aspect

From Last Time...

• Light shows both particle and wavelike properties
• Interference is an example of wavelike props.
• Photons are particles of light in the particle-like description.
• An Experiments demonstrating this was
  - Photocell effect

Nobel Trivia

For which work did Einstein receive the Nobel Prize?

A. Special Relativity: E=mc²
B. General Relativity: gravity bends Light
C. Photoelectric Effect & Photons

Photoelectric effect summary

• Light is made up of photons, individual ‘particles’, each with energy \( hf = \frac{1240 \text{ eV \ nm}}{\lambda} \)
• One photon collides with one electron - knocks it out of metal.
• If photon doesn’t have enough energy, cannot knock electron out.
• Intensity ( = # photons / sec) doesn’t change this.

Minimum frequency (maximum wavelength) required to eject electron

Photoelectric effect question

A scientist is trying to eject electrons from copper by shining light on it, but none are coming out. She should

A. Increase the frequency
B. Increase the wavelength
C. Decrease the frequency
D. Increase the brightness
Compton scattering

- Collision of photon and electron in vacuum
- Photon loses energy, transfers it to electron
- Photon loses momentum transfers it to electron
- Total energy and momentum conserved

Before collision

After collision

Photon energy $E = hf$
Photon mass = 0
Photon momentum $p = E/c$

Compton scattering question

A green photon collides with a stationary electron. After the collision the photon color is

A. unchanged
B. shifted toward red
C. shifted toward blue

Photon transfers energy to electron. Photon energy goes down, so photon wavelength gets longer

Why is all this so important?

- Makes behavior of light wave quite puzzling.
- Said that one photon interacts with one electron, electron ejected.
- If this wavefront represents one photon, where is the photon?
- Which electron does it interact with?
- How does it decide?

Particle-wave duality

- Light has a dual nature
  - Can show particle-like properties (collisions, etc)
  - Can show wavelike properties (interference).
- It is neither particle nor wave, but some new object.
  - In some ways, reminds us of waves.
  - In some ways of particles.

Probabilities

- Detect photon absorption at camera.
- Cannot predict where on camera photon will arrive.
  - determined probabilistically.
- Photon has a probability amplitude through space.
  - Square of this quantity gives probability that photon will hit particular position on detector.
- The photon is a probability wave!
  - The wave describes what the particle does.
Photons and Electromagnetic Waves

- Light has a dual nature. It exhibits both wave and particle characteristics.
  - Applies to all electromagnetic radiation
- The photoelectric effect shows the particle characteristics of light.
  - Light can behave as if it were composed of particles
- Interference and diffraction show the wave characteristics of light.

Photon interference?

Do an interference experiment again. But turn down the intensity until only ONE photon at a time is between slits and screen.

Is there still interference?

A. Yes
B. No
C. Single photon cannot be detected

Single-photon interference

<table>
<thead>
<tr>
<th>Exposure Duration</th>
<th>Image Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/30 sec exposure</td>
<td></td>
</tr>
<tr>
<td>1 sec exposure</td>
<td></td>
</tr>
<tr>
<td>100 sec exposure</td>
<td></td>
</tr>
</tbody>
</table>

Matter waves

- If light waves have particle-like properties, maybe matter has wave properties?
- de Broglie postulated that the wavelength of matter is related to momentum as
  \[ \lambda = \frac{h}{p} \]
- This is called the de Broglie wavelength. Nobel prize, 1929

Why \( \frac{h}{p} \)? Works for photons

- Wave interpretation of light:
  - Wavelength = (Speed of Light) / Frequency
  - \( \lambda = \frac{c}{f} \)
- Particle interpretation of light (photons):
  - Energy = (Planck's constant) x Frequency
  - \( E = hf \), so \( f = \frac{E}{h} \)
  - Wavelength = \( \lambda = \frac{c}{f} = \frac{c}{E/h} = \frac{h}{E/c} \)
  - But photon momentum = \( p = \frac{E}{c} \)
  - \( \lambda = \frac{h}{p} \) for a photon

- We argue that \( \lambda = \frac{h}{p} \) applies to everything.
- Photons and footballs both follow the same relation.
- Everything has both wave-like and particle-like properties.
**Wavelengths of massive objects**

- deBroglie wavelength: \( \lambda = \frac{h}{p} \)
- \( p = mv \) for a nonrelativistic (\( v \ll c \)) particle with mass.

\[ \lambda = \frac{h}{mv} \]

**Wavelength of a football**

- Momentum: \( mv = (0.4 \text{ kg})(30 \text{ m/s}) = 12 \text{ kg m/s} \)
  \[ \frac{h}{p} = \frac{6.6 \times 10^{-34} \text{ J s}}{12 \text{ kg m/s}} = 5.5 \times 10^{-35} \text{ m} = 5.5 \times 10^{-26} \text{ nm} \]

**This is very small**

- 1 nm = 10^{-9} m
- Wavelength of red light = 700 nm
- Spacing between atoms in solid ~ 0.25 nm
- Wavelength of football = 10^{-26} nm

- What makes football wavelength so small?
  \[ \lambda = \frac{h}{p} = \frac{h}{mv} \]
  Large mass, large momentum short wavelength