

PHYS 214 Exam 2 Review

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Welcome to the

Exam Review 1:

- Tuesday, 2

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Units Covered on Exam 2

- Unit 4: Photons
- Unit 5: Probability and Complex Numbers
- Unit 6: The Wave Function
- Unit 7: Momentum and Position

Photons

Photons: the quantized bits of light (particles of light)

- Energy of a single photon with frequency f :

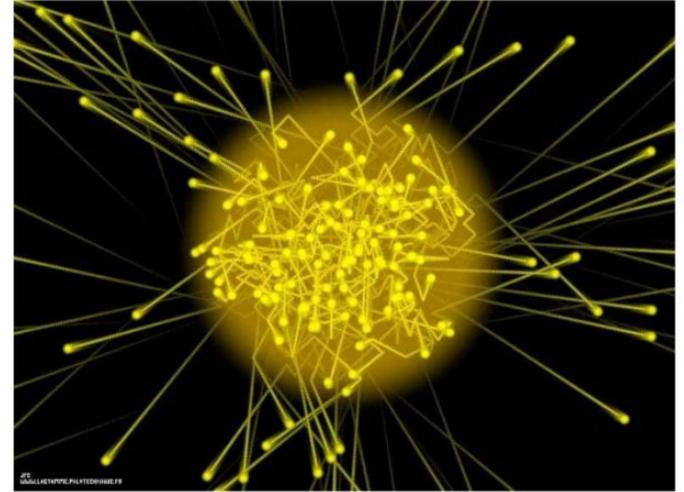
$$E = hf = \hbar\omega = \frac{1240 \text{ eV nm}}{\lambda}$$

- Momentum of a single photon with wavelength λ :

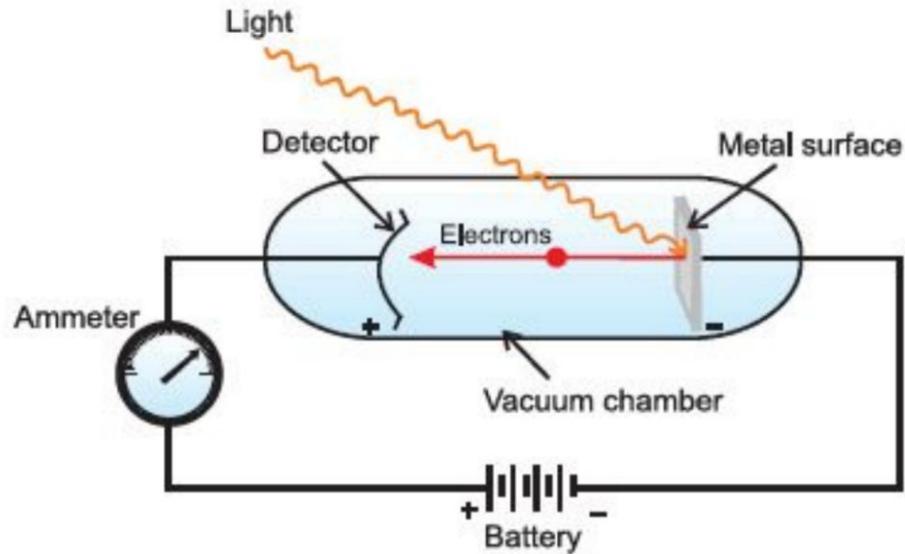
$$p = \hbar k = h/\lambda$$

- $h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s}$
- \hbar ('h-bar') = $h/2\pi$

- Photons have a velocity of c :
 - $c = 3 \times 10^8 \text{ m/s}$
 - $c = \lambda f \rightarrow E = (hc)/\lambda$



The Photoelectric Effect



The Photoelectric (Cont.)

This experiment proves the existence of photons and that light can be **BOTH** a particle and a wave

$$KE_{\text{electron}} = eV_{\text{stop}}$$

Stopping Potential:
Voltage applied to stop
electrons from flowing
between the two plates

Work Function (property of the material the light is shining on)

$$KE_{\text{electron}} = hf - \Phi$$

Maximum Kinetic Energy of an ejected electron

Planck's constant times frequency of incoming photons (light)

The diagram shows the equation $KE_{\text{electron}} = hf - \Phi$ enclosed in a hand-drawn white box. Three arrows point from text labels to parts of the equation: one from 'Work Function (property of the material the light is shining on)' to Φ , one from 'Maximum Kinetic Energy of an ejected electron' to KE_{electron} , and one from 'Planck's constant times frequency of incoming photons (light)' to hf .

Effect of Power Source

Increasing the power of a photon source will NOT increase photon energy!

It will only increase photon flux, since frequency/wavelength is what determines photon energy

$$\frac{\# \text{ photons}}{\text{sec}} = \frac{P \text{ Joules}}{\text{sec}} \times \frac{1 \text{ photon}}{X \text{ Joules}}$$

where $X = hf = hc/\lambda$

Force from Photons

$$F = \frac{dp}{dt} = \frac{\text{momentum}}{\text{second}}$$
$$\frac{\text{momentum}}{\text{second}} = \frac{P \text{ joules}}{\text{second}} * \frac{1 \text{ photon}}{hf \text{ joules}} * \frac{\frac{h}{\lambda} \text{ momentum}}{1 \text{ photon}}$$

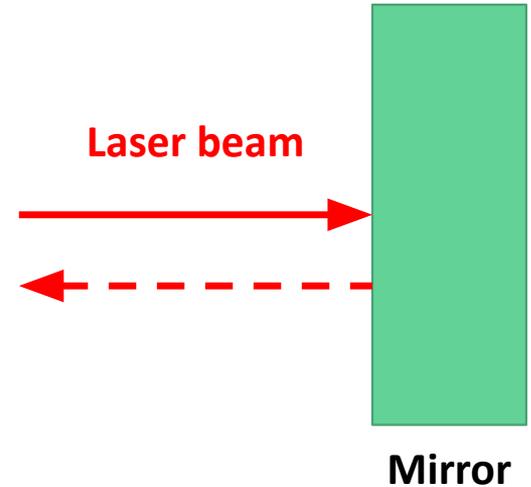
↓
photons/second

Simplified → $F = P/(\lambda f) = P/c$

Example Problem - Photons & Mirrors

A perfectly reflecting mirror is illuminated by a laser beam with a power of **10 mW** and wavelength of **500 nm**.

Determine the force exerted on the mirror by the photons



Example Problem - Photons & Mirrors (Cont.)

$$F = \frac{dp}{dt}$$

Example Problem - Photons & Mirrors (Cont.)

$$F = \frac{dp}{dt}$$

$$F = \frac{2P}{c} = \frac{2(10 * 10^{-3})}{3 * 10^8} = 66.67 \text{ pN}$$

Example Problem - Photons & Mirrors (Cont.)

$$F = \frac{dp}{dt}$$

$$F = \frac{2P}{c} = \frac{2(10 * 10^{-3})}{3 * 10^8} = 66.67 \text{ pN}$$

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Probability and Complex Numbers

Probability

- Probability Density Function:

$$\rho(x)$$

- Probability between two points:

$$P(a \leq x \leq b) = \int_a^b \rho(x) dx$$

- Normalization:

$$\int_{-\infty}^{\infty} \rho(x) dx = 1$$

Complex Numbers

- Two forms:

$$z = a + bi = |z|e^{i\theta}$$

- Conversion:

$$\theta = \arctan(b/a) \quad z = |z|(\cos \theta + i \sin \theta)$$

- Magnitude Squared:

$$|z|^2 = (z^*)(z)$$

- Identities:

$$\cos \theta = \frac{e^{i\theta} + e^{-i\theta}}{2} \quad \sin \theta = \frac{e^{i\theta} - e^{-i\theta}}{2i}$$

The Wave Function

- Wave function is notated as $\Psi(x)$
 - Contains ALL information about the properties of a quantum particle
- Properties of $\Psi(x)$:

$$\rho(x) = \psi^*(x)\psi(x) = |\psi(x)|^2$$

$\Psi^*(x)$ is the complex conjugate of $\Psi(x)$

$$P(a \leq x \leq b) = \int_a^b (\Psi^*)(\Psi) dx$$

Probability of detecting a particle
between points a and b

Example Problem - Detection Probability

Given the following normalized wavefunction, what is the integral that gives the chance of measuring the particle in the range $|x| \leq 1$?

$$\Psi(x) = \frac{1}{\sqrt{2}} e^{-|x|/2}$$

Example Problem - Detection Probability (Cont.)

$$P(|x| \leq 1) = \int_{-1}^1 \left(\frac{1}{\sqrt{2}}e^{-|x|/2}\right)^2 dx = \int_0^1 e^{-x} dx \approx 0.63$$

Momentum and Position

- For particles with momentum $\mathbf{p} = \hbar\mathbf{k}$, they are described by this wave function:

$$\psi(x) = Ae^{ikx} \longrightarrow \text{Momentum eigenstate (1 possible momentum)}$$

- Some particles' wave functions are a superposition of momentum eigenstates:

$$\psi(x) = \underbrace{Ae^{ik_1x}}_{\text{1st eigenstate}} + \underbrace{Be^{ik_2x}}_{\text{2nd eigenstate}}$$

Momentum and Position (Cont.)

- Probability of each momentum is given by:

$$P(\hbar k_1) = |A|^2 / (|A|^2 + |B|^2)$$

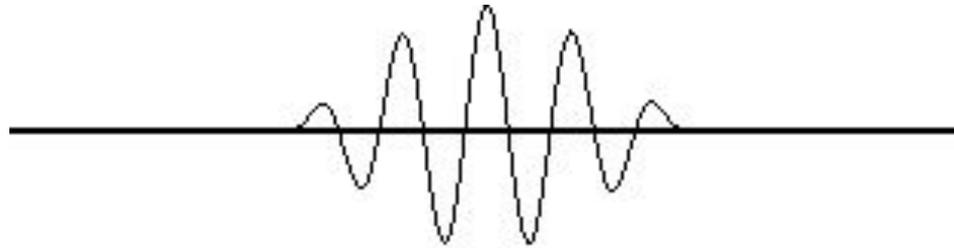
$$P(\hbar k_2) = |B|^2 / (|A|^2 + |B|^2)$$

- Where A and B are the coefficients seen in the wave function: $\psi(x) = \underline{A}e^{ik_1x} + \underline{B}e^{ik_2x}$

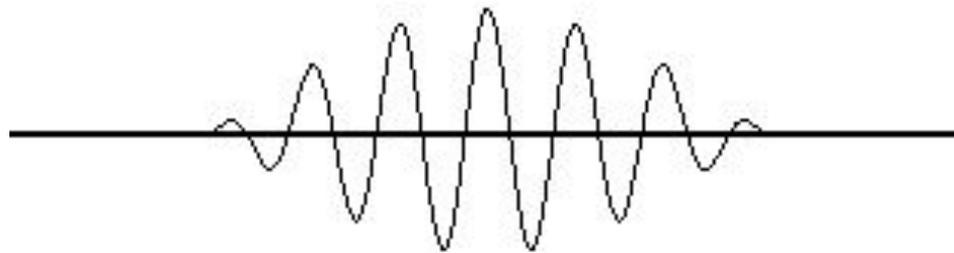
- Overall uncertainty is given by **Heisenberg's Uncertainty Principle**:
- The **fewer** momentum eigenstates, the more certain we are for momentum
- The **more** momentum eigenstates, the more certain we are for position

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

Momentum and Position (cont.)



Momentum (\rightarrow wavelength \rightarrow colour)



Position

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

Example Problem - Probability of $\hbar k_1$

Determine the probability of the momentum given by $\hbar k_1$:

$$\psi(x) = 2ie^{ik_1x} + 3e^{ik_2x}$$

Example Problem - Probability of $\hbar k_1$ (Cont.)

$$P(\hbar k_1) = \frac{|2i|^2}{|2i|^2 + |3|^2} = \frac{4}{4 + 9} = \frac{4}{13}$$

Good luck on your exam!



Solutions will be posted at the end of the session. Feel free to ask us questions on homework and practice exams as well!

