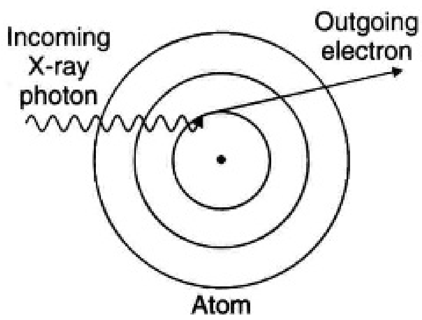
PHYSICS 3204

WORKSHEET #3 COMPTON EFFECT AND DEBROGLIE

Compton Effect/ Compton Scattering:

Arthur Compton (1923) believed that if photons were particles then they could collide with matter. He directed a beam of x-rays at a thin foil and found that the x-ray photons were deflected in many directions (scattering). Compton measured the energies of these photons and found that they were different from the incident x-ray photons. Also, electrons were ejected from the foil.



Light, as a wave, should not have momentum, since momentum requires p = mv. However, Compton's work showed that photons collide and exchange energy with particles according to the law of conservation of energy, that they possess momentum, and that this momentum is conserved during a collision.

$p = h / \lambda$ Where:

$m = E / c^2$ is known as the **mass equivalence**

The <u>Compton effect</u>, the increase in wavelength of x-rays after collision with electrons, shows that photons have momentum. This added support to the idea that light possesses both wave and particle properties.

<u>DeBroglie : Matter Waves</u>:

Louis de Broglie
(1892-1987)

Built on the work of Compton by proposing that since waves can act like matter, perhaps matter can be described as a wave. All matter, baseballs, humans and cats named Sue, can be through of as having a wavelength, but it is so incredibly small that it is not noticeable.

In 1924, Louis de Broglie ("de Broy") expanded on Compton's idea. He suggested that if photons had momentum, a particle property, then matter might have wave properties such as wavelength.

Beginning with Compton's equation, we can get; $\lambda = \frac{h}{p}$

This is often written in the following form;

de Broglie's Wave Equation: $\lambda = \frac{h}{m\,v}$

Note: We have seen earlier that waves (ex. light) can exhibit properties of matter (ex. momentum) and now we see that matter can exhibit properties of waves (ex. wavelength).

The wave properties of macroscopic objects, such as a softball, are not of noticeable scale for us to observe in our everyday lives.

Example: Calculate the de Broglie wavelength of a 0.075 kg softball thrown at a velocity of 54 km/h ?

$m = 0.075$ kg

$v = 54$ km/h $= 15$ m/s

$$\lambda = \frac{h}{m\,v}$$

$$\lambda = \frac{6.626 \times 10^{-34}\ \text{J s}}{(0.075\ \text{kg})\ (15\ \text{m/s})}$$

$$\lambda = 5.89 \times 10^{-34}\ \text{m}$$

(Too small to notice.) For diffraction, the opening (width ~ λ) would have to be smaller than the ball !

PART A: MULTIPLE CHOICE

Instructions: Instructions: Shade the letter of the correct answer on the computer scorable answer sheet provided.

1. What did Compton discover after bombarding electrons with high energy photons?

   (A) A photon's momentum depends on its wavelength.
   (B) A photon with a short wavelength can be ejected.
   (C) Electrons and positrons come in pairs.
   (D) Electrons can be split into smaller particles.

2. What happens to a high energy photon after it strikes an electron?

   (A) Decreases frequency
   (B) Decreases wavelength
   (C) Increases energy
   (D) Increases momentum

3. What is the momentum of a photon of light with a wavelength of 750 nm?

   (A) 8.8×10^{-31} kg•m/s
   (B) 8.8×10^{-28} kg•m/s
   (C) 6.8×10^{10} kg•m/s
   (D) 1.1×10^{27} kg•m/s

4. Which property does the Compton Effect describe about photons?

   (A) Mass
   (B) Momentum
   (C) Wave properties
   (D) Speed rates

5. What is the wavelength of a photon which has momentum of 5.60×10^{-27} kg A m/s?

   (A) 1.98×10^{-12} m
   (B) 3.64×10^{-9} m
   (C) 1.18×10^{-7} m
   (D) 8.45×10^{6} m

6. What is the wavelength of the matter wave associated with an electron moving at 2.5×10^{7} m/s?

(A) 2.9×10^{-11} m
(B) 4.7×10^{-11} m
(C) 2.9×10^{-7} m
(D) 4.7×10^{-7} m

7. If a photon has a 6.6×10^{-32} m wavelength, what is its momentum?

(A) 4.4×10^{-65} kg m/s
(B) 1.0×10^{-2} kg m/s
(C) 1.0×10^{-1} kg m/s
(D) 2.4×10^{12} kg m/s

8. Which characterizes a photon of light?

(A) Both energy and momentum
(B) Energy, but not momentum
(C) Momentum, but not energy
(D) Neither energy nor momentum

9. What speed must a 0.20 kg ball be moving if it has a de Broglie wavelength of 2.2×10^{-34} m?

(A) 0.60 m/s
(B) 15 m/s
(C) 73 m/s
(D) 150 m/s

10. What happens to the de Broglie wavelength of an electron if its momentum is doubled?

(A) Decreases by a factor of 2
(B) Decreases by a factor of 4
(C) Increases by a factor of 2
(D) Increases by a factor of 4

11. What is the de Broglie wavelength of a neutron travelling at 5.00 m/s?

(A) 1.58×10^{-8} m
(B) 7.91×10^{-8} m
(C) 3.96×10^{-7} m
(D) 7.92×10^{-7} m

12. The de Broglie wavelength of a proton is 5.57×10^{-7} m. What is the speed of the proton?

(A) 1.19×10^{-27} m/s
(B) 3.57×10^{-19} m/s
(C) 1.28×10^{-9} m/s
(D) 7.11×10^{-1} m/s

13. What is the de Broglie wavelength of a 125 g baseball moving at 28.0 m/s?

(A) 1.89×10^{-34} m
(B) 2.32×10^{-33} m
(C) 3.50×10^{0} m
(D) 5.28×10^{33} m

14. What is the momentum of a photon of yellow light with a wavelength of 5.89×10^{-7} m?

(A) 3.90×10^{-40} kg m/s
(B) 3.90×10^{-37} kg m/s
(C) 1.12×10^{-27} kg m/s
(D) 1.12×10^{-25} kg m/s

15. What is the mass of an object thrown with a speed of 45 m/s and having a de Broglie wavelength of 3.32×10^{-34} m?

(A) 0.011 kg
(B) 0.044 kg
(C) 22 kg
(D) 88 kg

16. What is the speed of a 50.0 kg person having a de Broglie wavelength of 4.4×10^{-37} m while running?

(A) 1.3×10^{-5} m/s
(B) 3.3×10^{-2} m/s
(C) 3.0×10^{1} m/s
(D) 7.5×10^{4} m/s

PART B: WRITTEN RESPONSE

1. Two subatomic particles with very different masses have the same de Broglie wavelength. Explain how this is possible. JUNE 2009

2. What is the deBroglie wavelength of an electron emitted with a kinetic energy of 2.4 eV? JUNE 2005

3. What is the frequency of photons that have a momentum of 2.80×10^{-27} kg •m/s? JUNE 2004

4. What is the frequency of photons that have a momentum of 2.80×10^{-27} kg · m/s?

5. What is the deBroglie wavelength of an electron emitted with a kinetic energy of 2.4 eV?

6. Calculate the energy (in Joules) gained by an electron in a hydrogen atom as it moves from the second to the fifth energy level.