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First Name:______________________________ Last Name:______________________________

## L16 – Worksheet – Compton Effect

### Textbook Questions

**Pg 723 #1:** What is the energy of an X-ray of wavelength 10nm?

$\lambda = 10\times10^{-9}\,m$
$c = 3.0\times10^{8}\,m/s$
$f = ?$
$h: 6.63\times10^{-34}\,J\cdot s$
$E = ?$

$c = f\lambda$
$3.0\times10^{8}\,m/s = f(10\times10^{-9}\,m)$
$f = 3.0\times10^{16}\,Hz$

$E = hf$
$= (6.63\times10^{-34}\,J\cdot s)(3.0\times10^{16}\,Hz)$
$= 1.989\times10^{-17}\,J$

**Pg 723 #2:** What is the momentum of an X-ray of wavelength 10nm?

$p = \frac{h}{\lambda}$ $\quad p = \frac{6.63\times10^{-34}\,J\cdot s}{10\times10^{-9}\,m} = 6.63\times10^{-26}\,\frac{J\cdot s}{m}$

where $W = F\cdot d$
$J = N\cdot m$

so $6.63\times10^{-26}\,\frac{(N\cdot m)\cdot s}{m}$

or $6.63\times10^{-26}\,N\cdot s$

**Pg 723 #3:** If a 10-nm X-ray scattered by an electron becomes an 11-nm X-ray, how much energy does the electron gain?

$\lambda_{10} = 10nm$
$E_{10} = 1.989\times10^{-17}\,J$ } From Pg 723 #1

$\lambda_{11} : 11\times10^{-9}\,m$

$c = f\lambda$
$3.0\times10^{8}\,m/s = f(11\times10^{-9}\,m)$
$f = 2.727\times10^{16}\,Hz$

$E_{11} = hf$
$= (6.63\times10^{-34}\,J\cdot s)(2.727\times10^{16}\,Hz)$
$= 1.808\times10^{-17}\,J$

so $\Delta E = 1.808\times10^{-17}\,J - 1.989\times10^{-17}\,J$
$= -1.808\times10^{-18}\,J$

If the photon lost $1.808\times10^{-18}\,J$, then the electron gained it.

KEY

**Pg 724 #1:** An X-ray of wavelength 0.010 nm scatters at $90^0$ from an electron. What is the wavelength of the scattered photon?

$\lambda = 0.010 \times 10^{-9} m$ $\quad m_e = 9.11 \times 10^{-31} kg$

$\theta = 90°$

$\Delta\lambda = \frac{h}{mc}(1 - \cos\theta)$

$\Delta\lambda = \frac{(6.63 \times 10^{-34} J \cdot s)}{(9.11 \times 10^{-31} kg)(3.0 \times 10^{8} m/s)}(1 - \cos 90°)$

$= (2.4259 \times 10^{-12})(1 - 0)$

$= 2.4259 \times 10^{-12} m$

$\Delta\lambda = \lambda_f - \lambda_i$

$2.4259 \times 10^{-12} m = \lambda_f - 0.010 \times 10^{-9} m$

$\lambda_f = 1.24259 \times 10^{-11} m$

or $0.0124259 \times 10^{-9} m$

or $0.012 nm$

**Pg 725 #1:** What is the momentum of a 500-nm photon?

$\lambda = 500 \times 10^{-9} m$

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

$= \frac{6.63 \times 10^{-34} J \cdot s}{500 \times 10^{-9} m}$

$= 1.326 \times 10^{-27} N \cdot s$

**Pg 725 #3:** A photon has a momentum of $6.00 \times 10^{-21}$ kg*m/s. What is the wavelength and energy of this photon?

$p = 6.00 \times 10^{-21} kg\, m/s$

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

$6.00 \times 10^{-21} kg\, m/s = \frac{6.63 \times 10^{-34} J \cdot s}{\lambda}$

$\lambda = 1.105 \times 10^{-13} m$

$c = f\lambda$

$3.0 \times 10^{8} m/s = f(1.105 \times 10^{-13} m)$

$f = 2.7149 \times 10^{21} Hz$

$E = hf$

$= (6.63 \times 10^{-34} J \cdot s)(2.7149 \times 10^{21} Hz)$

$= 1.80 \times 10^{-12} J$

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## Diploma Questions – Photoelectric Effect (Basic Concepts)

**Q737:** The wave model of light is deficient because by itself it CANNOT explain the

a. Reflection of light
b. Diffraction of light
c. Polarization of light
(d.) Interaction of light with some atomic particles

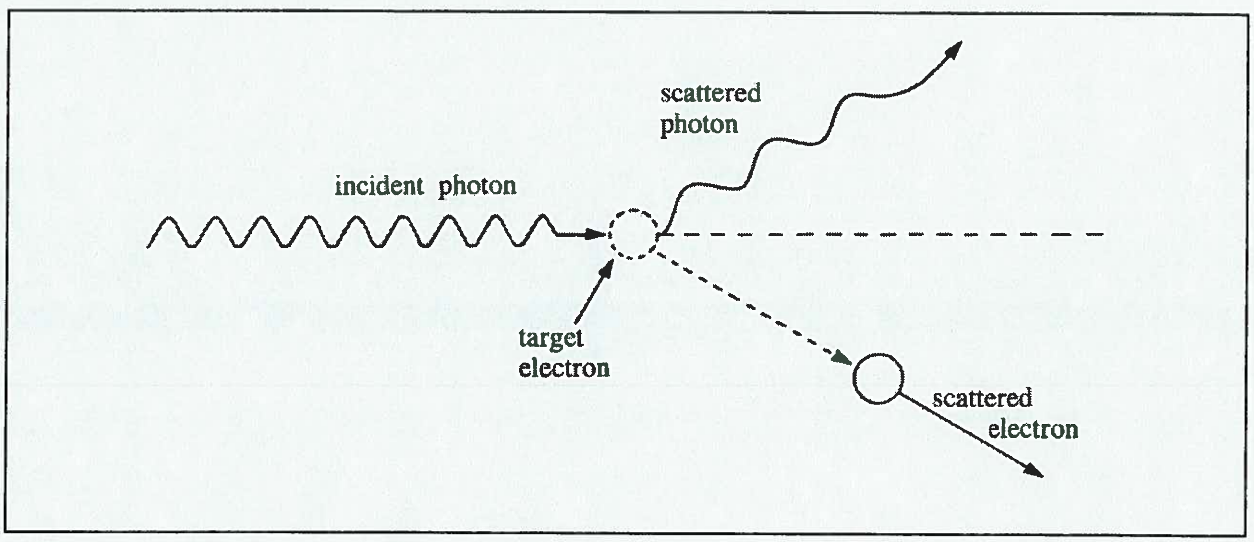
**Q738:** In the Compton effect, a stream of photons, all of the same energy and momentum, strikes the scattering material. Some photons bounce off with reduced

a. Wavelength $p = \frac{h}{\lambda}$ so as a photon loses momentum, its wavelength increases.
b. Velocity All travel at $3.0 \times 10^8$ m/s
(c.) Energy
d. Mass Photons don't have mass.

**Q739:** A process that changes both the frequency and the wavelength of an electromagnetic wave is

a. Refraction Doesn't change freq.
b. Polarization Doesn't change either.
(c.) Compton scattering
d. Double-slit interference Doesn't change either.

*Use the following information to answer Q740:*




**Q740:** The interaction illustrated in the diagram is known as

a. X-ray diffraction
(b) The Compton effect
c. Rutherford scattering
d. The photoelectric effect

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**Q741:** The BEST description of the Compton effect is that

(a) Photons transfer momentum to electrons
b. Electrons strike metal atoms and produce photons → X-Ray production
c. Electrons exist as standing waves around the nucleus → Unit 4
d. Alpha particles strike gold foil and pass through unaffected → Unit 4

**Q743:** In Compton's X–ray scattering experiment, the analysis of the collision of X-ray photons with electrons involves the use of the law(s) of the conservation of

a. Energy only
b. Momentum only
(c.) Both momentum and energy
d. Neither momentum nor energy

**Q750:** When the frequency of electromagnetic radiation is doubled, each photon's momentum

(a) Doubles and its energy doubles
b. Doubles and its energy does not change
c. Remains the same but its energy doubles
d. Remains the same but its energy quadruples

$p = \frac{h}{\lambda}$ where $c = f\lambda$ or $\frac{c}{\lambda} = f$ or $\frac{1}{\lambda} = \frac{f}{c}$

so $p = \frac{h}{1} \cdot \frac{f}{c}$ or $\boxed{p = \frac{hf}{c}}$ $\boxed{E = hf}$

Double freq doubles p.

Double freq doubles E.

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## Diploma Questions – Photoelectric Effect (Momentum of a Photon Calculations)

**Q756:** If the momentum of a photon is 2.2 x 10$^{-38}$ kg*m/s, its frequency is a.bc x 10$^{d}$ Hz, where a, b, c, and d are ___, ___, ___, and ___.

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

$2.2\times10^{-38} = \frac{6.63\times10^{-34}}{\lambda}$

$\lambda = 3.0136\times10^{4}$ m

$c = f\lambda$

$3.0\times10^{8} = f(3.0136\times10^{4})$

$f = 9.95\times10^{3}$ Hz

| 9 | 9 | 5 | 3 |
|---|---|---|---|

**Q757:** A photon of period 5.0 x 10$^{-16}$ s has a momentum of

a. 1.3 x 10$^{-18}$ kg*m/s
(b.) 4.4 x 10$^{-27}$ kg*m/s
c. 3.3 x 10$^{-48}$ kg*m/s
d. 1.1 x 10$^{-57}$ kg*m/s

$f = \frac{1}{T} = 2.0\times10^{15}$ Hz

$c = f\lambda$

$(3.0\times10^{8}) = (2.0\times10^{15})\lambda$

$\lambda = 1.50\times10^{-7}$ m

$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{1.50\times10^{-7}} = 4.42\times10^{-27}$ kg m/s

**Q759:** A photon of wavelength 5.0 x 10$^{-7}$ m has the same momentum as an electron. The speed of this electron is

a. 6.9 x 10$^{-4}$ m/s
b. 3.8 x 10$^{-1}$ m/s
c. 2.7 x 10$^{2}$ m/s
(d.) 1.5 x 10$^{3}$ m/s

$p_{photon} = p_{electron}$

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

$\frac{(6.63\times10^{-34})}{5.0\times10^{-7}} = (9.11\times10^{-31})v$

$v = 1455.543$ m/s

$\approx 1.5\times10^{3}$ m/s

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## Diploma Questions – Photoelectric Effect (Conservation of Energy)

*Use the following information to answer Q762:*

> In an experiment similar to the Compton effect experiment, X-ray photons of energy 1.0 x $10^5$ eV strike target electrons. Each electron gains 4.0 x $10^4$ eV of kinetic energy and X-ray photons are scattered. The collision is one dimensional and perfectly elastic.

**Q762:** The frequency of a scattered photon is

a. 1.0 x $10^{19}$ Hz
(b.) 1.4 x $10^{19}$ Hz
c. 2.4 x $10^{19}$ Hz
d. 3.4 x $10^{19}$ Hz

$E_i = E_f$

$E_{i\,photon} = E_{electron} + E_{f\,photon}$

$1.0\times10^5\,eV = 4.0\times10^4\,eV + E_{f\,photon}$

$E_{f\,photon} = 6.0\times10^4\,eV.$

$E = hf$

$6.0\times10^4 = (4.14\times10^{-15})f$

$f = 1.449275\times10^{19}\,Hz$

$f \approx 1.4\times10^{19}\,Hz$

**Q763:** A photon of wavelength 7.86 x $10^{-11}$ m strikes an electron at rest and imparts 1.47 x $10^{-16}$ J of energy to the electron. The wavelength of the departing photon is

a. 1.3 x $10^{-9}$ m
(b) 8.3 x $10^{-11}$ m
c. 7.4 x $10^{-11}$ m
d. 2.4 x $10^{-15}$ m

Initial $E_{photon} = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^8)}{(7.86\times10^{-11})} = 2.5305\times10^{-15}\,J$

$E_{photon\,i} \rightarrow E_e + E_{photon\,f}$

$2.5305\times10^{-15} \rightarrow 1.47\times10^{-16} + E_{photon\,f}$

$E_{photon\,f} = 2.3835\times10^{-15}\,J$

$E = \frac{hc}{\lambda}$

$2.3835\times10^{-15} = \frac{(6.63\times10^{-34})(3.0\times10^8)}{\lambda}$

$\lambda = 8.3\times10^{-11}\,m$

## Diploma Questions – Photoelectric Effect (Conservation of Momentum)

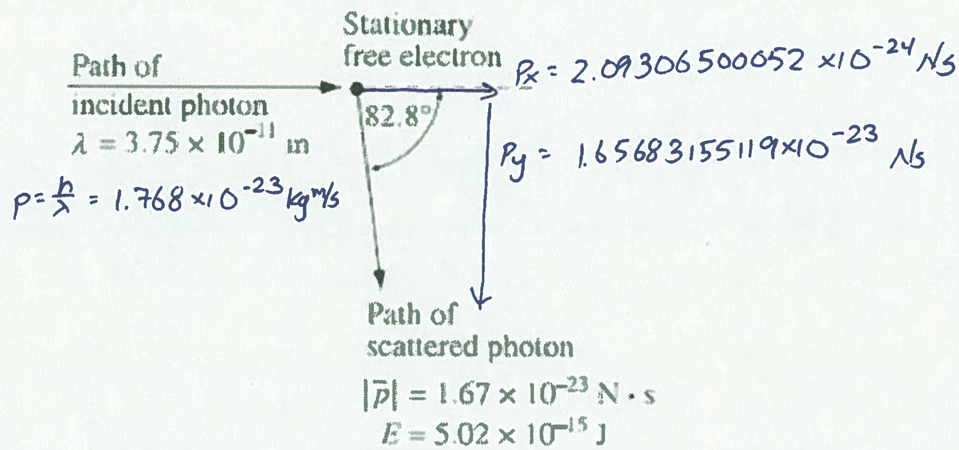
L15 - Compton Effect (Collisions using Conservation of Momentum) – None

KEY

## Challenge Questions

*Use the following information to answer Q1:*

In an observation of the Compton Effect, a photon is incident on a free electron. The scattered photon is detected, as shown below. The scattered electron is not shown.




**Q1:** What is the velocity of the electron, in Polar Coordinates?

Need to know direction → Vector quantity → Use momentum.

x-comp

$P_i = P_f$

$1.768 \times 10^{-23} + 0 = 2.09306500052 \times 10^{-24} + P_{ef_x}$

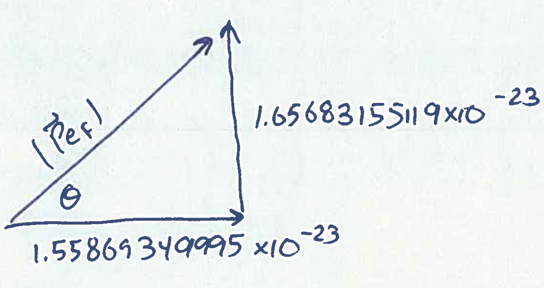
$P_{ef_x} = +1.55869349995 \times 10^{-23}$ Ns

y-comp

$P_i = P_f$

$0 + 0 = (-1.65683155119 \times 10^{-23}) + P_{ef_y}$

$P_{ef_y} = +1.65683155119 \times 10^{-23}$ Ns




$\tan\theta = \frac{o}{a}$

$\theta = 46.748°$

$a^2 + b^2 = c^2$

$c = 2.27477827838 \times 10^{-23}$ Ns or kg m/s

⇧ Better & an electr

$\vec{v}_e = 2.497 \times 10^7$ m/s [46.7°]

KEY

**Q2:** In a Compton - like experiment, a photon is directed towards a stationary electron and is scattered at an angle of 75°. If the initial wavelength of the photon was $2.50 \times 10^{-11}$ m, calculate the speed of the electron.

Don't care about direction? Could either use conservation of energy or conservation of momentum.

$$\Delta\lambda = \frac{h}{mc}(1-\cos\theta)$$

$m$ → Mass of electron; $\theta$ → Angle of scattered photon.

$$\Delta\lambda = \frac{(6.63\times10^{-34})}{(9.11\times10^{-31})(3.0\times10^{8})}(1-\cos 75)$$

$$\Delta\lambda = 1.79803502779\times10^{-12}\ \text{m}$$

$$\Delta\lambda = \lambda_f - \lambda_i$$

$$1.7980\ldots\times10^{-12} = \lambda_f - 2.50\times10^{-11}$$

$$\lambda_f = 2.6798035027 8\times10^{-11}\ \text{m}$$

Method #1 / Method #2

**METHOD #1: CONS. OF E**

$$E_{photon_i} \rightarrow E_{photon_f} + E_{k_e}$$

$$\frac{hc}{\lambda_i} \rightarrow \frac{hc}{\lambda_f} + \frac{1}{2}m_e v^2$$

$$\frac{(6.63\times10^{-34})(3.0\times10^{8})}{(2.50\times10^{-11})} = \frac{(6.63\times10^{-34})(3.0\times10^{8})}{(2.6798035\ldots\times10^{-11})} + \frac{1}{2}mv^2$$

$$7.956\times10^{-15} = 7.42218598467\times10^{-15} + \frac{1}{2}mv^2$$

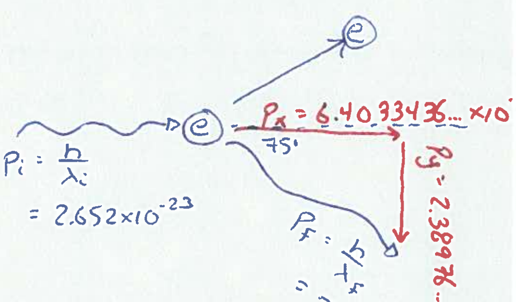
$$5.3381401533\times10^{-16} = \frac{1}{2}mv^2$$

$$v^2 = 1.171929\ldots\times10^{15}$$

$$\boxed{v = 3.42\times10^{7}\ \text{m/s}}$$

Conservation of energy is easier, but conservation of momentum gives an angle.

**METHOD #2: CONS. OF $\vec{P}$**




$$P_i = \frac{h}{\lambda_i} = 2.652\times10^{-23}$$

$$P_f = \frac{h}{\lambda_f} = 2.4740619948\ldots\times10^{-23}$$

x-comp

$$P_i = P_f$$

$$2.652\times10^{-23} + 0 = 6.403346\ldots\times10^{-24} + P_{e_{fx}}$$

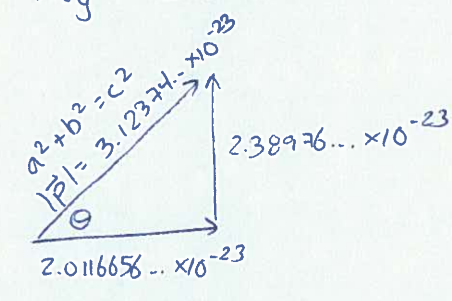
$$P_{e_{fx}} = 2.0116656\ldots\times10^{-23}$$

y-comp

$$P_i = P_f$$

$$0 + 0 = (-2.38976\ldots\times10^{-23}) + P_{fe_y}$$

$$P_{fe_y} = +2.38976\ldots\times10^{-23}$$




$$\tan\theta = \frac{o}{a}$$

$$\theta = 49.9°$$

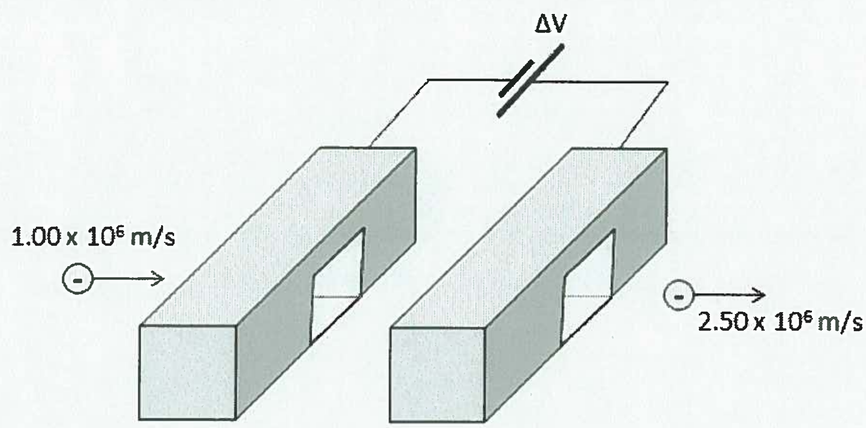
$$\vec{v}_e = 3.43\times10^{7}\ \text{m/s}\ [49.9°]$$

KEY

## Cumulative Review from Previous Units

*Use the following information to answer Q3:*

An electron travelling at a constant speed enters a parallel plate, at which point the electron accelerates before leaving the parallel plates again.




The separation distance of the plates is 5.00 cm.

**Q3:** What is the magnitude of the accelerating voltage, in Volts?

Method #1

$E_i \rightarrow E_f$

$E_{k_i} + E_{p_i} \rightarrow E_{k_f}$

$\frac{1}{2}mv_i^2 + q\Delta V \rightarrow \frac{1}{2}mv_f^2$

$\frac{1}{2}(9.11\times10^{-})(1.00\times10^6)^2 + (1.60\times10^{-19})\Delta V = \frac{1}{2}(9.11\times10^{-31})(2.50\times10^6)^2$

$4.555\times10^{-19} + (1.60\times10^{-19})\Delta V = 2.846875\times10^{-18}$

$(1.60\times10^{-19})\Delta V = 2.391375\times10^{-18}$

$\Delta V = 14.94609375\ V$

$\approx 1.49\times10^1\ V$

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Method #2

$v_f^2 = v_i^2 + 2ad$

$(2.5\times10^6)^2 = (1.0\times10^6)^2 + 2a(0.05)$

$a = 5.25\times10^{13}\ m/s^2$

$F = ma$

$= (9.11\times10^{-31})(5.25\times10^{13})$

$= 4.78275\times10^{-17}\ N$

$F = q|\vec{E}|$

$4.78275\times10^{-17} = (1.60\times10^{-19})|\vec{E}|$

$|\vec{E}| = 298.921875$

$|\vec{E}| = \frac{\Delta V}{\Delta d}$

$298.921875 = \frac{\Delta V}{0.05}$

$\Delta V = 14.94609375\ V$