

First Name: _____

Last Name: _____

L18 - Worksheet - EMR as Particles

L13 - Photons

Q1: Atoms in the phosphorescent screen absorb the energy of the cathode ray particles. They re-emit this energy in the form of photons of energy 4.11×10^{-19} J. One of these photons has a wavelength, expressed in scientific notation, of

- a) 1.61×10^{-15} m
- b) 4.84×10^{-7} m**
- c) 2.07×10^6 m
- d) 6.20×10^{14} m

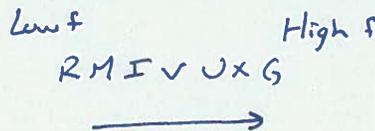
$$E = \frac{hc}{\lambda}$$

$$4.11 \times 10^{-19} = \frac{(6.63 \times 10^{-34})(3.0 \times 10^8)}{\lambda}$$

$$\lambda = 4.84 \times 10^{-7} \text{ m}$$

Q2: Which of the following lists has selected regions of the electromagnetic spectrum arranged in order of increasing photon energy?

- a) Radio, microwave, X-rays, visible
- b) Infrared, ultraviolet, X-rays, gamma**
- c) Gamma, visible, infrared, microwaves
- d) Microwaves, ultraviolet, visible, infrared



Q3: A 2.50 W flashlight emitting a 600nm wavelength emits $a.b \times 10^{cd}$ photons per second, where $a, b, c,$ and d are __, __, __, and __.

(Record your **four digit** answer in the Numerical Response boxes below)

7	5	1	8
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$$E_{\text{TOTAL}} = n(E_{\text{photon}})$$

$$2.5 = n \left(\frac{hc}{\lambda} \right)$$

$$2.5 = n \frac{(6.63 \times 10^{-34})(3.0 \times 10^8)}{600 \times 10^{-9}}$$

$$n = 7.5417... \times 10^{18}$$

$$\approx 7.5 \times 10^{18} \text{ photons}$$

Q4: The rate at which solar energy reaches Earth's surface at the equator is 800 W/m^2 . If all of the energy were in the form of yellow light, which has a wavelength of 520 nm, then the number of photons that would reach 1.00 m^2 of Earth's surface at the equator in 3.00 s is

- a) 6.27×10^{21} photons**
- b) 2.09×10^{21} photons
- c) 6.27×10^{18} photons
- d) 2.09×10^{18} photons

$$E_{\text{TOTAL}} = n(E_{\text{photon}})$$

$$800 \text{ J} = \frac{n(6.63 \times 10^{-34})(3.0 \times 10^8)}{520 \times 10^{-9}}$$

$$n = 2.09 \times 10^{21} \text{ photons per second per m}^2$$

In 3sec, $n = 6.27 \times 10^{21} \text{ photons.}$

L13 – X-Ray Production

Use the following information to answer Q5:

Forms of Energy

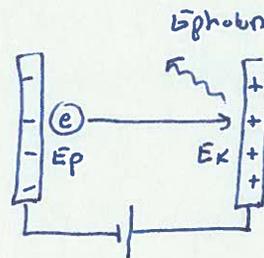
1 – Kinetic Energy, $E_k = \frac{1}{2}mv^2$

2 – Photon Energy, $E = hf$

3 – Potential Energy, $\Delta E_p = q\Delta V$

Q5: During X-Ray production, energy exists in three different forms.

Direction: 3 1 2
 Force: First Form Second Form Third Form



(Record your **three digit** answer in the Numerical Response boxes below)

3	1	2	
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Q6: An X-ray tube operates with a potential difference of 4.5×10^4 V. The minimum wavelength of X-rays being produced, expressed in scientific notation, is $a.b \times 10^{-cd}$ m. The values of **a**, **b**, **c**, and **d** are ____, ____, and ____.

(Record your **four digit** answer in the Numerical Response boxes below)

2	8	1	1
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$$E_p \rightarrow E_k \rightarrow E_{\text{photon}}$$

$$q\Delta V \rightarrow \frac{hc}{\lambda}$$

$$(1.60 \times 10^{-19}) (4.5 \times 10^4) = \frac{(6.63 \times 10^{-34}) (3.0 \times 10^8)}{\lambda}$$

$$\lambda = 2.7625 \times 10^{-11} \text{ m}$$

$$\approx 2.8 \times 10^{-11} \text{ m}$$

Alternate

$$q\Delta V = \frac{hc}{\lambda}$$

$$(1e)(4.5 \times 10^4) = \frac{(4.14 \times 10^{-15})(3.0 \times 10^8)}{\lambda}$$

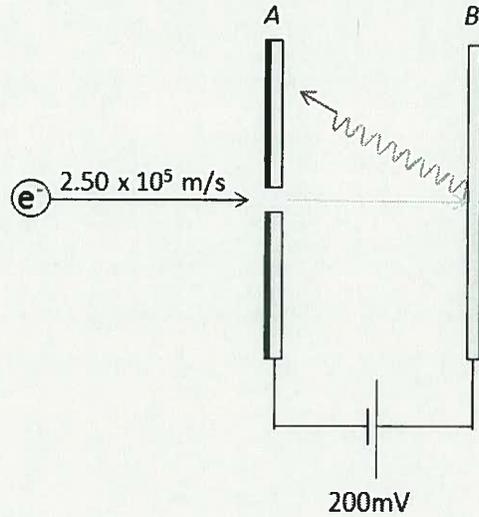
$$\lambda = 2.76 \times 10^{-11} \text{ m}$$

$$\approx 2.8 \times 10^{-11} \text{ m}$$

■ Key ■

Use the following information to answer Q7:

An electron travelling at 2.50×10^5 m/s enters a parallel plate apparatus with a potential difference of 200mV. Upon reaching *Plate B*, the electron decelerates, generating a photon.



Q7: The frequency of the photon generated is $a.b \times 10^{cd}$ Hz, where a , b , c , and d are __, __, __, and __.

(Record your four digit answer in the Numerical Response boxes below)

9 1 1 3

$$E_{K_i} + E_{P_i} \rightarrow E_{K_f} \rightarrow E_{\text{photon}}$$

$$\frac{1}{2}(9.11 \times 10^{-31})(2.50 \times 10^5)^2 + (1.60 \times 10^{-19})(200 \times 10^{-3}) = (6.63 \times 10^{-34})f$$

$$2.846875 \times 10^{-20} + 3.20 \times 10^{-20} = (6.63 \times 10^{-34})f$$

$$6.046875 \times 10^{-20} = (6.63 \times 10^{-34})f$$

$$f = 9.12 \dots \times 10^{13} \text{ Hz}$$

$$\approx 9.1 \times 10^{13} \text{ Hz}$$

L14&15 – Photoelectric Effect 1&2

Q8: Which equation best models the Photoelectric Effect?

- a) $q\Delta V = hf$
- b) $\frac{1}{2}mv^2 = hf$
- c) $hf = W + \frac{1}{2}mv^2$
- d) $hf = -W + \frac{1}{2}mv^2$

$$E_{\text{photon}} \rightarrow W + E_k$$

$$hf \rightarrow W + \frac{1}{2}mv^2$$

Q9: The work function of silicon is 7.76×10^{-19} J. The maximum wavelength of electromagnetic radiation that will cause photoelectrons to be emitted from a silicon surface, expressed in scientific notation, is $a.bc \times 10^d$ m. The values of **a**, **b**, **c**, and **d** are ____, ____, ____, and ____. (2 marks)

((Record your **four digit** answer in the Numerical Response boxes below))

2	5	6	7
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$$E_{\text{photon}} \rightarrow W + E_k$$

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

$$\frac{(6.63 \times 10^{-34})(3.0 \times 10^8)}{\lambda} = 7.76 \times 10^{-19}$$

$$\lambda = 2.563144... \times 10^{-7} \text{ m}$$

$$= 2.56 \times 10^{-7} \text{ m}$$

Use the following information to answer Q10:

A photon that had a frequency of 7.20×10^{14} Hz struck a polished metal surface and caused a single electron to be released. The released electron had a kinetic energy of 1.00 eV.

Q10: The work function of the metal surface was

- a) 1.00 eV
- b) 1.98 eV
- c) 2.98 eV
- d) 3.98 eV

$$E_{\text{photon}} \rightarrow W + E_k$$

$$hf \rightarrow W + E_k$$

$$(4.14 \times 10^{-15})(7.20 \times 10^{14}) \rightarrow W + 1.00 \text{ eV}$$

$$W = 1.9809 \text{ eV}$$

■ KEY ■

Q11: A photocathode that has a threshold frequency of 5.6×10^{14} Hz is illuminated with light that has a frequency of 8.2×10^{14} Hz. The maximum kinetic energy of the ejected photoelectrons is

- a) 1.7×10^{-19} J
- b) 3.7×10^{-19} J
- c) 5.4×10^{-19} J
- d) 9.1×10^{-19} J

$$E_{\text{photon}} \rightarrow W + E_K$$

$$hf \rightarrow hf_0 + E_K$$

$$(6.63 \times 10^{-34})(8.2 \times 10^{14}) \rightarrow (6.63 \times 10^{-34})(5.6 \times 10^{14}) + E_K$$

$$5.4366 \times 10^{-19} \rightarrow 3.7128 \times 10^{-19} + E_K$$

$$E_K = 1.7238 \times 10^{-19} \text{ J}$$

Use the following information to answer Q12:

Classical wave theory and quantum physics make different predictions about the effect of incident electromagnetic radiation on a photoelectric surface.

Four Photoelectric Effect Predictions

1. Low-intensity electromagnetic radiation incident on a photoelectric surface for long periods of time will cause photoemission. \rightarrow *Classical*
2. High-intensity electromagnetic radiation will not cause photoemission unless its frequency is greater than the photoelectric surface's threshold frequency. \rightarrow *Quantum*
3. The energy of the emitted photoelectrons will increase if the intensity of the incident electromagnetic radiation is increased. \rightarrow *Classical* *Brightness*
4. The energy of the emitted photoelectrons is independent of the intensity of the incident electromagnetic radiation. *Brightness*

Q12: Match each of the predictions above with the appropriate theory of physics as labelled below. (There is more than one correct answer.)

Prediction:

1 3
Classical wave theory

2 4
Quantum physics

(Record your **four digit** answer in the Numerical Response boxes below)

1	3	2	4
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\rightarrow or

3124

\rightarrow or

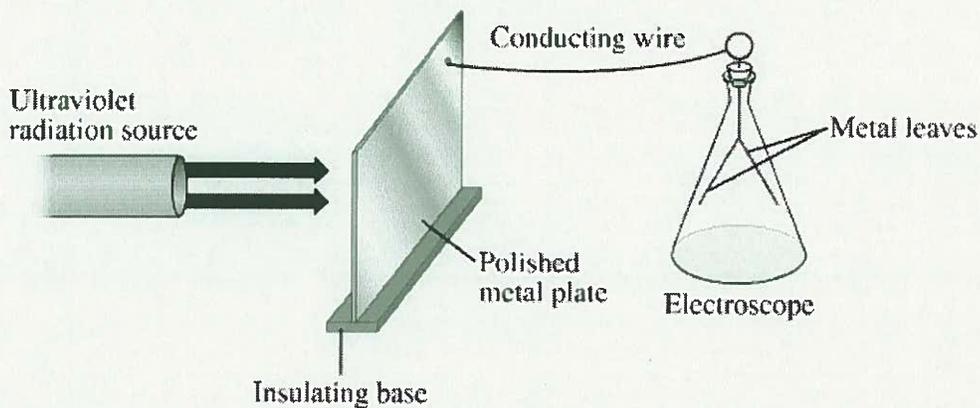
1342

\rightarrow or

3142

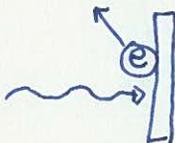
Use the following information to answer Q13:

In a classroom investigation, a student observes that when an ultraviolet radiation source is on, and the ultraviolet radiation is incident on a polished metal surface, the metal leaves of a charged electroscope collapse, indicating that the charge has decreased.



Q13: Based on the student's observation, it can be inferred that the phenomenon that is occurring is

- a) Compton scattering
- b) Rutherford scattering
- c) Charging by induction
- d) The photoelectric effect



Q14: A photocathode that has a threshold frequency of 5.6×10^{14} Hz is illuminated with light that has a frequency of 8.2×10^{14} Hz. The maximum kinetic energy of the ejected photoelectron is

- a) 1.7×10^{-19} J
- b) 3.7×10^{-19} J
- c) 5.4×10^{-19} J
- d) 9.1×10^{-19} J

Whoops! Repeat of #11.

I'm curious how many people will catch this, so I'm leaving it in.

Q15: Which of the following equations represents the relationship among the stopping voltage, the photon frequency, and the threshold frequency for the photoelectric effect?

a) $V_{stop} = \frac{hf - hf_0}{q_e}$

b) $V_{stop} = (hf - hf_0)q_e$

c) $f = \frac{h}{q_e V_{stop} + hf_0}$

d) $f = hq_e V_{stop} - hf_0$

Photoelectric Effect

$E_{photon} \rightarrow W + E_K$

where $W = hf_0$
and $E_{K,max} = qV_{stop}$

$hf \rightarrow hf_0 + qV_{stop}$

$hf - hf_0 = qV_{stop}$

$\frac{hf - hf_0}{q} = V_{stop}$

Use the following information to answer Q16:

A satellite in orbit around Earth is exposed to radiation from the Sun. This radiation may cause the satellite to become positively charged.

Some Wavelengths Incident on a Satellite

I $2.25 \times 10^{-7} \text{ m}$

II $2.33 \times 10^{-7} \text{ m}$

III $3.24 \times 10^{-7} \text{ m}$

IV $4.28 \times 10^{-7} \text{ m}$

Platinum is commonly used to coat satellites and has a work function of $8.5 \times 10^{-19} \text{ J}$.

Q16: Which of the wavelengths listed above would cause a satellite with a platinum coating to become positively charged?

a) Wavelength I only

b) Wavelength IV only

c) Wavelengths I and II

d) Wavelengths III and IV

$E_{photon} \rightarrow W + E_K$

$\frac{hc}{\lambda} \rightarrow W$

$\frac{(6.63 \times 10^{-34})(3.0 \times 10^8)}{\lambda} = 8.5 \times 10^{-19}$

$\lambda_{max} = 2.34 \times 10^{-7} \text{ m}$

So any photon with a lesser wavelength will have more energy to overcome work function, with excess going to E_K of the electron.

Use the following information to answer Q17-Q21:

A student performed a photoelectric effect experiment in which they exposed an unidentified metal to various frequencies of incident electromagnetic radiation and measured the stopping voltage of the emitted photoelectrons.

They calculated the maximum kinetic energy of the emitted photoelectrons.

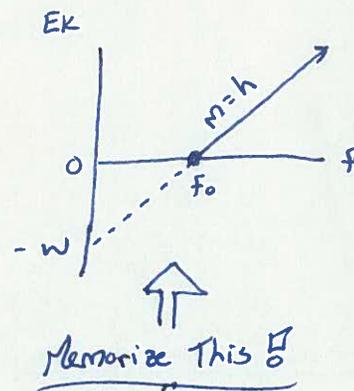
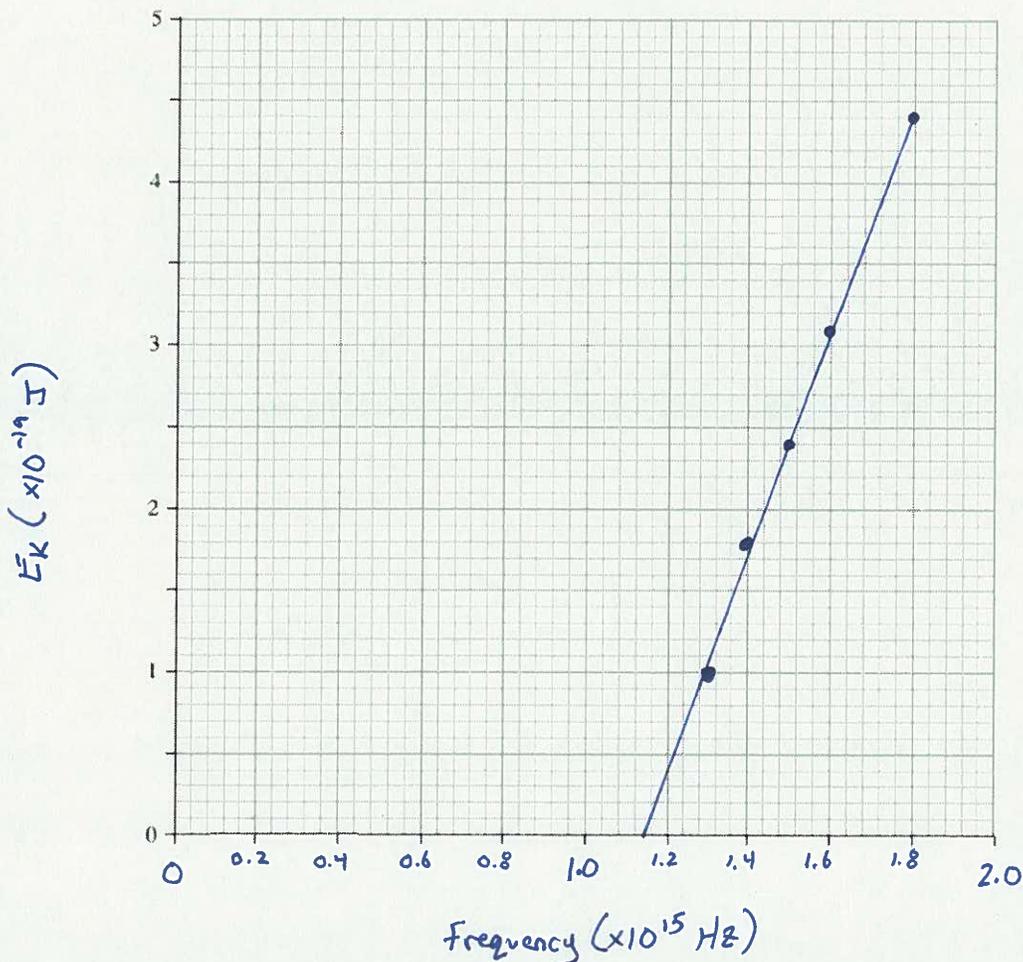
Their results are given in the table below.

Frequency of incident electromagnetic radiation ($\times 10^{15}$ Hz)	1.3	1.4	1.5	1.6	1.7	1.8
Maximum kinetic energy of emitted photoelectrons ($\times 10^{-19}$ J)	1.0	1.8	2.4	3.1	3.8	4.4

The teacher provided the student with the following table of work functions for selected metals.

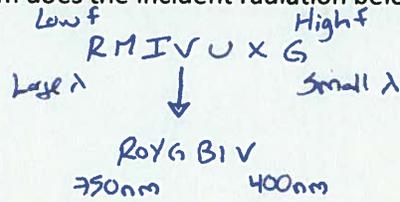
Metal	Na	Co	Pb	Zn	Fe	Ag	Pt
Work Function (eV)	2.28	3.90	4.14	4.31	4.50	4.73	6.35

Q17: (Long Answer) Graph the relationship. (2 marks)



Q18: Which region of the electromagnetic spectrum does the incident radiation belong?

- a. Infrared
- b. Microwave
- c. Ultraviolet**
- d. Visible



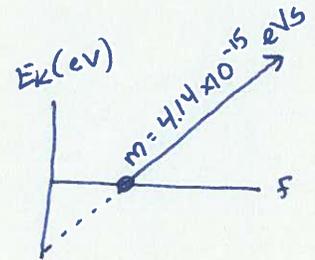
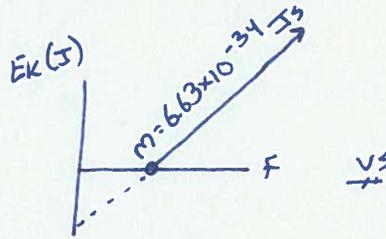
F	λ
1.3×10^{15}	231 nm
1.8×10^{15}	167 nm

Q19: The significance of the x-intercept is the f_0 , and the significance of the y-intercept is the $-W$.

	i.	ii.
A.	Threshold Frequency	Work Function
B.	Threshold Frequency	Negative Work Function
C.	Work Function	Threshold Frequency
D.	Negative Work Function	Threshold Frequency

Q20: The value of the slope should be

- a. 6.63×10^{-34}**
- b. 4.14×10^{-15}
- c. 6.67×10^{-11}
- d. 3.00×10^8



Q21: (Long Answer) Identify the metal. Justify your answer. (2 marks)

Option #1: Single Data Point

$$E_{\text{photon}} \rightarrow W + E_k$$

$$hf \rightarrow W + E_k$$

$$(6.63 \times 10^{-34}) (1.3 \times 10^{15}) = W + (1.0 \times 10^{-19})$$

$$W = \frac{7.619 \times 10^{-19} \text{ J}}{1} \times \frac{1 \text{ eV}}{1.60 \times 10^{-19} \text{ J}} = 4.761875 \text{ eV}$$

So the metal is Ag.

Option #2: x-intercept from graph (f_0)

$$W = hf_0$$

$$= (4.14 \times 10^{-15}) (1.14 \times 10^{15})$$

$$= 4.7196 \times 10^{-15} \text{ eV}$$

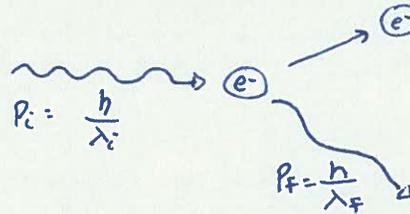
So the metal is Ag.

L16 - Compton Effect

Q22: A photon of X-ray radiation is incident on a metal surface and is scattered when it strikes an electron. During this process some of the photon's energy and momentum are transferred to the electron. Compared to the initial X-ray photon's characteristics, the scattered photon will have a

- a) Shorter wavelength and a slower speed
- b) Longer wavelength and a slower speed
- c) Shorter wavelength and the same speed
- d) Longer wavelength and the same speed**

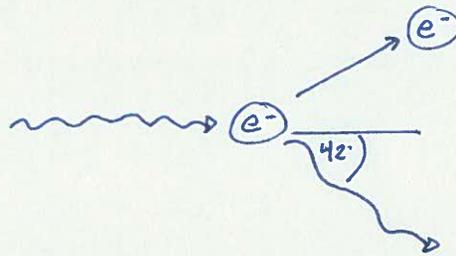
$c = 3.0 \times 10^8 \text{ m/s}$



Q23: An X-Ray of frequency 3.8×10^{17} Hz strikes an electron and then the photon scatters at an angle of 42° . The X-Ray lost $b \times 10^{-w}$ Ns of momentum during the collision. The value of b , written in scientific notation, is _____. (2 marks)

(Record your three digit answer in the Numerical Response boxes below)

6	6	2	8
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Initial

$$c = f\lambda$$

$$(3.0 \times 10^8) = (3.8 \times 10^{17})\lambda$$

$$\lambda_i = 7.89473684211 \times 10^{-10} \text{ m}$$

$$p_i = \frac{h}{\lambda_i} = \frac{(6.63 \times 10^{-34})}{(7.8947 \dots \times 10^{-10})}$$

$$p_i = 8.39799999999 \times 10^{-25} \text{ Ns}$$

Collision

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

$$\Delta\lambda = \frac{(6.63 \times 10^{-34})}{(9.11 \times 10^{-31})(3.0 \times 10^8)} (1 - \cos 42)$$

$$\Delta\lambda = 6.23106405812 \times 10^{-13} \text{ m}$$

After

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

$$6.23106405812 \times 10^{-13} = \lambda_f - 7.89473684211 \times 10^{-10}$$

$$\lambda_f = 7.90096790617 \times 10^{-10} \text{ m}$$

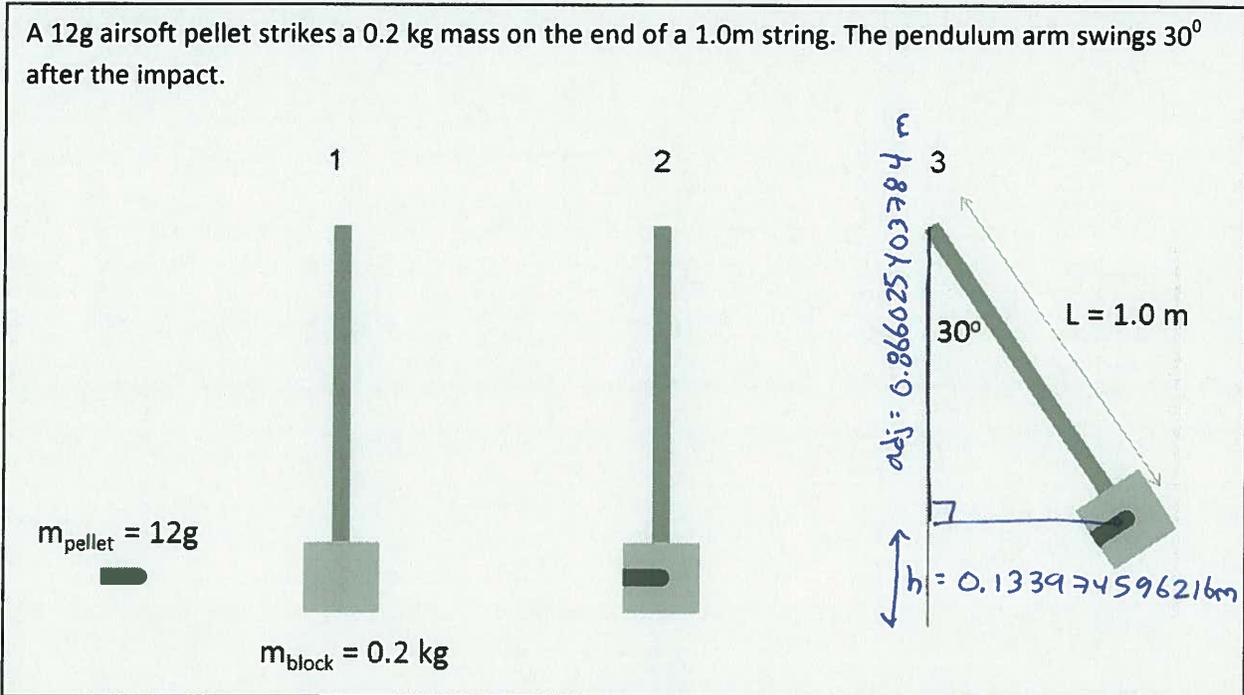
$$p_f = \frac{h}{\lambda_f} = \frac{(6.63 \times 10^{-34})}{(7.90096 \dots \times 10^{-10})} = 8.39137695373 \times 10^{-25} \text{ Ns}$$

$$\Delta p = 6.62304626 \times 10^{-28} \text{ Ns}$$

$$\approx 6.6 \times 10^{-28} \text{ Ns}$$

Cumulative Review

Use the following information to answer Q24:



Q24: The initial speed of the airsoft pellet, prior to impact, is $a.bc \times 10^d$ m/s, where $a, b, c,$ and d are __, __, __, and __.

(Record your **four digit** answer in the Numerical Response boxes below)

2	8	6	1
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FINAL

$$E_k \rightarrow E_p$$

$$\frac{1}{2}mv^2 \rightarrow mgh$$

$$\frac{1}{2}v^2 = (9.81)(0.1339\dots)$$

$$v = 1.62129009673\text{ m/s}$$

COLLISION

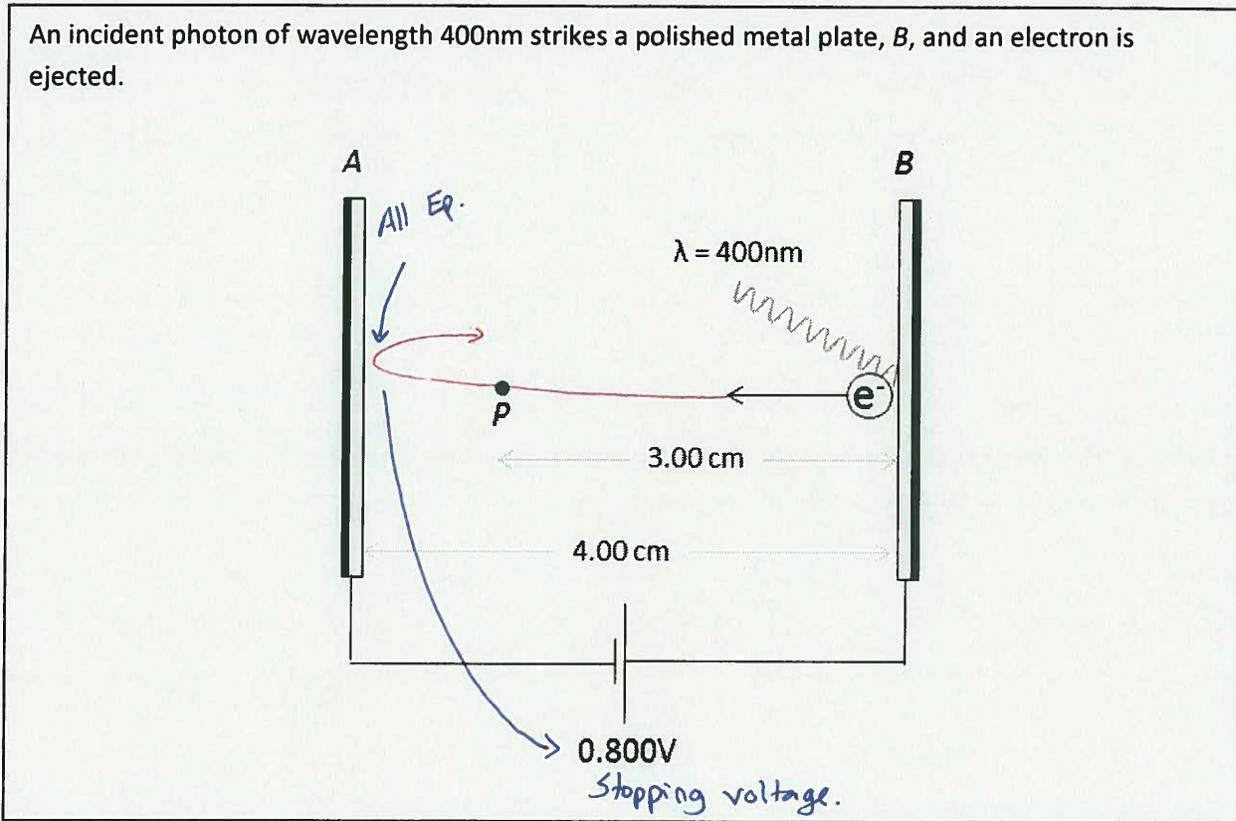
$$p_i \rightarrow p_f$$

$$(0.012)v_i + 0 \rightarrow (0.212)(1.62129\dots)$$

$$v_i = 28.6427917089\text{ m/s}$$

$$v_i \approx 2.86 \times 10^1\text{ m/s}$$

Use the following information to answer Q25-30:



Q25: The frequency of the incident photon is $a.b \times 10^{cd}$ Hz, where $a, b, c,$ and d are __, __, __, and __.

(Record your **four digit** answer in the Numerical Response boxes below)

7 5 1 4

$$c = f\lambda$$

$$(3.0 \times 10^8) = f(400 \times 10^{-9})$$

$$f = 7.5 \times 10^{14} \text{ Hz}$$

Q26: The work function of the polished metal plate, B, is ___ eV.

(Record your **three digit** answer in the Numerical Response boxes below)

2 . 3 1

$$E_{\text{photon}} \rightarrow W + E_{k\text{max}} \quad \text{where } E_{k\text{max}} = qV_{\text{stop}}$$

$$\frac{hc}{\lambda} \rightarrow W + qV_{\text{stop}}$$

$$\frac{(4.14 \times 10^{-15})(3.0 \times 10^8)}{(400 \times 10^{-9})} = W + (1e)(0.8)$$

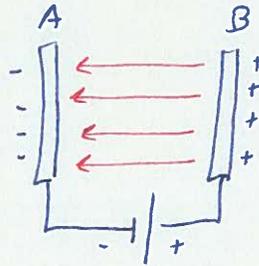
$$3.105 \text{ eV} = W + 0.8 \text{ eV}$$

$$W = 2.305 \text{ eV}$$

$$\approx 2.31 \text{ eV}$$

Q27: The electric field at Point P is directed

- (a) Towards Plate A
- b) Towards Plate B
- c) Into the page
- d) Out of the page



Q28: Which diagram represents the magnetic field of the electron as it moves from Plate B to Plate A?

- a)
- b)
- c)
- d)

Q29: The electric field strength at Point P is at EVERY point!

- a) 0.20 N/C
- b) 2.00 N/C
- (c) 20.0 N/C
- d) 200 N/C

$$|\vec{E}| = \frac{\Delta V}{\Delta d} = \frac{0.8}{0.04} = 20 \text{ N/C}$$

Q30: While at Point P, the electron is moving with a speed of $a.bc \times 10^d$ m/s, where $a, b, c,$ and d are , , , and .

(Record your **three digit** answer in the Numerical Response boxes below)

2 6 5 5

METHOD #1

$$\begin{aligned} \Delta E_p &= q \Delta V \\ &= (1.60 \times 10^{-19})(0.8) \\ &= 1.28 \times 10^{-19} \text{ J} \end{aligned}$$

Three quarters of the way there?
Then we have $3/4$ of the E_p .
The remaining $1/4$ is still E_k
 $E_k = 1/4 (1.28 \times 10^{-19}) = 3.2 \times 10^{-20} \text{ J}$
 $E_k = \frac{1}{2} m v^2$
 $(3.2 \times 10^{-20}) = \frac{1}{2} (9.11 \times 10^{-31}) v^2$
 $v = 2.65051 \times 10^5 \text{ m/s}$

METHOD #2

$$\begin{aligned} |\vec{E}| &= \frac{\Delta V}{\Delta d} = 20 \text{ N/C} \\ F &= q|\vec{E}| = (1.60 \times 10^{-19})(20) \\ &= 3.20 \times 10^{-18} \text{ N} \\ a &= \frac{F_{\text{net}}}{m} = \frac{3.20 \times 10^{-18}}{9.11 \times 10^{-31}} = 3.51262349067 \times 10^{12} \text{ m/s}^2 \\ v_f^2 &= v_i^2 + 2ad \\ v_f^2 &= (5.30163 \times 10^5)^2 + 2(3.512623 \dots \times 10^{12})(0.03) \\ v_f^2 &= 2.810098 \dots \times 10^{11} - 2.10757 \dots \times 10^{11} \\ v_f^2 &= 7.02524 \dots \times 10^{10} \\ v_f &= 2.65051 \times 10^5 \text{ m/s} \end{aligned}$$

Photon $\rightarrow W + E_k$
 $3.105 \text{ eV} \rightarrow 2.305 \text{ eV} + E_k$
 $E_k = 0.8 \text{ eV}$
 $= 1.28 \times 10^{-19} \text{ J}$
 $v_i = 5.30103 \times 10^5 \text{ m/s}$