Physics 30 – Activity 6.4

Pre-Test Assignment – The Particle Model of Light

1. How fast would a proton have to travel to have the same momentum as a 6.0-MeV photon?

i) $6.0\ MeV = 6.0\times10^{6}\ eV \times 1.6\times10^{-19}\frac{J}{eV} = 9.6\times10^{-13}\ J$

ii) $p_{photon} = \frac{E}{c} = \frac{9.6\times10^{-13}\ J}{3.00\times10^{8}\ \frac{m}{s}} = 3.2\times10^{-21}\ kg\frac{m}{s}$

iii) $V_{proton} = \frac{p}{m} = \frac{3.2\times10^{-21}\ kg\frac{m}{s}}{1.67\times10^{-27}\ kg} = 1.9\times10^{6}\frac{m}{s}$

2. A certain metal has a work function of 4.45 eV. If the metal is exposed to ultraviolet light with a wavelength of 1.25×10^{-7} m, calculate the stopping voltage required by this apparatus.

$E_{photon} = E_{k\ electron} + W$ $E_k = qV_{stop}$

$\frac{hc}{\lambda} = qV_{stop} + W$

$\frac{(6.63\times10^{-34})(3.00\times10^{8})}{1.25\times10^{-7}\ m} = (1.60\times10^{-19})V_{stop} + (4.45\ eV\times1.6\times10^{-19}\frac{J}{eV})$

$1.59\times10^{-18}\ J = 1.60\times10^{-19}V_{stop} + 7.12\times10^{-19}\ J$

$5.50\ V = V_{stop}$

2. Approximately 5.0% of the electric energy supplied to an incandescent light bulb converts into light energy. How many photons per seconed are emitted each second by a 40.0W bulb is the wavelength of light is 5.5×10^{-7} m?

i) $E = Pt$

$= 40.0\frac{J}{s}\cdot1.0s$

$= 40\ J$ only 0.05 converted to light $= 2.0\ J$

ii) $E_{photon} = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{5.5\times10^{-7}\ m} = 3.616\times10^{-19}\frac{J}{photon}$

iii) $\frac{E}{E_{photon}} = \frac{2.0\ J}{3.616\times10^{-19}\frac{J}{photon}} = 5.5\times10^{18}$ photons

3. What is the Compton Effect? Does it support the particle (Photon) or wave model of light?

Compton's experiment confirmed the particle nature of light. The experiment used high frequency X-rays directed at a graphite crystal. Electrons were emitted, however Compton focused on the scattered X-rays. He noticed that the scattered X-rays had a lower frequency. He interpreted these observations as the photons having momentum.

4. An alpha particle is travelling at 5.0 x 10^5 m/s. Calculate the wavelength of a photon with the same momentum as the alpha particle.

i) $p_\alpha = mv$

$= (6.65 \times 10^{-27} \cdot 5.0 \times 10^{5})$

$= 3.325 \times 10^{-21}\ kg \cdot \frac{m}{s}$

ii) $p_{photon} = \frac{h}{\lambda}$

$3.325 \times 10^{-21} = \frac{6.63 \times 10^{-34}}{\lambda}$

$\lambda = 1.99 \times 10^{-13}\ m$

5. In a Compton effect experiment, the following data was collected

Wavelength of incident photon 4.00 x 10^{-11}m

Wavelength of scattered photon 4.12 x 10^{-11} m.

Calculate the scattering angle of the emr.

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

$\Delta\lambda = 4.12 \times 10^{-11} - 4.00 \times 10^{-11}$

$\Delta\lambda = 1.2 \times 10^{-12}\ m$

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

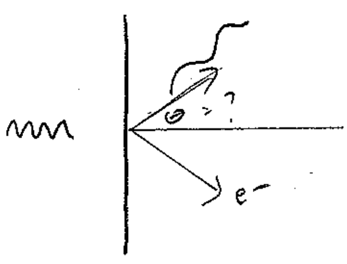
$1.2 \times 10^{-12} = \frac{6.63 \times 10^{-34}(1-\cos\theta)}{9.11 \times 10^{-31} \times 3 \times 10^{8}}$

$\frac{3.2796 \times 10^{-34}}{6.63 \times 10^{-34}} = 1 - \cos\theta$

$0.4946 = 1 - \cos\theta$

$0.505 = \cos\theta$

$59.6° = \theta$



Use the following information to answer the next question.

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

He calculated the maximum kinetic energy of the emitted photoelectrons.

His results are given in the table below.

Frequency of incident electromagnetic radiation (10^{15} Hz)	1.3	1.4	1.5	1.6	1.7	1.8
Maximum kinetic energy of emitted photoelectrons (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	**Work function (eV)**
Na	2.28
Co	3.90
Pb	4.14
Zn	4.31
Fe	4.50
Ag	4.73
Pt	6.35

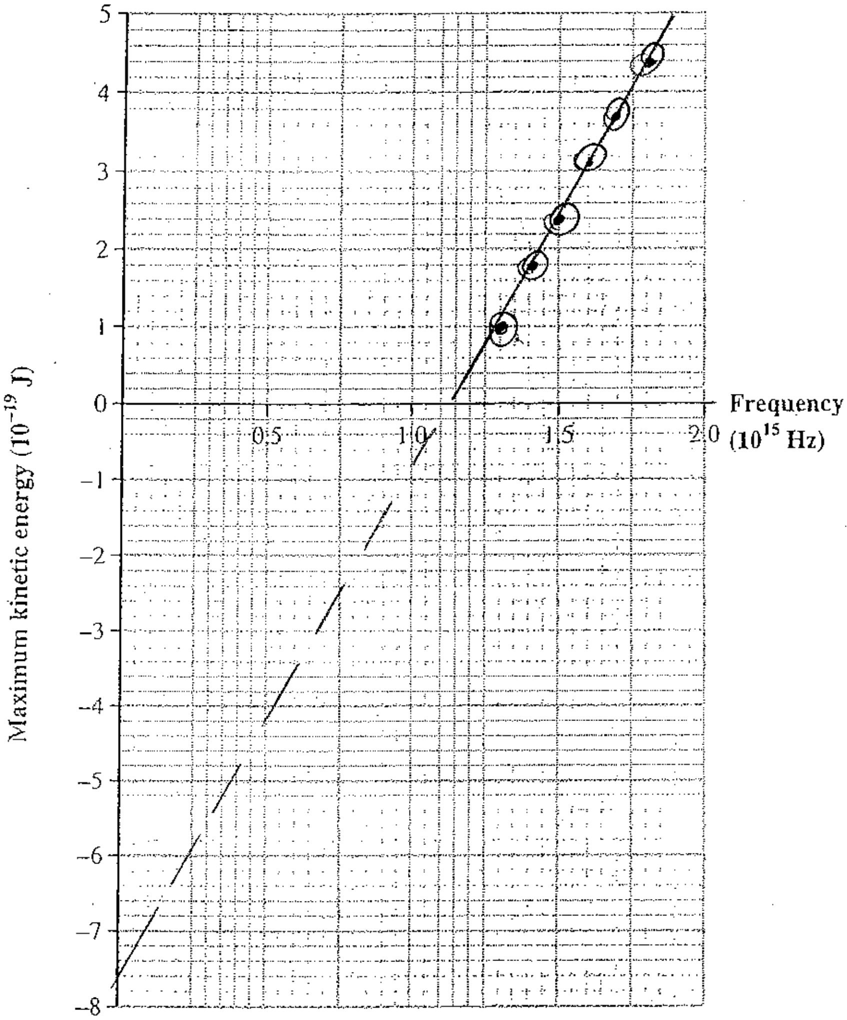
Written Response—15%

6. You must completely **analyze** the data and **identify** the metal. In your response,

- **identify** the region of the electromagnetic spectrum to which the incident frequency radiation belongs
- **provide** a graph of the results
- **determine** the values, with units, of the x-intercept and the y-intercept. **Identify** the significance of each of the intercepts
- **determine** the value, with units, of the slope. **Identify** the significance of the slope
- **identify** the metal. **Justify** your answer

Clearly communicate your understanding of the physics principles that you are using to solve this question. You may communicate this understanding mathematically, graphically, and/or with written statements.

Maximum Kinetic Energy as a Function of Incident Frequency



i) region of em-spectrum 10^{15} Hz is Ultraviolet (since 10^{14} Hz is visible)

ii) graph

iii) x-intercept = f_0 (threshold freq) 1.1×10^{15} Hz

y-intercept = W (work function) 7.6×10^{-19} J

iv) slope = $\frac{E}{f}$ = h (Planck's constant) $\frac{y_2 - y_1}{x_2 - x_1} = \frac{(4.4 - 1.0) \times 10^{-19} \text{ J}}{(1.8 - 1.3) \times 10^{15} \text{ Hz}} = 6.8 \times 10^{-34} \frac{\text{J}}{\text{Hz}}$

v) use Work function to identify the metal $\frac{7.6 \times 10^{-19} \text{ J}}{1.60 \times 10^{-19} \frac{\text{J}}{\text{eV}}} = 4.75 \text{ eV}$ (Ag) or consistent with your graph

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Pre-test 6.4 - Particle Model of Light - Show work when required

Multiple Choice

Identify the choice that best completes the statement or answers the question.

D 1. A photon with a wavelength of 950 nm has a frequency and energy of

a. 3.16×10^{5} Hz and 2.09×10^{-28} J, respectively.
b. 3.16×10^{5} Hz and 2.09×10^{-19} J, respectively.
c. 3.16×10^{14} Hz and 2.09×10^{-28} J, respectively.
(d.) 3.16×10^{14} Hz and 2.09×10^{-19} J, respectively.

$f = \frac{c}{\lambda} = \frac{3 \times 10^{8}}{950 \times 10^{-9}\,m} = 3.16 \times 10^{14}\,Hz$

$E = hf = (6.63 \times 10^{-34})(3.16 \times 10^{14}) = 2.09 \times 10^{-19}\,\frac{J}{photon}$

C 2. The closest whole number of photons that have a frequency of 3.98×10^{16} Hz and an energy of 1.32×10^{-13} J is

a. 5.00×10^{-21}
b. 2.00×10^{-4}
(c.) 5.00×10^{3}
d. 2.00×10^{20}

① $E_{photon} = hf = (6.63 \times 10^{-34})(3.98 \times 10^{16}) = 2.63.. \times 10^{-17}\,\frac{J}{photon}$

② $\frac{1.32 \times 10^{-13}\,J}{2.63 \times 10^{-17}\,\frac{J}{photon}} = 5002$ photons

D 3. The energy of a photon of wavelength 4.00×10^{-7} m is

a. 1.66×10^{-21} eV
b. 4.97×10^{-19} eV
c. 1.04 eV
(d.) 3.11 eV

$E = \frac{hc}{\lambda} = \frac{(4.14 \times 10^{-15})(3 \times 10^{8})}{4.00 \times 10^{-7}} = 3.11\,eV$

C 4. Which of the following is not a correct unit for Planck's constant?

a. $J \cdot s$
b. $eV \cdot s$ } see data book
(c.) $\frac{kg \cdot m^2}{s^3}$
d. $\frac{kg \cdot m^2}{s}$

since $J = \left(kg \cdot \frac{m^2}{s^2}\right) \cdot s = \frac{kg \cdot m^2}{s}$ is correct

D 5. A burglar alarm is designed to use a photocell with a threshold frequency of 8.35×10^{14} Hz. Light with a frequency of 1.10×10^{15} Hz shines on the photocell, resulting in the release of photoelectrons with a kinetic energy of

a. 1.28×10^{-18} J
b. 7.29×10^{-19} J
c. 5.54×10^{-19} J
(d.) 1.76×10^{-19} J

$E_{photon} = E_{k\,electron} + W$

$hf = E_{k\,electron} + hf_0$

$(6.63 \times 10^{-34})(\;\times 10^{1}) = E_{k\,electron} + (6.63 \times 10^{-34})\,8.35 \times 10^{14}$

$E_k = 1.76 \times 10^{-19}\,J$

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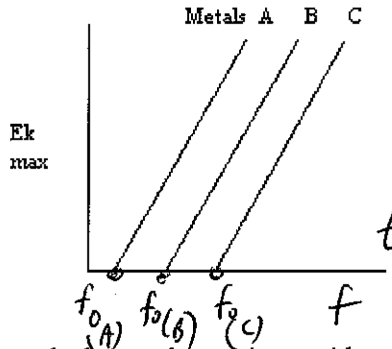
____ 6. Use the following information to answer the next question.

Graph of Maximum Kinetic Energy versus Frequency of Incident Light For Three Metals



the x-intercept represents the threshold frequency for the different metals.

The graph shown above gives evidence that

a. a photoelectron's maximum kinetic energy is dependent upon the intensity of the light incident on the metal.
b. photoelectrons are emitted only when the intensity of the light incident on the metal is greater than some specific value.
c. photoelectrons are emitted only when the frequency of light incident on the metal is greater than some specific value.
d. at a given frequency, photoelectron kinetic energy for Metal C is greater than photoelectron kinetic energy for Metal B.

B 7. Night vision goggles are made so that the user and the goggles are protected from sudden increases in brightness. A circuit in the goggles is activated when the

a. kinetic energy of the photoelectrons ejected by the bright light increases.
b. the photoelectric current that results from the bright light increases.
c. kinetic energy of the photoelectrons ejected by the bright light decreases.
d. the photoelectric current that results from the bright light decreases.

brightness affects photoelectric current

frequency affects E_k of emitted e^-

B 8. Albert Einstein contributed significantly to the development of the theory of the photoelectric effect. He hypothesized that

a. the energy of light is spread and creates a wave front similar to that suggested by Huygens.
b. the energy of light is concentrated in and moves as a particle that became known as a photon or quantum.
c. the energy of light, when shone upon photosensitive material, can cause the emission of photoelectrons.
d. the energy of light travels at a constant speed, known as the speed of light.

"quantum idea"

D 9. Many photosensitive substances require ultraviolet light. If ultraviolet light with a wavelength of about 4.10 $\times 10^{-8}$ m illuminates a surface that releases photoelectrons with a maximum kinetic energy of 28.0 eV, the work function of the material is

a. 9.33×10^{-18} J
b. 485×10^{-18} J
c. 4.48×10^{-18} J
d. 3.71×10^{-19} J

should be 3.67×10^{-19} J

$E_{photon} = E_{k\,e^-} + W$

$\frac{hc}{\lambda} = 28.0\,eV + W$

$\frac{(4.14 \times 10^{-15})(3 \times 10^{8})}{4.1 \times 10^{-8}} = 28.0 + W$

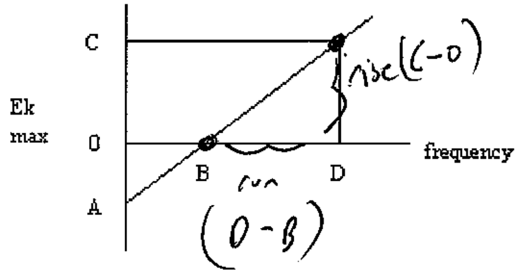
$30.29\,eV = 28.0 + W$

$W = 2.29\,eV \times \frac{1.6 \times 10^{-19}\,J}{1\,eV}$

$= 3.67 \times 10^{-19}$ J

Name: ______________________ note $Hz = \frac{1}{s}$ ID: A

C 10. Use the following information to answer the next question.



slope = $\frac{J}{Hz} = \frac{J}{\frac{1}{s}} = J \cdot s$ ← units for Plank's constant

The expression for Planck's constant is

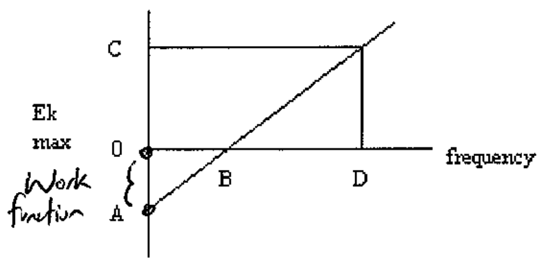
a. $\frac{C-0}{A-B}$

b. $\frac{C-0}{D-0}$

c. $\frac{C-0}{D-B}$ (circled)

d. $B - A$

D 11. Use the following information to answer the next question.



y intercept = Work function

The expression for work function is

a. $\frac{C-0}{A-B}$

b. $\frac{C-0}{D-0}$

c. B

d. A (circled) or $(A-0)$

D 12. The Compton effect illustrates that photons have

a. neither momentum nor mass.

b. neither kinetic energy nor momentum.

c. both momentum and mass.

d. both kinetic energy and momentum. (Compton effect!)

A 13. An incident photon with an energy of 34.7 eV collides with an electron. The scattered photon retains 31.5 eV of energy. What is the resultant speed of the electron?

a. 1.06×10^{6} m/s (circled)

b. 4.82×10^{6} m/s

c. 5.15×10^{7} m/s

d. 1.10×10^{8} m/s

$E_{initial\ photon} = E_{scattered\ photon} + E_{scattered\ e^-}$

$34.7 = 31.5 + E_{scattered\ e^-}$

$3.2\,eV = E_{electron}$

$E_k = \frac{1}{2}mv^2$

$3.2\,eV \times 1.6 \times 10^{-19}\,\frac{J}{eV} = \frac{1}{2}\,9.11 \times 10^{-31}\,v^2$

$1.06 \times 10^{6}\,m/s = v$

A 14. The momentum of a 340-nm photon is

a. 1.95×10^{-27} kg·m/s

b. 2.25×10^{-37} kg·m/s

c. 2.25×10^{-37} kg·m/s

d. 1.95×10^{-42} kg·m/s

$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{340 \times 10^{-9}}$

$= 1.95 \times 10^{-27}$ kg·m/s

Name: ______________________ ID: A

____ 15. A photon experiences a decrease in frequency after Compton scattering. Changes to momentum, energy, and wavelength, respectively, are

a. increases, increases, and increases.
b. increases, increases, and deceases.
(c) decreases, decreases, and increases.
d. decreases, decreases, and decreases.

____ 16. A photon with a wavelength of 9.78×10^{-11} m undergoes Compton scattering at an angle of 27.5°. Its change in wavelength is

a. 9.78×10^{-11} m
b. 9.75×10^{-11} m
c. 2.43×10^{-12} m
d. 2.74×10^{-13} m

15) A high energy photon collides with an electron and transfer some of its momentum and energy to the electron. This is why the momentum and energy of the photon will decrease. The scattered photon has less energy and since $E \propto \frac{1}{\lambda}$ it will have a longer wavelength

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

$= \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(3 \times 10^{8})}(1 - \cos 27.5°)$

$= 2.425.. \times 10^{-12}(.1129...)$

$= 2.74 \times 10^{-13}$ m

* NB the scattered λ is always longer!