Example

1. Cesium metal has a work function of 2.10 eV. Determine the maximum wavelength of light required to produce emission of photoelectrons.

$W = 2.10 eV$

$\lambda_{max} = ?$

$W = hf_0$

$f_0 = \frac{W}{h}$

$f_0 = \frac{2.10 eV}{4.14\times10^{-15} eV\cdot s}$

$f_0 = 5.0725\times10^{14} Hz$

$c = \lambda f$

$\lambda = \frac{c}{f}$

$= \frac{3\times10^8 m/s}{5.0725\times10^{14} Hz}$

$\lambda = 5.914\times10^{-9} m$

The maximum wavelength that would produce photoelectrons is 591 nm.

Problems

1. A photon having an energy of 6.0 eV contacts the photoelectric surface of a metal having a work function of 2.0 eV. Determine the kinetic energy of the ejected photoelectron. [4.0 eV]

2. Photons having energy of 3.20 eV are incident on cesium metal having a work function of 2.02 eV resulting in the emission of electrons. Use the Law of Conservation of Energy to determine the
   a. kinetic energy of the emitted electrons in electron volts. [1.18 eV]
   b. speed of the emitted electrons. [6.44 x 10^5 m/s]

$E_{in} = 3.20 eV$

$W = 2.02 eV$

a) $E_{in} = E_{out}$

$E_{in} = E_K + W$

$E_K = E_{in} - W$

$E_K = 3.20 eV - 2.02 eV$

$E_K = 1.18 eV$

$\frac{1.6\times10^{-19} J}{1 eV} = \frac{x J}{1.18 eV}$

$x = 1.888\times10^{-19}$

b) $E_K = \frac{1}{2}mv^2$

$v = \sqrt{\frac{2E_K}{m}}$

$v = \sqrt{\frac{2\times1.88\times10^{-19} J}{9.11\times10^{-31} kg}}$

$v = 643808 m/s$

$v = 6.44\times10^5 m/s$

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3. The carbon in an HB pencil has a work function of 4.81 eV. A 6.21 eV photon is incident on the carbon. Determine the
   a. energy in electron volts of the emitted photoelectrons. [1.40 eV]
   b. speed of the emitted photoelectrons. [7.01×10^5 m/s]

W = 4.81eV
E_{in} = 6.21 eV
E_K = ?

a) $E_{in} = E_K + W$
$E_K = E_{in} - W$
E_K = 1.40eV ✓

b) $\frac{1.6\times10^{-19} J}{1 eV} = \frac{x J}{1.40 eV}$
$x = 2.24\times10^{-19}$ J
$v = \sqrt{\frac{2E_K}{m}} = \sqrt{\frac{2(2.24\times10^{-19})}{9.11\times10^{-31}}}$
v = 701261 m/s = 7.01×10^5 m/s

2 ✓

4. Einstein's explanation of the photoelectric effect based on the idea that light was a particle was not quickly accepted by many scientists. Millikan spent 10 years performing sophisticated photoelectric experiments in an effort to disprove Einstein's photon interpretation. In the end he provided verification of the photon interpretation. Light falls on a photoelectric surface with a work function of 1.60 eV resulting in the emission of electrons with a kinetic energy of 3.78 eV.
   a. Determine the energy of each photon of the incident light. [5.38 eV]
   b. Identify the region of the electromagnetic spectrum where the photon belongs. [Appendix A]

5. Electrons are emitted with a kinetic energy of 1.90 eV from a photoelectric surface having a work function of 2.12 eV. Determine the incident
   a. photon's energy. [4.02 eV]
   b. light's frequency. [9.71×10^{14} Hz]
   c. light's wavelength. [309 nm]
   d. light's location in the electromagnetic spectrum. [Appendix A]

a)
E_K = 1.90
W = 2.12 eV
E_i = ?
$E_i = E_K + W$
E_i = 1.90 + 2.12
E_i = 4.02eV ✓

b) $E = hf$
$f = \frac{E}{h}$
E = 4.02eV
$h = 4.14\times10^{-15}$ eV·s
$f = \frac{4.02 eV}{4.14\times10^{-15} eV}$
$f = 9.71\times10^{14}$ Hz ✓

c) $E = \frac{hc}{\lambda}$
$\lambda = \frac{hc}{E}$
$\lambda = \frac{4.14\times10^{-15} eV\cdot s \cdot 3.0\times10^8 m/s}{4.02 eV}$
$\lambda = 3.089\times10^{-7}$ m
λ = 309nm ✓

d) UV ✓

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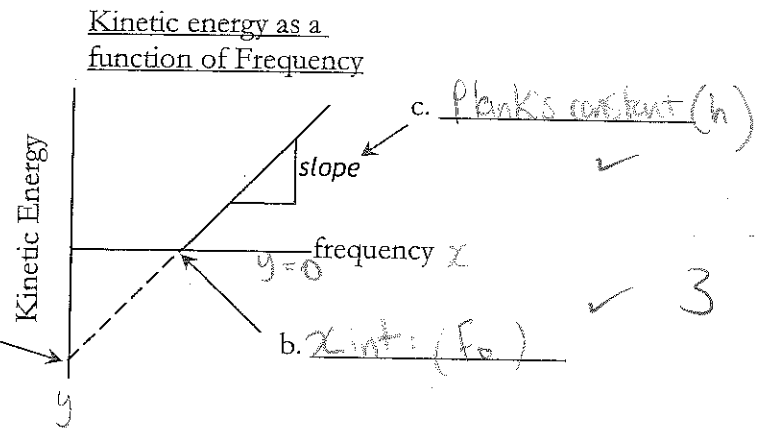
6. A photon having a frequency of 8.2×10^{14} Hz contacts the photoelectric surface of a metal having a work function of 4.4×10^{-19} J. Determine the kinetic energy of the ejected photoelectron. [1.0×10^{-19} J]

$f = 8.2\times10^{14}$ Hz
$W = 4.4\times10^{-19}$ J
$E_k = ?$
$E_i = hf = 6.63\times10^{-34}$ J·s $\times 8.2\times10^{14}$ Hz
$E_i = 5.436\times10^{-19}$
$E_i = E_k + W$
$E_k = E_i - W$
$E_k = 5.436\times10^{-19}$ J $- 4.4\times10^{-19}$ J
$E_k = 1.036\times10^{-19}$ J
$E_k = 1.0\times10^{-19}$ J

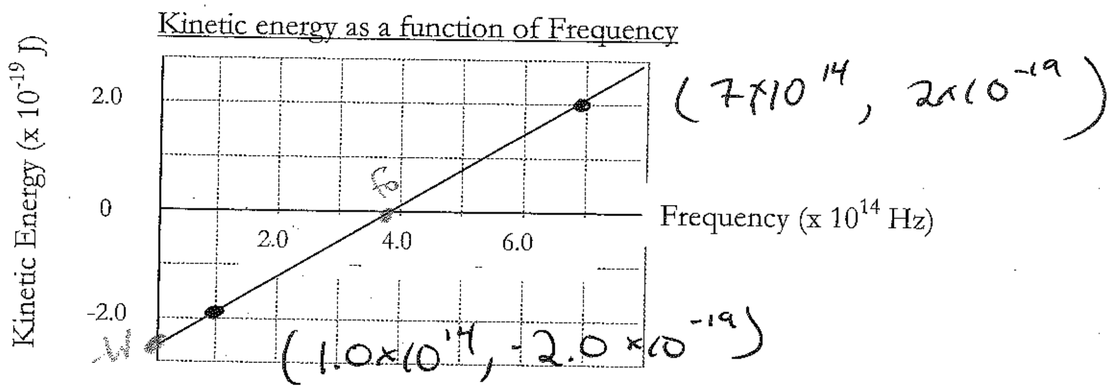
7. A graph of kinetic energy as a function of frequency for a photoelectric experiment is shown to the right. Label the sections of the graphs indicated. [Appendix A]

$E_k = hf - W$
$E_k = h \cdot f - W$
$E_i = E_k + W$
$hf = E_k + W$



Use the graph to answer questions 8 – 11.

Hertz discovered the photoelectric effect while investigating EMR. Millikan spent 10 years precisely examining the effect. A graph of kinetic energy of emitted electrons versus frequency of incident light is plotted for a photoelectric tube.



8. Determine the work function of the metal used in the phototube. [~2.6×10^{-19} J]

y int $(-W) = -(-2.6\times10^{-19}$ J$) = 2.6\times10^{-19}$ J

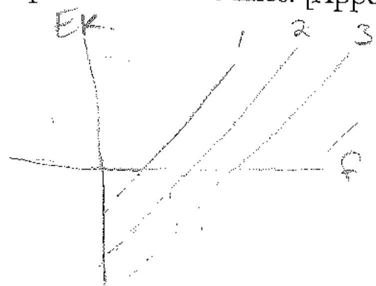
9. Determine the metal's threshold frequency. [~3.8×10^{14} Hz]

x int $(f_0) = 3.8\times10^{14}$ Hz

10. Calculate the threshold wavelength of the metal. [~7.9 x 10^{-7} m]

11. Use the graph to determine Planck's constant. [~8.2 x 10^{-34} J•s]

12. The work function of three different metals was determined in a lab to be 1.30 eV, 2.60 eV, and 4.10 eV. The values for the work functions were obtained from a graph of energy versus frequency. Compare the slopes of the three lines. [Appendix A]



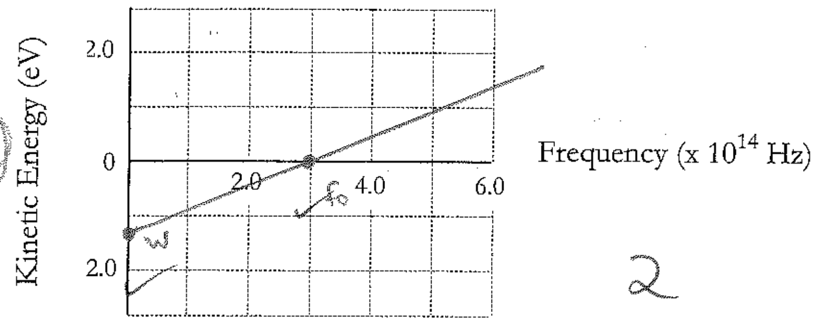
13. Convert Planck's constant in units of J•s to units of eV•s. [4.14 x 10^{-15} eV•s]

14. Fill in the blank. Incoming photons strike a photoelectric surface. If the energy of the photons is greater than the work function of the metal, electrons are ejected. [Appendix A]

15. A photoelectric experiment uses a metal having a work function 1.24 eV. It was determined that the threshold frequency of the metal is 3.00×10^{14} Hz. Draw a graph of kinetic energy of the photoelectrons as a function of frequency for sodium. [Appendix A]

Kinetic energy as a function of Frequency

$-W = 1.24 eV$ ($x=0$, y int)
$f_0 = 3 \times 10^{14}$ Hz ($y=0$, x int)



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16. Determine the work function of platinum having a threshold frequency of 1.28×10^{15} Hz. [8.49×10^{-19} J or 5.30 eV]

$f = 1.28 \times 10^{15}$ Hz
$W = ?$
$W = hf_0$
$W = 6.63 \times 10^{-34} J \cdot s \times 1.28 \times 10^{15} \frac{1}{s} = 8.49 \times 10^{-19} J$

17. The threshold frequency or wavelength of light may be used to help identify an unknown substance in a photoelectric experiment. Complete the chart below. [Appendix A]

Element	Work Function ($\times 10^{-19}$ J)	Threshold Wavelength (nm)	Threshold Frequency ($\times 10^{15}$ Hz)
Beryllium	8.00	249	1.21
Iron	7.21	276	1.09
Uranium	5.77	345	0.870

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note: do it too!

18. Assume the three substances listed in the previous question are used in an experiment. Each substance has the identical light of 220 nm incident on their surface. Identify the substance that would result in photoelectrons with the greatest kinetic energy. [Appendix A]

$\lambda = 220$ nm $E_{photon} = E_k + W$

Uranium has smallest W ∴ it will result in greatest E_k → $E_{photon} - W = E_k$

19. Heinrich Hertz first observed the photoelectric effect in the latter part of the 19th century while working with his spark gap generator. He found that his spark-gap generator worked better in the presence of visible light and even better with UV light. Determine the threshold frequency of light shining on a metal with a work function of 4.32 eV. [1.04 x 10^15 Hz]

$W = 4.32$ eV $h = 4.14\times10^{-15}$ eV·s

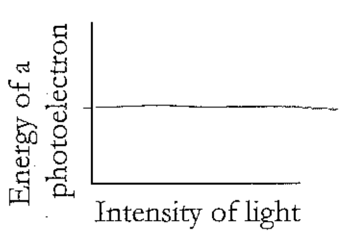
$f = ?$

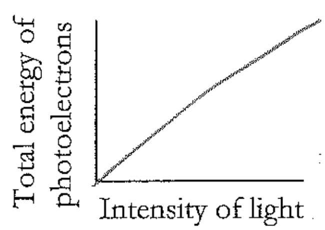
$W = hf_0$ $f_0 = \frac{4.32 \text{ eV}}{4.14\times10^{-15} \text{ eV·s}} = 1.04\times10^{15}$ Hz $= f_0$

$\frac{W}{h} = f_0$

20. Fill in the blanks. As the intensity of light increase, the number of photoelectrons _increases_ as long as the wavelength of incident light is _greater_ than the threshold frequency. [Appendix A]

21. Light, having a frequency greater than the threshold frequency is incident on a metal's surface and photoelectrons are emitted. Sketch the graph shapes below as the intensity of the incident light is manipulated and frequency is held constant. [Appendix A]





22. Electrons are emitted from a photoelectric surface at speed of 5.20×10^5 m/s. If the work function of the metal surface is 3.39×10^{-19} J, determine the frequency of the incident photons. [6.97×10^{14} Hz]

$v = 5.20 \times 10^5$ m/s
$W = 3.39 \times 10^{-19}$ J
$f = ?$

$E_i = E_k - W$

$hf = E_{kmax} - W$

/

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

$E_k = \frac{1}{2}(9.11 \times 10^{-31}\text{ kg}) \times (5.20 \times 10^5\text{ m/s})^2$

$f = \frac{E_{kmax} - W}{h} = 6.97 \times 10^{14}$ Hz

23. Light with a wavelength of 610 nm falls on a photoelectric surface with a work function of 2.56 x 10^{-19} J. Determine the maximum kinetic energy of the emitted photoelectrons in units of
a. joules. [7.01×10^{-20} J]
b. electron volts. [0.438 eV]

24. Old film projectors used the photoelectric effect to synchronize the sound image as the projector was played. Consider a certain metal being used in an old film projector that has a threshold frequency of 2.10×10^{15} Hz. Calculate be the maximum kinetic energy of electrons emitted by light with a frequency 3.40×10^{15} Hz. [8.62×10^{-19} J or 5.38 eV]

$f = 3.40 \times 10^{15}$ Hz
E_{kmax}

$E_{in} = E_{kmax} + W$

$E_{in} - W = E_{kmax}$

$hf - hf_0 = E_{kmax}$ ✓ /

$W = hf_0$

$f_0 = 2.10 \times 10^{15}$ Hz

$E_{kmax} = (6.63 \times 10^{-34} \times 3.4 \times 10^{15}) - (6.63 \times 10^{-34} \times 2.10 \times 10^{15}\text{ Hz})$

$E_{kmax} = 8.619 \times 10^{-19}$ J $= 8.62 \times 10^{-19}$ J

25. Determine the stopping voltage of an electron having a kinetic energy of 3.1 eV. [Appendix A]

$E_{kmax} = q_e V_{stop}$

$3.1\text{ eV} \times \frac{1.6 \times 10^{-19}\text{ J}}{1\text{ eV}} = 4.96 \times 10^{-19}$ J

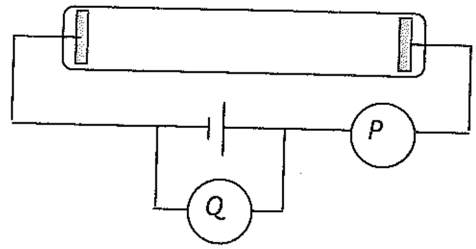
$V_{stop} = \frac{E_{kmax}}{q_e} = \frac{4.96 \times 10^{-19}\text{ J}}{1.6 \times 10^{-19}\text{ J}} = 3.1$ V ✓ /

3

26. The stopping voltage of electrons released through a photoelectric process may be determined using the following apparatus. Identify the type of meter used in position

a. P. [Appendix A]

b. Q. [Appendix A]



27. Light with a wavelength of 470 nm is directed on a photoelectric surface having a work function of 1.40 eV. Determine the stopping voltage needed to reduce the current through the cell to zero. [1.24 V]

$\lambda = 470\,nm$

$W = 1.40\,eV$

$V_{stop} = ?$

$E_{kmax} = q \cdot V_{stop}$

$E_i = E_{kmax} + W$

$E_i - W = E_{kmax}$

$\frac{hc}{\lambda} - W = E_{kmax}$

$\frac{6.63\times10^{-34} \cdot 3\times10^{8}}{470\times10^{-9}} - 2.24\times10^{-19} = E_{kmax}$

$E_{kmax} = 1.99\times10^{-19}\,J$

$V_{stop} = \frac{1.99\times10^{-19}\,J}{1.6\times10^{-19}\,C} = 1.2449\,V$

$W = 1.4\,eV \times \frac{1.6\times10^{-19}\,J}{1\,eV}$

$W = 2.24\times10^{-19}\,J$

$V_{stop} = \frac{E_{kmax}}{q_e}$

$V_{stop} = 1.24\,V$

28. Define, [Appendix A]

a. photocurrent:

b. photoelectron:

29. Explain how the photoelectric effect supports the particle nature of light. [Appendix A]

30. In the equation for the photoelectric effect, the expression "maximum kinetic energy" is used. Explain the use of the word "maximum". [Appendix A]

1

$E_{in} = E_{kmax} + W$ $\quad hf = \frac{V_{stop}}{q_e} - W$

$E_{in} = \frac{V_{stop}}{q_e} + W$ $\quad q_e(hf + W) = V_{stop}$

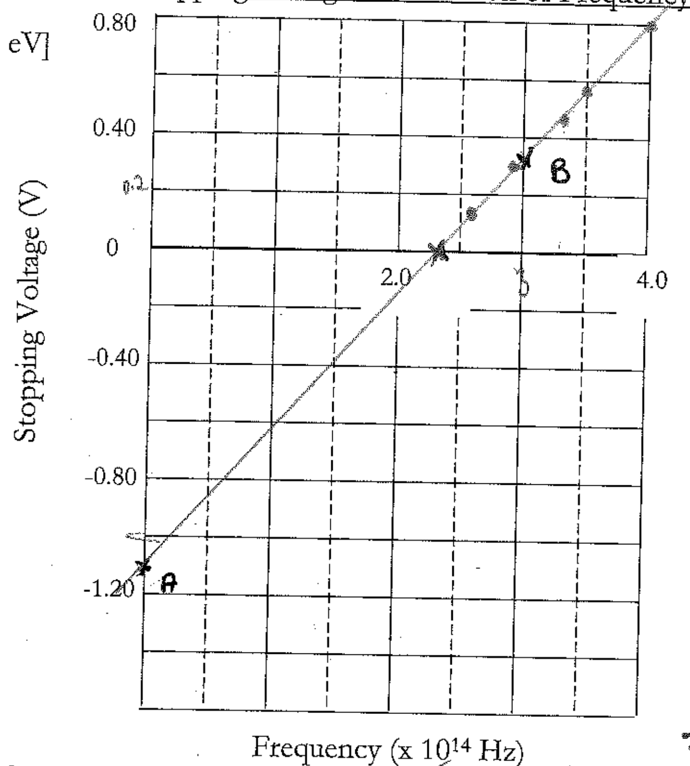
B.

31. In a photoelectric experiment a variable frequency light source was incident upon a photoelectric metal and the following stopping voltages were recorded.

6.2a

a. Graph the data.
b. Use the graph to determine
   i. the threshold frequency of the metal. [~2.4 x 10^{14} Hz]
   ii. the work function of the metal. [~1.0 eV]
   iii. Planck's constant. [~ 4.3 x 10^{-15} eV•s or ~8.0 x 10^{-34} J•s]

Stopping Voltage as a function of Frequency



Frequency (x 10^{14} Hz)	Stopping Voltage (V)
2.6	0.15
2.9	0.31
3.3	0.45
3.5	0.59
4.0	0.80

$V_{stop} = q_e(hf + W)$

$V_{stop} = \frac{hf}{q_e} + Wq_e$

$V_{stop} = \frac{h}{q_e} \times f + Wq_e$

$y = m \quad x + b$

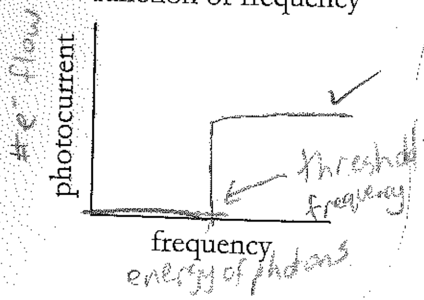
3

i) $f_0 = x\,int = 2.4 \times 10^{14}$ Hz

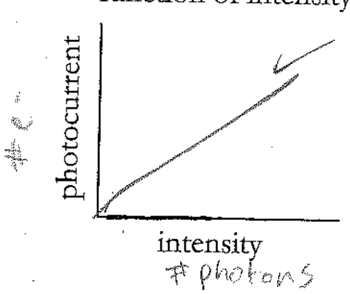
ii) $W = \frac{y\,int}{q_e} = \frac{-1.15V}{1.6 \times 10^{-19} C} = 7.18 \times 10^{18} J \times \frac{1.6 \times 10^{-19} J}{1 eV} = 1.15 eV$

32. Sketch graphs for the following photoelectric relationships. [Appendix A]

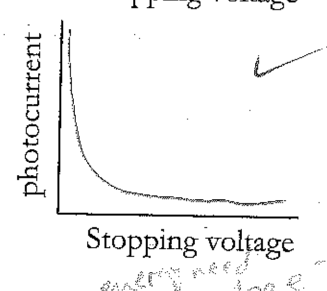
a. Photocurrent as a function of frequency



b. Photocurrent as a function of intensity



c. Photocurrent as a function of stopping voltage



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iii) $\frac{h}{q_e} = slope$ $\quad slope \times q_e = h$

$\frac{(0.3 - -1.2V)}{(3 - 0) \times 10^{14} Hz} = 5 \times 10^{-15} \times 1.6 \times 10^{-19} = 8.0 \times 10^{-34}$ J·s

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