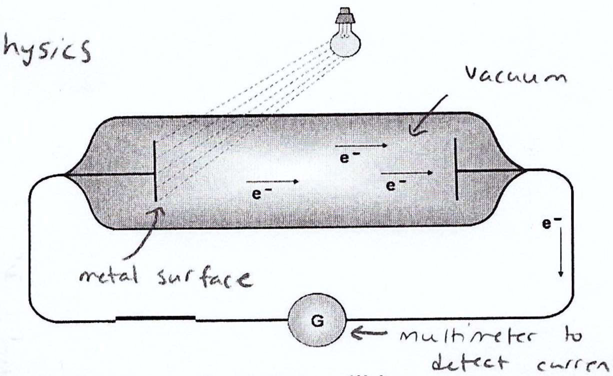
Photoelectric Effect

- The photoelectric effect is an experiment that supports the particle theory of light /quantum physics



- When light shines on a metal surface (photoelectric surface), electrons are emitted and travel across a vacuum to a metal conductor which will detect a current.

- When light is shone on a metal surface, either electrons will be emitted immediately (there is no time for the electrons to build up energy and be ejected) or no electrons will be ejected at all (ie. no current detected).
    - This means that light/EMR is behaving like a particle and that each photon either has the potential to collide with a single electron and release the electron or the photon doesn't have enough energy to release the electron
    - * One photon only has the potential to release one electron from the metal surface

- If no current was detected, this meant the photons had a frequency less than the *threshold frequency* for that metal (every metal has its own unique threshold frequency). The **threshold frequency** is the minimum frequency required to emit any electrons from the metal surface. If the light is below the threshold frequency, no electrons will be emitted from the metal surface, no matter the intensity of the light or duration the light is shone on the surface. ← wave theory would suggest otherwise!
    - * The *intensity*/brightness of the light source is a measure of the *number of photons* emitted by that light source. For example, a very intense light source means that many photons are being emitted. Therefore, if the photons from the light source have a frequency equal to or greater than the threshold frequency, the current (a measure of the number of electrons) will increase as the intensity of the light source increases.
    - * If the photons from the light source have a frequency equal to or greater than the threshold frequency, the *kinetic energy* of the emitted electrons will increase as the *frequency/energy of the light* increases (and vise versa)

- Therefore, the photoelectric effect can be explained using the conservation of energy ↳ principle #5

$$E_{in} = E_{out}$$

$$E_{incident\ light} = E_k + W$$

where $E_{incident\ light}$ is the energy of *one photon*
E_k is the kinetic energy of *one emitted/ejected electron*
W is the *work function*

} units of J or eV

- The **work function** is the minimum amount of energy required to release an electron from a metal surface; the electron will have no kinetic energy yet
- Therefore, the work function and threshold frequency are related to each other by the following equation

$$W = hf_o$$

where h is Planck's constant (6.63×10^{-34} J·s or 4.14×10^{-15} eV·s)
W is the work function (eV or J)
f_o is the threshold frequency (Hz)

- The kinetic energy of the emitted electrons could be measured by applying a voltage/potential difference to the photoelectric apparatus, which would decelerate the electrons to a stop. This is known as the **stopping voltage** and is represented by the following equation.

$$E_{k,max} = q_e V_{stop}$$

where $E_{k,max}$ is the kinetic energy of the emitted electron (J) can only be in joules!
q_e is the charge on the electron (C)
V_{stop} is the voltage require to stop the electron (V)

EXAMPLES

1. The threshold frequency of a particular metal is1.14x10^{15} Hz. What is the work function of the metal?

$f_o = 1.14 \times 10^{15}$ Hz

$W = ?$

$W = hf_o$

$W = (4.14 \times 10^{-15} \text{ eV·s})(1.14 \times 10^{15} \text{ Hz})$

$W = 4.7196$ eV

$W = 4.72$ eV

2. Electrons are ejected from a photoelectric surface with a maximum kinetic energy of 1.92×10^{-19} J. If the incident light has a wavelength of 4.10×10^{2} nm, what is the threshold frequency of the photoelectric surface?

→ start with conservation of energy

$E_{k,max} = 1.92 \times 10^{-19}\ J$ → set up equation in joules!

$\lambda = 4.10 \times 10^{2}\ nm \times \left(\frac{10^{-9}\ m}{1\ nm}\right)$

$\lambda = 4.10 \times 10^{-7}\ m$

$f_0 = ?$

$$E_{in} = E_{out}$$

$$E_{incident} = W + E_{k,max}$$

$$\frac{hc}{\lambda} = hf_0 + E_{k,max}$$

$$hf_0 = \frac{hc}{\lambda} - E_{k,max}$$

$$hf_0 = \frac{(6.63 \times 10^{-34}\ J \cdot s)(3.0 \times 10^{8}\ m/s)}{(4.10 \times 10^{-7}\ m)} - 1.92 \times 10^{-19}\ J$$

$$hf_0 = 4.85121... \times 10^{-19}\ J - 1.92 \times 10^{-19}\ J$$

$$hf_0 = 2.9312... \times 10^{-19}\ J$$

$$f_0 = \frac{2.9312... \times 10^{-19}\ J}{h} = \frac{2.9312... \times 10^{-19}\ J}{(6.63 \times 10^{-34}\ J \cdot s)}$$

$$f_0 = 4.4211... \times 10^{14}\ Hz$$

$$\boxed{f_0 = 4.42 \times 10^{14}\ Hz}$$

3. The work function of silver is 4.72eV. Electromagnetic radiation with a wavelength of 2.50×10^{-7}m strikes a piece of pure silver. Determine the speed of the electrons emitted from the piece of silver.

$W = 4.72 eV$

$\lambda = 2.50 \times 10^{-7} m$

$v_e = ?$

$$E_{in} = E_{out}$$

$$E_{incident} = W + E_{k,max}$$

$$\frac{hc}{\lambda} = W + E_{k,max}$$

$$E_{k,max} = \frac{hc}{\lambda} - W$$

$$E_{k,max} = \frac{(4.14 \times 10^{-15} eV \cdot s)(3.0 \times 10^{8} m/s)}{2.50 \times 10^{-7} m} - 4.72 eV$$

$$E_{k,max} = 4.968 eV - 4.72 eV$$

$$E_{k,max} = 0.248 eV \times \left(\frac{1.6 \times 10^{-19} J}{1 eV}\right)$$

$$E_{k,max} = 3.968 \times 10^{-20} J$$

* always need units of joules for $E_k = \frac{1}{2}mv^2$

$\therefore E_k = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2E_k}{m}}$

$$v = \sqrt{\frac{2(3.968 \times 10^{-20} J)}{9.11 \times 10^{-31} kg}} = 295149.22\ldots m/s$$

$$\boxed{v = 2.95 \times 10^{5} m/s}$$

photoelectric effect

4. A light source with a frequency of 6.65×10^{14} Hz is shone on a piece of copper. In order to bring the emitted electrons to a stop, a voltage of 0.48V is required. What is the speed of the emitted electrons?

$f = 6.65 \times 10^{14}$ Hz

$V_{stop} = 0.48V$

$v_{e^-} = ?$

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

$E_{K,max} = q_e V_{stop}$ (1)

* needs to be joules!

(1) $E_{K,max} = (1.6 \times 10^{-19} C)(0.48V) = 7.68 \times 10^{-20} J$

(2) $E_K = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2E_K}{m}}$

$$v = \sqrt{\frac{2(7.68 \times 10^{-20} J)}{9.11 \times 10^{-31} kg}} = 410616.5 \, m/s$$

$v = 4.11 \times 10^5$ m/s

Now try pg. 259 #3, 5, 6 (acceptable), 14, 16, 18-20, 22-24, 27 (intermediate)

Use the following information to answer the next question.

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

Four Photoelectric Effect Predictions

1 Low-intensity electromagnetic radiation on a photoelectric surface for long periods of time will cause photoemissions.

2 High-intensity electromagnetic radiation will not cause photoemission unless its frequency is greater than the photoelectric surface's threshold frequency.

3 The energy of the emitted photoelectrons will increase if the intensity of the incident electromagnetic radiation is increased.

4 The energy of the emitted photoelectrons is independent of the intensity of the incident electromagnetic radiation.

Numerical Response

Match each of the predictions above with the appropriate theory of physics as labeled below. There is more than one correct answer.

Prediction:	1	3	2	4
Appropriate Theory:	**Classical wave theory**		**Quantum physics**	