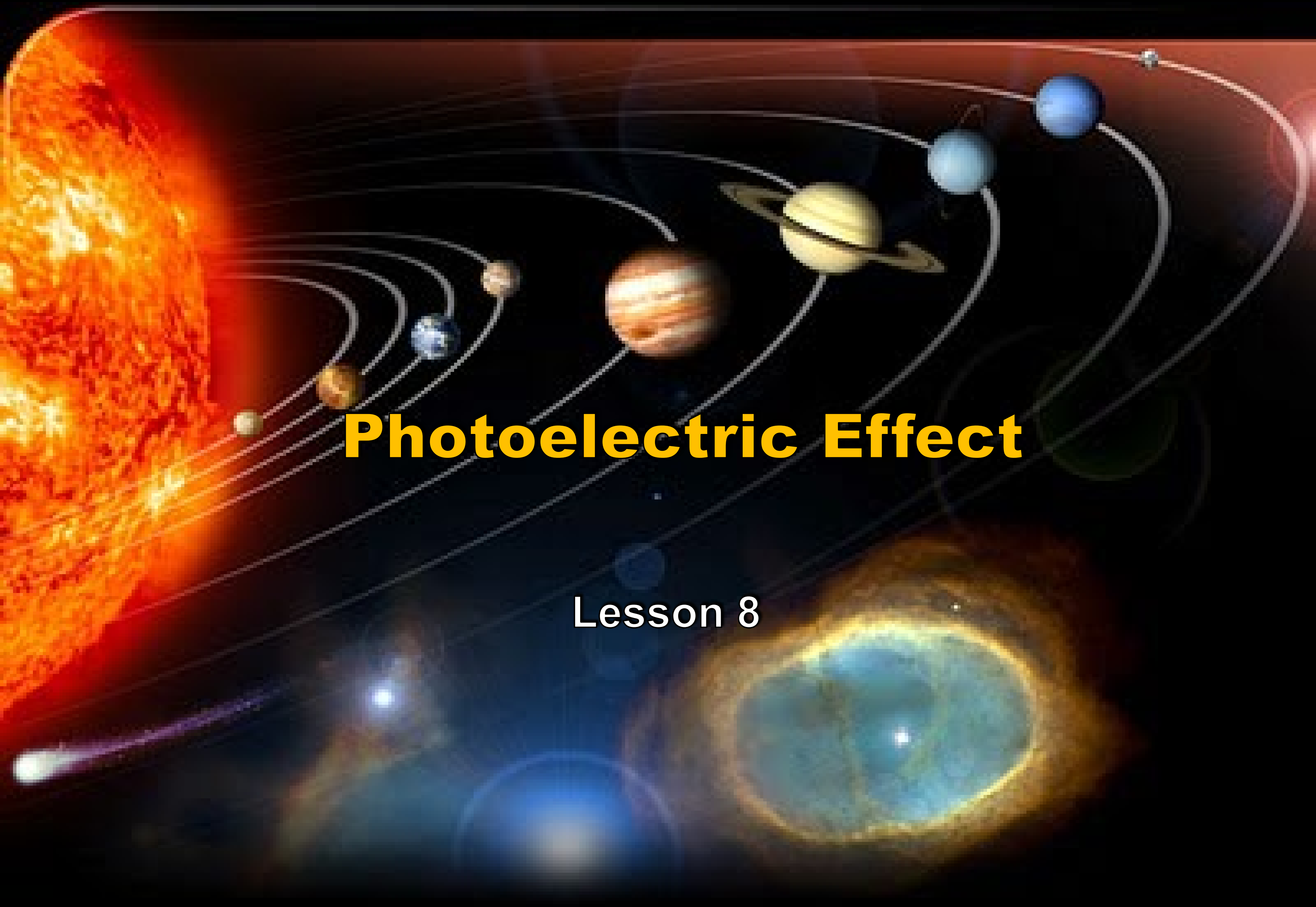
# Photoelectric Effect

Lesson 8



# POS Checklist:

- ☐ describe the photoelectric effect in terms of the intensity and wavelength or frequency of the incident light and surface material
- ☐ describe, quantitatively, photoelectric emission, using concepts related to the conservation of energy
- ☐ describe the photoelectric effect as a phenomenon that supports the notion of the wave-particle duality of EMR

**Diploma Question Alert!**

24. Electromagnetic radiation is always produced as a result of the

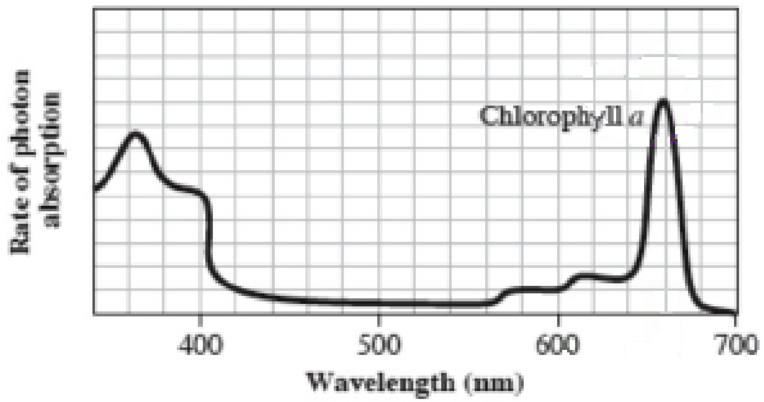
    A. acceleration of electric charges
    B. movement of electric charges
    C. acceleration of masses
    D. magnetic fields

# Diploma Question Alert!

*Use the following information to answer the next question.*

Chlorophyll in plants absorbs photons of electromagnetic radiation and converts them into chemical potential energy. Chlorophyll *a* is one of the main types of chlorophyll. The graph below shows the relationship between the absorption of photons by chlorophyll *a* and the wavelength of the photons striking the plants.

**Absorption Rate as a Function of Incident Wavelength**




25. To produce the maximum rate of photon absorption by chlorophyll *a*, photons should have an energy of

**A.** 1.77 eV

**B.** 1.88 eV

**C.** 2.48 eV

**D.** 3.40 eV

## Diploma Question Alert!

26. Compared with the wavelength and frequency of visible light, the electromagnetic waves emitted during nuclear fission have

A. longer wavelengths but a lower frequency

B. longer wavelengths and a higher frequency

C. shorter wavelengths and a lower frequency

D. shorter wavelengths but a higher frequency

# Diploma Question Alert!

27. An electromagnetic wave travels vertically upward, perpendicular to Earth's surface. If the magnetic field component of the wave oscillates in a north-south direction, then the electric field component will oscillate in

A. an east-west direction

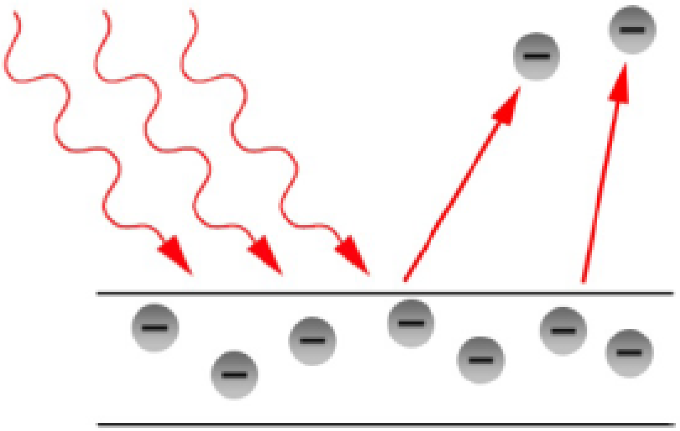
B. a north-south direction

C. a vertically upward direction

D. a vertically downward direction

# Photoelectric Effect

- When H. Hertz was testing Maxwell's theory of electromagnetic waves he discovered that ultraviolet light caused some metallic surfaces to lose their negative charge.
- This is the photoelectric effect. It refers to the observation that light shining on a negatively charged metal surface causes electrons to be emitted from that surface.
- Einstein theorized that when electrons absorb a photon of light, they jump off the surface of certain metals.
- He devised an experiment to determine how much energy was needed to make the metal eject electrons



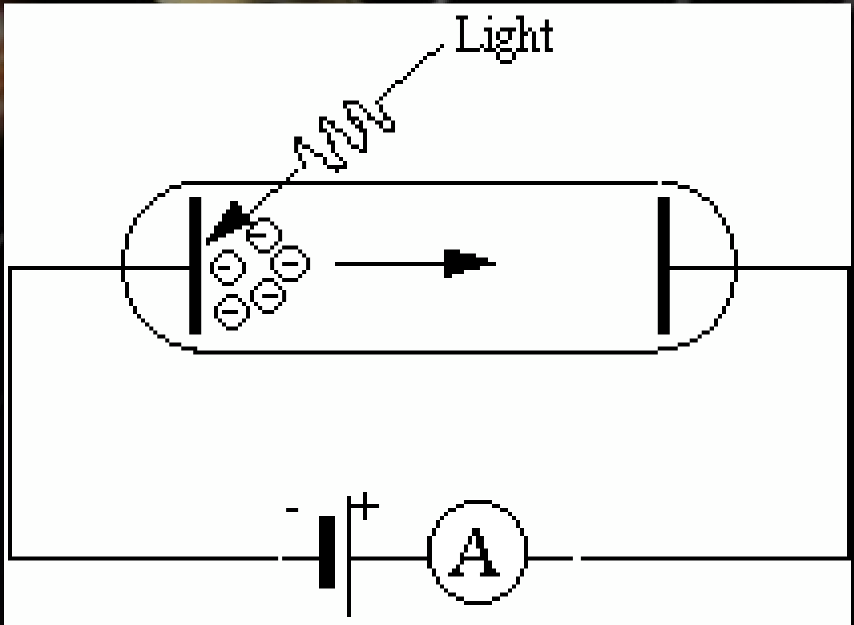
**Einstein theorized that when electrons absorb a photon of light, they jump off the surface of certain metals.**

**When one electron absorbs one photon, it is released.**

**But any old photon won't do. It has to be a very special photon...**

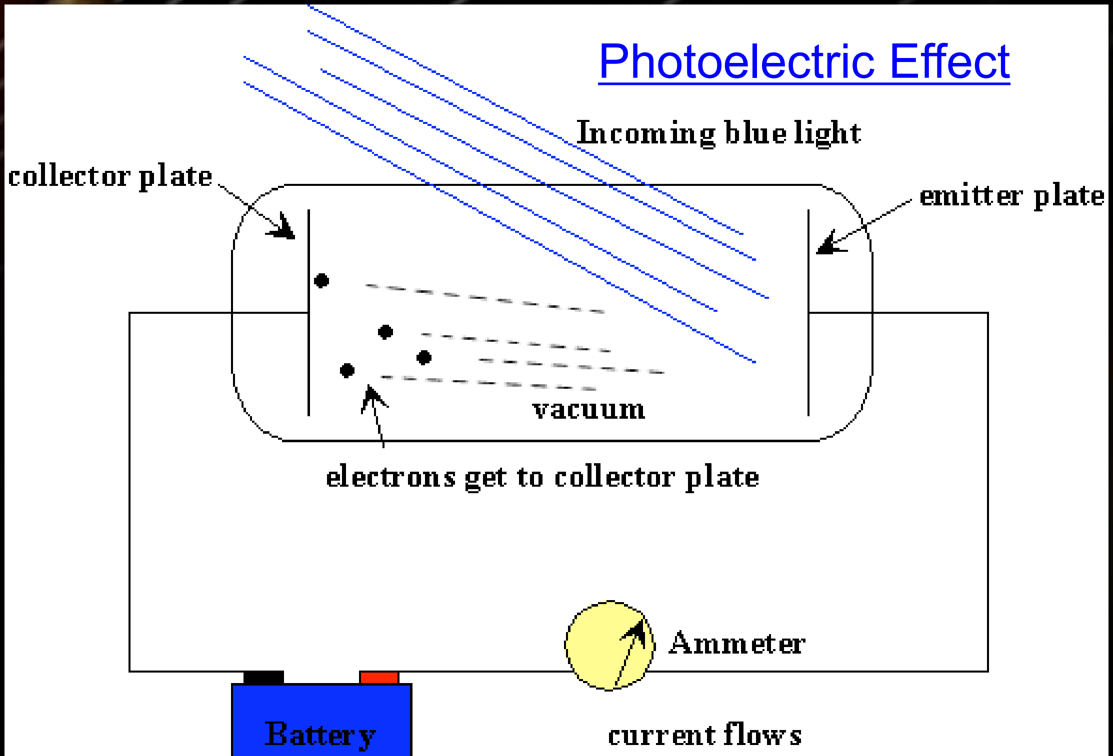
# Experiment Results

- Not all types of EMR caused electrons to be emitted for a particular metal.
- It was found that if a certain frequency of EMR did not cause a current, then it would never cause a current; no matter how long the EMR shone on the surface.
- If a frequency of EMR did cause a current, then all frequencies above it would also cause a current.



# Stopping Voltage

- What is the energy associated with the photoelectrons?
- To determine this, a variable source of potential difference was placed such that the negative plate would repel the photoelectrons.



# Stopping Voltage

When the voltage was increased, it would eventually cut off the electron flow. This special voltage where electron emission stops is called the **stopping voltage**.

$$\Delta E_{max} = qV_{stop}$$

where:

$\Delta E_{max}$ = maximum possible energy of electron

$q$ = charge of electron

$V_{stop}$ = voltage needed to stop the photoelectrons

- By measuring the stopping voltage one could then calculate the kinetic energy of the photoelectrons; $qV = 0.5\ m\ v^2$

# Summary of Results

- No delay between exposing the surface to the EMR and the emission of photoelectrons. If electrons were emitted they were emitted immediately, the length of time the EMR was shone on the surface was not a factor.
- Frequency is the key! Only EMR having a certain frequency, and therefore energy, or greater resulted in ejection of electrons. The energy of EMR at this specific frequency is used to overcome the energy binding the electron to the metal plate.

**This particular frequency is called the threshold frequency of the metal.**

- Each metal has its own unique threshold frequency.

# Summary of Results

- The greater the frequency of the incident EMR, the greater was the kinetic energy of the photoelectrons. Frequencies above the threshold frequency caused higher stopping voltages to be used.
- Greater intensity (brighter light or number of photons of at least $f_o$) resulted in increased current. More electrons were emitted with higher intensity EMR, not ones with greater energy.

**Einstein found that the intensity (the number of photons) of the light had <u>nothing</u> to do with the emission! It was frequency that produced just the right energy to release an e-.**

# Classical Physics

- The results were puzzling for physicists at the time. It was thought that energy was continuous, so adding energy over time should result in electrons being emitted eventually, no matter what the frequency.
- Analogous to a ping pong ball in a container and adding water a little at a time. Eventually enough water (energy) will cause the ball to leave the container.

# Explanation

- Einstein used Planck's equation to explain the photoelectric effect.

$$\Delta E = hf$$

**The energy needed to remove an electron from a metal is thought of in terms of work. This quantity is called the <u>work function</u> of the metal.**

$$W = \Delta E$$

$$W = hf_o$$

**work function**

**where:**
**W = work function (J)**
**h = Planck's Constant**
**$f_o$ = threshold frequency of metal**

**frequency of that special photon needed to spew an e-.**

# Work Function

- The work function is the amount of energy needed to just get the electron off the surface of the metal (binding energy of the electron).
- Any extra energy the photon might happen to have is converted to $E_k$ for the electron. This way the electron obeys the conservation of energy.

$$E_{light} = E_{k\ e-} + E_{binding\ e-}$$

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

## Note that:

The energy is provided by the incident light (photon):

Some energy is lost to the metal to peel off the electron:

Any left over energy is the KE of the electron.

$$KE_{max} = hf - W$$

where:
KE = kinetic energy of electron
hf = energy of photon
W = work function

# Summary:

Energy from the Light = Energy that goes to Electron + Work Function

or

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

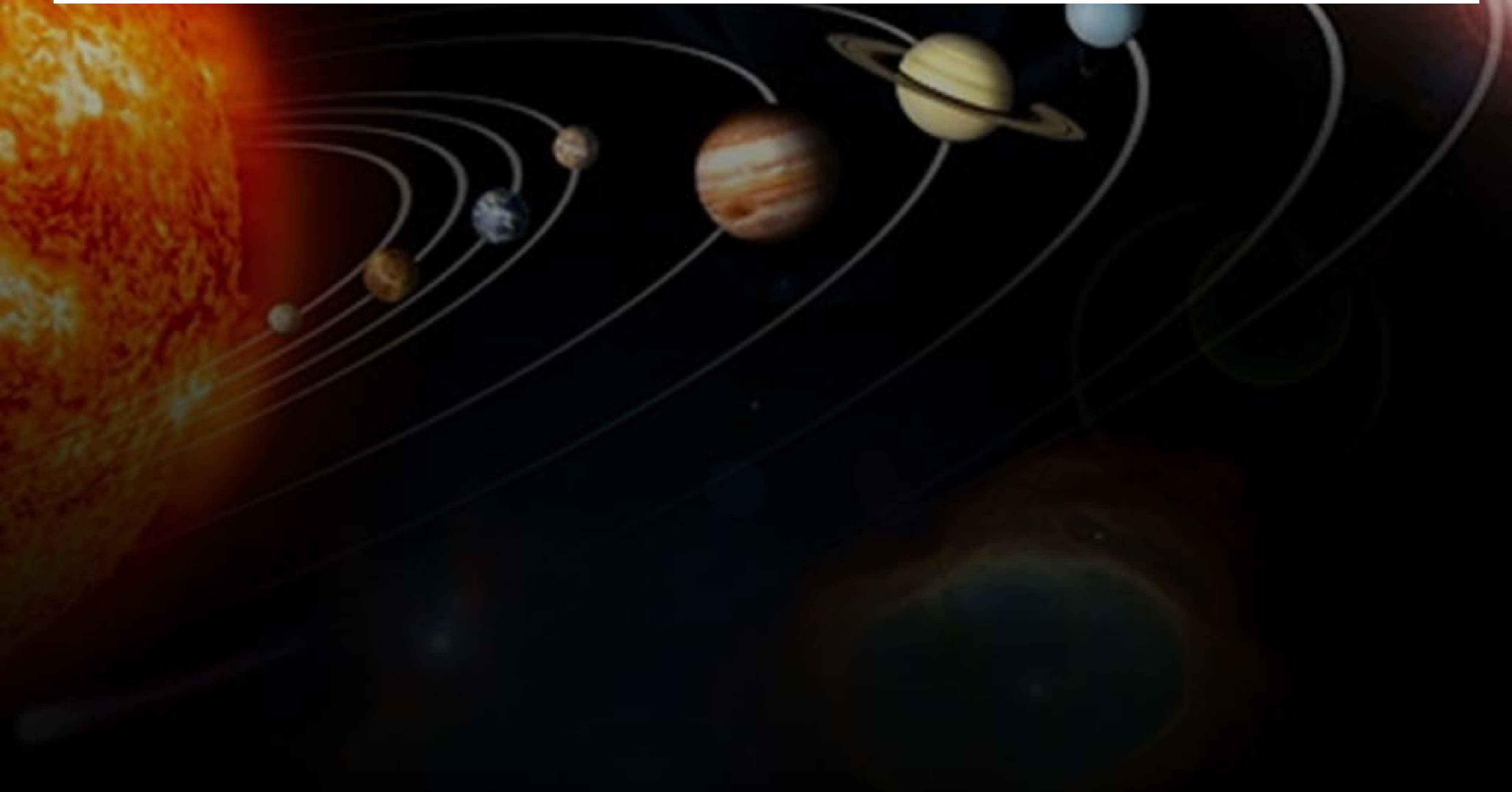
or

$$hf = qV_{stop} + hf_o$$

Note: this eqn. can and has been rearranged.

Note on the total energy from the light (*hf*): this will be given as “the frequency of the incident light”.

**ex) Langdalium has a work function of 2.00 eV. What is the threshold frequency?**



**ex) If light of f = 5.00 x $10^{14}$ Hz is incident on a metal with work function of 2.10 x $10^{-19}$ J, what is the:**

**a) maximum KE of the electron?**

**b) speed of the electron?**

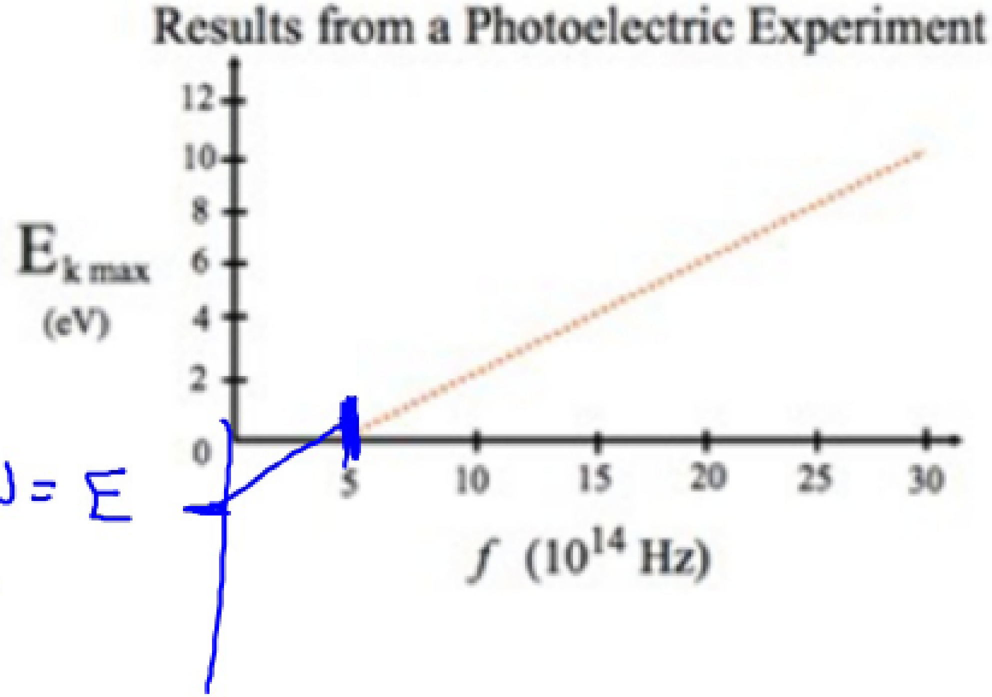
# Graphing the Effect:

$E_{kmax} = hf + W$

can be related to...

$y = mx + b$

W = E




- the slope = h (planck's constant)
- x-int = threshold frequency
- y-int (if extended) = W (work function)