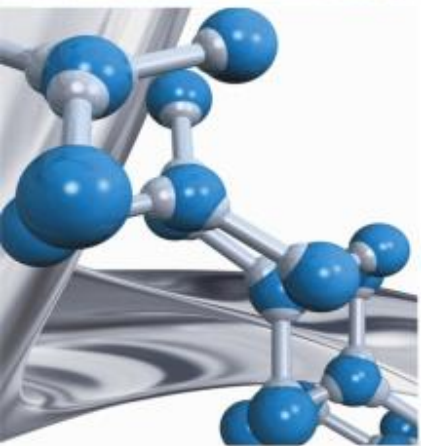
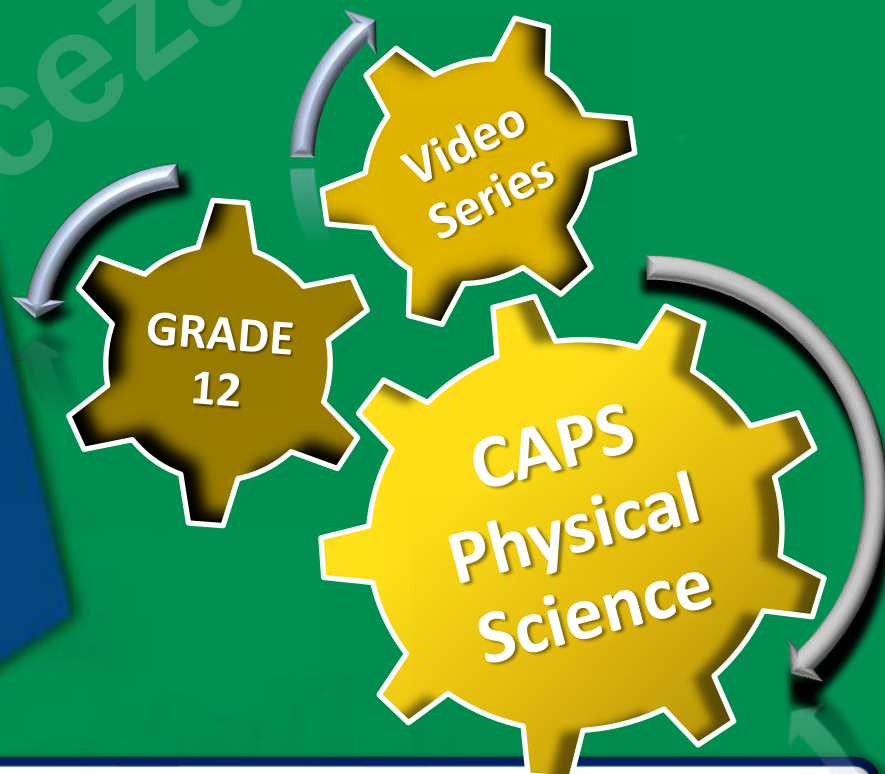




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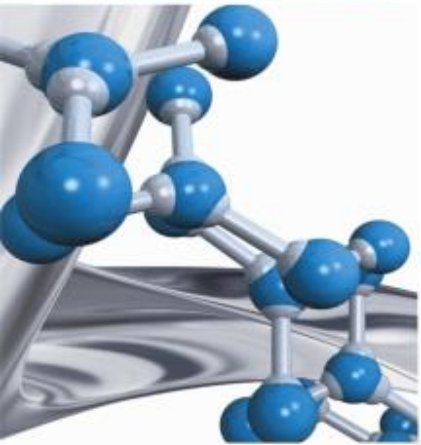
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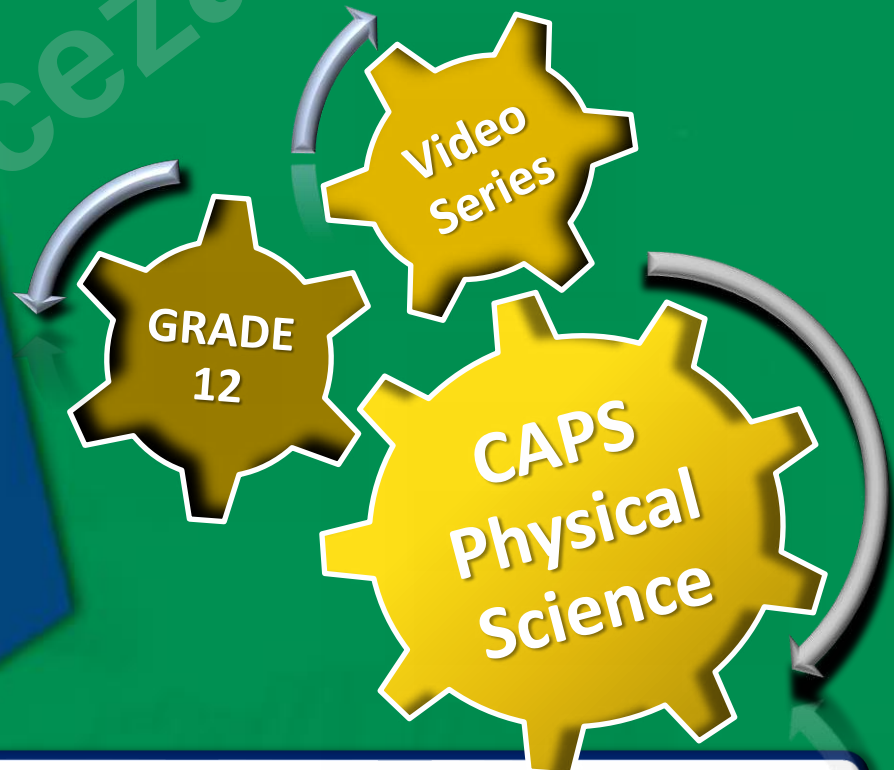
MATTER & MATERIALS

Lesson 3: Photoelectrons

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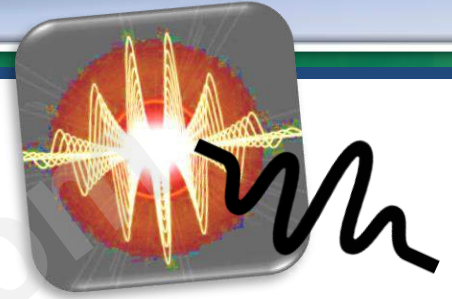
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Optical Phenomena

Lesson Objectives

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Class Exercise 1/1

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The threshold frequency of a certain metal is $1,5 \times 10^{15}$ Hz.

1. Find the work function for this metal.
2. Will light with a wavelength of 150nm eject electrons from this metal?

$$\begin{aligned} 1. \quad W &= hf_0 \\ &= 6,63 \times 10^{-34} \times 1,5 \times 10^{15} \\ &= 9,95 \times 10^{-19} \text{ J} \end{aligned}$$

$$\begin{aligned} 2. \quad E &= hf = h \frac{c}{\lambda} \\ &= 6,63 \times 10^{-34} \times \frac{3 \times 10^8}{150 \times 10^{-9}} \\ &= 1,33 \times 10^{-18} \text{ J} \end{aligned}$$

Yes, the photons of light with wavelength of 150nm possesses enough energy to overcome the work function of this metal
 $\Rightarrow$ it will eject electrons from the metal.

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Class Exercise 1/2

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2. Explain how the light manages to eject the electrons from the metal.

Light carries energy in packets, called photons. This energy is transferred to an electron and if the energy is enough to excite the electron to an energy level high enough to overcome the interatomic forces within the metal, the electron is ejected from the metal.

3. If the energy of the photon is $1,33 \times 10^{-18}$ J, how much of the energy of the photon is left after overcoming the work function of $9,95 \times 10^{-19}$ J ?

$$E_{\text{left}} = 1,33 \times 10^{-18} - 9,95 \times 10^{-19}$$

$$= 3,35 \times 10^{-19} \text{ J}$$

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The electrons that are ejected from the metal are called ...

Photo-electrons

When the energy of the photon is MORE than what is required to overcome the work function, the **PHOTO-ELECTRON** acquires this “left over” energy in the form of **kinetic energy**.

$$E - W = E_k$$

$$hf - hf_0 = \frac{1}{2}mv^2$$

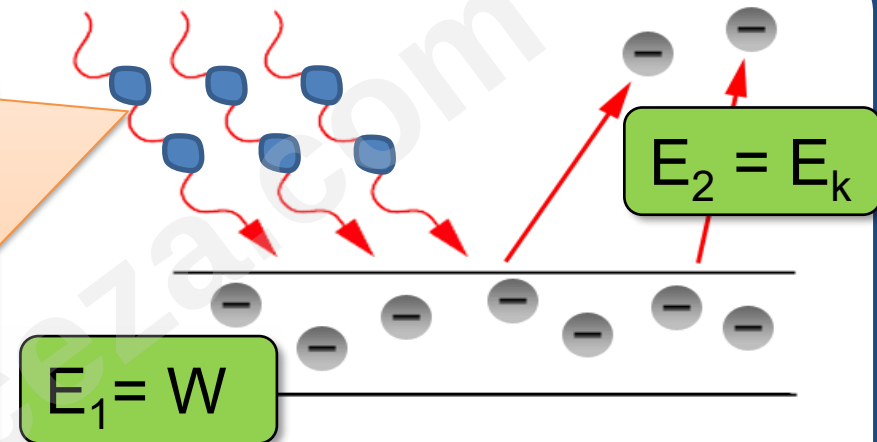
This kinetic energy determines the **speed** of the photo-electron leaving the metal.

Kinetic Energy 2

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The energy of the photon is divided into:

- Energy used to overcome **the work function**
- **Kinetic energy** supplied to the photoelectron.



$$E = W + E_k$$
$$hf = hf_0 + \frac{1}{2}mv^2$$

Since these photoelectrons possess kinetic energy (energy of movement) it could **create a current** (flow of charge) if it could be contained within a closed circuit.

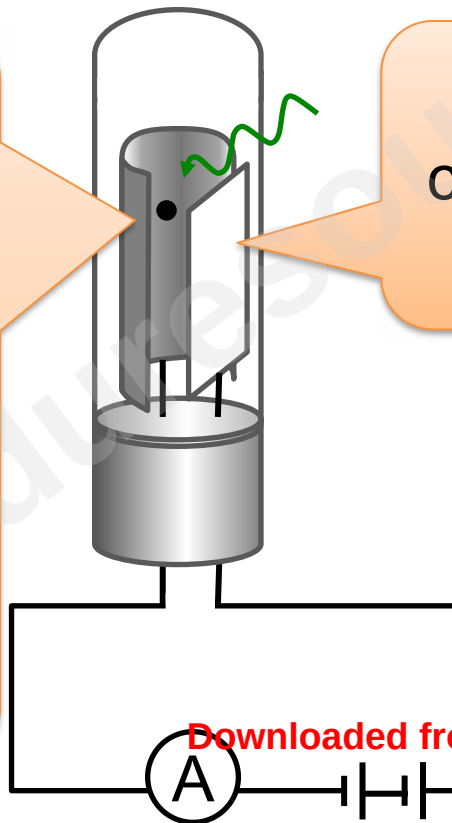
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The Phototube

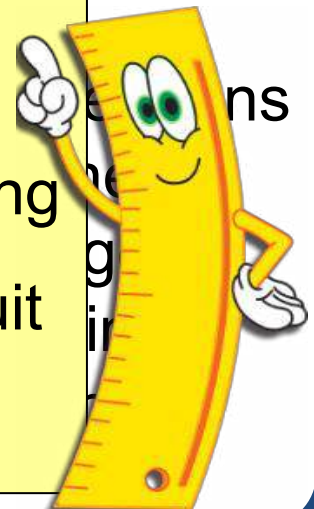
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A **PHOTOTUBE** is a device that could be used to “catch” the photoelectrons and utilize them when connected to a DC power source.

CATHODE, connected to –. Consists of metal that can emit photo-electrons.



This is a simplified presentation! Remember that all conducting wires are filled with electrons. As one electron enters the anode, another electron leaves it, setting all charges in the circuit into motion.



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Photoelectron Current

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CURRENT is defined as the **RATE OF FLOW OF CHARGE**,
i.e. how much charge flows past a particular point (*flow of charge*) per unit time (*rate*).

$$\text{Electric Current} = \frac{\text{charge flowing past a point}}{\text{time elapsed}}$$

What factors would influence the number of charge flowing through the circuit in a certain time?

- Intensity of light?
- Distance of light source?
- Frequency of light?

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Influencing Factors 1

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Let's assume that green light could eject electrons from the cathode of this phototube, but red light couldn't.

What will the effect of the following procedures be on the current measured by the ammeter?

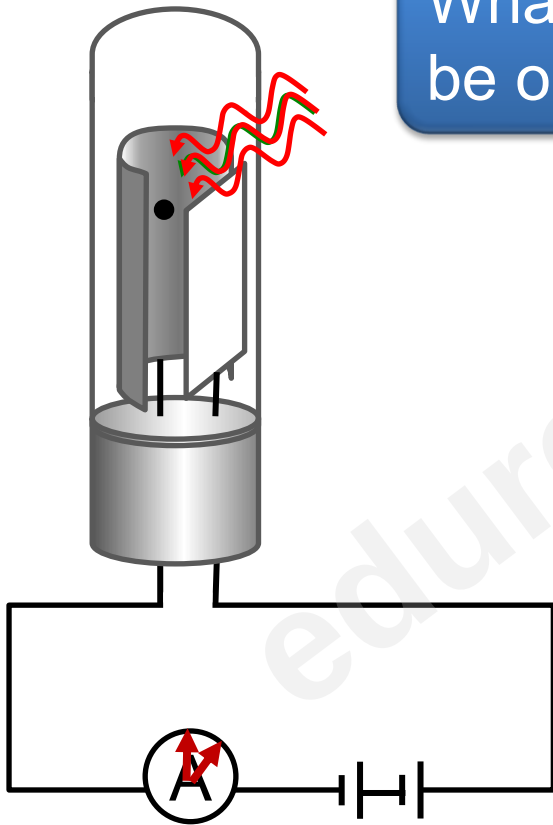
1. Using red light of a **greater intensity**.
No effect.

The photons of red light is too small to overcome the work function of the metal.

Adding more of these "incompetent" photons will have NO EFFECT!

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The ammeter will show no reading.



Influencing Factors 2

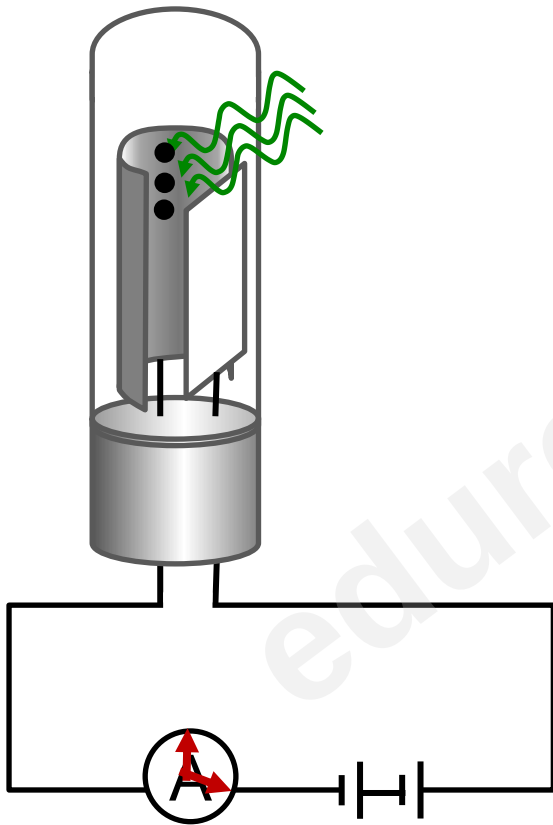
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2. Using green light of a **greater intensity**.

Green light of a greater intensity implies that more light beams shines on the metal $\Rightarrow$ more photons are available.

Since the energy of the photons of the green light is big enough to eject electrons from the metal, more electrons will be ejected.

The ammeter will show a BIGGER reading, since more charges flows per time interval.



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Influencing Factors 3

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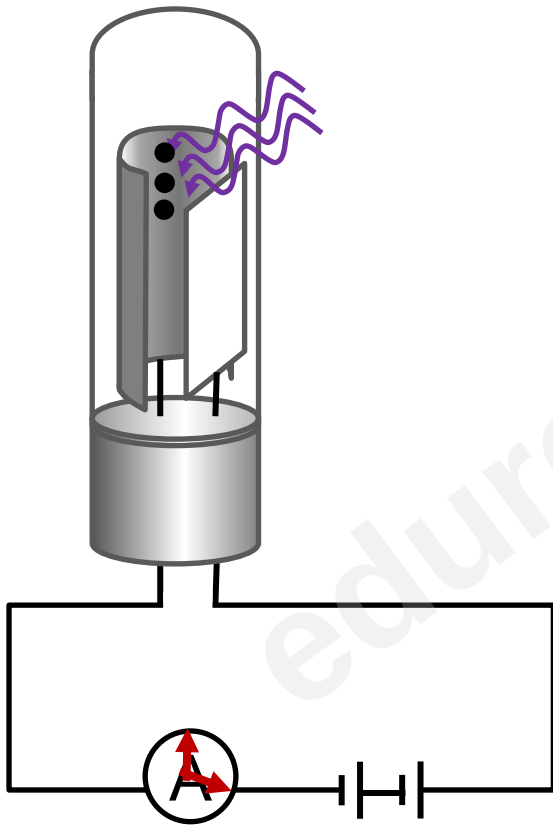
2. Using **purple** light of a the same intensity.

Purple light of the same intensity implies that photons have more energy (greater frequency)

Since the energy of the photons of the purple light is also big enough to eject electrons from the metal, the same number of electrons will be ejected.

The ammeter will show a the SAME reading as with the green light.

The only difference is that the photoelectrons possess more E_k .



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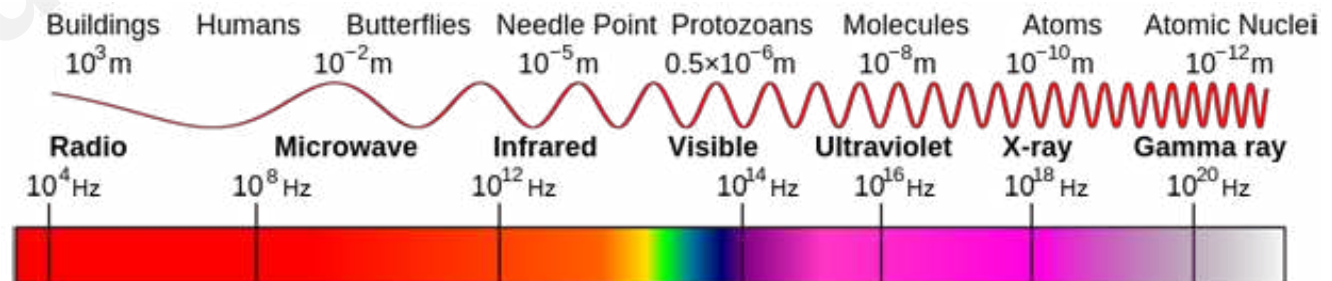
Class Exercise 1/1

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1. Which ONE of the following provides evidence that light behaves as particles?
A Light can be diffracted
B Light is refracted by a triangular prism
☒ C Light ejects electrons from a metal surface
D The speed of light decreases when it travels from air to glass
2. What has more energy? A photon of ...
A red light ☒ B blue light C green light D yellow light

Energy of a photon:

$$E = hf$$



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⇒ Highest frequency, highest energy

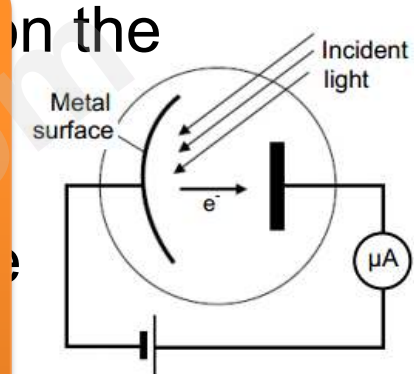
Class Exercise 2/2

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If the ammeter registers a reading, then the frequency of the incident light exceeds the threshold frequency of the cathode.

An increase in the frequency of the incident light will then eject more energetic photoelectrons, but the number of photoelectrons ejected remains the same ... tempo of flow of charge (current) will remain the same.

$$I = \frac{Q}{t}$$



g on the

per second

B	increases	the speed of the photoelectrons increases
C	remains the same	the number of photoelectrons remains the same
D	remains the same	the speed of the photoelectrons remains the same

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Class Exercise 2/3

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4. A **200 W UV light** is shone on zinc metal and electrons are ejected from the metal. The 200 W UV light is **replaced with a 40 W** of the same UV light. Which of the following correctly **describes the electrons being ejected?**

	Number of photo-electrons ejected per second	K
A	decreases	decreases
B	increases	increases
C	decreases	stays the same
D	increases	decreases

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The energy of the photo-electrons remains unchanged as the f & λ of the photons did not change. When the intensity is decreased the number of photons will decrease, releasing an decreased number of electrons. The number of e^- per second is decreased.

Class Exercise 2/4

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5. If the threshold frequency for light in the photoelectric effect for metal B is greater than that of metal A, which metal has a greater work function?
- A metal A ☒ B metal B
C same for both D W_0 must be zero for one of the metals

The minimum amount of energy needed to remove an electron from the metal is called the **Work Function** (W_0) = hf_0 .

The **Threshold Frequency** (f_0) is the minimum frequency of the light that can eject an electron from a certain metal.

$$f_{0 \text{ of B}} > f_{0 \text{ of A}} \\ \Rightarrow W_{0 \text{ of B}} > W_{0 \text{ of A}}$$

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Class Exercise 2/6

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5. When light shines on a metal plate in a photocell, electrons are emitted. The graph below shows the relationship between the kinetic energy of the emitted photoelectrons and the frequency of the incoming light.

Which ONE of the points (A, B, C or D) on the graph represents the **threshold frequency**?

A point A

B point B

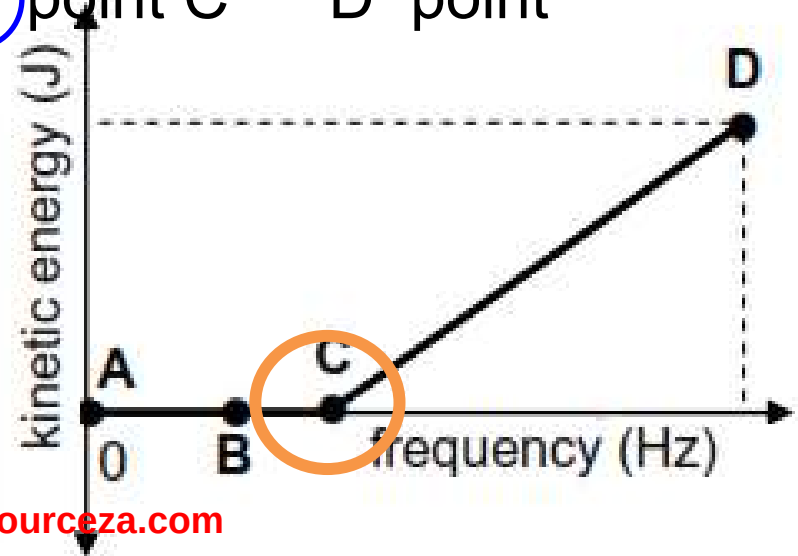
C point C

D point

If $hf < W$, no e^- emitted

If $hf = W$, e^- emitted, but no gain in E_k

If $hf > W$, e^- emitted, gain E_k .



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Class Exercise 2/7

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6. A learner wants to demonstrate the photoelectric effect. He uses a disk of zinc placed on an electroscope. The work function of zinc is $6,9 \times 10^{-19} \text{ J}$.

6.1. Calculate the maximum wavelength of light that will eject electrons from the zinc.

$$E = hc/\lambda \quad 6,9 \times 10^{-19} = (6,63 \times 10^{-34})(3 \times 10^8) / \lambda$$
$$\lambda = 2,88 \times 10^{-7} \text{ m}$$

6.2. The electroscope is negatively charged and then exposed to ultraviolet light of wavelength 260 nm from a mercury discharge lamp. Calculate the kinetic energy of an electron emitted from the zinc disk by a photon of this light.

$$E_k = hc/\lambda - W$$

$$= (6,63 \times 10^{-34})(3 \times 10^8) / (260 \times 10^{-9}) - 6,9 \times 10^{-19}$$
$$= 7,65 \times 10^{-19} - 6,9 \times 10^{-19} = 7,5 \times 10^{-20} \text{ J}$$

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Class Exercise 2/8

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6.3. When the student attempts the experiment with a positively charged electroscope, he finds that the ultraviolet light has no apparent effect. Explain this observation.

The positively charged zinc plate will attract electrons preventing them from being emitted.

6.4. The intensity of incident light on a metal plate is increased, keeping the wavelength constant. State and explain what effect this change has on the following:

- (i) Energy of the emitted photo-electrons, and
- (ii) number of emitted photo-electrons.

The energy of the photo-electrons remains unchanged as the frequency / wavelength of the photons did not change.

The number of photo-electrons (per second) is increased.

When the intensity is increased the number of photons will increase, releasing an increased number of electrons.

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Class Exercise 2/9

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7. A photocell is used in a burglar alarm. Ultraviolet light of wavelength 250 nm is used to illuminate the photocell. When a person interrupts the ultraviolet beam, the sudden drop in current activates a switch, which sets off the alarm. The work function of the metal used as a cathode in the photocell is 1.41×10^{-18} J. A burglar plans to set up a red laser to shine in front of the photocell of the alarm. He reasons that the laser beam is much more intense than the UV light and would definitely keep the alarm from going off. (f of red light: 384 to 482×10^{12} Hz) Is his assumption correct? Explain.

Please add sound of alarm going off.

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

$$= \frac{1,41 \times 10^{-18}}{6,63 \times 10^{-34}}$$

$$0,482 \times 10^{15} \text{ Hz} < 1,72 \times 10^{15} \text{ Hz}$$

$$= 1,72 \times 10^{15} \text{ Hz}$$

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NO. Red light will not emit photoelectrons!

Class Exercise 2/10

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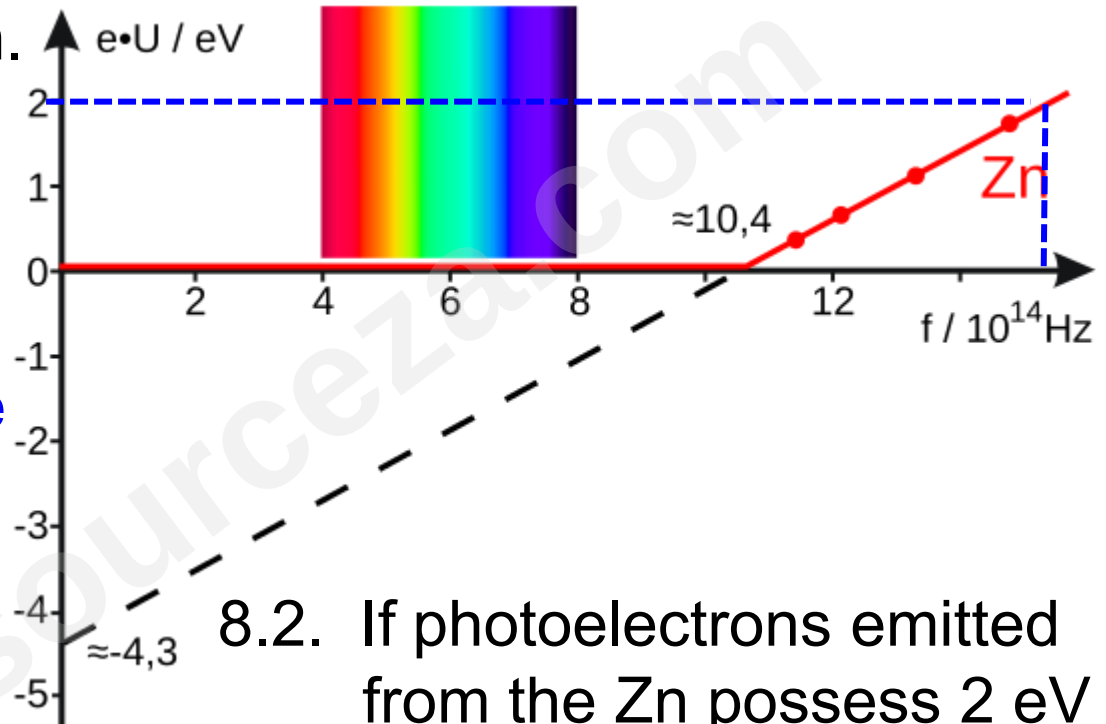
8.1. Explain this graph.

The graph shows the relationship between the kinetic energy of photoelectrons and the frequency of incident light falling on Zn metal.

Visual light does not eject photoelectrons from the Zn metal.

Threshold frequency

for Zn $\approx 10,4 \times 10^{14}$ Hz



8.2. If photoelectrons emitted from the Zn possess 2 eV of energy, determine the frequency of incident light.

$$E_k = hf - hf_0$$

$$f = \frac{2 \times 1,6 \times 10^{-19} + 6,63 \times 10^{-34} \times 10,4 \times 10^{14}}{6,63 \times 10^{-34}}$$

$$= 1,53 \times 10^{15} \text{ Hz}$$

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Key Concepts 1

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Each metal has its own **WORK FUNCTION** and **THRESHOLD FREQUENCY**.

$$W = hf_0$$

$$h_f < W$$

Energy of photon not enough to eject electron.

$$h_f = W$$

Energy of photon JUST enough to eject electron.

$$h_f > W$$

Electron receives more energy than required.

Remainder of energy ($hf - W$) used as kinetic energy for photoelectron.

$$E - W = E_k$$

$$hf - hf_0 = \frac{1}{2}mv^2$$

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INTENSITY effects **number of emitted photoelectrons**:

Increase in intensity of incident light ...

- More photons strike the metal
- More photoelectrons are emitted.

NOTE: If the frequency of the light is $< f_0$, it will **NEVER** eject photoelectrons, even if the intensity is increased!

A bright light (with $f > f_0$) causes more e^- emissions, but not energy increase.

FREQUENCY effects **energy of emitted photoelectrons**:

Increase in frequency of incident light ...

- Photons have more energy
- Photoelectrons have more kinetic energy.

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The same number of photoelectrons are emitted!

Isigama / Words to Know

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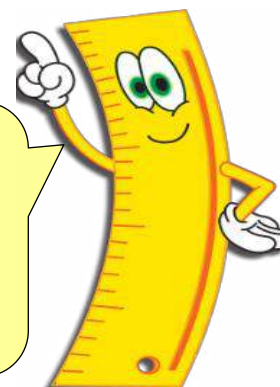
What Next?

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- **Memorise** the various definitions
- **Review** the exercises you had difficulty with ...
- and do some **additional exercise** ...
 - as given in your **workbooks** that accompany this video series or from your school textbook

Continue your learning by watching the
next video lesson in this series:

Lesson 4: Atomic emission



"It always seems impossible until it's done." — Nelson Rolihlahla Mandela

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