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King Saud University
College of Science
Physics & Astronomy Dept.

Phys 145 (General Physics)

Chapter 28 Particle Properties of Light: The Photon

Week n° 11

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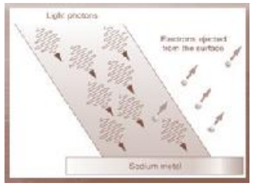
Chapter 8: Particle Properties of Light: The Photon

- **We will learn in this chapter 8:**
- Photoelectric Effect
- X-Rays

Photoelectric Effect

- First observed by Heinrich Hertz in 1887 - light shining on a metal plate causes electrons to be ejected from the metal plate.



- Several aspects of the phenomena could not be explained in terms of an electromagnetic wave:
  - **Increasing the brightness** of the light did **not eject faster electrons**. If we think of light as a wave, brighter light (bigger amplitude wave) should eject more energetic (faster) electrons.
  - For some metals, **red light** would **not eject any electrons** at all even it is very high, however blue lights ejects very fast electrons even if it is very dim.

Photoelectric Effect

***Einstein's* explanation:**

- He proposed an explanation for the photoelectric effect which would play a large role in his receiving the Nobel Prize in Physics of 1921.
- Rather than the classical model of light as a continuous wave, Einstein viewed light as discrete packets of energy called photons.
- Taking advantage of Planck's discovery of the quantization of energy, Einstein determined that each photon had the energy $E_{photon} = hf$. *So,* the energy transferred to an electron by light was no longer considered to depend on intensity, but on frequency f (h is the Planck constant).
- The electrons are bound to the material by attractive forces. Hence, work must be done to free an electron. Work function W is the minimum amount of energy that has to be given to an electron to release it from the surface of the material and varies depending on the material. The exceeding energy will be kinetic (KE):

$$E_{photon} = hf = W + KE$$

Photons

- **General proprieties of photons:**
  - A) move with speed of light
  - B) have no mass
  - C) electrically neutral
- **Energy and momentum of a photon :**

$$E_{photon} = hf = h\frac{c}{\lambda} \qquad p_{photon} = \frac{hf}{c} = \frac{h}{\lambda}$$

where

h = Planck's constant= $6.6\text{x}10^{-34}$ J.s

f = frequency of a light wave (number of crests passing a fixed point in 1 second)

c = velocity of light= $3\text{x}10^{8}$ m/s

λ = wavelength of a light wave (distance between successive crests)

Photoelectric Effect

Work function W:

- It is the work that must be done to free an electron, it depends on the material.
- Each photon can give all its energy to an electron in the metal.
- The work function is related with the threshold frequency f_o (minimum frequency of the photon necessary to have photoelectric effect) and with the cutoff wavelength λ_o (maximum wavelength of the photon necessary to have photoelectric effect):

$$W = hf_o = h\frac{c}{\lambda_o}$$

- Because of energy conservation the maximum kinetic energy of the liberated photoelectron is:

$$KE = hf - W = h(f - f_o) = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$$

Photoelectric Effect

***Example*:**

Light is incident on the surface of a metal for which the work function is 2eV

1°) What is the minimum frequency the light can have and cause the emission of electron ?

2°) If the frequency of the incident light is $2.5\text{x}10^{14}$Hz what is the maximum kinetic energy of the electron in e.V?

Solution:

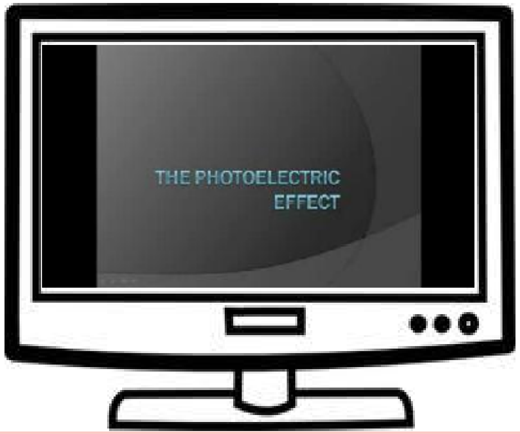
1°) We have: e = charge of the electron = 1.6 10^{-19} C,

so: 1 e.V = 1.6 10^{-19} J.

$$W = hf,\ \text{so}\ f = \frac{W(\text{J})}{h} = \frac{eW(\text{e.V})}{h} = \frac{2\times1.6\times10^{-19}}{6.62\times10^{-34}} = 4.83\times10^{14}\,\text{Hz}$$

2°) $KE = hf - W = h(f - f_o) = 1.6\times10^{-19}\times6.62\times10^{-34}\times2.5\times10^{14} - 2 = 0.65$ e.V

Video 01 of week 11: Photoelectric effect



X-Rays

X-Rays: Electromagnetic radiation with short wavelengths

- **Wavelengths less than for ultraviolet**
- **Wavelengths are typically about 0.1 nm**
- **X-rays have the ability to penetrate most materials with relative ease**

Discovered and named by Roentgen in 1895

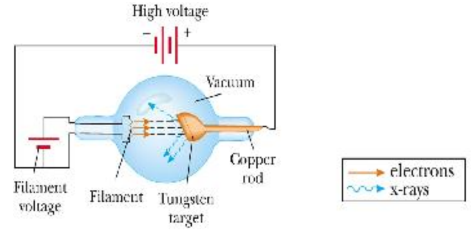
X-Rays production

X-rays are produced when high-speed electrons are suddenly slowed down.

They can be caused by the electron striking a metal target.

A current in the filament causes electrons to be emitted.

These freed electrons are accelerated toward a dense metal target.



X-Rays production

The maximum x-ray energy, and minimum wavelength results when the electron loses all its energy are related by:

$$e\Delta V = hf_{max} = \frac{hc}{\lambda_{min}}$$

***Example*:**

An electron is accelerated through 50,000 Volts.

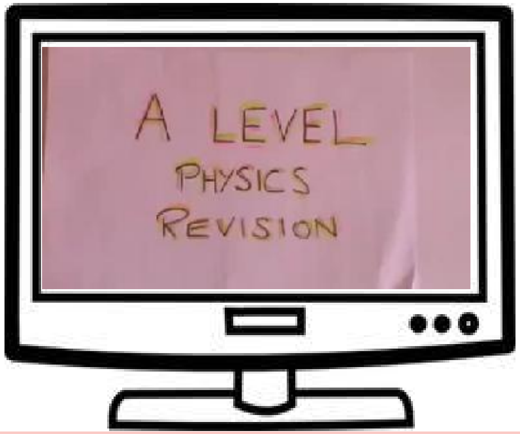
What is the minimum wavelength photon it can produce when striking a target?

Solution:

We have:

$$e\Delta V = \frac{hc}{\lambda_{min}} \text{ so } \lambda_{min} = \frac{hc}{e\Delta V} = \frac{6.62\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times50000} = 2.5\times10^{-11}\,m = 0.025 \text{ nm}$$

Video 02 of week 11: X rays production



Compton effect

An experiment performed in 1923 by A. H. Compton (1892-1962) showed that when monochromatic X rays are scattered by graphite, their frequency decreases.

Classically, the scattering of electromagnetic radiation by matter occurs because the electric field of waves incident at frequency f causes charges to oscillate at that frequency. These oscillating charges re-radiate electromagnetic waves in various directions at the same frequency.

Compton's solution was to treat the scattering as an elastic collision of a photon and an electron. The conservation of energy before and after the collision gives:

$$hf = hf' + E_{el}$$

hf and hf' are respectively the energies of the photon before and after the collision. E_{el} is the electron recoils energy (h Planck constant).

Compton effect

***Example*:**

In a Compton scattering experiment, the incident X rays have a frequency of 10^{20} Hz. At a certain angle, the outgoing X rays have a frequency of 8x101^{19} Hz.

Find the energy of the recoiling electron in e.V

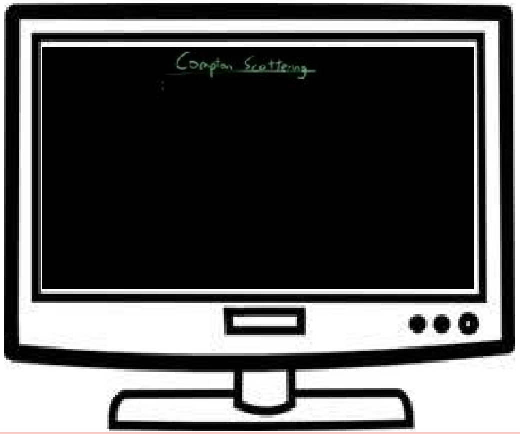
Solution:

$$E_{el} = hf - hf' = h(f - f')$$

$$E_{el} = 1.326\times10^{-14}\ \text{J} = \frac{1.326\times10^{-14}}{1.6\times10^{-19}} = 82875\ \text{e.V}$$

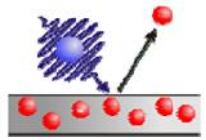
(Because we have $1\ \text{e.V} = 1.6\times10^{-19}\ \text{J}$)

Video 03 of week 11: Compton effect



Summary of week 11

Monochromatic light incident on a metal plate yields sufficient energy to allow electrons to escape from the metal. This is the photoelectric effect.



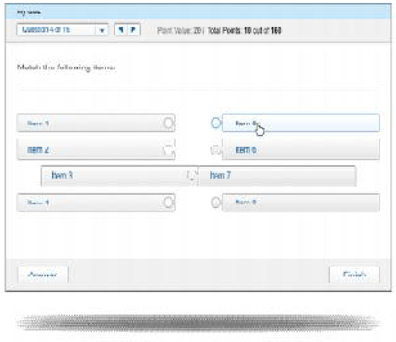
A photon has an energy $E = hf$

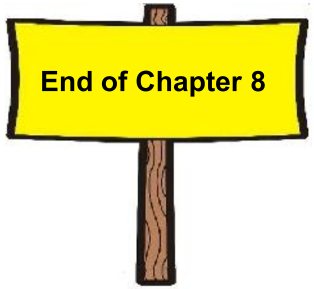
and a momentum $p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$

The Compton effect consist on a collision between a photon and an electron. The photon gives part of its energy to the electron:

$$hf = hf' + E_{el}$$

Quiz for week 11





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