Photoelectric effect

Ejection of electrons from a surface by the action of light

(solar cells)

Hertz (1886/1887) : studies of electromagnetics waves
Maxwell's electromagnetic theory of light propagation

Reduced electric discharge between electrodes for UV (

Lenard continued studies

Attracts the electrons ejected by A

Incident light

Measures photoelectric current

Potential difference

May be varied

Observations

→ V large : current reaches a limiting value irrespective of all photo-electrons ejected from A or collected by B

→ Sign of V is reversed : current does not drop immediately → e from A or emitted with kinetic energy

Only for large values of reversed potential difference Vₐₐ₉ will the current drop to zero
1st surprise: $V_0$ (and therefore $K_{\text{max}}$) is independent of the intensity of the light.\(\uparrow\) Compare curves 2 and 1.\(\downarrow\)

From classical wave theory we would expect $K_{\text{max}}$ to increase with $I$, so

$I$ increase $\Rightarrow$ $E$ increase $\Rightarrow$ for a $E$ applied on $e^{-}$ should increase.

2nd surprise:

There is a cutoff frequency ($\nu_0$) below which no photoelectric effect occurs, no matter how intense the radiation.

But from classical theory we would expect that the effect should occur for any $\nu > \nu_0$ if light was intense enough.

3rd surprise: there is no detectable time lag.

From classical theory, if the light is sufficient there should be a time lag between the moment light starts to impinge on the surface and the ejection of the $e^{-}$.

$e^{-}$ would need a time to accumulate enough energy to escape.
Example.

Potassium plume

\[ \text{can collect energy from} \]

\[ \text{circular area of radius } R = 1 \times 10^{-2} \text{ m} \]

Energy to remove the e\(^{-}\) = 2.1 eV = 3.4 \times 10^{-19} \text{ J}

(work function)

\[ (1 \text{ eV} = 1.60 \times 10^{-19} \text{ J is the energy gained by an e}^{-} \text{ when it accelerates through a potential difference of 1 V}) \]

Obs

\[ V = Ed \quad \text{(potential difference)} \]

\[ U = qV \quad \text{(potential energy)} \]

According to classical physics

how long would it take

for the target to absorb enough energy from the source?

target area: \( \pi R^2 = \pi \times 10^{-2} \text{ m}^2 \)

area of sphere unheated at source: \( 4\pi R^2 \text{ (m}^2) \)

\[ \text{power} = 1 \text{ W} \quad \text{for} \quad 4\pi R^2 \text{ m}^2 \]

\[ \chi = \frac{1 \text{ J}}{5 \pi \times 10^{-2} \text{ m}^2} \]

\[ = \frac{2.5 \times 10^{-11} \text{ J/s}}{4\pi R^2 \text{ m}^2} \]

\[ \text{power absorbed by target} \]

\[ 1 \text{s} \rightarrow 2.5 \times 10^{-11} \text{ J} \]

\[ \chi \rightarrow 3.4 \times 10^{-19} \text{ J} \]

\[ \chi \times 2.5 \times 10^{-12} \text{ J} = 2 \times 10^{-2} \text{ s} \approx 2 \text{ min} \]
Einstein's quantum theory of the photoelectric effect

Planck: energy quantized for blackbody

Einstein: extended the idea — energy is quantized into lumps — photons

\[ E = hv \quad \rightarrow \text{energy of photon} \]

He assumed: \{In the photoelectric process, one photon is completely absorbed by one electron\}

\[ e^- \text{ emitted with kinetic energy} \quad \frac{K = hv - \omega}{\text{work to remove } e^- \text{ from metal}} \]

\[ K_{\max} = hv - \omega_0 \quad \text{characteristic of metal} \]

minimum energy for \( e^- \) to escape

Conclusions:

1) \( K_{\max} \) has no dependence on \( I \)

(increasing \( I \) only increases # of photons and current; \( \text{if } \) \( \text{does not} \) change energy \( hv \) of photon

2) cutoff is justified

\[ K_{\max} = 0 \Rightarrow \frac{hv = \omega_0}{v < v_0 \Rightarrow \text{no matter how many photons}} \]

\( \Rightarrow \text{no influence} \) the source

3) energy of photon is conserved and \textbf{not} spread

\( \text{photon hits surface is immediately absorbed } \Rightarrow e^- \text{ is emitted} \)
\[ K_{\text{max}} = e V_0 \]
\[ K_{\text{max}} = h \nu - \omega \]
\[ V_0 = \frac{h}{e} \sqrt{\frac{\nu - \omega}{e}} \]
\[ \text{slope of experimental curve} = \frac{h}{e} = 4.0 \times 10^{-15} \text{Vs} \]
\[ \text{slope of experimental curve} \]
\[ 1 V = \frac{1 J}{e} \]
\[ h = 6.6262 \times 10^{-34} \text{J.s} \]

\[ \text{which agrees with } h \text{ derived from Planck's radiation formula} \]

\[ \text{(Numerical agreement of } h \text{ for 2 different phenomena)} \]

**Exercise:** \( \lambda \) for visible light 380nm - 750nm

a) What is the range of photon energies (in eV) in visible light?

\[ 1 \text{nm} = 10^{-9} \text{m} \]
\[ 1 \text{eV} = 1.60 \times 10^{-19} \text{J} \]

\[ E = h \nu = \frac{h c}{\lambda} = \frac{6.6262 \times 10^{-34} \text{J.s}}{3 \times 10^8 \text{m/s}} \times 10^9 (\text{m/s}) \]

\[ E = \frac{6.6262 \times 10^{-34} (\text{eV.s})}{1.60 \times 10^{-19}} \times 3 \times 10^3 \text{ (nm/s)} \times \frac{1}{\lambda} \]

\[ E = \frac{1242 \text{ (eV.nm)}}{\lambda} \]

\[ \lambda = 380 \text{nm} \Rightarrow E = 3.27 \text{eV} \]
\[ \lambda = 750 \text{nm} \Rightarrow E = 1.66 \text{eV} \]

\[ Hw: \ 3.26, \ 3.28, \ 3.30 \]