Photoelectric effect:

ejection of electrons from a surface by the action of light

(solar cells)

Hertz (1886/1887) : studies of electromagnetic waves

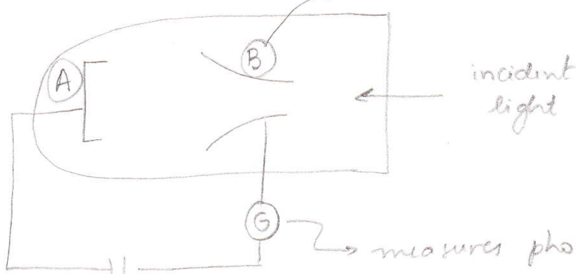
Maxwell's electromagnetic theory of light propogation

→ noticed electric discharge between electrodes for UV (ν)

↑

Lenard continued studies

→ attracts the electrons ejected by A



→ measures photoelectric current

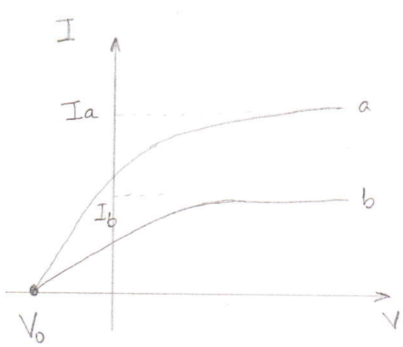
V potential difference

→ may be varied

Observations

→) V large : current reaches a limiting value / saturates

all photoelectrons ejected from A are collected by B



→) sign of V is reversed : current does not drop immediately ⇒

⇒ e^- from A are emitted with kinetic energy

→ only for large value of reversed of the potential difference $\boxed{V_0}$ will the current drop to zero

$$\boxed{K_{max} = e V_0}$$

→ Kinetic energy of the fastest e^-

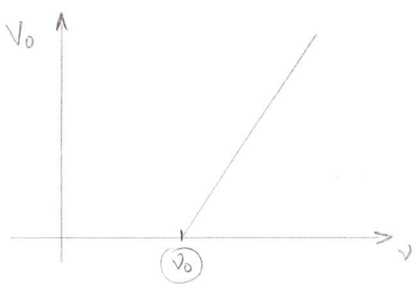
! 1st surprise : V_0 (and therefore K_{max}) is independent of the intensity of the light

(compare curves a and b)

from classical/wave theory we would expect K_{max} to increase with I, since

I increases $\Rightarrow |\vec{E}|$ increases $\Rightarrow$ force eE applied on e^- should increase

! 2nd surprise :



value is characteristic of the surface

there is a cutoff frequency (ν_0) below which no photoelectric effect occurs, no matter how intense the radiation

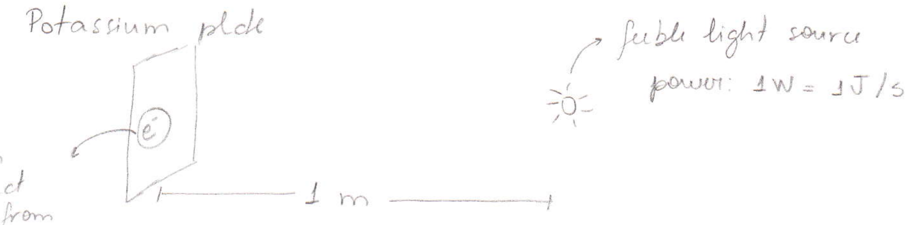
but from classical theory we would expect that the effect should occur for any ν if light was intense enough

! 3rd surprise : there is no detectable time lag

from classical theory, if the light is feeble 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



can collect energy from circular area of radius (r) $\simeq 1 \times 10^{-10}$ m

Energy to remove the e^- = 2.1 eV = 3.4×10^{-19} J
(work function)

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

Obs

$V = E d$ (potential difference)

$U = q V$ (potential energy)

According to classical theory
how long would it take for the target to absorb enough energy from the source?

target area: $\pi r^2 = \pi \times 10^{-2} m^2$

area of sphere centred at source: $4\pi (1m)^2$

$$\left.\begin{array}{llll} \text{power} = 1\,W & \text{for} & 4\pi m^2 \\ x & \text{for} & \pi \times 10^{-2} m^2 \end{array}\right\} \quad x = 1 \frac{J}{s} \frac{\cancel{\pi} \times 10^{-2} \cancel{m^2}}{4 \cancel{\pi} \cancel{m^2}} = \overline{\underline{2.5 \times 10^{-21}\ J/s}}$$

power absorbed by target

$$\left.\begin{array}{lll} 1\,s & \longrightarrow & 2.5 \times 10^{-21}\ J \\ x & \longrightarrow & 3.4 \times 10^{-19}\ J \end{array}\right\} \quad x = \frac{3.4 \times 10^{-19}\ J\ (1s)}{2.5 \times 10^{-21}\ J} = 1.4 \times 10^2\ s \simeq \underline{\underline{2\,min}}$$

Einstein' quantum theory of the photoelectric effect

Planck: energy quantization for blackbody

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

$$\boxed{E = h\nu} \rightarrow \text{energy of photon}$$

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

e^- emitted with kinetic energy: $\boxed{K = h\nu - w}$

↳ work to remove e^- from metal

↳ energy of the absorbed incident photon

for the loosest binding

$$\boxed{K_{max} = h\nu - w_0}$$

↳ 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;

↳ it DOES NOT change energy $h\nu$ of photon

2) cutoff is justified

$K_{max} = 0 \Rightarrow \boxed{h\nu_0 = w_0}$

$\nu < \nu_0 \Rightarrow$ no matter how many photons, how intense the source ⇒ NO ejection

3) energy of photon is concentrated and NOT spread

photon hits surface / is immediately absorbed

e^- is " emitted

$K_{max} = eV_0$

$\boxed{K_{max} = h\nu - w_0}$

Einstein

$$\boxed{V_0 = \frac{h}{e}\nu - \frac{w_0}{e}}$$

$\Downarrow$

linear relationship between V_0 (stopping potential) and ν

(agrees with experiments)

slope of experimental curve $\Rightarrow$ $\frac{h}{e} = 4.0 \times 10^{-15}$ V.s

$1V = \frac{1J}{C}$

$$\boxed{h = 6.6262 \times 10^{-34} \text{ J.s}}$$

which agrees with h derived from Planck's radiation formula (!)

(Numerical agreement of h for 2 different phenomena)

<u>Exercise</u>: λ for visible light 380nm — 750nm

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

$1\text{nm} = 10^{-9}\text{m}$ $\qquad c = \lambda\nu$

$1\text{eV} = 1.60 \times 10^{-19}$ J

$$E = h\nu = \frac{hc}{\lambda} = \frac{6.6262 \times 10^{-34} (\text{J s}) \; 3 \times 10^8 (\text{m/s})}{\lambda}$$

$$E = \frac{6.6262 \times 10^{-34}}{1.60 \times 10^{-19}} (\text{eV.s}) \; \frac{3 \times 10^8}{10^{-9}} (\text{nm/s}) \; \frac{1}{\lambda}$$

$$\boxed{E = \frac{1242 \; (\text{eV.nm})}{\lambda}}$$

$\lambda = 380\text{nm} \Rightarrow E = 3.27\text{eV}$

$\lambda = 750\text{nm} \Rightarrow E = 1.66\text{eV}$

<u>HW</u>: 3.26, 3.28, 3.30