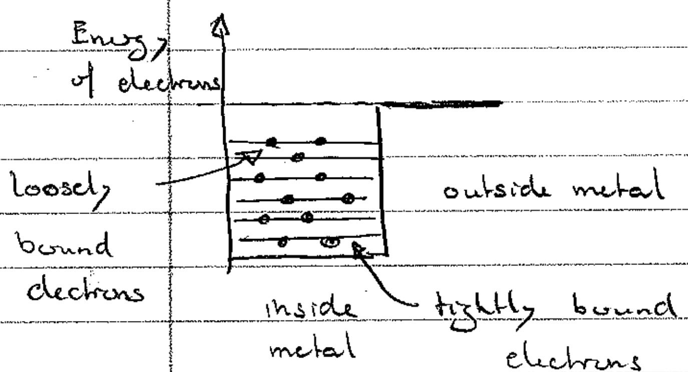
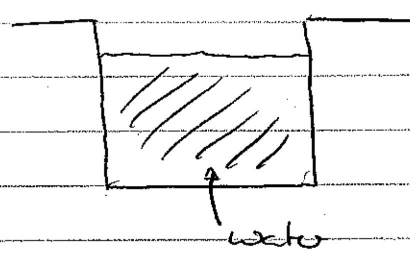
2.2 Classical Electromagnetic Wave Predictions

Lenard observed that light sets electrons in metal free? How can we understand this based on interpretation of light as classical electromagnetic wave.

In metal: Electrons are bound but can freely move

Analogy: Water in pool





Heating (by light)

→ Bit of energy
  ⇒ some electrons with little energy will leave metal

→ Lots of energy
  ⇒ many electrons with high max energy will leave metal

Pool party:

→ Bit of splashing
  ⇒ bit of water will swap out

→ Lots of splashing
  ⇒ much of water will swap out (with lots of energy)

Remember: ◦ number of electrons reaching second plate
= amount of current in photoelectric effect

◦ maximum kinetic energy in distribution
= stopping voltage in photoelectric effect.

Remember: Light as EM waves transports energy

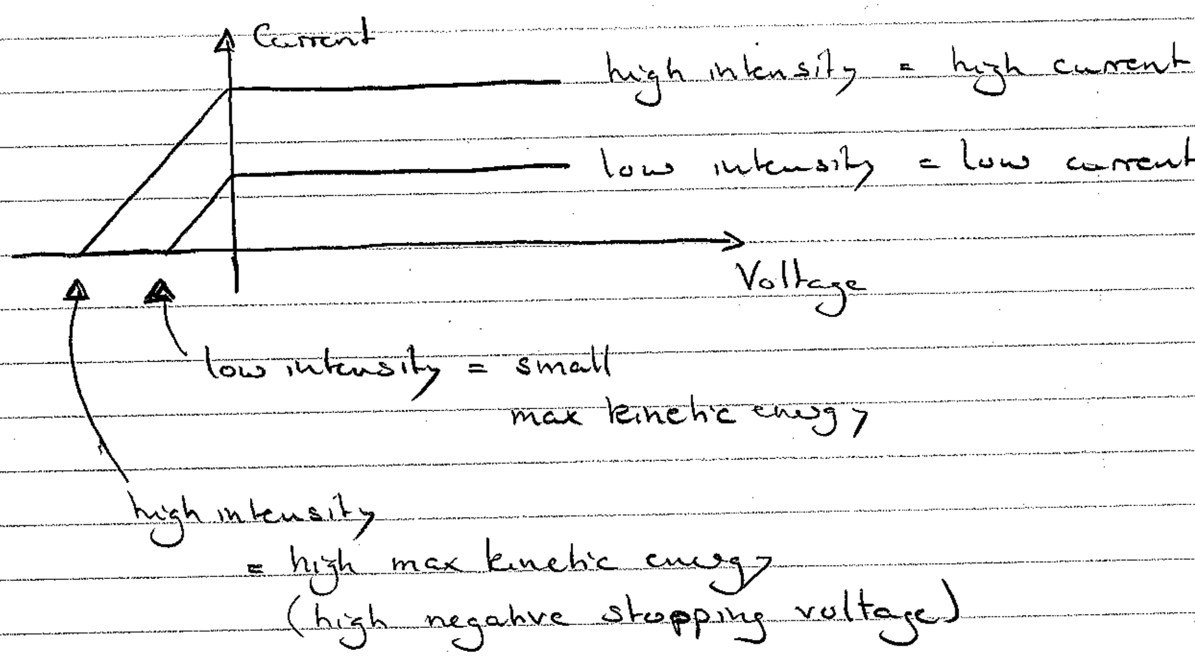
Energy ~ Intensity of light but

Energy independent of frequency

⇒ Classical wave expectations for photoelectric effect

(1) Increase of light intensity leads to
increase of energy in light leads to
increase of energy transfered to electrons in metal

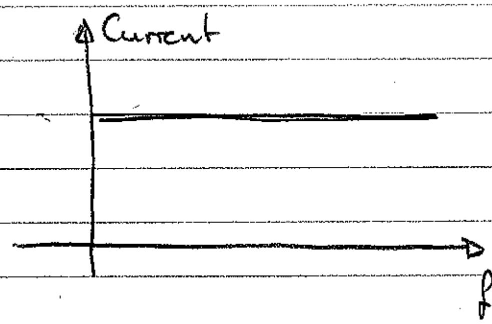
⇒ more electrons are emitted
maximum kinetic energy increases

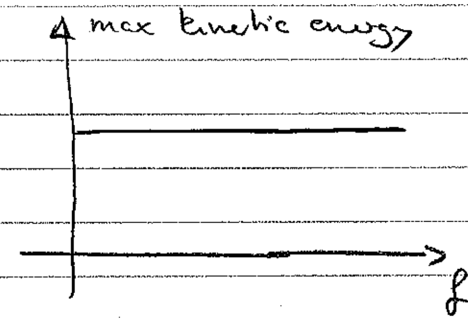


(2) Change in light frequency leads to

no change in number of electrons emitted
→ no change in current

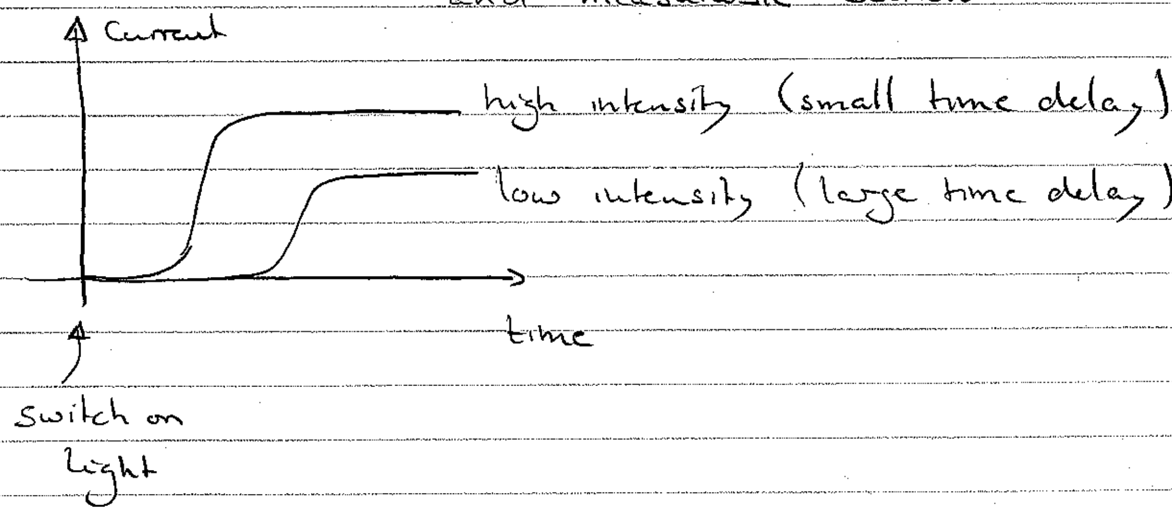
no change in max kinetic energy of electrons
→ no change in stopping voltage





(3) There is a continuous accumulation of energy in metal. Electrons are set free as soon as enough energy is accumulated

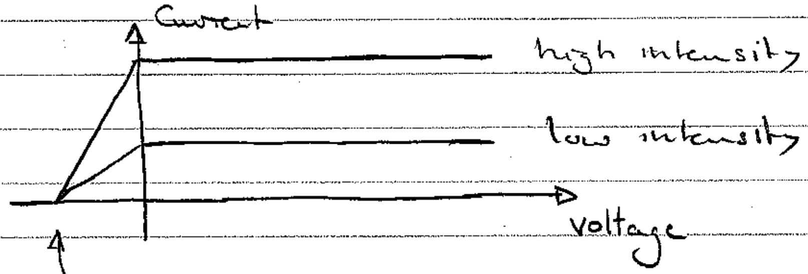
⇒ Time delay between switch-on of light and measurable current



2.3 Observations

We will now confront these classical expectations against Lenard's observations

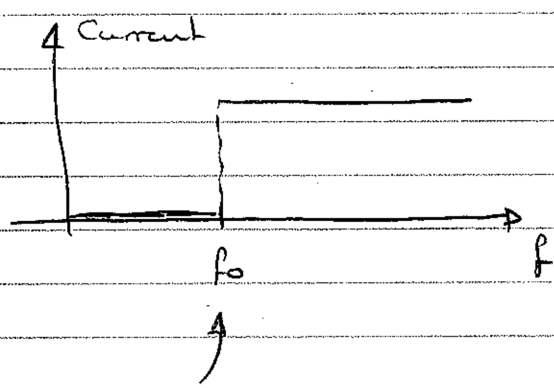
(1) Change in light intensity



independent (!) of intensity

While the current increases with increase of intensity (in agreement with classical expectations), the maximum kinetic energy is independent of intensity (in contrast to classical predictions)

(2) Change in light frequency



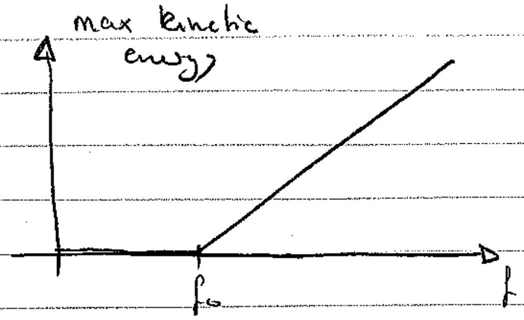
threshold frequency depends on metal

Experiment shows there is a threshold frequency.

Below fo : There is no current measured

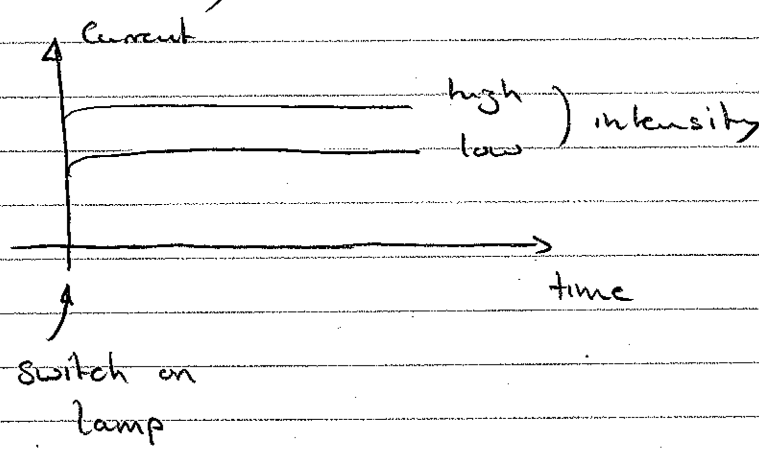
Above fo : There is a current measured.

in contradiction to classical predictions



Above the threshold frequency the maximum kinetic energy increases linearly with frequency. (in contrast to classical predictions)

(3) Time delay



There is no time delay for measurable current after the light is applied.

(in contrast to classical predictions)

2.4. Einstein's postulates and interpretation

As we have seen the observations made by Lenard cannot be explained based on classical electromagnetic wave predictions.

Einstein framed a number of postulates about the nature of light and the interaction of light with matter. He suggested that electromagnetic radiation is quantized.

(1) Light of frequency f consists of discrete energy quanta. (also called photons)

Each quanta has the energy $E = hf$

where h is the Planck's constant

$$h = 6.63 \times 10^{-34} \text{ Js}$$

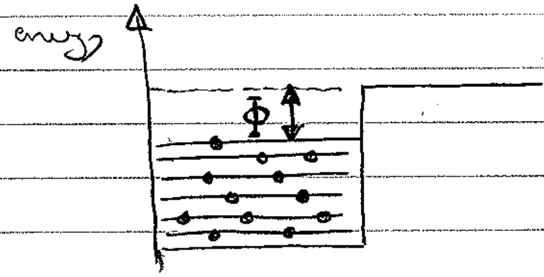
(2) One light quantum is absorbed (interacts with)

- with one electron in metal
- entirely (not in halves or other fractions)
- and instantaneously

Let's see how Einstein's postulates apply to the interpretation of the photoelectric effect.

- Energy conservation → Frequency dependence.

Let's go back to our energy diagram for electrons in metal



There is a work function ϕ = energy needed to free most loosely bound electron

Energy conservation:

$$KE = E_{light} - \Phi = hf - \phi$$

↑ kinetic energy of electron

⇒ Kinetic energy depends <u>linearly</u> on frequency

and there exist a <u>threshold frequency</u>

$$0 = hf_0 - \Phi \Rightarrow f_0 = \frac{\Phi}{h}$$

below which <u>no</u> electrons are set free

and this threshold frequency depends on <u>metal</u> via work function Φ

- There is a distribution of kinetic energies since different photoelectrons require different amount of energy.

- Intensity considerations

The maximum kinetic energy or the stopping potential is given by

$$KE = hf - \phi = eV_{stop}$$

$$\Rightarrow V_{stop} = \frac{hf - \phi}{e}$$

These are <u>independent</u> of intensity.

Let's determine intensity (according to Einstein)

$$\text{Intensity} = \frac{\text{Power}}{\text{Beam area}}$$

$$= \frac{\text{Energy}}{(\text{Time})\ (\text{Beam area})}$$

$$= \frac{N\,hf}{(\text{Time})\ (\text{Beam area})}$$; N : number of photons in beam

Since <u>one</u> photon interacts with <u>one</u> electron, we see

current ~ # ejected electrons

~ # absorbed photons ~ Intensity

⇒ Current ~ Intensity

- Time considerations

Each energy quantum (photon) is instantaneously absorbed entirely by one electron

⇒ There is no time delay between emission of electrons (current) and moment when light is applied.