

QUANTUM

Physics



فَمَنْ يَعْمَلْ مِثْقَالَ ذَرَّةٍ خَيْرًا يَرَهُ ۗ

So whoever does an atom's weight of **good** will see it.

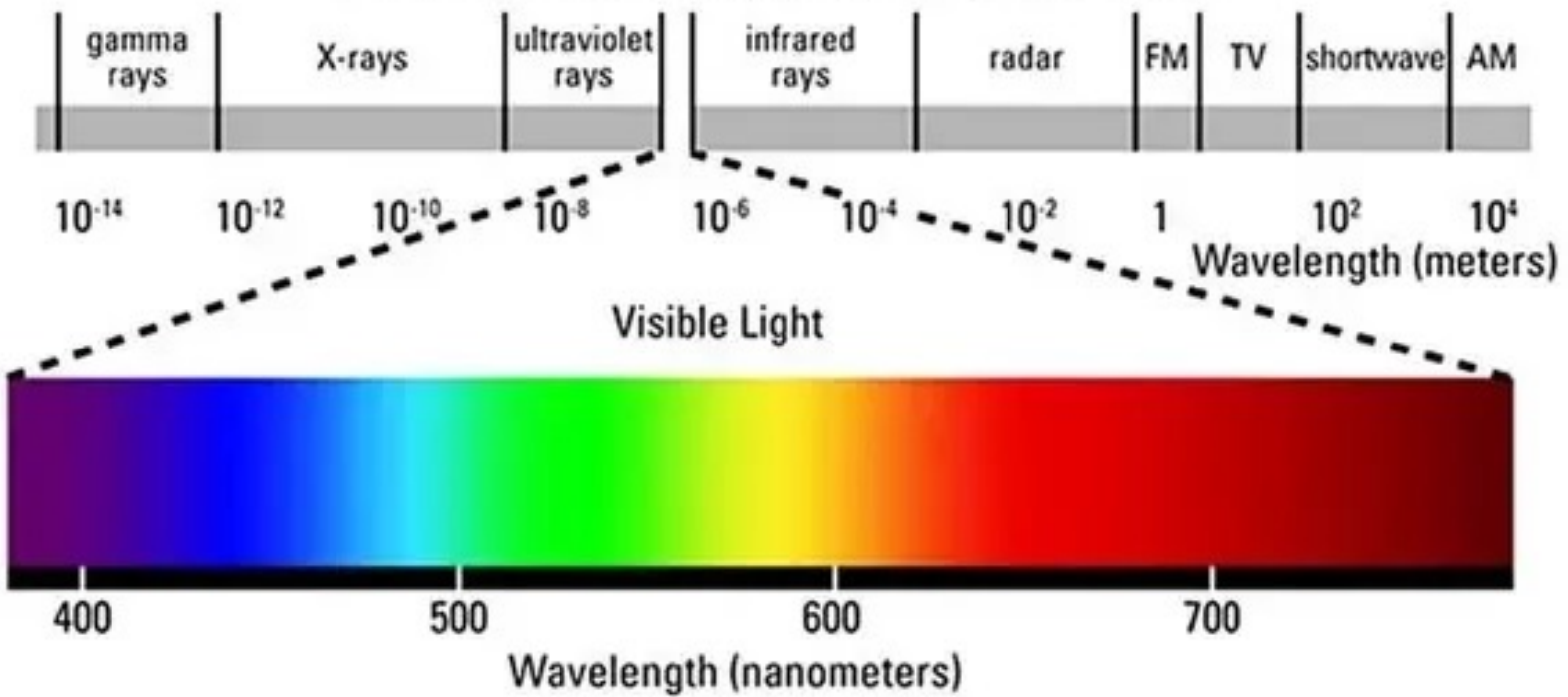
وَمَنْ يَعْمَلْ مِثْقَالَ ذَرَّةٍ شَرًّا يَرَهُ ۗ

And whoever does an atom's weight of **evil** will see it.


Surah Az-Zalzalah

7.1 QUANTUM THEORY OF LIGHT

The Electromagnetic Spectrum

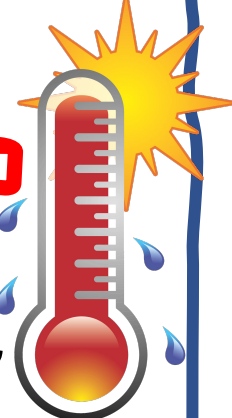


λ increase f decrease



COLD
object
LOW f

hot
object
HIGH f



BLACK BODY

- A **surface** that **absorbs** and **emit** all electromagnetic radiation which is **ideal**
- emit **thermal radiation** (Cannot be seen by the human eye)

Ideal : absorbed = emitted

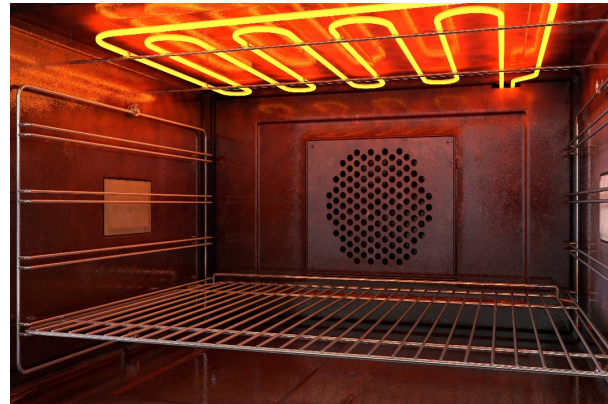
BLACK body emission = Black Body Radiation

An ideal electromagnetic radiation in the form of **heat** or **light**

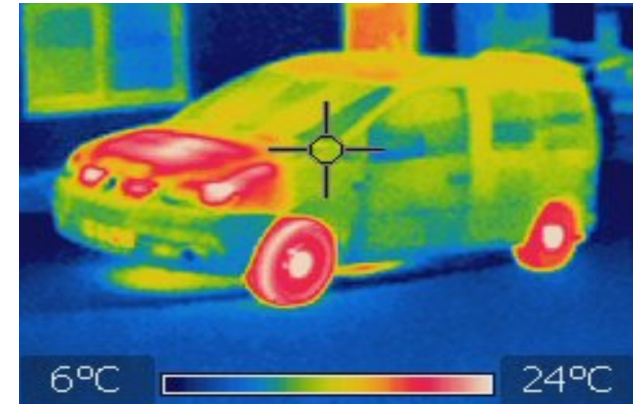
energy emitted by



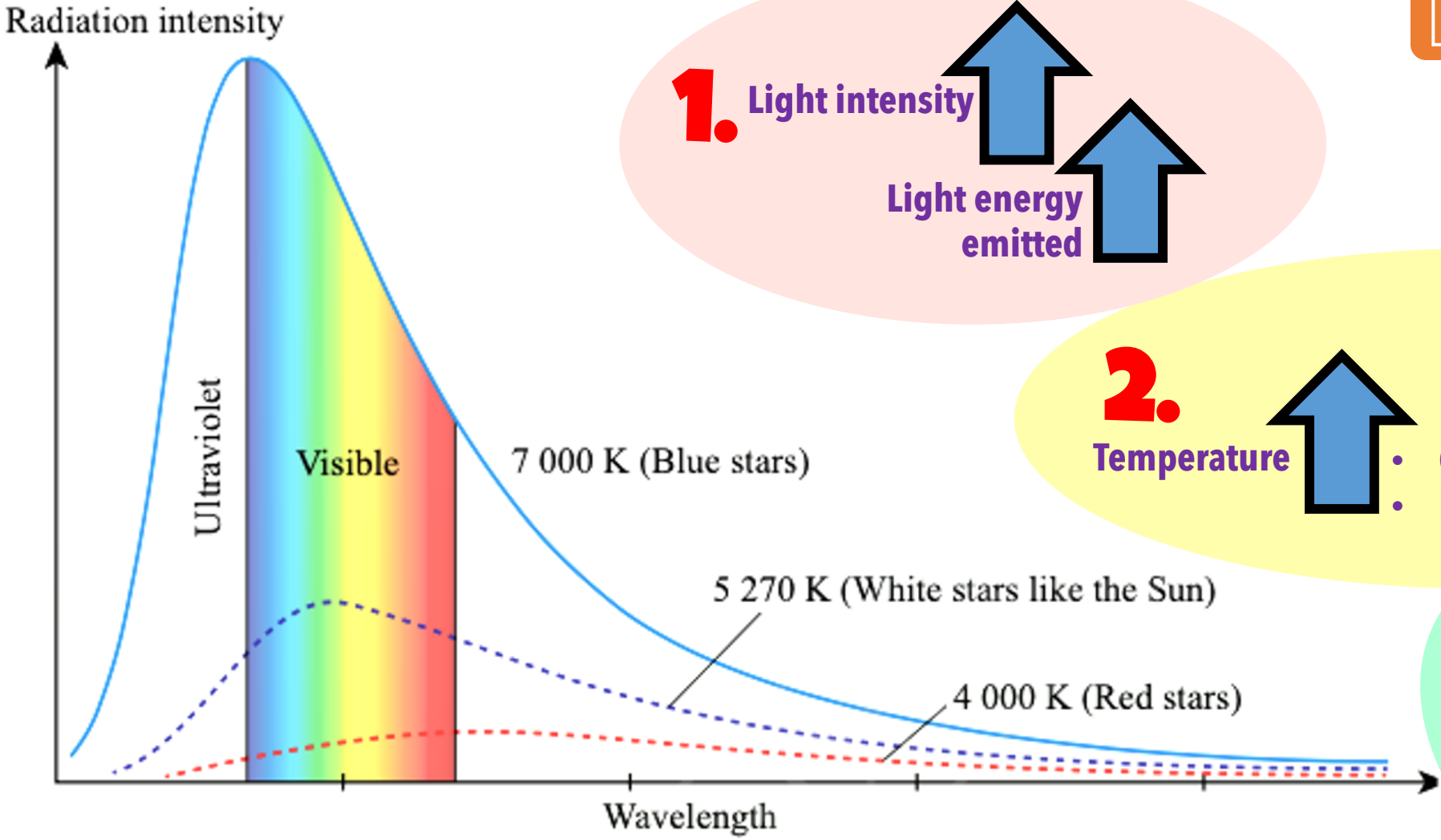
Thermal radiation in light bulbs at different temperatures



Oven heating element



Thermographic image of a car



1. Light intensity ↑
Light energy emitted ↑

2. Temperature ↑

- Object as a black body radiator
- Emit thermal radiation

3. Temperature ↑
Wavelength ↓

→ λ increase f decrease



**Isaac Newton
(1643-1727)**

- Described the **particle nature of light**
- **Unable** to explain the **refraction of light**



**Thomas Young
(1773-1829)**

- Showed **light** as a **wave** (Double-slits experiment)
- **Unable** to explain the **black body radiation spectrum**



**John Dalton
(1766-1844)**

- **Atoms** as the **smallest particle** of matter
- **Unable** to explain the **light spectrum produced by atoms**



**J.J. Thompson
(1856-1940)**

- Discovered negatively-charged subatomic particles (**electrons**)
- **Unable** to explain the **light spectrum produced by atoms**

QUANTUM THEORY

7.1 QUANTUM THEORY OF LIGHT



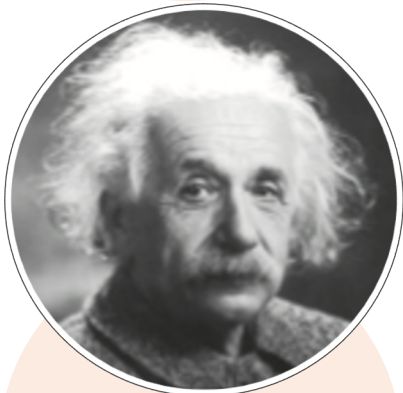
Max Planck
(1858-1947)

- Introduced the **idea of quantum** as **packet of discrete energy**
- Electromagnetic wave emitted by a black body is in discrete packet of energy (quantum of energy)
- **$E = hf$**



Niels Bohr
(1885-1962)

- The **line spectrum** is produced by **Hydrogen atoms**
- **Photons** are emitted when electrons transit from **high energy** levels to **low energy** levels



Albert Einstein
(1879-1955)

- Developed Planck's theory by stating that **light exist in quanta (photon)**
- From $E = hf$ (relate the kinetic energy of the photoelectrons that are emitted with light frequency)
- Discovered the **photoelectric effect**



Louis de Broglie
(1892-1987)

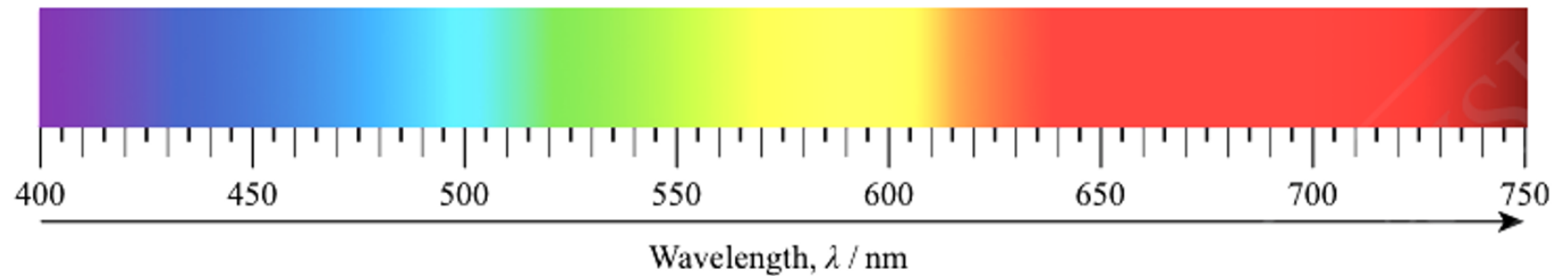
- Introduced a hypothesis that **particles** can also show **wave properties**
- Einstein & de Broglie postulated the idea of **wave-particle duality** of light and all subatomic particles



QUANTUM OF ENERGY

CONTINUOUS SPECTRUM

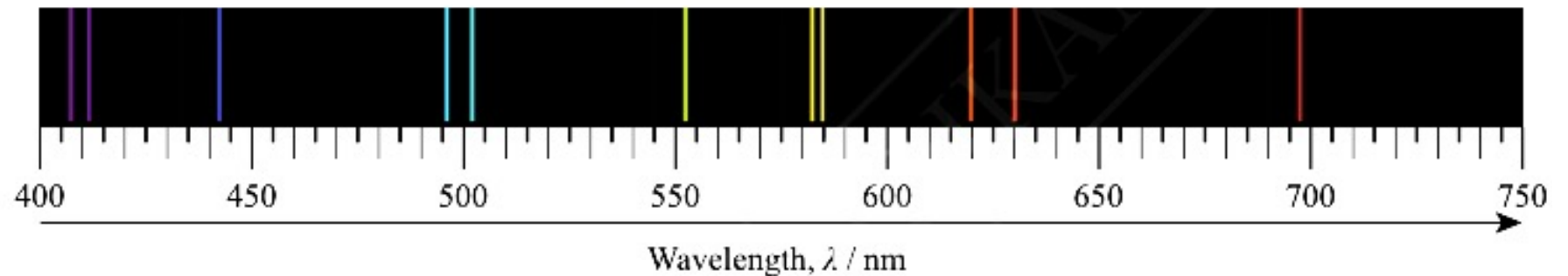
The **Visible light** is considered **continuous** because there is **NO gap separation** between each color in the spectrum



LINE SPECTRUM

The line spectrum shows the **electromagnetic radiation** of **specific frequencies**.

Every line in the line spectrum is caused by a **transition**, from one quantum state to another quantum state involving **electrons**



f increase
Energy quantum increase

QUANTUM OF ENERGY: PLANCK'S QUANTUM THEORY

discrete energy packet and **not** a continuous energy

- light exist in quanta (photon)
- Energy size of the radiation depends on frequency

$$E = hf$$

E = photon energy

f = frequency

h = Planck's constant (6.63×10^{-34} Js)

f increase
Energy quantum increase

Speed of the electromagnet radiation in vacuum is **c** (3.0×10^8 ms⁻¹)

$$c = f\lambda$$

$$f = \frac{c}{\lambda}$$

$$\therefore E = \frac{hc}{\lambda}$$

λ decrease
Energy quantum increase

DE BROGLIE'S WAVELENGTH: WAVE-PARTICLE DUALITY

7.1 QUANTUM THEORY OF LIGHT

Reflection of light : Particle
Refraction of light : Wave



De Broglie's principle:

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

λ = wavelength
 p = momentum of particle = mv
 m = mass of particle
 v = velocity of particle
 h = Planck's constant (6.63×10^{-34} Js)



Wave properties of matter = De Broglie waves or matter waves

EXPERIMENTAL EVIDENCES:

Wave	Particle
Young's double-slit	Photoelectric effect
Diffraction	Compton effect

Photon = electron + light



Wave-particle duality



- All electromagnetic spectrum
- Subatomic particle (proton & neutron)

Photon energy

$$E = hf$$

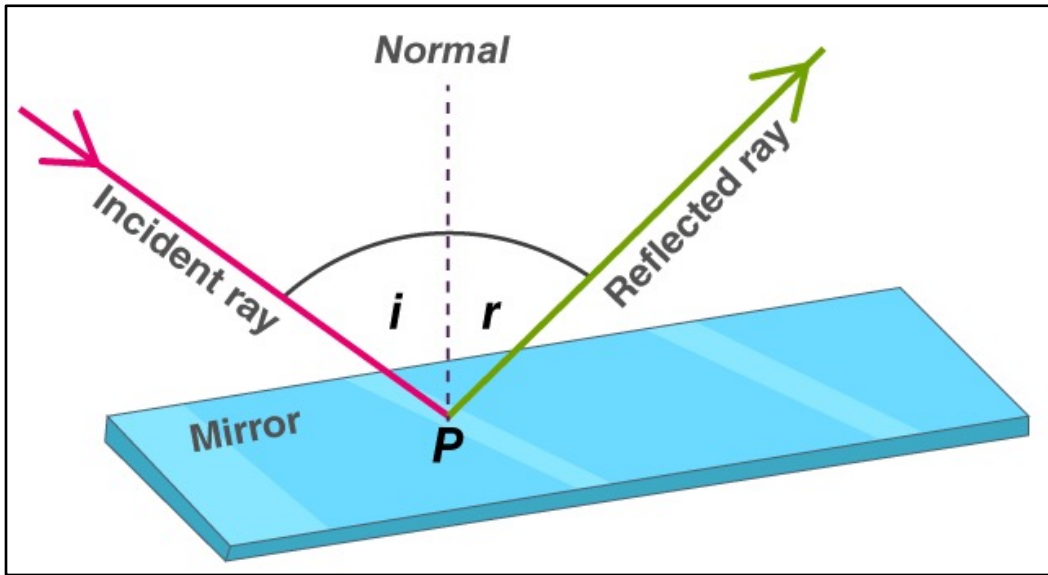
Photon power
(n = number of photon
emitted per second)

$$P = nhf$$

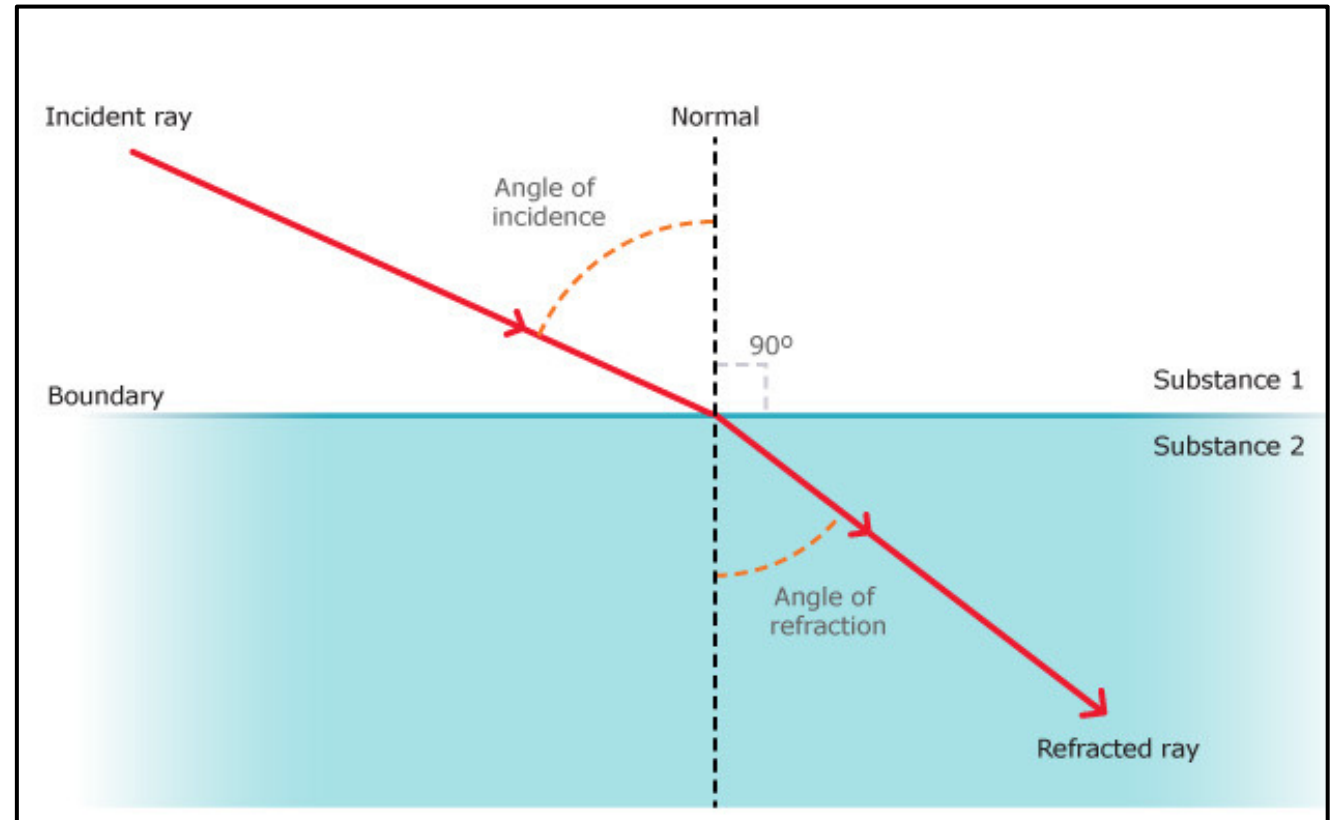


WAVE-PARTICLE DUALITY

Reflection of light : **particle**
 Refraction of light : **wave**



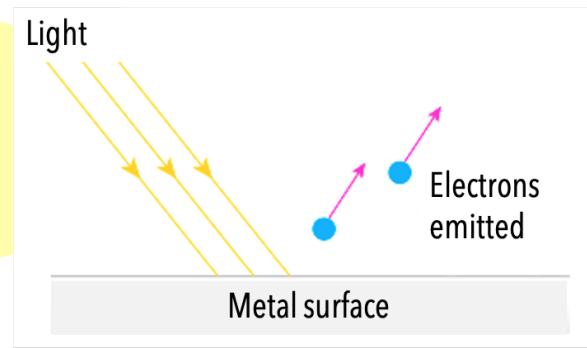
Reflection of light : **particle**



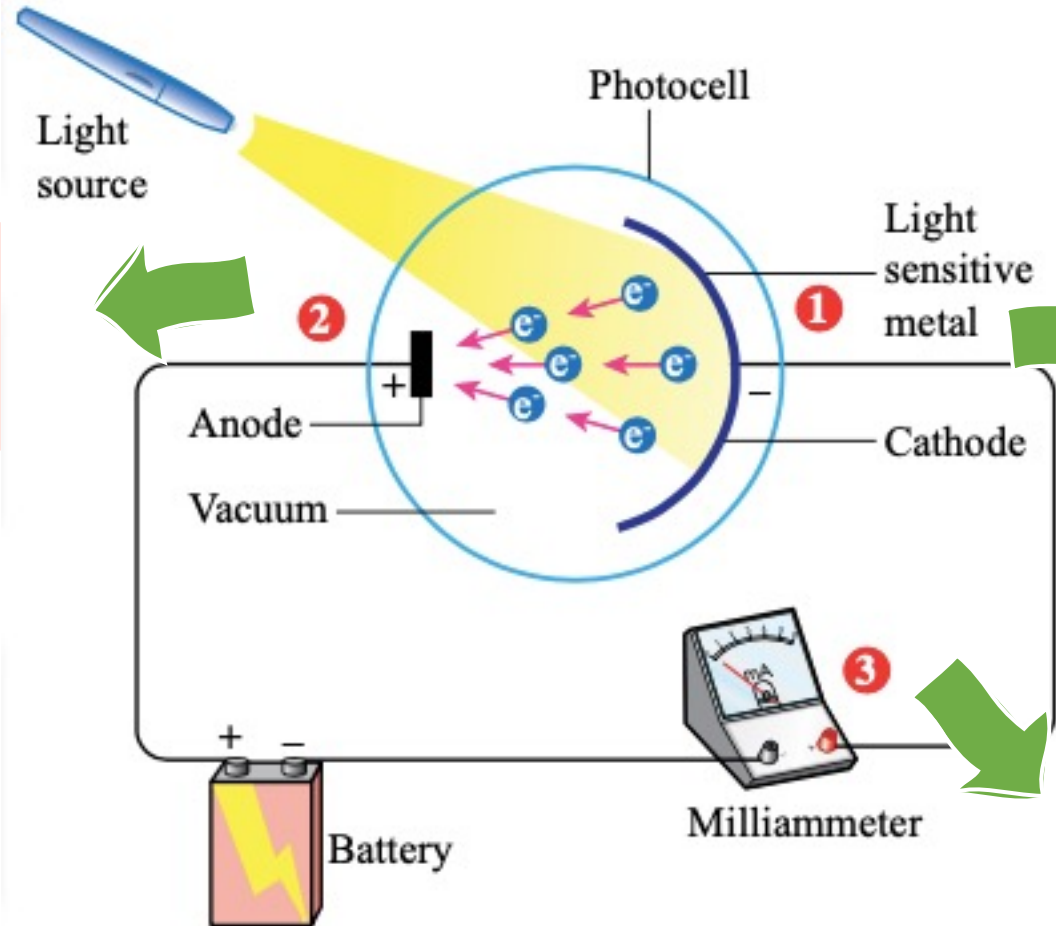
Refraction of light : **wave**

7.2 PHOTOELECTRIC EFFECT

Emission of Photoelectrons from a metal surface when light at a certain frequency illuminates the metal



The emitted Photoelectrons (**electrons**) attracted to the **anode**



Light sensitive metal surface (cathode)

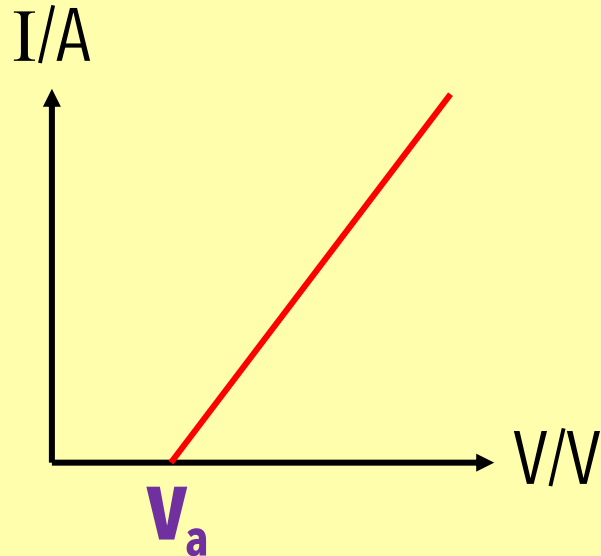
- Illuminated with a certain light beam
- Photoelectrons (**electrons**) will be emitted from surface metal

The movement of Photoelectrons (cathode → anode) produces **current**

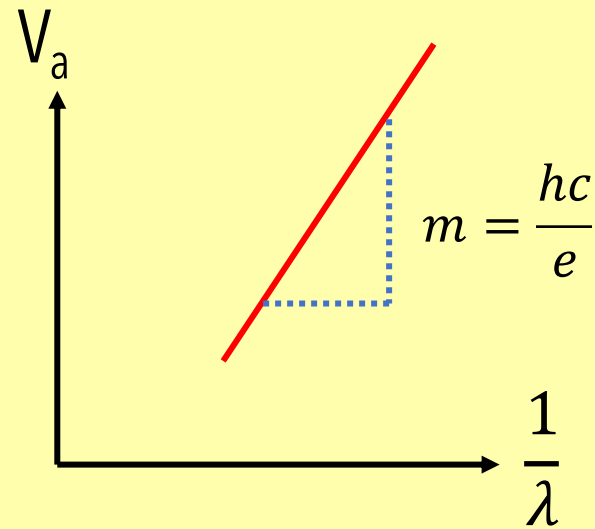
7.2 PHOTOELECTRIC EFFECT

Relationship between the **activation voltage (V_a)** and the light **wavelength**.

Graph I against V



Graph V_a against λ



$$\text{Gradient} = m = \frac{hc}{e}$$
$$\therefore h = \frac{me}{c}$$

λ decrease
 V_a increase

7.2 PHOTOELECTRIC EFFECT

- Photoelectric effect occurs when light strikes the surface of a metal.
- The electrons in the metal absorb energy from the light and escape from the metal surface.
- **CLASSICAL THEORY**, light in wave form is a spectrum with continuous energy and photoelectric effect should be able to occur at any light wave frequency.
- **Bright light** which has high energy should be able to emit electrons quickly.
- **Dim light** has low energy so the electrons need a longer time to absorb enough energy to escape from the metal surface.

- The **PHOTOELECTRIC EFFECT EXPERIMENTS** show that the emission of photoelectrons **ONLY** apply to light waves with frequencies that **exceed a certain value** without being affected by the **intensity** of the light.
- Photoelectrons are also emitted instantaneously at those light frequencies even at low light intensities.

1

f photon: **increase**

Kinetic energy of Photoelectrons: **increase**

2

f_0 (threshold frequency):

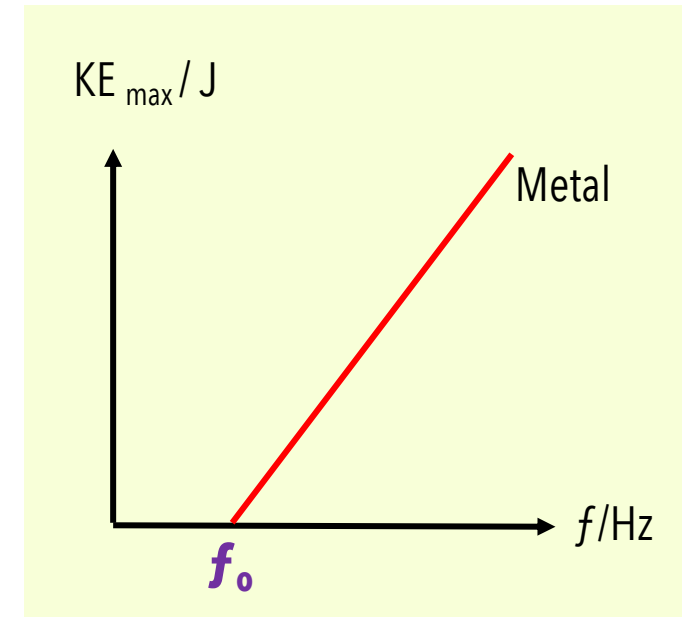
Minimum frequency of light needed for metal to **emit electrons**

3

Kinetic energy of Photoelectrons **does NOT depend** on the **intensity of light**

4

Photoelectrons are emitted **instantaneously** when **metal surface is illuminated by light**



Characteristics of PHOTOELECTRIC EFFECT

CLASSICAL WAVE THEORY PREDICTIONS

HIGHER intensity of light
GREATER energy imparted to the metal surface
(emission of photoelectrons)

Emission of photoelectrons occurs for all frequencies of radiation

Energy of radiation depends on intensity **NOT FREQUENCY**

Radiation energy is spread over the wavefront.
The **amount of energy incident** on any one electron is very **small**.

An electron **MUST** gather sufficient energy to be emitted (there is a time lapse between irradiation & emission)

OBSERVATIONS FROM THE PHOTOELECTRIC EFFECT EXPERIMENT

LOW intensity of light (HIGHER frequency)
will eject the photoelectrons

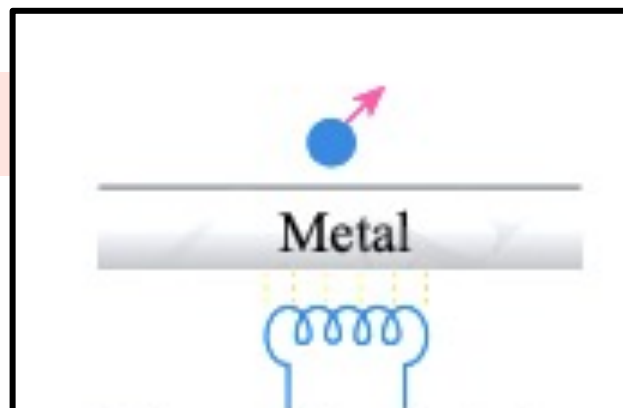
Kinetic energy of Photoelectrons **does NOT depend** on the **intensity of light**

Emission of photoelectrons **ONLY** when frequency of radiation **exceeds** the threshold frequency, f_0 , for metal surface

Energy (kinetic energy) of radiation **depends** on FREQUENCY

Photoelectrons are ejected instantaneously.
NO time delay between irradiation & emission
(even the intensity is **low**)

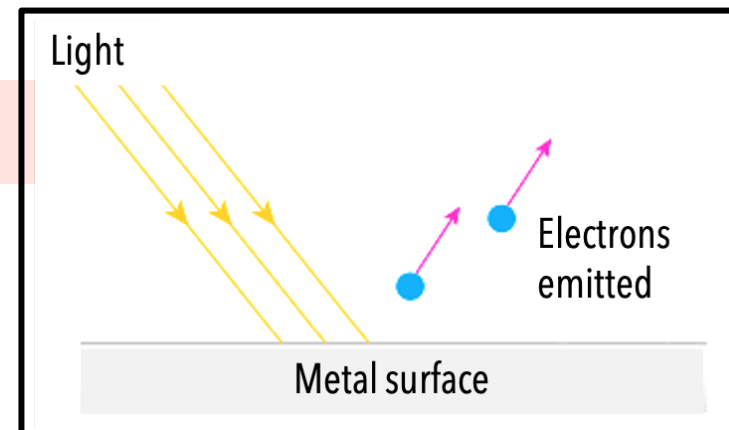
7.2 PHOTOELECTRIC EFFECT



THERMIONIC EMISSION

Emission of electron from heated surface metal

Take some time
(**longer** time)

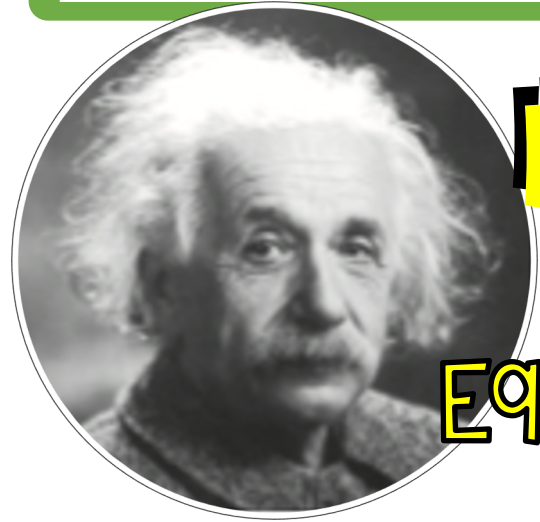


PHOTOELECTRIC EFFECT

Emission of photoelectrons from a metal surface when light at a certain frequency illuminates the metal

Instantaneous
(**Shorter** time)

7.3 EINSTEIN'S PHOTOELECTRIC THEORY



Idea!

Photons are light **particles** that bring energy.
Photon energy is **directly proportional** to the frequency of light, f .

Equation:

$$E = hf$$

E = photon energy

f = frequency

h = Planck's constant (6.63×10^{-34} Js)

Threshold frequency, f_0 :

Minimum frequency of light needed for metal to **emit electrons**

Work function, W :

Minimum energy needed for photoelectrons to be emitted from a metal surface

7.3 EINSTEIN'S PHOTOELECTRIC THEORY

FOR THE ELECTRONS ON THE METAL SURFACE

Photon Energy = MINIMUM
energy required
to release a
photoelectron + MAXIMUM
kinetic energy of
a photoelectron

$$E = W + K_{\max}$$

$$hf = W + \frac{1}{2}mv_{\max}^2$$

$$\frac{1}{2}mv_{\max}^2 = hf - W$$

*Accordance with the Principle of Conservation of Energy

AT THE THRESHOLD FREQUENCY, f_0

Photoelectrons are emitted without kinetic energy

$$\frac{1}{2}mv_{\max}^2 = 0$$



$$0 = hf_0 - W$$

$$W = hf_0$$



$$\frac{1}{2}mv_{\max}^2 = hf - W$$

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

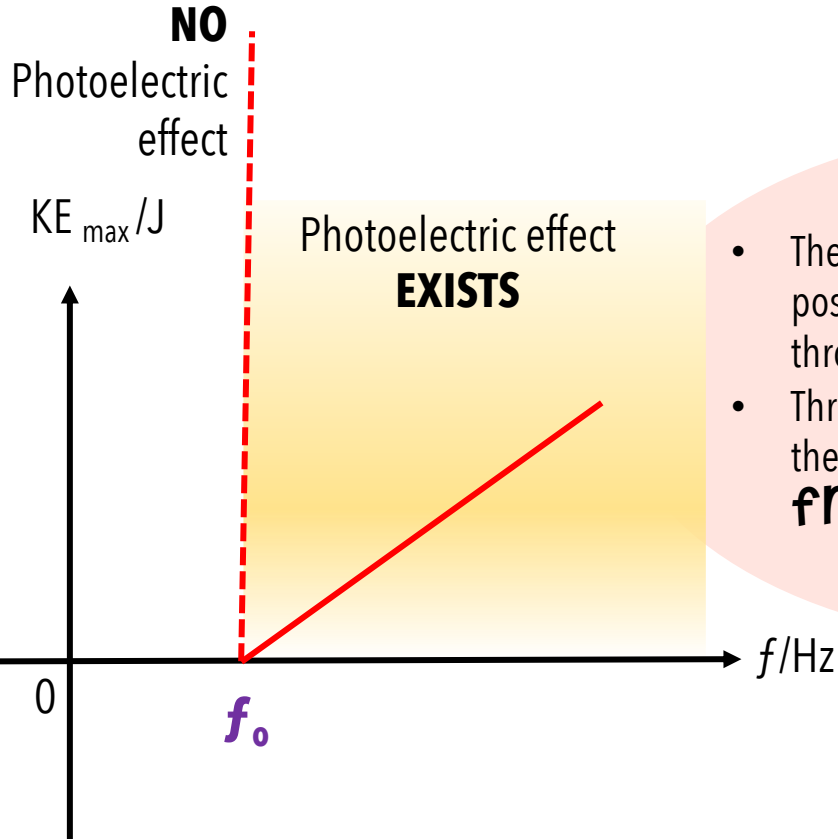
$$\frac{1}{2}mv_{\max}^2 = h(f - f_0)$$

7.3 EINSTEIN'S PHOTOELECTRIC THEORY

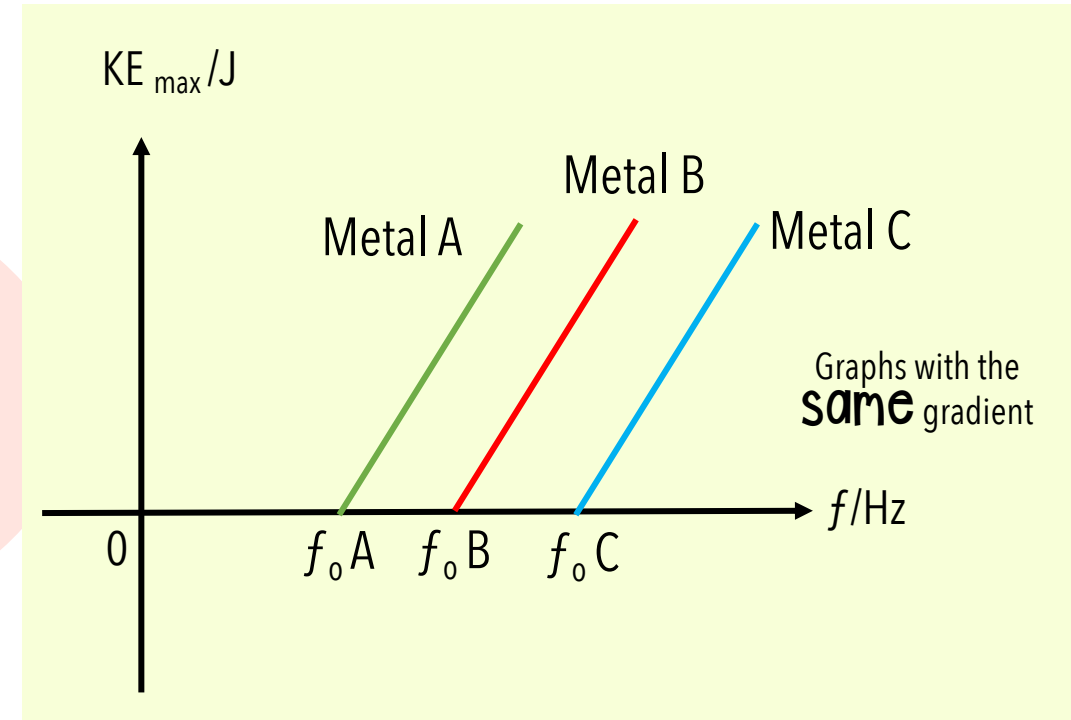
Work Function and Threshold Frequency for Photoelectric Effect



Work function, W : Minimum energy needed for photoelectrons to be emitted from a metal surface
 f_0 (threshold frequency): Minimum frequency of light needed for metal to **emit electrons**

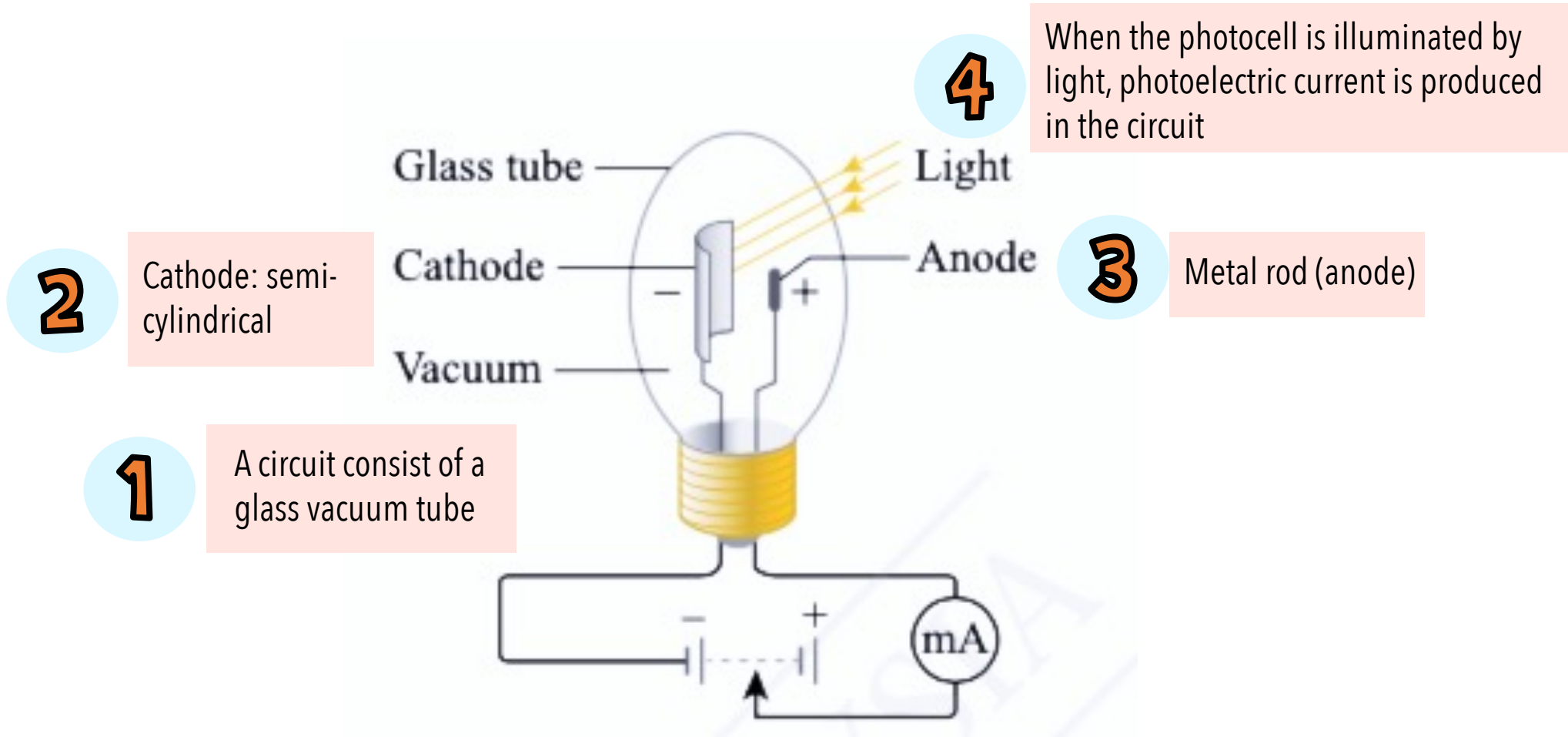


- The graph is a straight line with a positive gradient and NOT passing through the ORIGIN.
- Threshold frequency, f_0 is the value of the **intercept on the frequency axis.**



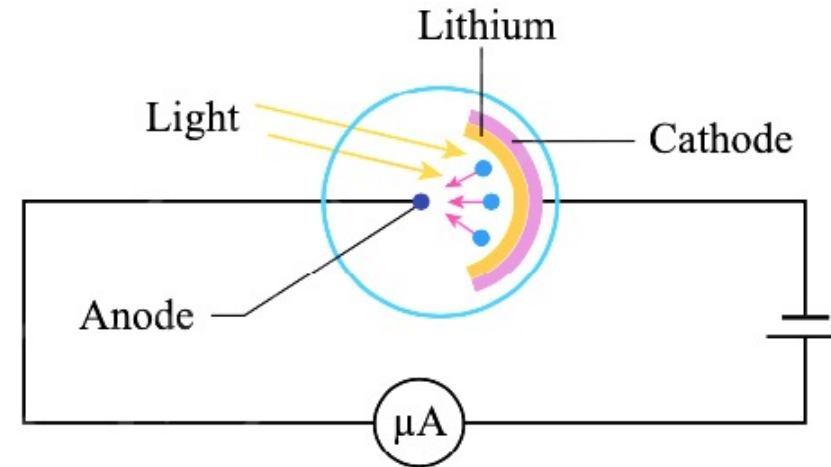
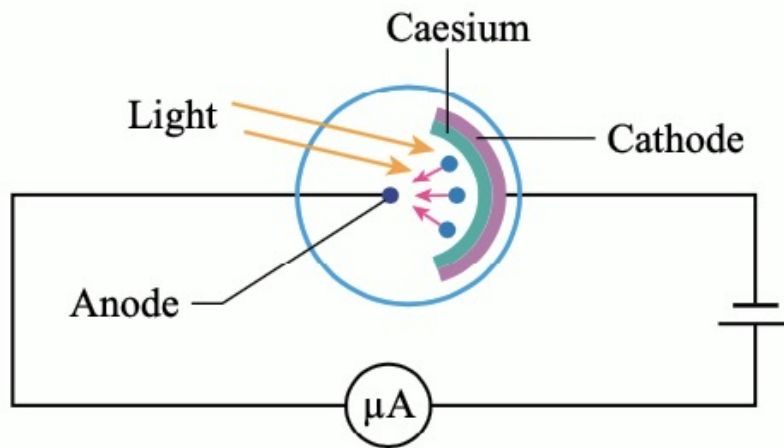
Threshold frequency, f_0 : **increase**
Work Function: **increase**

This means the minimum energy required for photoelectric effect to occur is higher.
Different metals have different threshold frequencies.



7.3 EINSTEIN'S PHOTOELECTRIC THEORY

Production of PHOTOELECTRIC CURRENT by photocells coated with CAESIUM and LITHIUM



CAESIUM

Work function of caesium, $W = 2.14 \text{ eV}$
Threshold frequency, $f_0 = 5.16 \times 10^{14} \text{ Hz}$
Maximum wavelength to produce photoelectric current, $\lambda = 579 \text{ nm}$

LITHIUM

Work function of lithium, $W = 2.50 \text{ eV}$
Threshold frequency, $f_0 = 6.03 \times 10^{14} \text{ Hz}$
Maximum wavelength to produce photoelectric current, $\lambda = 496 \text{ nm}$

Work Function: **increase**
Shorter max. wavelength to produce photoelectric current

Light Intensity: **increase**
Photoelectric current: **increase**

7.3 EINSTEIN'S PHOTOELECTRIC THEORY

PHOTOELECTRIC EFFECT APPLICATIONS



LED Solar Cells



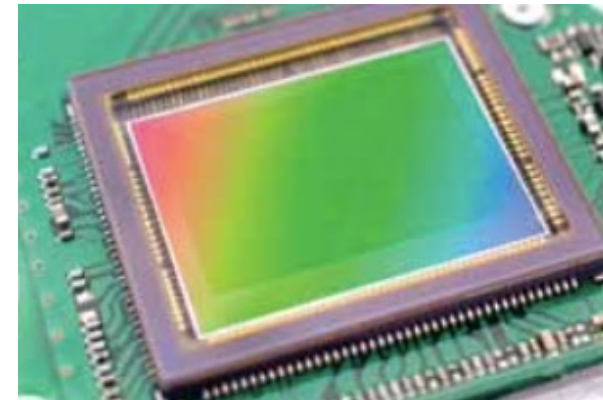
NOOR COMPLEX POWER PLANT
(MOROCCO)



Satellite powered by solar cells



Light detectors at the automatic doors use
infrared beam and photocells as switches



The image sensor is a main component
in high- resolution cameras

اللَّهُ خَالِقُ كُلِّ شَيْءٍ

ALLAH IS THE CREATOR OF ALL THINGS

SURAH AR-RA'D: AYAT 16