Particle nature of EM radiation

- **Planck's constant:** h

The units of h are units of angular momentum.

$E_\gamma = h\nu$

Units of h: $[h] = \frac{[E]}{[\nu]} = \frac{[ML^2T^{-2}]}{[T^{-1}]} = [ML^2T^{-1}]$

$[h] = L \cdot [MLT^{-1}] = [r] \cdot [p] = [l]$

Length Momentum Angular momentum

Example:

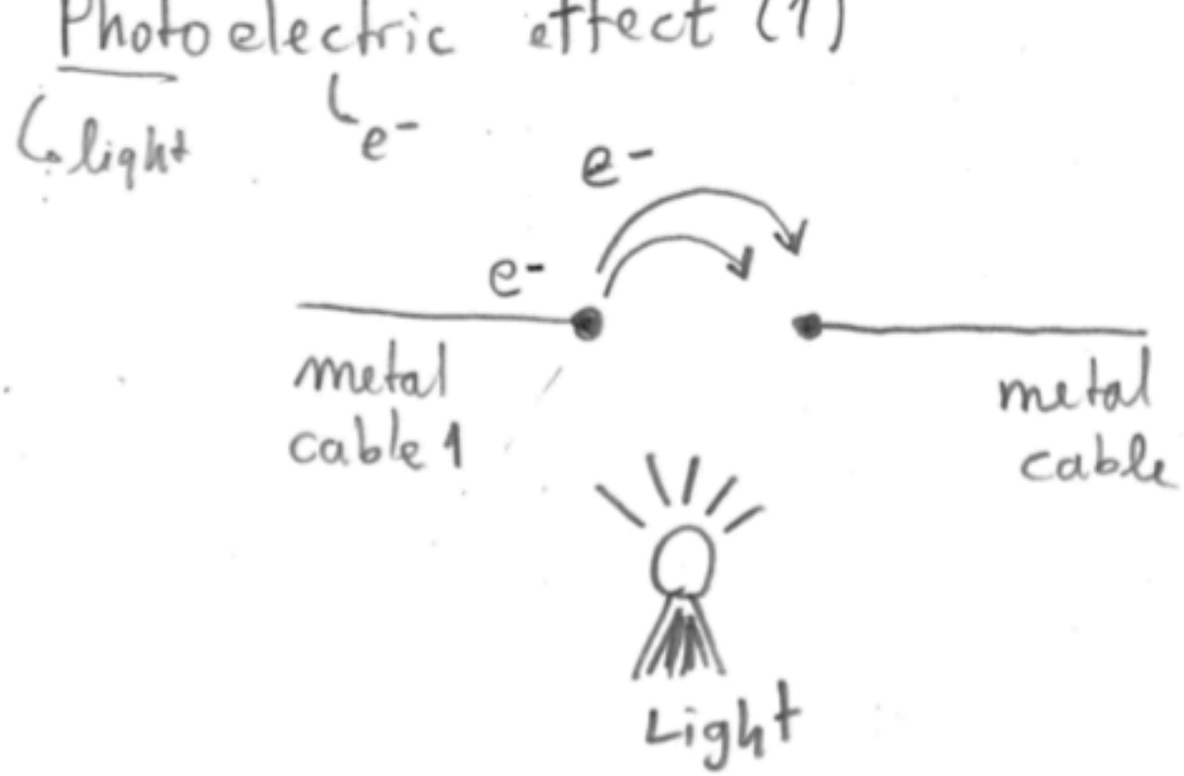
Spin 1/2 particle

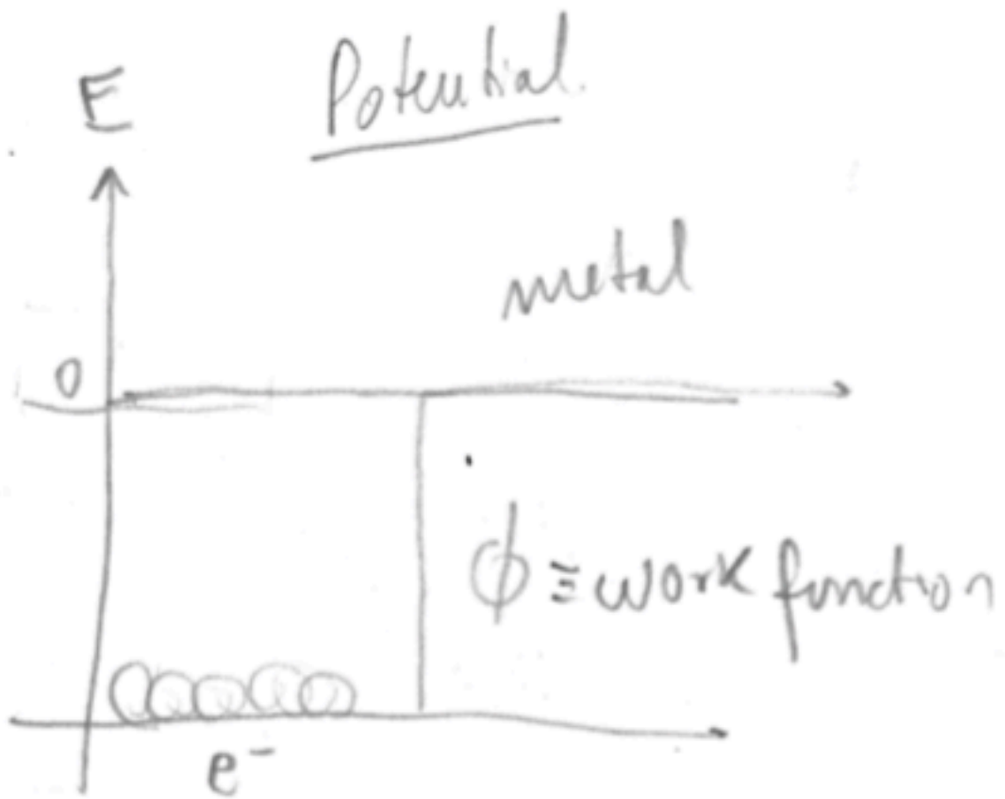
$|\vec{S}| = \frac{1}{2}\hbar$

The Photoelectric Effect

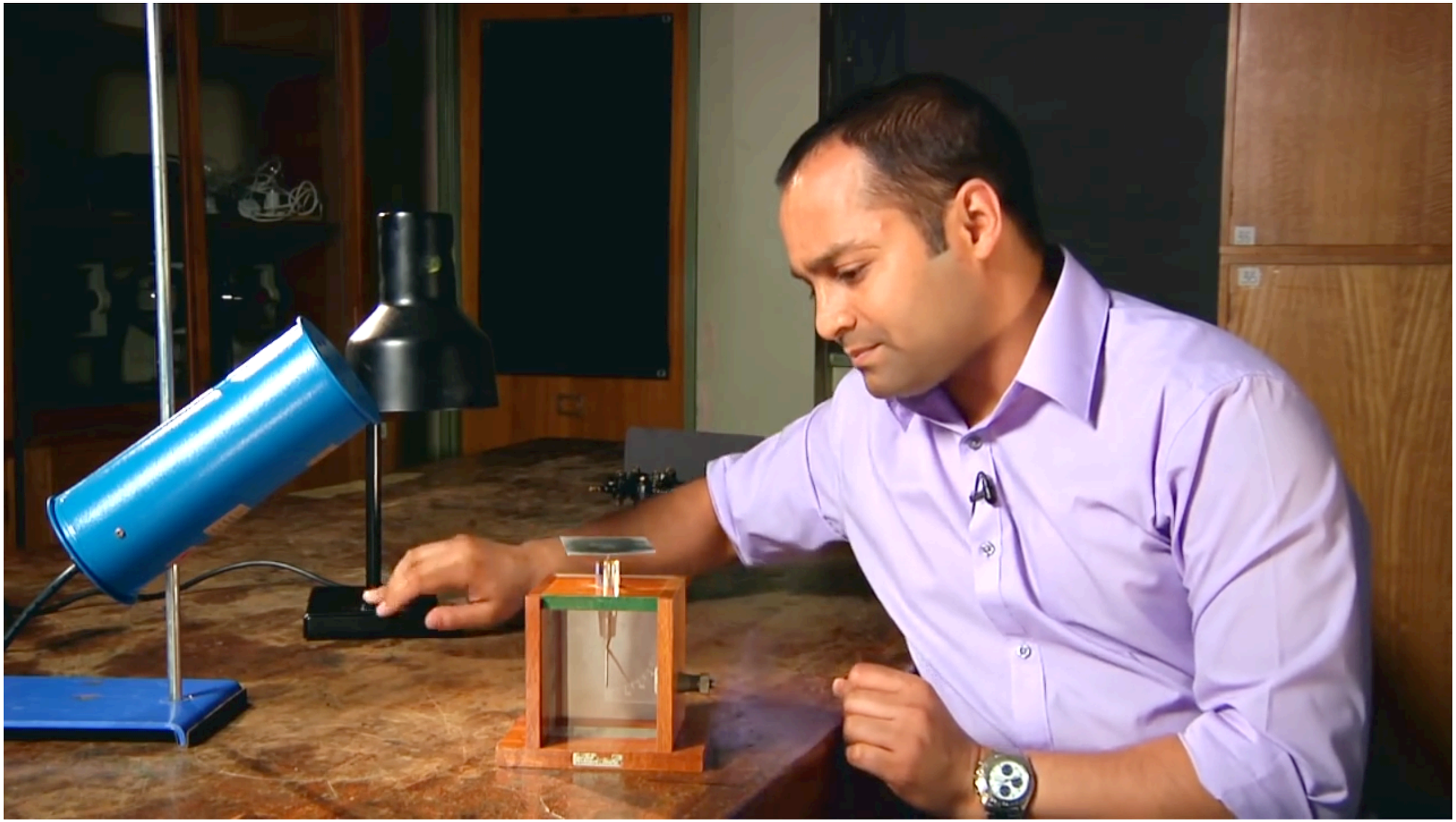
It is a process by which e- can be removed from a metal surface.

- **1887 -** H. Hertz discovers the Photoelectric Effect by irradiating metal plates with light.
- Irradiated polished plates emit e- called photo-electrons.





The Photoelectric Effect



Video: https://www.youtube.com/watch?v=v-1zjdUTu0o

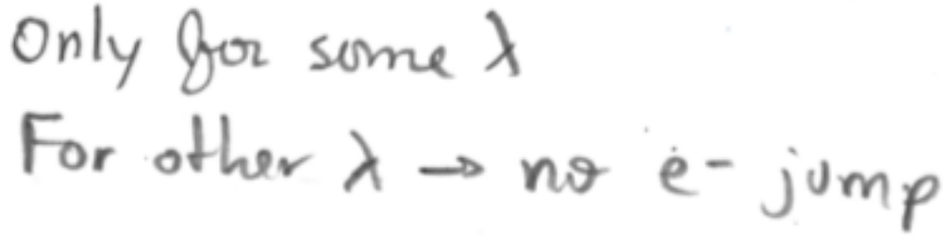
The Photoelectric Effect

- **Why does the photoelectric effect occurs?**

Classical (wave) view:

- **Did experiments agree?** No.

Photoelectric effect occurs:



The Photoelectric Effect

- **Einsteins' view:** photons come in packets of energy.

Einstein: Beam of light ν

Photons γ $\quad E_\gamma = h\nu$

$h \equiv$ Planck's constant $= 6.63 \times 10^{-34}\ J \cdot s$

$$E_\gamma = h\frac{c}{\lambda} = \frac{2\pi\hbar c}{\lambda}$$

$$\hbar = \frac{h}{2\pi}$$

$\hbar c = 200\ MeV \cdot fm$ → fermi

$fm = 10^{-15}\ m$

$\hbar c = (197.33)$

- **Einsteins' prediction:**

$$E_{e^-} = \frac{1}{2}mv^2 = E_\gamma - \phi = h\nu - \phi$$ ← Einstein's prediction

$\frac{1}{2}mv^2$: Leftover energy

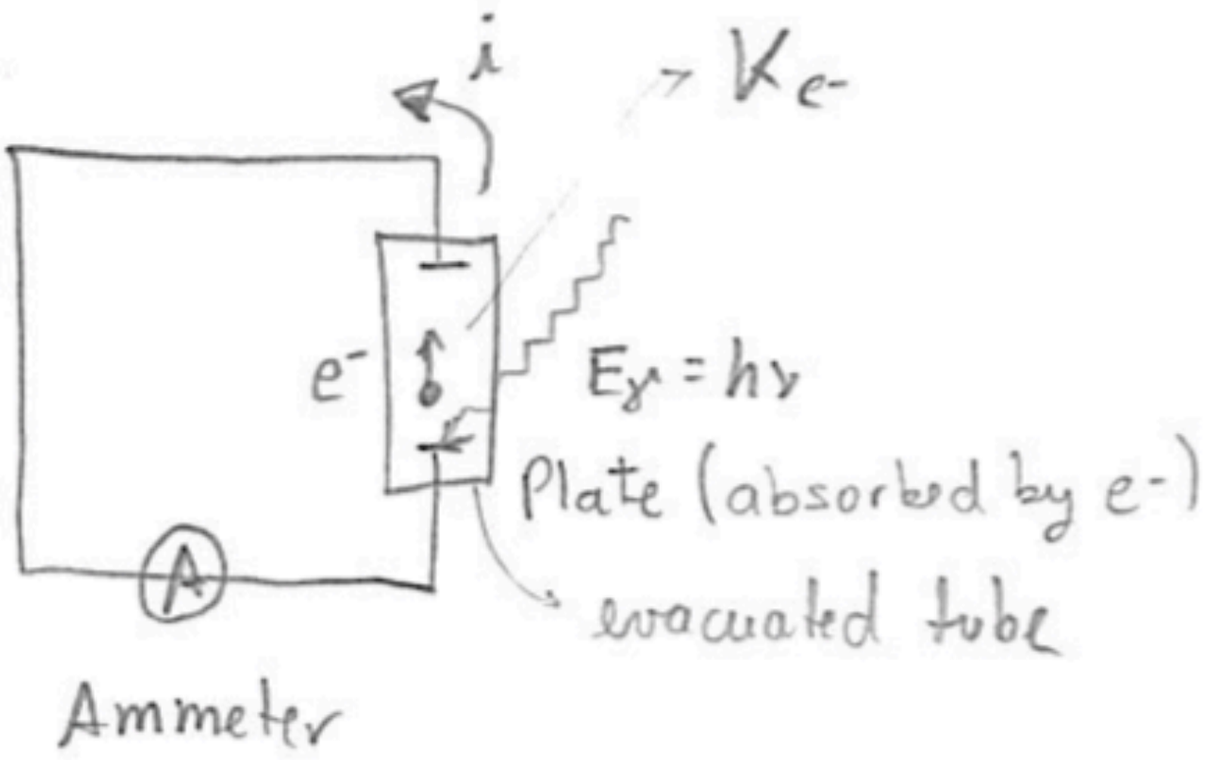
E_γ: E given to e⁻

ϕ: E needed to liberate e⁻

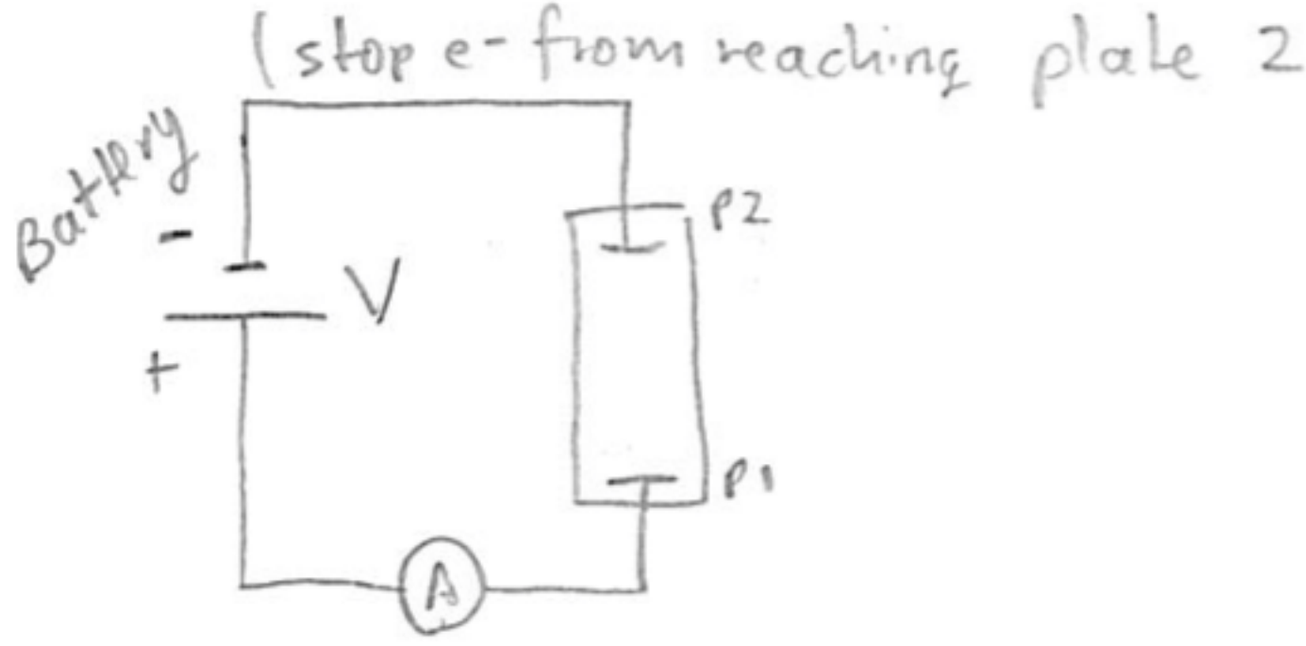
The Photoelectric Effect

- **1915 -** Millikan's experiment:

Instance 1 (no battery)



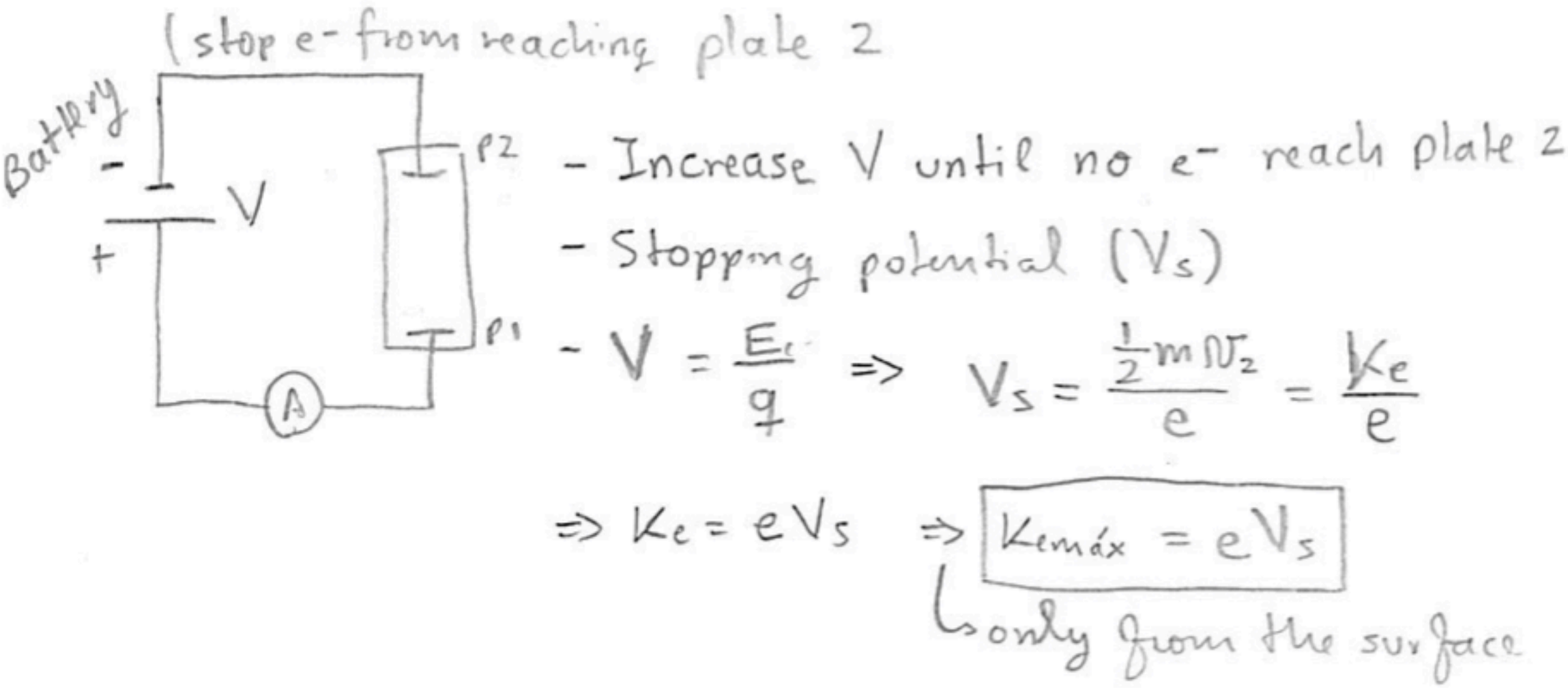
Instance 2 (battery added)



- There is a threshold frequency above which there is electric current.
- Energy to remove e- from the metal plates depends on the metal, crystalline structure on the surface of the plates.

The Photoelectric Effect

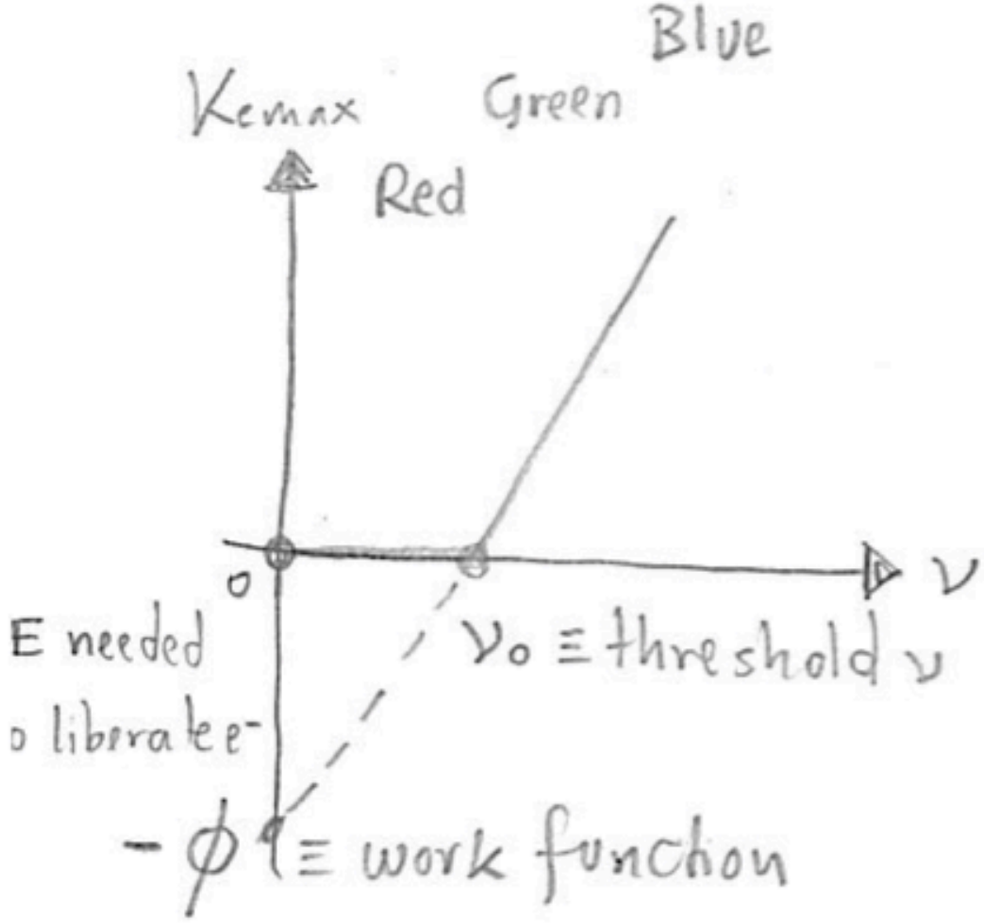
- **1915 -** Millikan's experiment:



Applet: https://applets.kcvs.ca/photoelectricEffect/PhotoElectric.html

The Photoelectric Effect

- **1915 -** Millikan's experiment:



$$E_{e^-} = \frac{1}{2}mv^2 = E_\gamma - \phi = h\nu - \phi$$ } Einstein's prediction

$$\Rightarrow \boxed{K_{e\,max} = h\nu - \phi}$$

- $K_{e\,max}$: Leftover energy for e- after liberation
- $h\nu$: E given to e- by γ
- ϕ: E needed to liberate e-

$$0 = h\nu_0 - \phi$$

$$\nu_0 = \frac{\phi}{h}$$

$$\Rightarrow \boxed{\phi = \nu_0 h}$$

$$\boxed{K_{e\,max} = h(\nu - \nu_0)}$$

Higher Intensity
- More γ do not ↑ $K_{e^-_{max}}$
- 1 γ absorbed by 1 e-
- Light exists as quanta

The Photoelectric Effect

- **1915 -** Millikan's experiment conclusions:

- Millikan (1915) verifies Einstein's prediction.
- h is measured to better than 1% of its currently accepted value

h is is the slope of this linear eq:

$$K_{e\,max} = h\nu - \phi$$

- Magnitude of the current (# of photo-e-) is proportional to light intensity.
- Energy of photo-e- is independent of light intensity
- Energy of photo-e- increases linearly with the frequency of the light.

It is NOT easy to understand the above with waves.

Light duality

- **1905** - Einstein proposes light's wave/particle duality.

  Light is made of wave-packets, bundles of energy.

  Did not say explicitly that light is a particle.

  It comes in discrete packets of energy -> **photons**

  (Lewis proposes the name photon in the 1920s)

Discovery of photons

- **Properties of photons:**
  - Photons are packets of energy.
  - Photons are the smallest pieces of light.
  - Energy = constant times a colour.
  - Charge = 0, Rest mass = 0, Spin = 1 (Right and Left)
  - Light speed c, E=pc, inability of experience time-space