Energy-momentum relation

$$E^2 = p^2c^2 + m^2c^4$$

$E = mc^2$ if $p=0$	$E = pc$ if $m=0$
Rest energy	photons

$E = p^2/2m$ non-Rel KE

Electrons (non-Rel)

$$E = \frac{p^2}{2m} \qquad \hbar = h/(2\pi) \qquad k = 2\pi/\lambda$$

$$p = \sqrt{2mE}$$

$$p = h/\lambda = \hbar k$$ de Broglie

$$\lambda = h/p$$

$$\lambda = \frac{hc}{\sqrt{2\ mc^2\ E}}$$

Light

Waves $f\lambda = c$ $f = c/\lambda$

Photo effect

$$E = h f = h c/\lambda$$

$$E = (h/2\pi)(2\pi f)$$

$$E = \hbar\omega$$

Photons $E = pc$ $p = h/\lambda$

$f \lambda = c$

$\omega = 2\pi f$ $\qquad$ $k = 2\pi/\lambda$

$\omega/k = f \lambda = c$

---

approximate

$$\hbar c = 200\ \mathrm{eV-nm} \qquad \mathrm{hc} = 1240\ \mathrm{eV-nm}$$

$$mc^2 \approx 0.5\ \mathrm{MeV}$$ (electron)

$$\lambda = \frac{hc}{\sqrt{2\ mc^2\ E}}$$

$$E = 100\ \mathrm{eV}$$

$$\lambda = \frac{1240\ \mathrm{eV-nm}}{\sqrt{10^6\ \mathrm{eV}\ \times\ 100\ \mathrm{eV}}} = 0.12\ \mathrm{nm}$$

Energy-momentum relation

$$E^2 = p^2c^2 + m^2c^4$$

$E = mc^2$ if p=0 $E = pc$ if m=0 $E=p^2/2m$ non-Rel KE

Light

Waves $f\lambda = c$

Photo effect $E = hf = hc/\lambda$

$$E = \hbar\omega$$

Photons $E = pc$

Electrons (non-Rel)

$$E = \frac{p^2}{2m}$$

$$p = \sqrt{2mE}$$

$$p = h/\lambda = \hbar k$$ de Broglie

$$\lambda = \frac{hc}{\sqrt{2\ mc^2\ E}}$$

$\omega = 2\pi f$ $k = 2\pi/\lambda$ $\hbar c = 200\ \mathrm{eV-nm}$ $\mathrm{hc} = 1240\ \mathrm{eV-nm}$

$$mc^2 \approx 0.5\ \mathrm{MeV}$$

$$E = 100\ \mathrm{eV}$$

$$\lambda = \frac{1240\ \mathrm{eV-nm}}{\sqrt{10^6\ \mathrm{eV}\ \times\ 100\ \mathrm{eV}}} = 0.12\ \mathrm{nm}$$

Photon Energy is proportional to frequency: $E = hf$

$$\lambda f = c \qquad \frac{f}{c} = \frac{1}{\lambda}$$

$$E = hf = hc\frac{f}{c} = \frac{hc}{\lambda}$$

$hc \approx 1240 \text{ eV} \cdot \text{nm}$
Assume $\lambda = 500$ nm

$$E = \frac{1240 \text{ eV} \cdot \text{nm}}{500 \text{ nm}} \approx 2.5 \text{ eV}$$

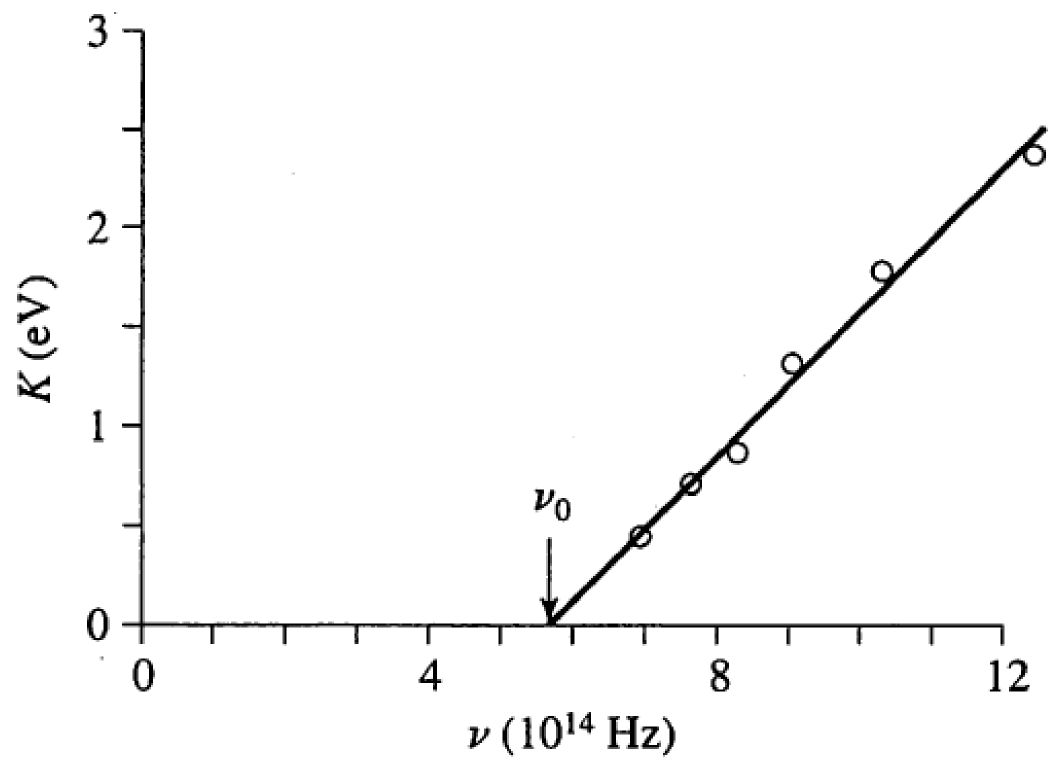
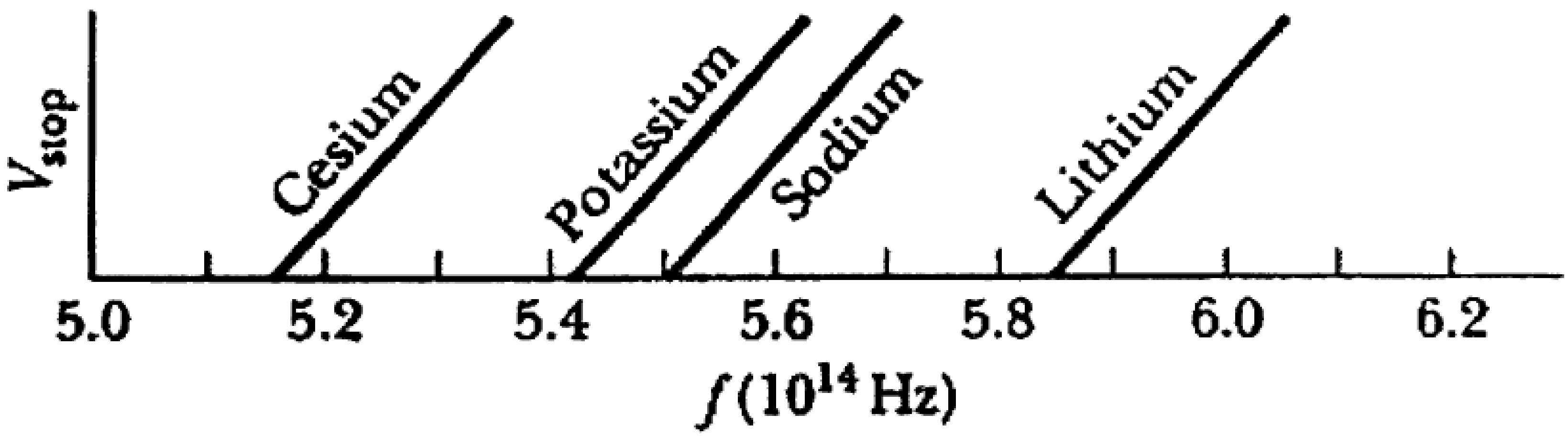


Figure 1.14 The maximum kinetic energy K of the photoelectrons vs. frequency for sodium. The data are from R. A. Millikan, *Phys. Rev.* 7, 355 (1916). The threshold frequency ($\nu_0 = 5.6 \times 10^{14}$ Hz) has been adjusted to allow for the contact potential between the anode and the cathode (see Section 8.2). Millikan obtained a value for h, Planck's constant, from the slope of the straight line.

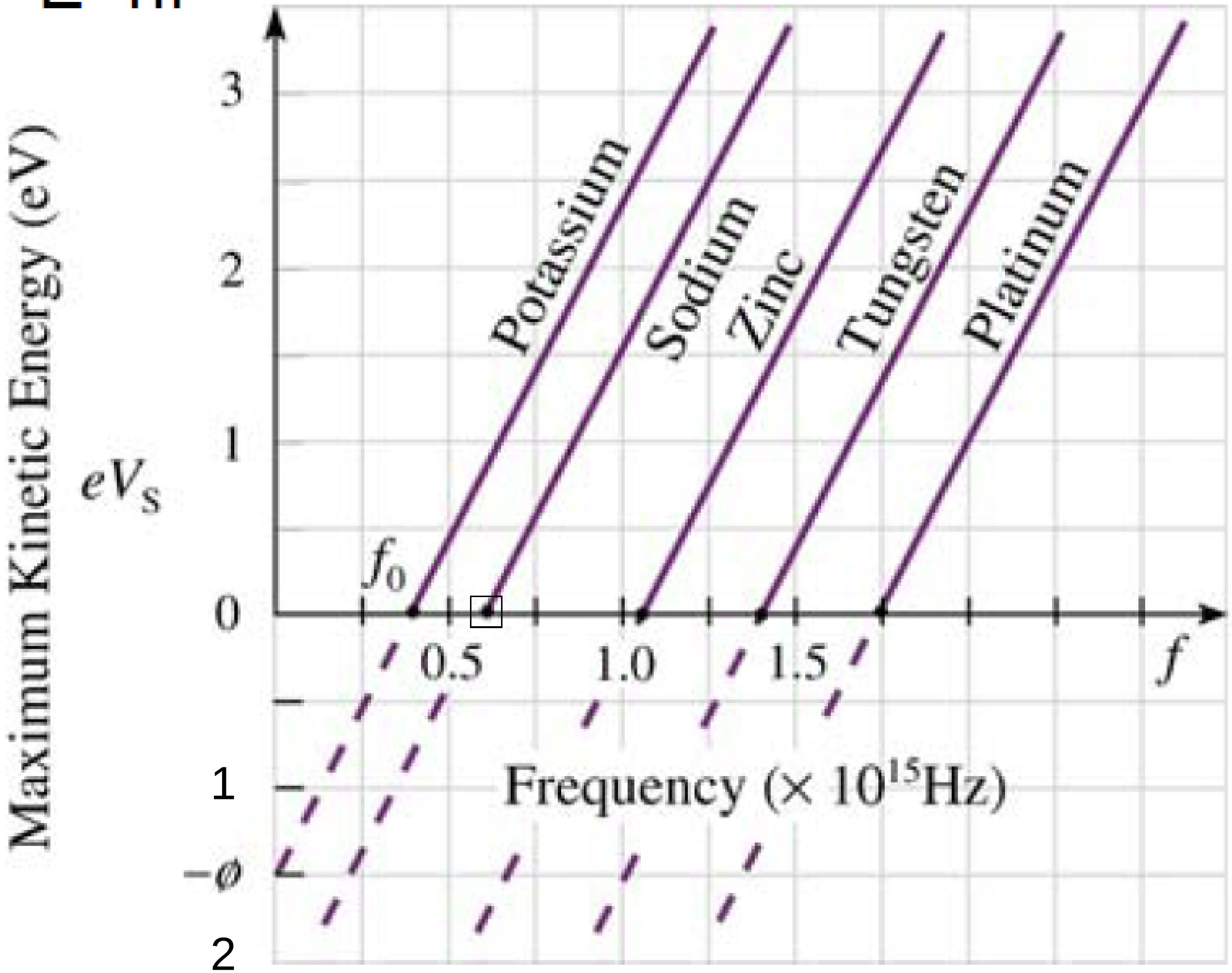


V_{stop}
Cesium
Potassium
Sodium
Lithium
5.0
5.2
5.4
5.6
5.8
6.0
6.2
$f\,(10^{14}\ \mathrm{Hz})$

E=hf

hc= 1240 eV-nm

c = 3 10^8 m/s



$\lambda f = c$

$1/\lambda = f/c$

λ = c/f = 3 10^8/(0.6 10^{15}) = 500 nm

E=hf = hc(f/c) = hc/λ = 1240 eV-nm/(500 nm) = 2.5 eV

Work Functions of Selected Metals

Metal	ϕ (eV)
Na	2.46
Al	4.08
Fe	4.50
Cu	4.70
Zn	4.31
Ag	4.73
Pt	6.35
Pb	4.14

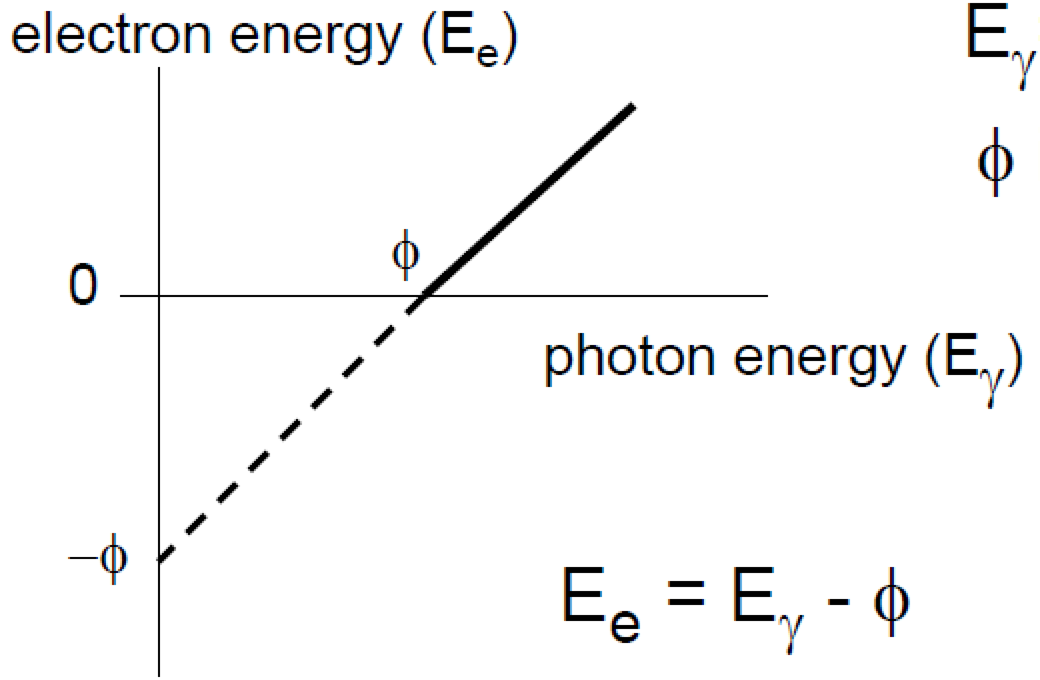
Photon Energy is proportional to frequency: $\quad E = hf$

$$\lambda f = c \qquad \frac{f}{c} = \frac{1}{\lambda}$$

$$E = hf = hc\frac{f}{c} = \frac{hc}{\lambda}$$

$hc \approx 1240 \text{ eV} \cdot \text{nm}$
Assume $\lambda = 500$ nm

$$E = \frac{1240 \text{ eV} \cdot \text{nm}}{500 \text{ nm}} \approx 2.5 \text{ eV}$$



$E_\gamma = h\,f$

ϕ is the work function

$$E_e = E_\gamma - \phi$$

Zinc work function $= 4.31$ eV

The threshold wavelength:

$$\lambda = \frac{hc}{\text{Energy}} = \frac{1240\ \text{eV}\cdot\text{nm}}{4.31\ \text{eV}} = 288\ \text{nm}$$

from graph the threshold frequency is

$$f = 1.05\ 10^{15}\ \text{Hz} \qquad\qquad c \approx 3\ 10^{8}\ \text{m/s}$$

$$\lambda = \frac{c}{f} = \frac{3\ 10^{8}}{1.05\ 10^{15}}\ 10^{9}\ \text{nm}$$

$$\lambda \approx 285\ \text{nm}$$