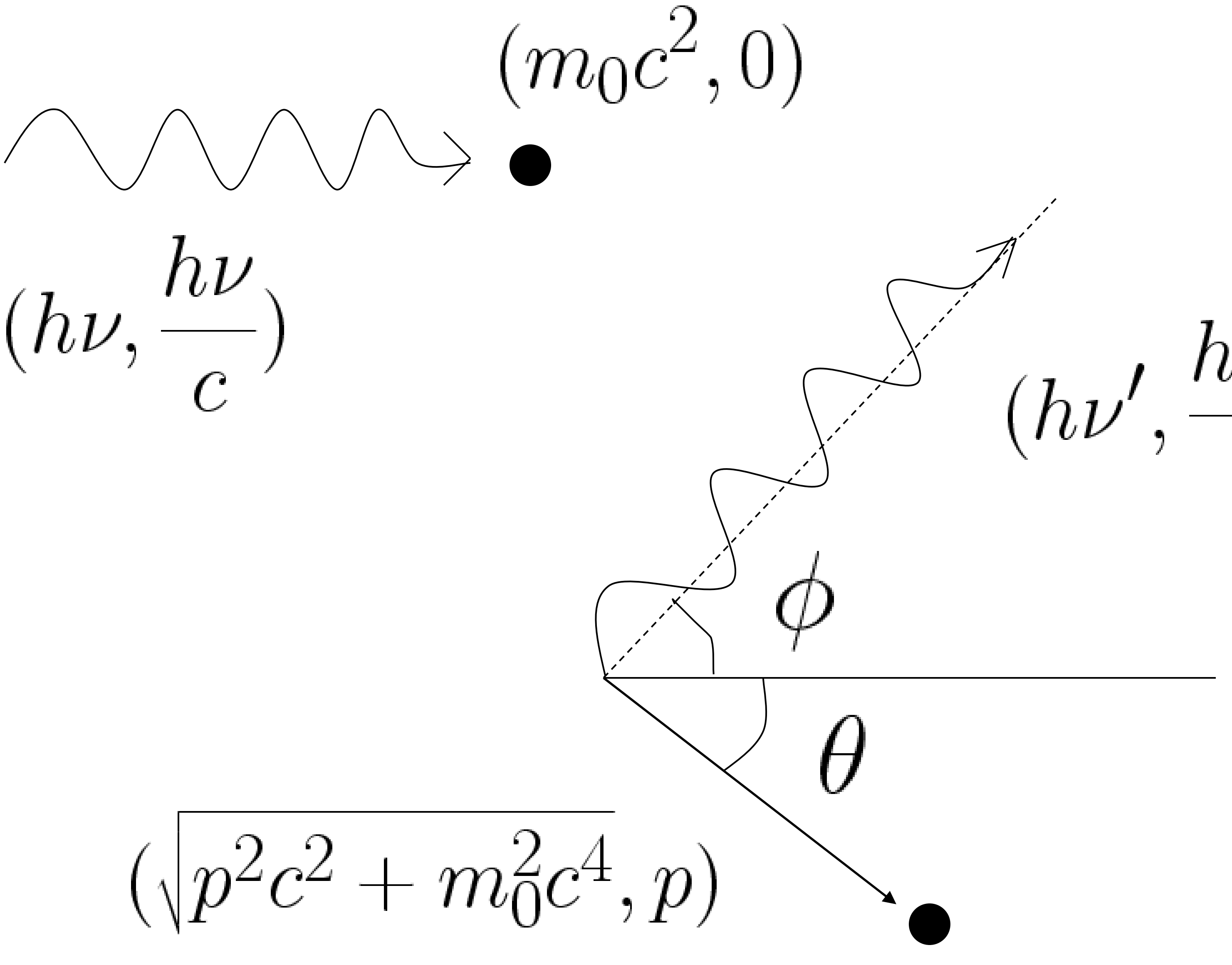
Compton effect

Partial transfer of photon energy



$$E^2 = p^2c^2 + m_0^2c^4$$

$$E = mc^2 = \frac{m_0}{\sqrt{1 - v^2/c^2}}c^2$$

$$KE_{classical} = \frac{1}{2}m_0v^2$$

$$h\nu - h\nu' = KE_{electron}$$

$$E_{photon} = pc$$

$$p_{photon} = \frac{h\nu}{c}$$

Conservation of momentum along initial photon direction

$$\frac{h\nu}{c} = \frac{h\nu'}{c}\cos\phi + p\cos\theta$$

Conservation of momentum along perpendicular to initial photon direction

$$\frac{h\nu'}{c}\sin\phi = p\sin\theta$$

$$p^2c^2 = (h\nu)^2 + (h\nu')^2 - 2(h\nu)(h\nu')\cos\phi$$

Energy conservation

$$h\nu + m_0c^2 = h\nu' + \sqrt{p^2c^2 + m_0^2c^4}$$

$$(h\nu)^2 + (h\nu')^2 + 2(h\nu)m_0c^2 - 2(h\nu)(h\nu')$$

$$-2(h\nu')m_0c^2 = p^2c^2$$

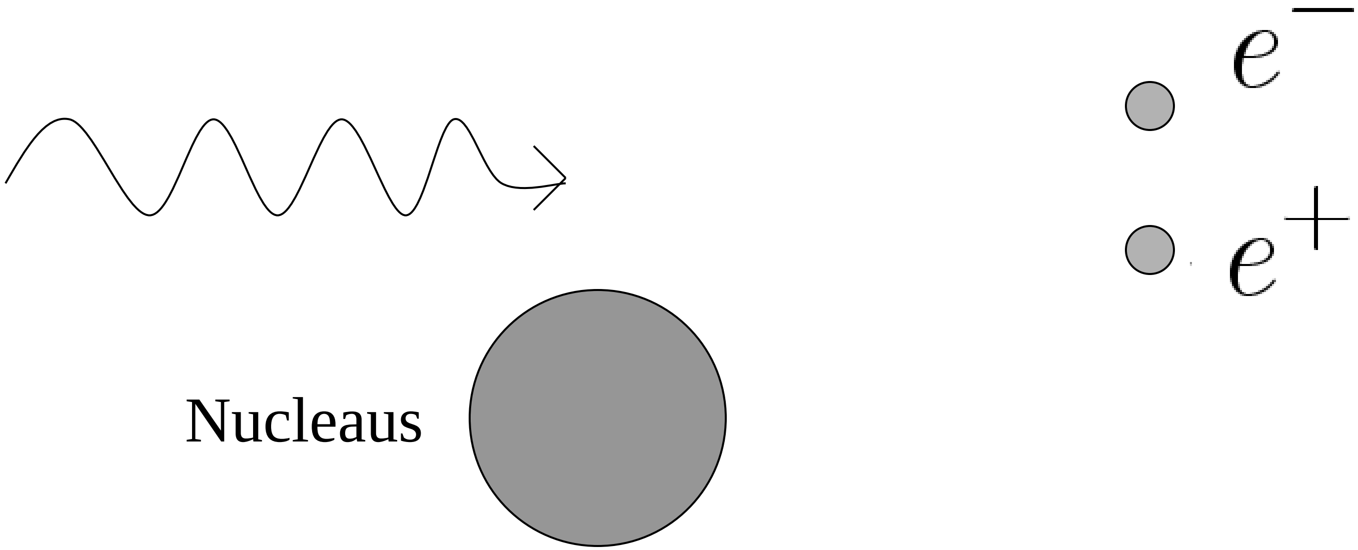
$$\frac{m_0 c}{h}\left(\frac{\nu}{c} - \frac{\nu'}{c}\right) = \frac{\nu}{c}\frac{\nu'}{c}(1 - \cos\phi)$$

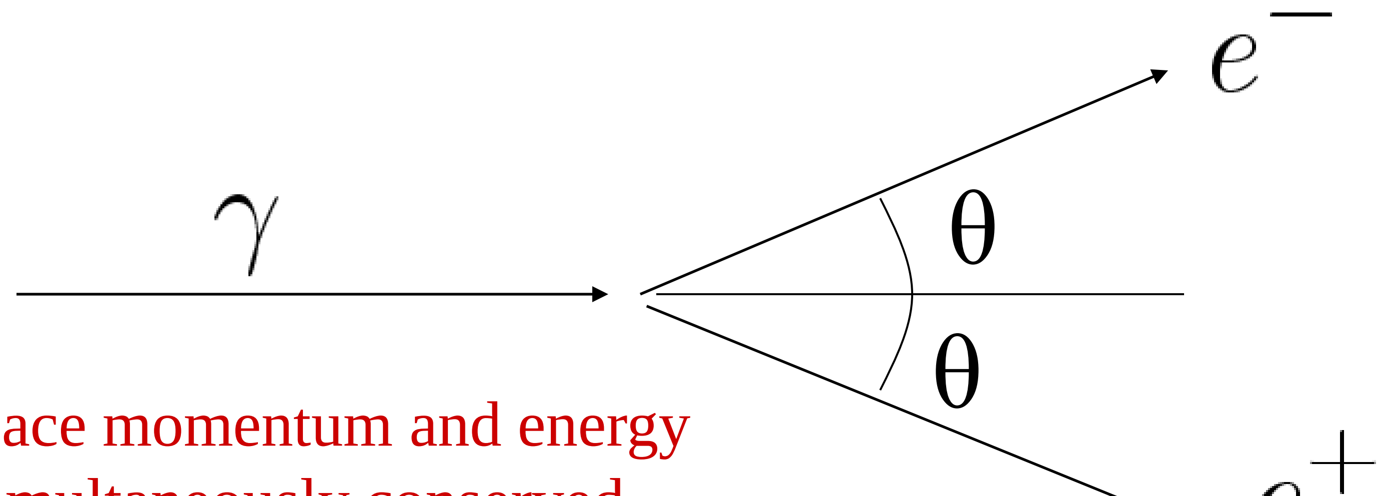
$$\lambda' - \lambda = \frac{h}{m_0 c}(1 - \cos\phi)$$

Compton wavelength $\lambda_c = \frac{h}{m_0 c} \cong 2.4$ pm

Compton shift $\lambda' - \lambda = \lambda_c(1 - \cos\phi)$

Pair production

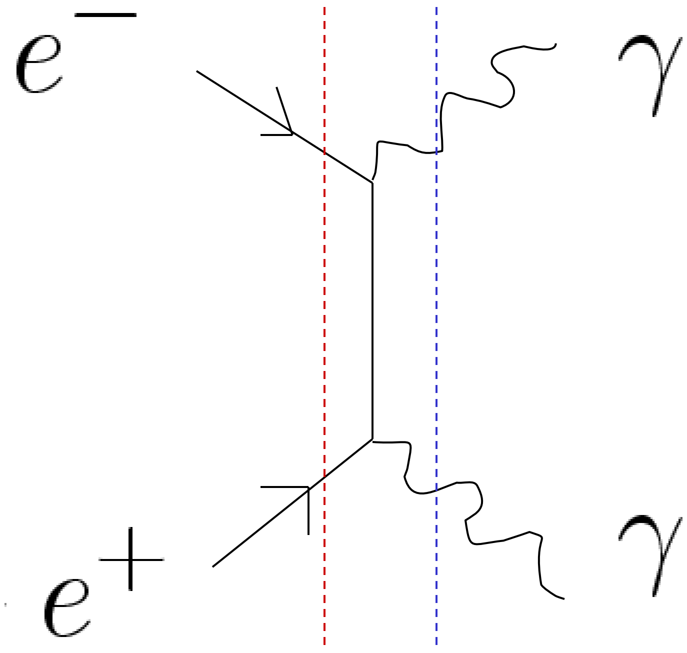


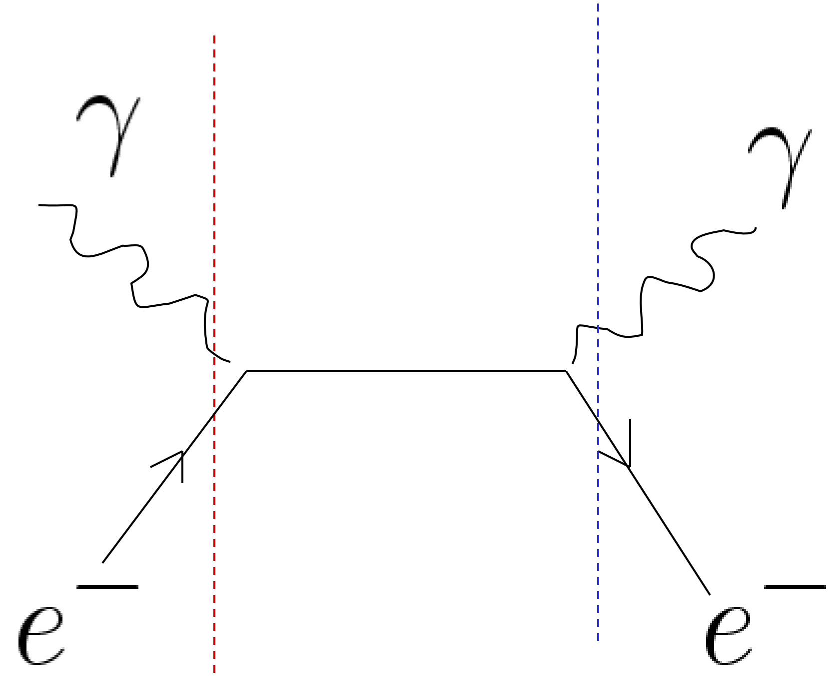


In empty space momentum and energy
cannot be simultaneously conserved

Pair production

$$e^- + e^+ = \gamma + \gamma$$





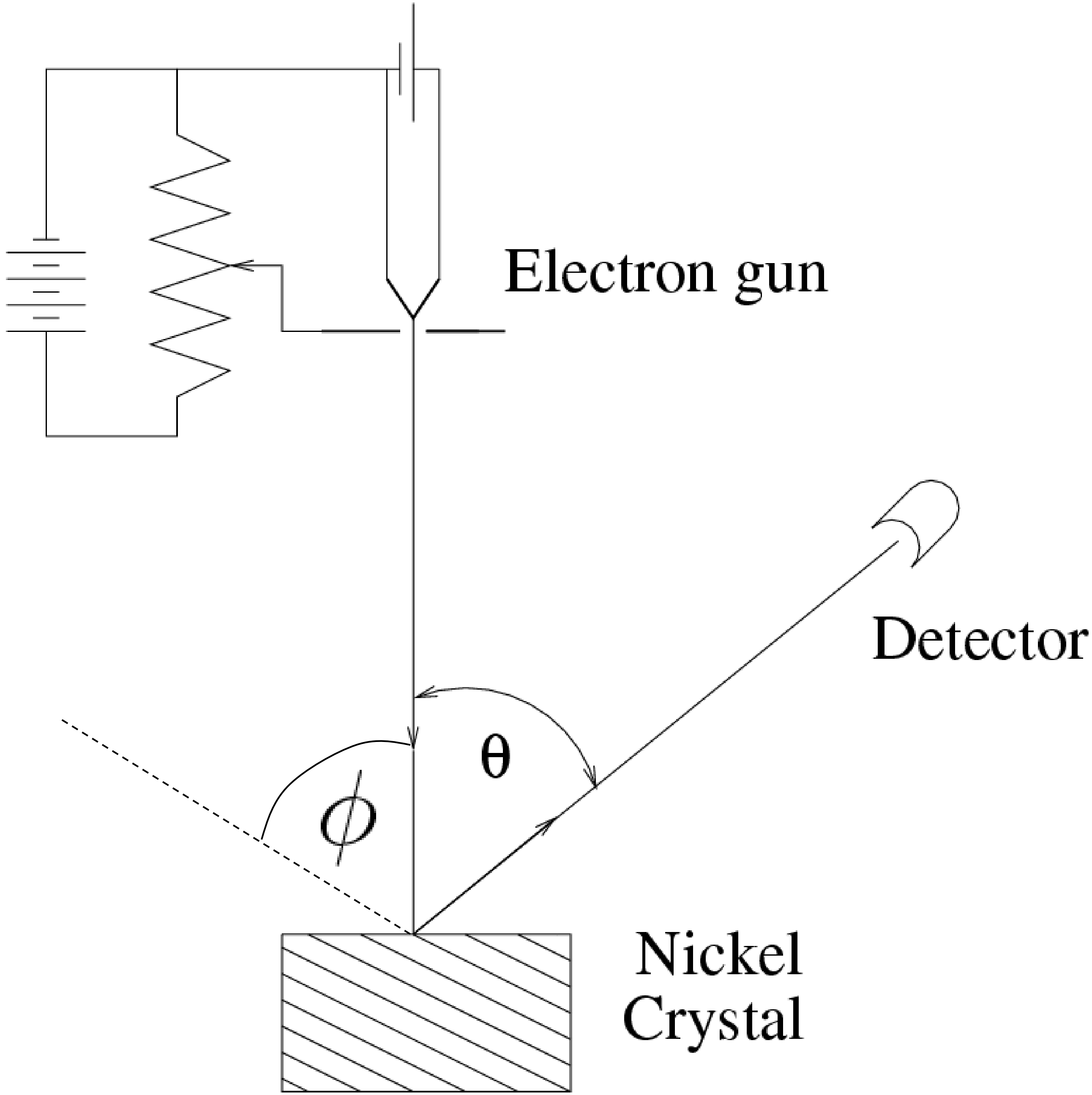
Compton scattering

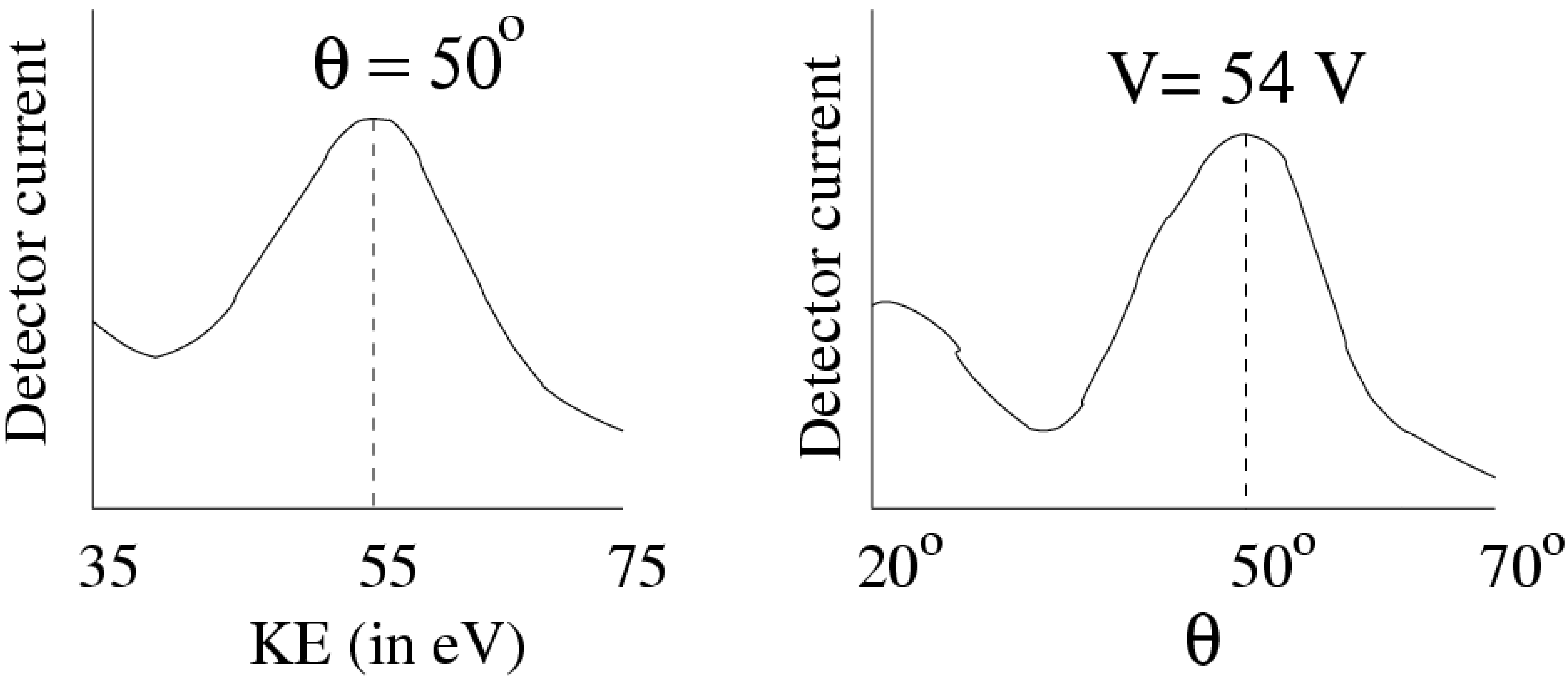
Particles behaving as waves

Electron diffraction

Davisson –Germer (USA)
and Thompson (UK) (1927)

Electron microscope


Electron gun
Detector
θ
ϕ
Nickel
Crystal


Detector current
θ = 50°
35
55
75
KE (in eV)
Detector current
V= 54 V
20°
50°
70°
θ

$$d = 0.91A^{\circ}$$

$$n\lambda = 2d\sin\phi$$

$$n = 1$$

$$\lambda = 2 \times 0.91 \times \sin 65^{\circ} = 1.65A^{\circ}$$

$$m_0c^2 = (9.1\times10^{-31})(3\times10^8)^2 = 8.19\times10^{-14}J$$

$$m_0c^2 = 8.19\times10^{-14}/1.6\times10^{-19} \simeq 511\,keV$$

KE=54 eV is non relativistic

$$KE = \frac{1}{2} m_0 v^2$$

$$p = m_0 v = \sqrt{2m_0 \times KE}$$

$$= \sqrt{2(9.1 \times 10^{-31})(54)(1.6 \times 10^{-19})}$$

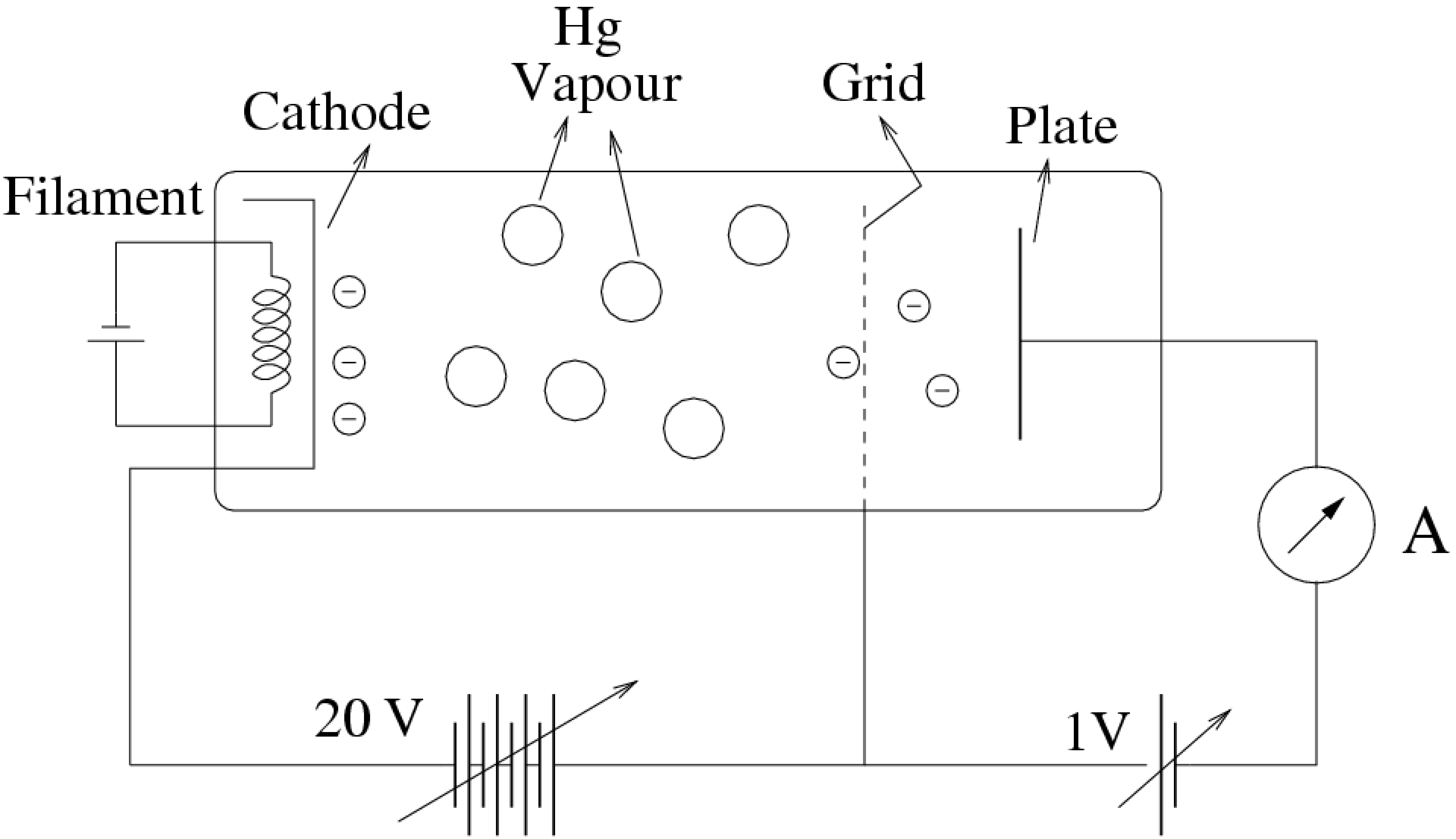
$$p = 4.0 \times 10^{-24} \ kg \ m/s$$

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{4.0 \times 10^{-24}}$$

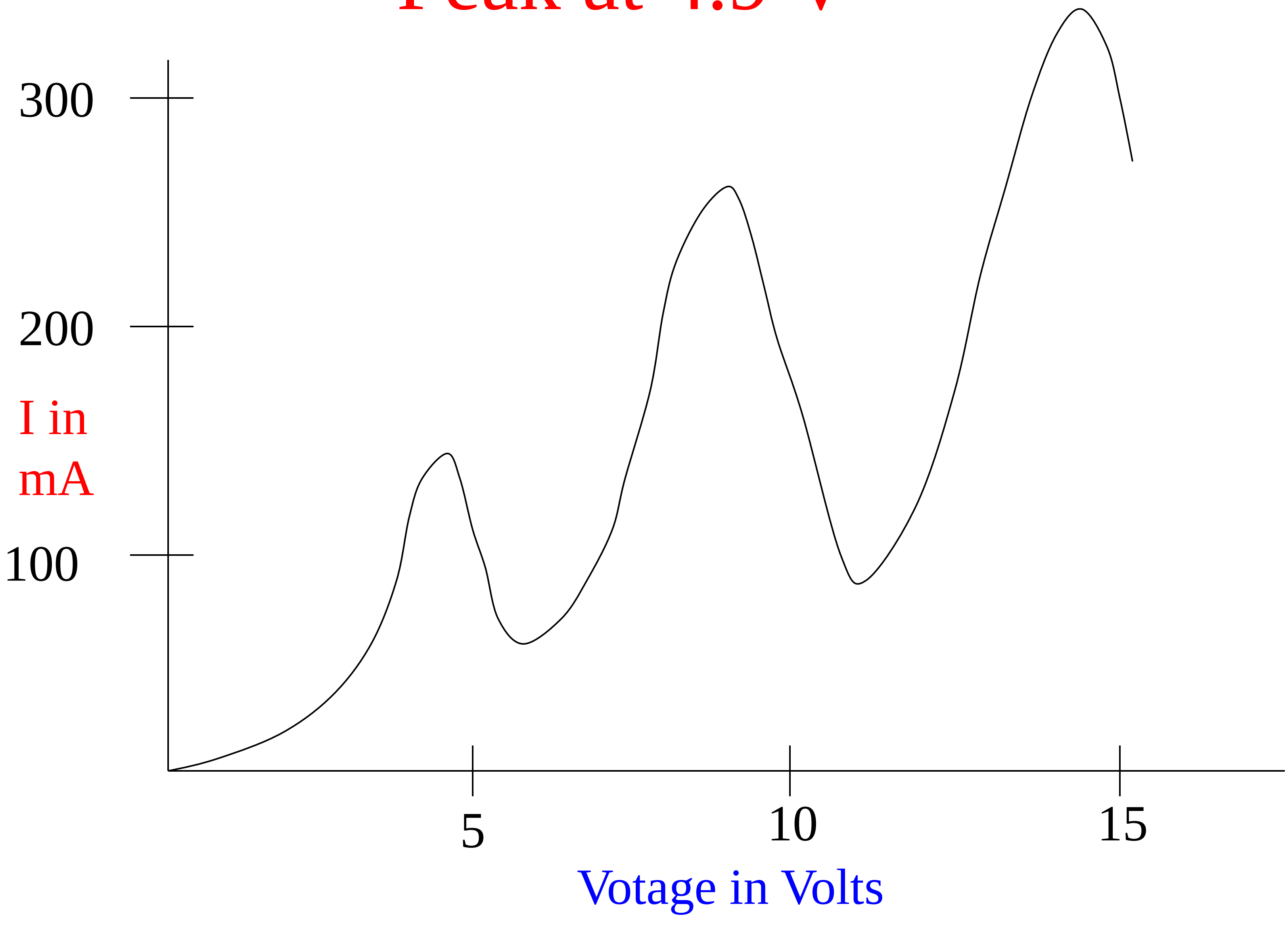
$$\lambda = 1.66 \times 10^{-10}\ m = 1.66\ A^{\circ}$$

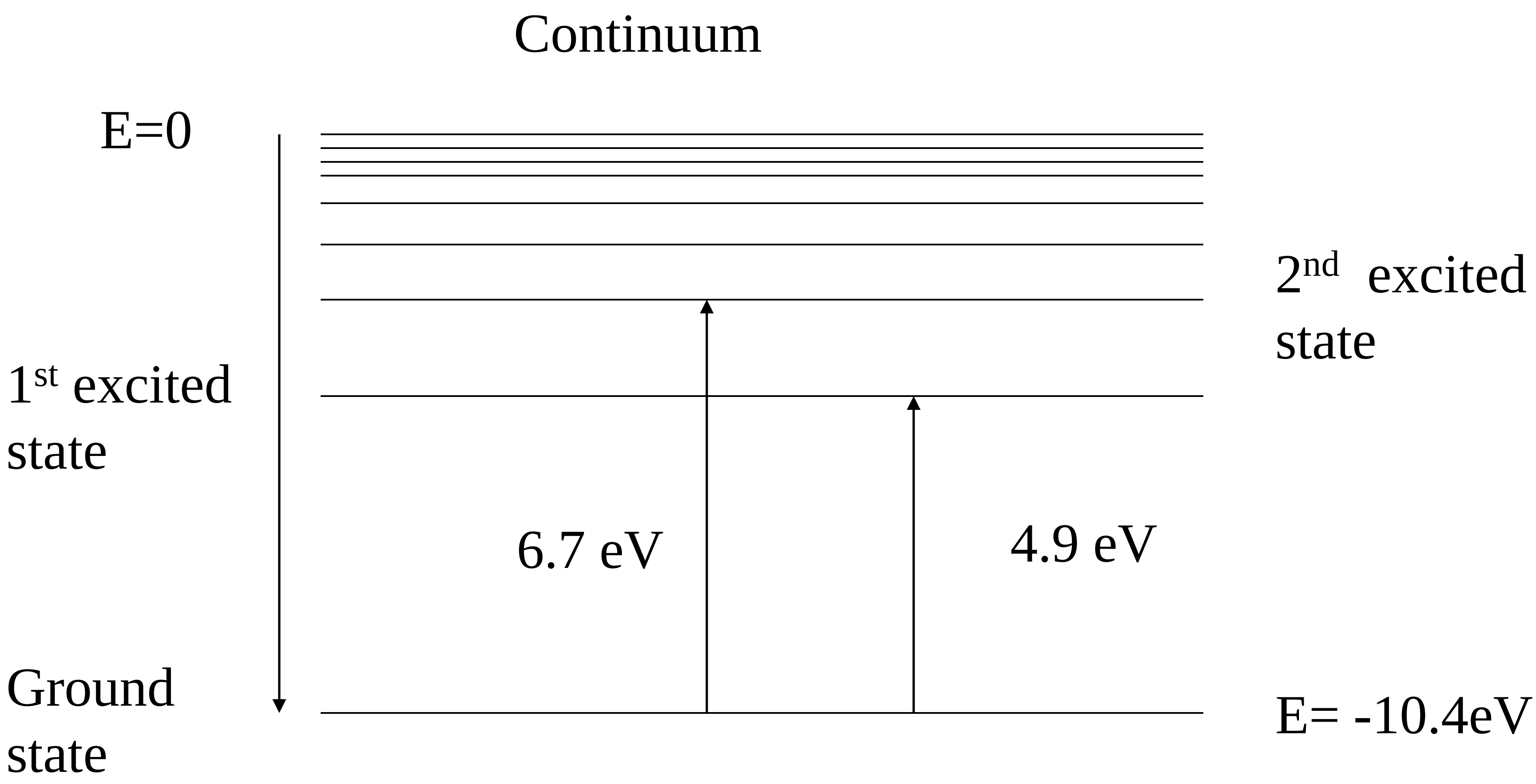
Confirmation of discrete energy levels in atom

Franck and Hertz experiment (1914)


Hg
Vapour
Cathode
Grid
Plate
Filament
A
20 V
1V

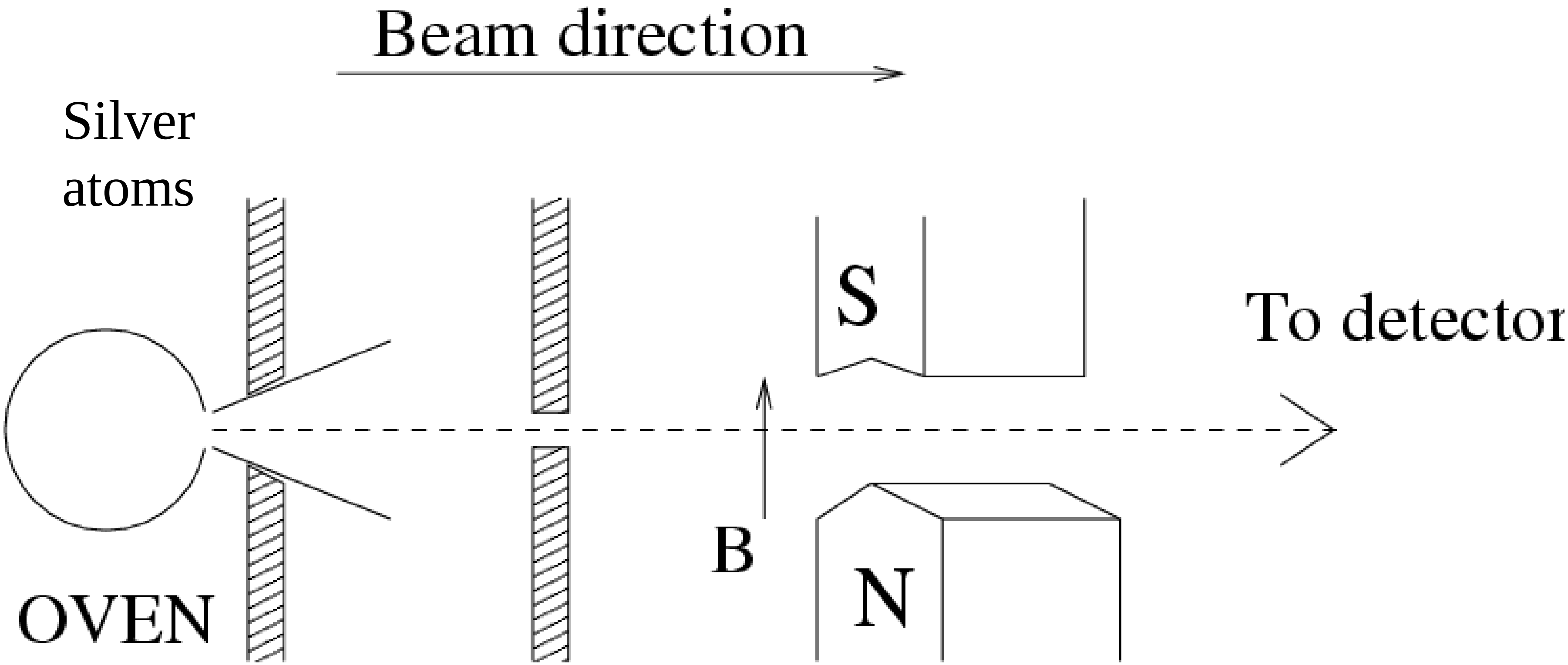
Peak at 4.9 V



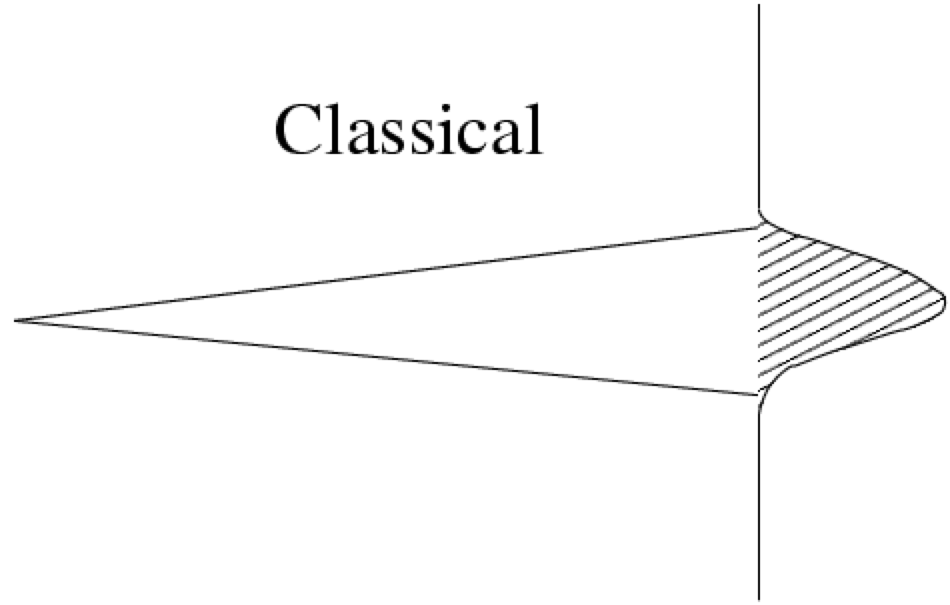

Continuum
E=0
1st excited state
2nd excited state
6.7 eV
4.9 eV
Ground state
E= -10.4eV

Electron spin

Stern and Gerlach Experiment

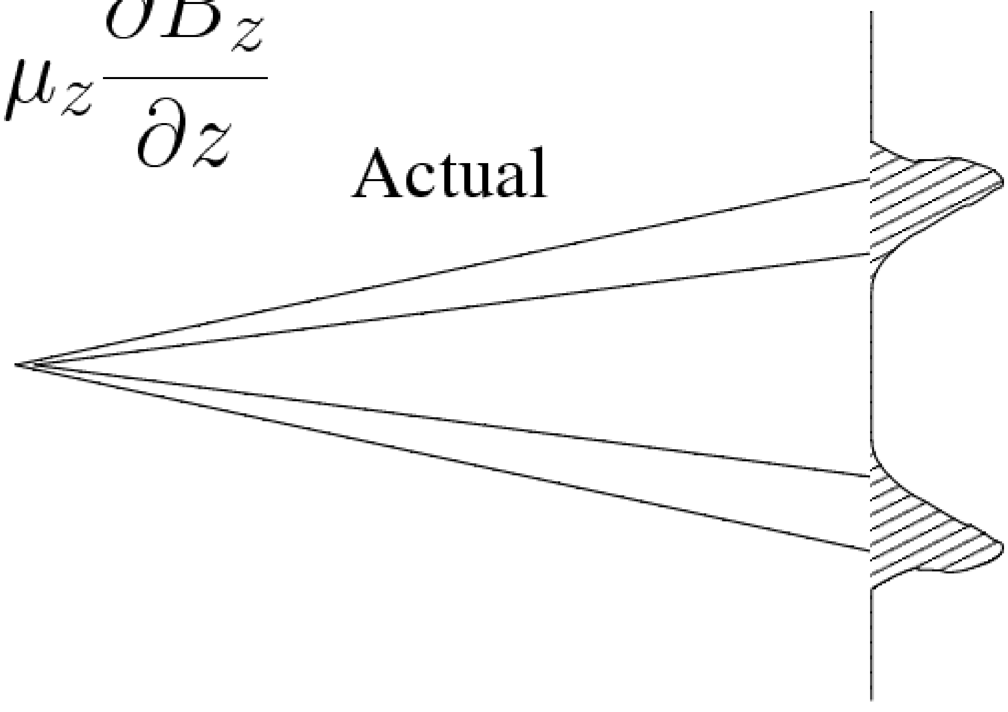


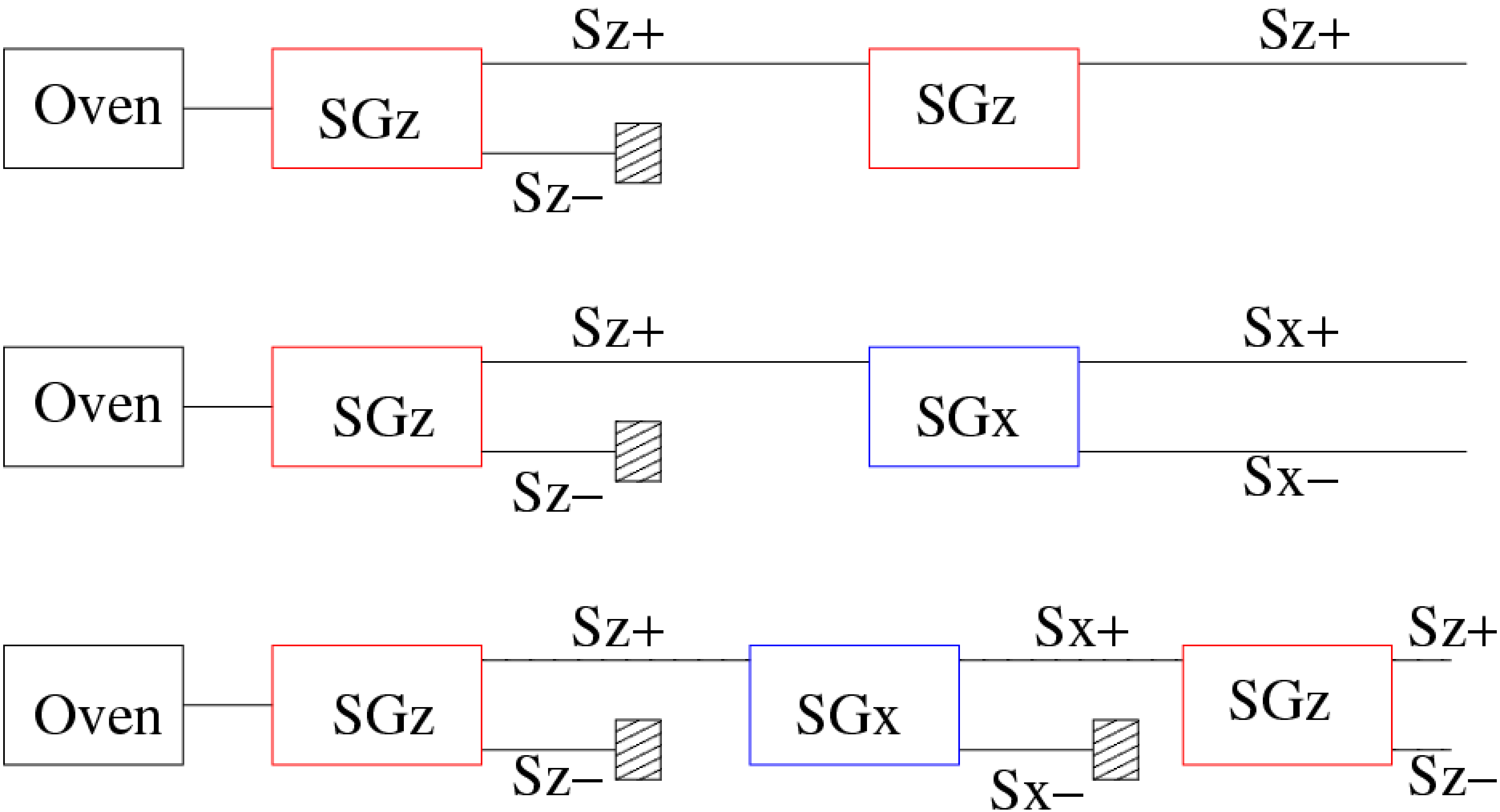
Beam direction
Silver
atoms
S
To detector
B
N
OVEN

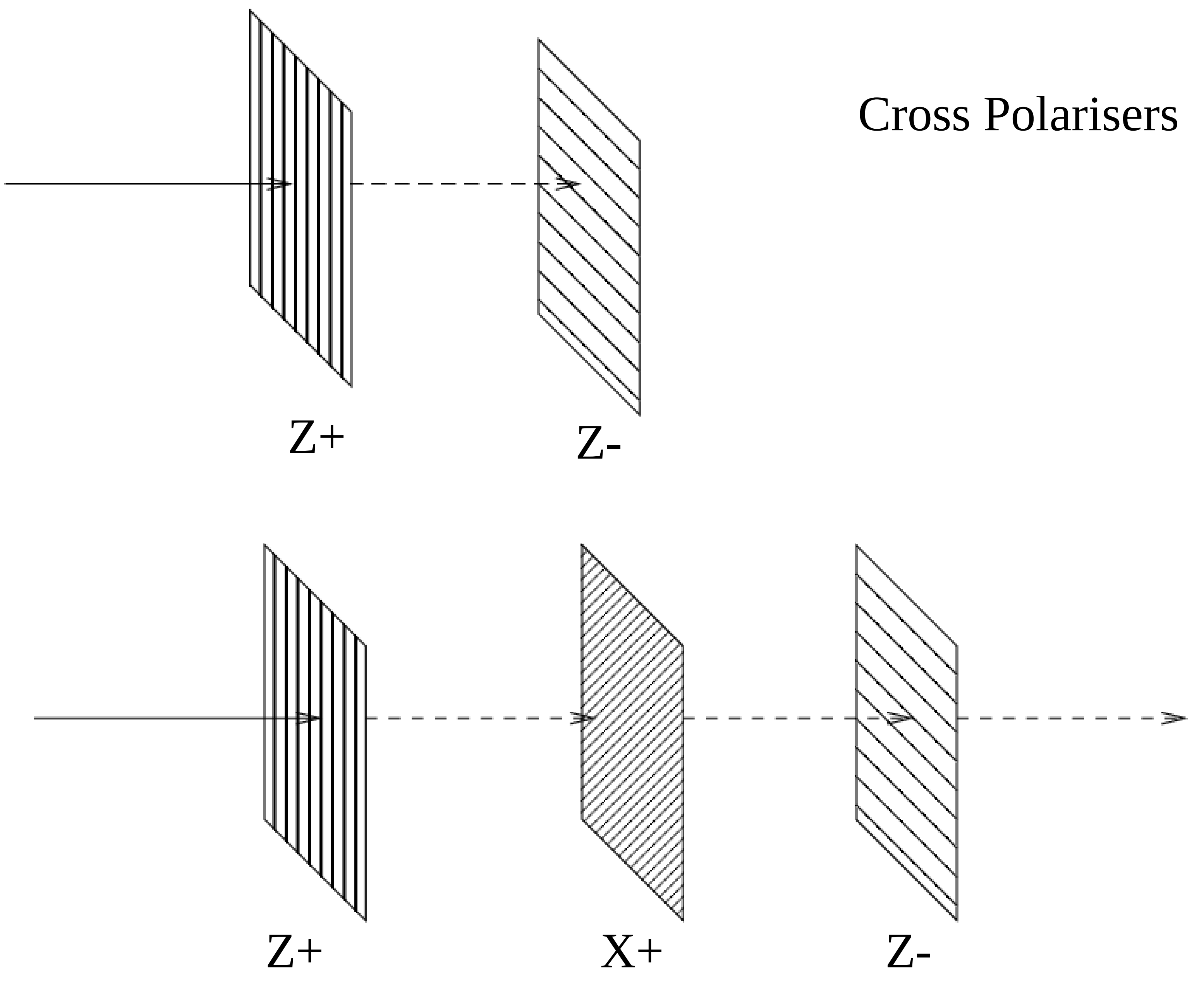


$$\mu = \frac{e}{m_0 c}\mathbf{S}$$

$$F_z = \frac{\partial}{\partial z}(\mu \cdot \mathbf{B}) = \mu_z \frac{\partial B_z}{\partial z}$$




Oven
SGz
Sz+
Sz−
SGz
Sz+
Oven
SGz
Sz+
Sz−
SGx
Sx+
Sx−
Oven
SGz
Sz+
Sz−
SGx
Sx+
Sx−
SGz
Sz+
Sz−


Cross Polarisers
Z+
Z-
Z+
X+
Z-