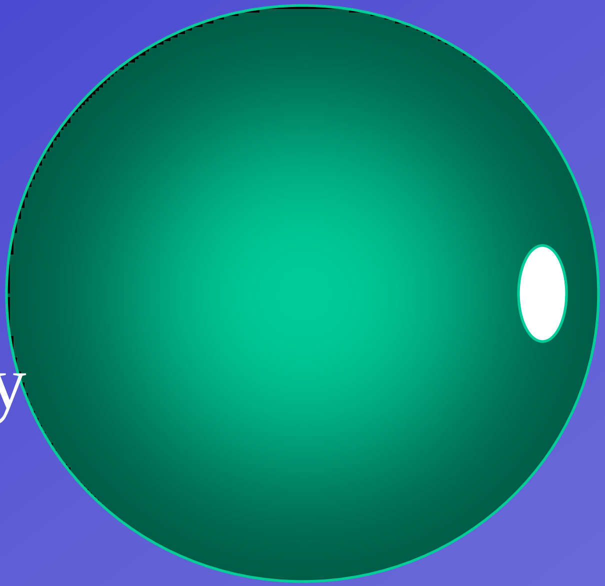
Photon

Agenda today

1. Photon: the particle nature of radiation
2. Blackbody radiation
3. photoelectric effect
4. Compton effect

Blackbody radiation(黑体辐射）

Blackbody is a body
that would absorb all the
radiation falling on it



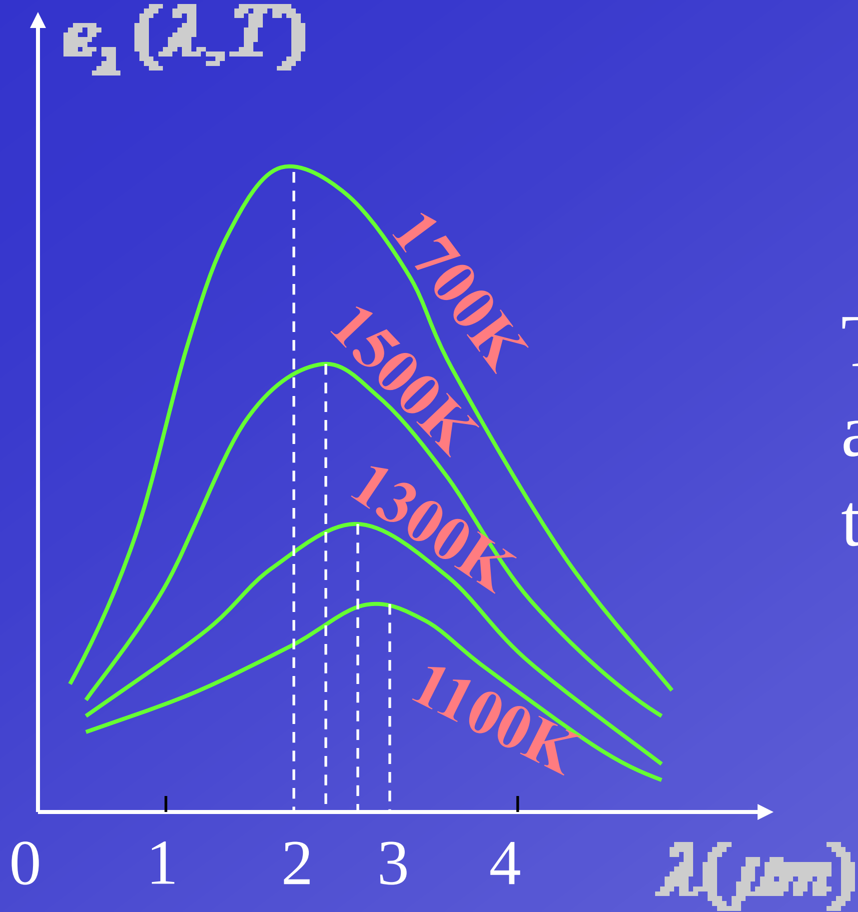
Radiation intensity of blackbody

（单色辐出度）

Energy of electromagnetic
waves of wavelength from
λ to λ+dλ by unit surface
of blackbody in unit time
interval.

$$e_\lambda(\lambda, T) = \frac{dE_\lambda}{d\lambda}$$

A good emitter is also a good absorber



The rate of radiation

（总辐出度）

The energy emitted by unit area of surface per unit time.

$$E(T) = \int_0^{\infty} e(\lambda, T)\, d\lambda$$

Stefan-Boltzmann equation

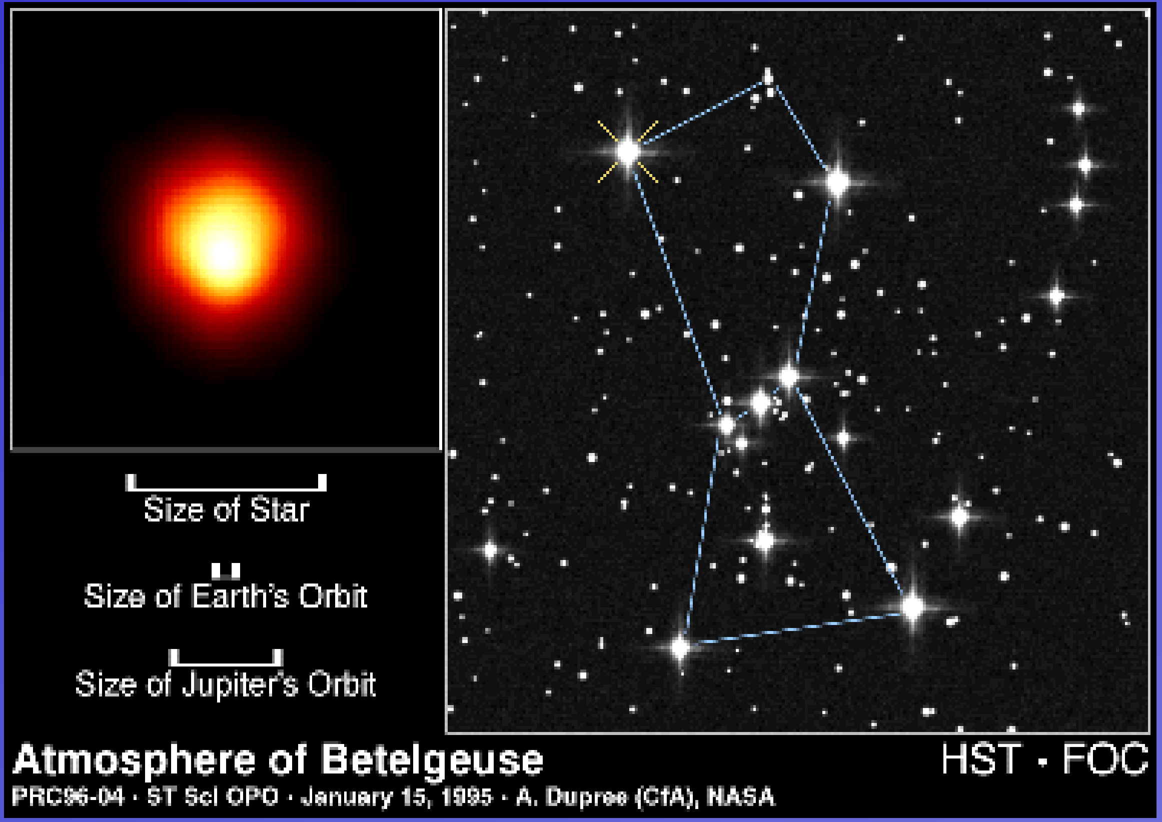
$$\boxed{E_o(T) = \sigma_o T^4}$$

Stefan constant: $\sigma_o = 5.6703 \times 10^{-8} (W \cdot m^{-2} \cdot K^{-4})$

Wien's Law（维恩位移定律）

$$\lambda_m \cdot T = b$$

$$b = 2.898 \times 10^{-3} (m \cdot K)$$

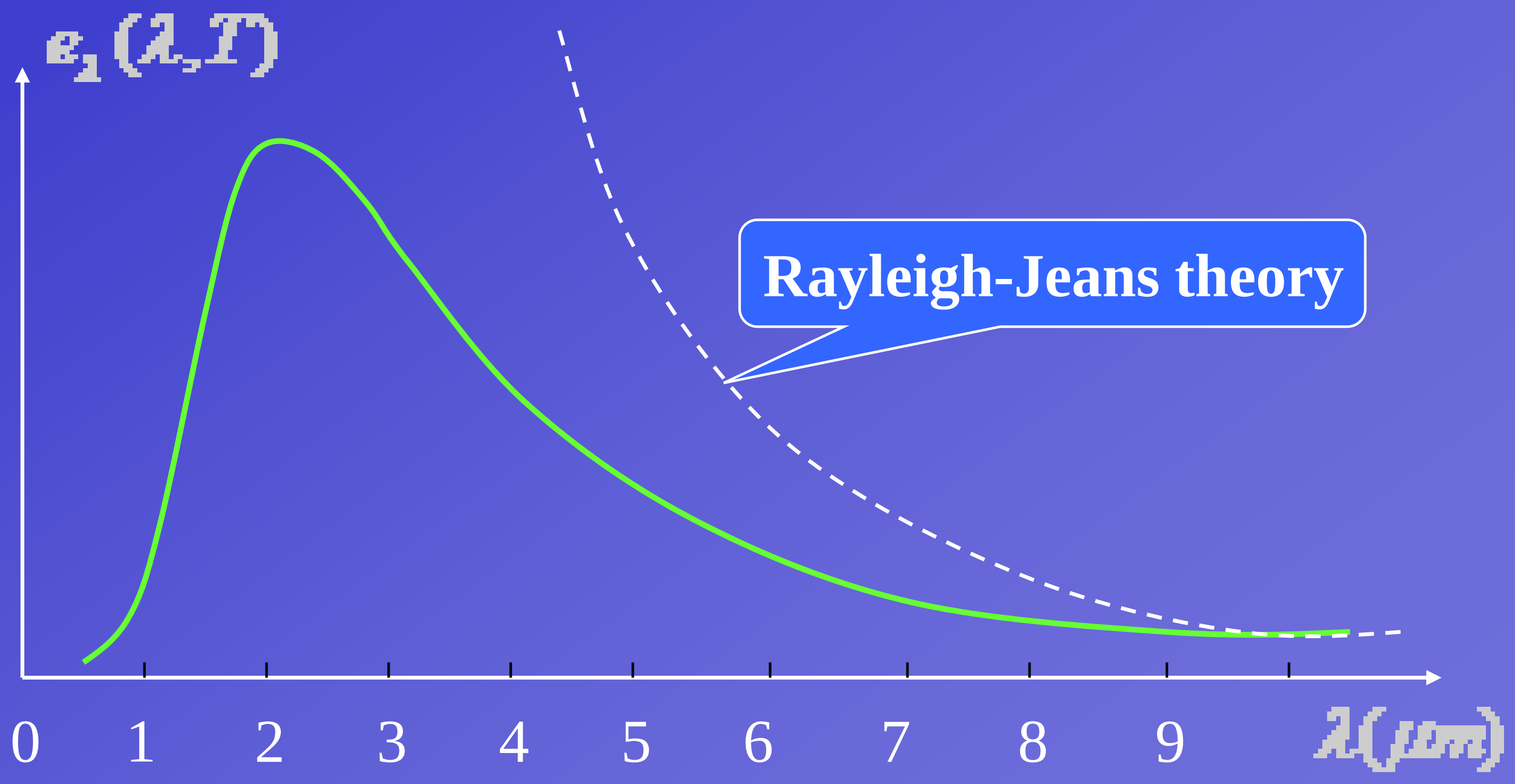


We can measure the surface temperature of stars by its

peak of radiation curve

The ultraviolet catastrophe （紫外灾难）

$$e_o(\lambda, T) = c_1 \cdot \lambda^{-4} \cdot T$$



Planck’s explanation

Quantization of energy: photon（光子）

$$\boxed{\varepsilon = hf}$$

$$h = 6.626\times10^{-34}\,J\cdot s$$

$$e_o(\lambda,T) = \frac{2\pi hc^2\lambda^{-5}}{e^{\frac{hc}{\lambda kT}} - 1}$$

Momentum of photon

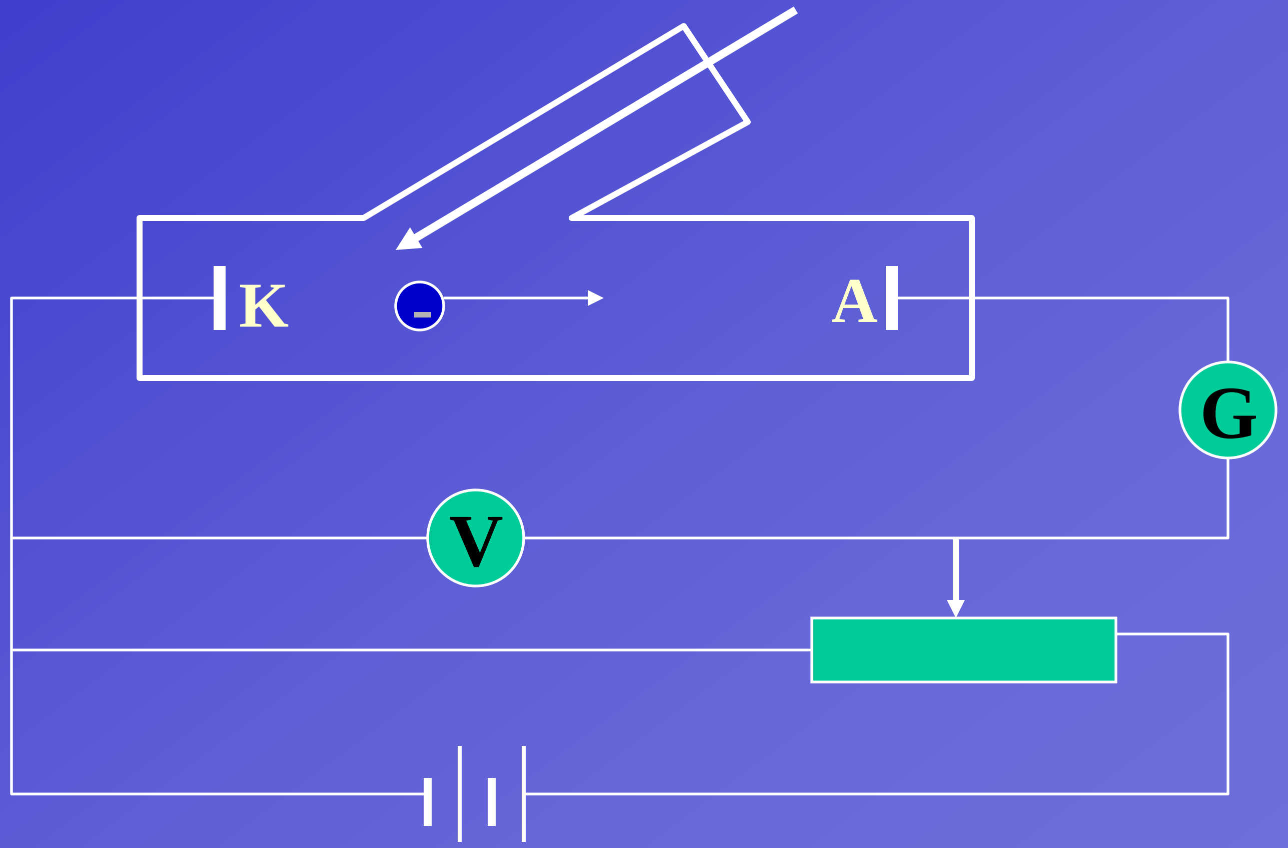
The rest mass of photon is zero

By theory of relativity

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

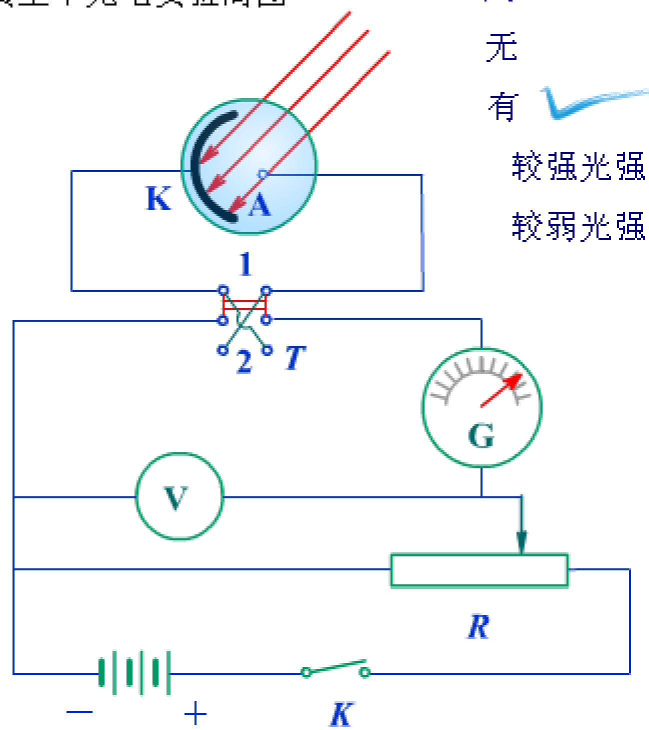
$$p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$$

Photoelectric effect（光电效应）



光 电 效 应

真空中光电实验简图



入射光：

无

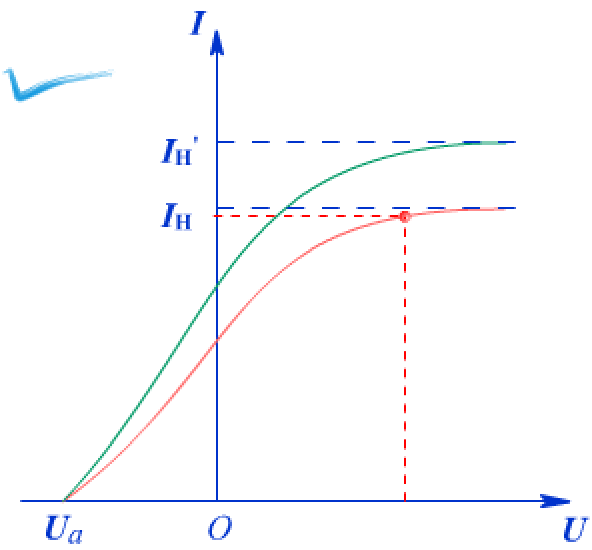
有

较强光强

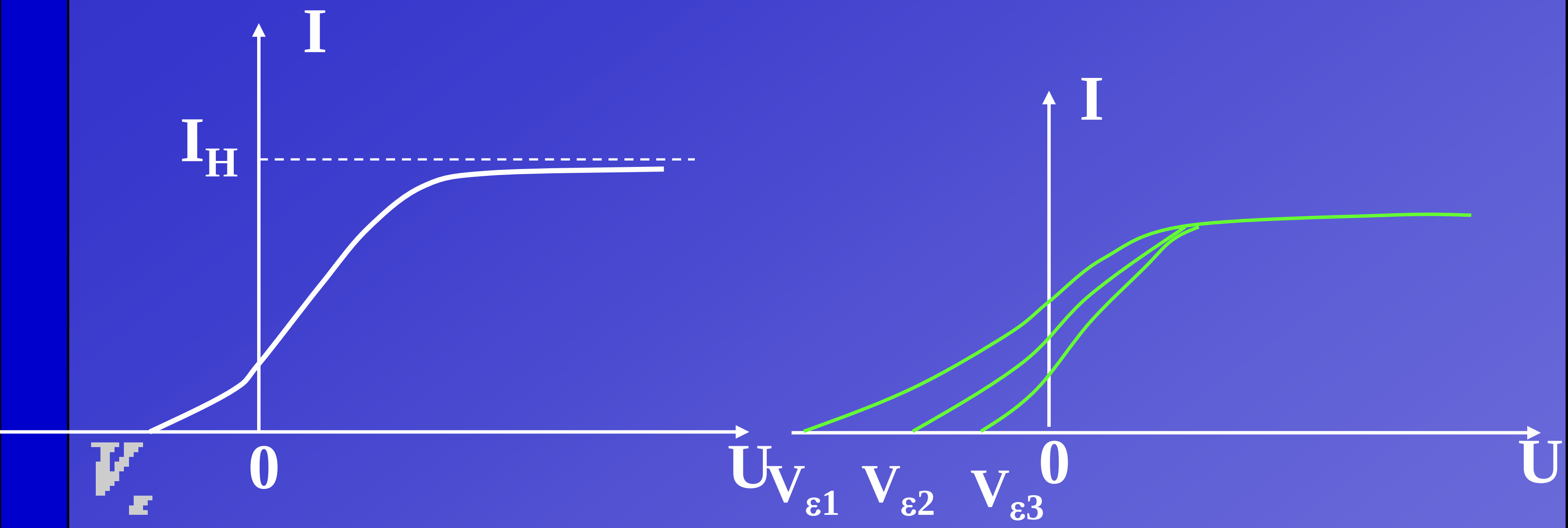
较弱光强

提示：

换向开关T可变。滑动变阻器阻值可调，入射光可调。



电势差和光电流关系曲线



Lenard’s result

Experimental facts on photoelectric effects

1. Electrons will be emitted when the plate is imposed in radiation.

2.electron will emitted only if the frequency of the radiation is high enough.

3.the time delay between the arrival of radiation and the appearance of photoelectron is not measurable.

4. The magnitude of current is determined by the intensity of incident rays.

Difficulty in explanation by classical theory

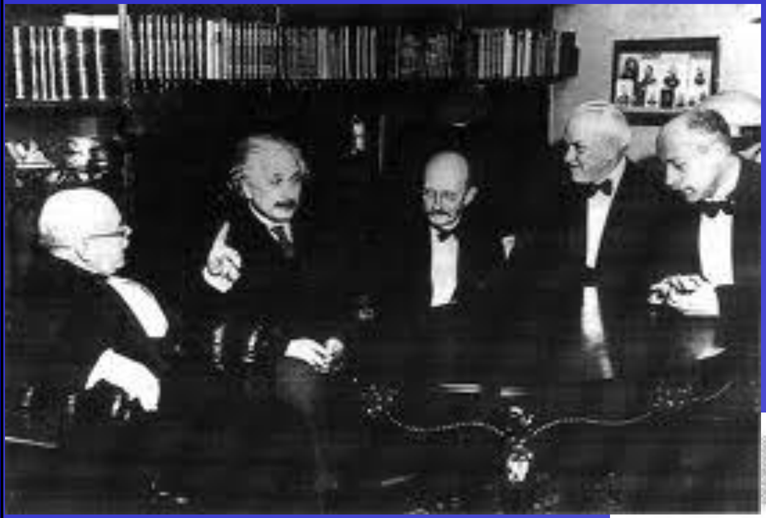
Einstein's explanation

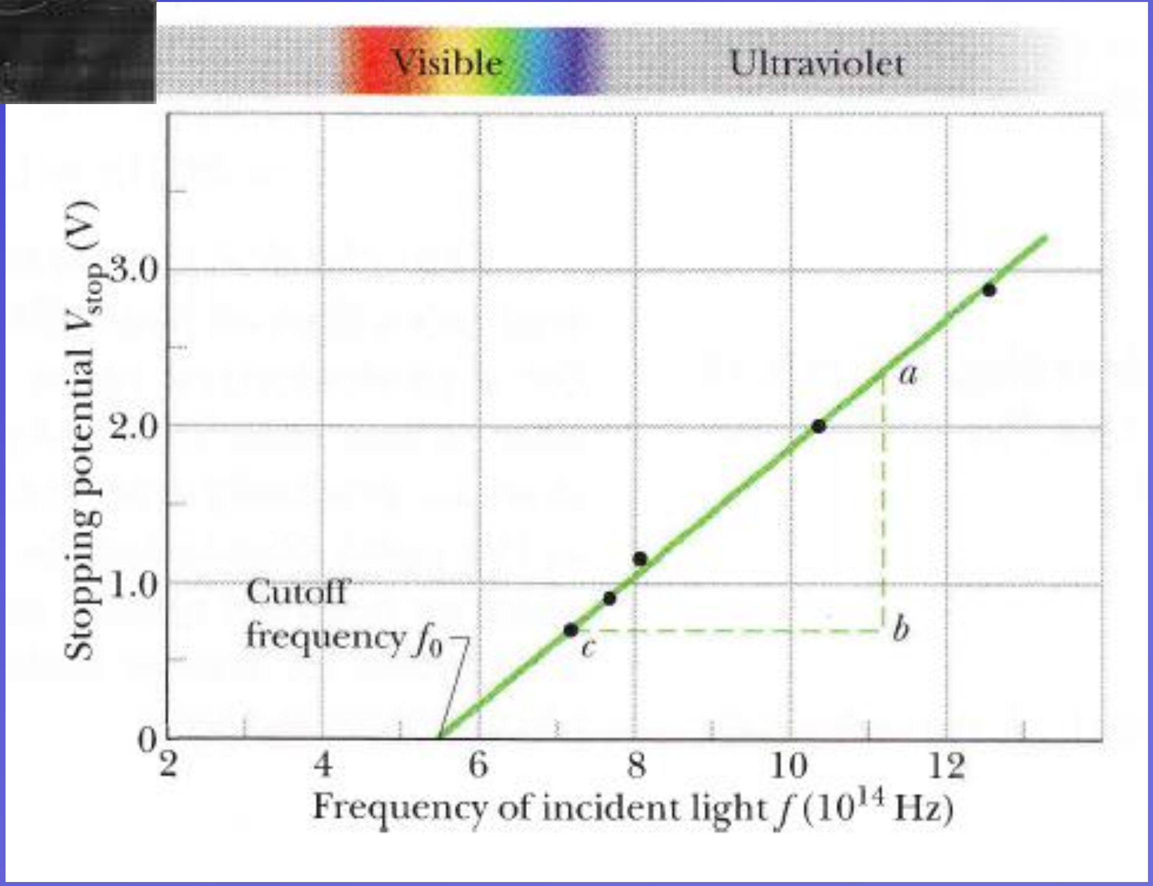
$$hf = K_{max} + \Phi$$

Where Φ is called work function of the metal （脱出功）

cutoff frequency（截止频率）

$$f_0 = \frac{\Phi}{h}$$

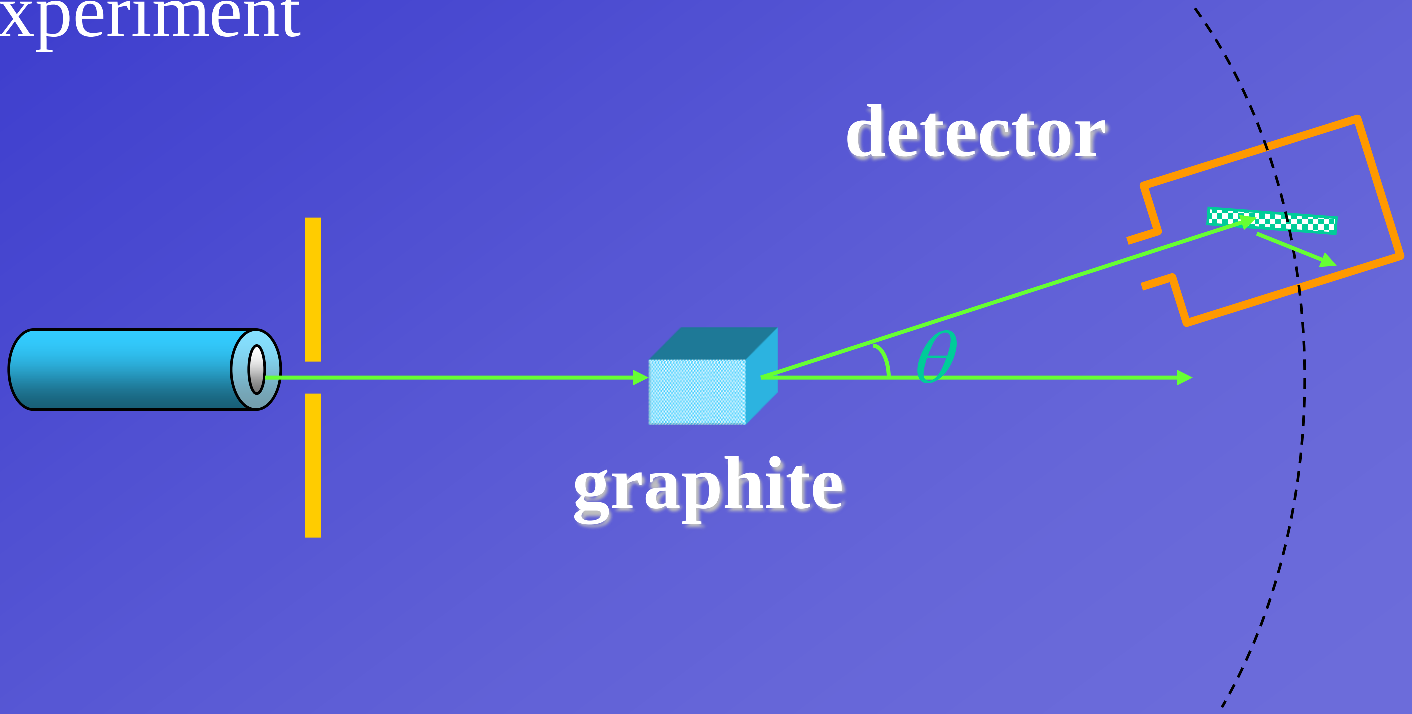




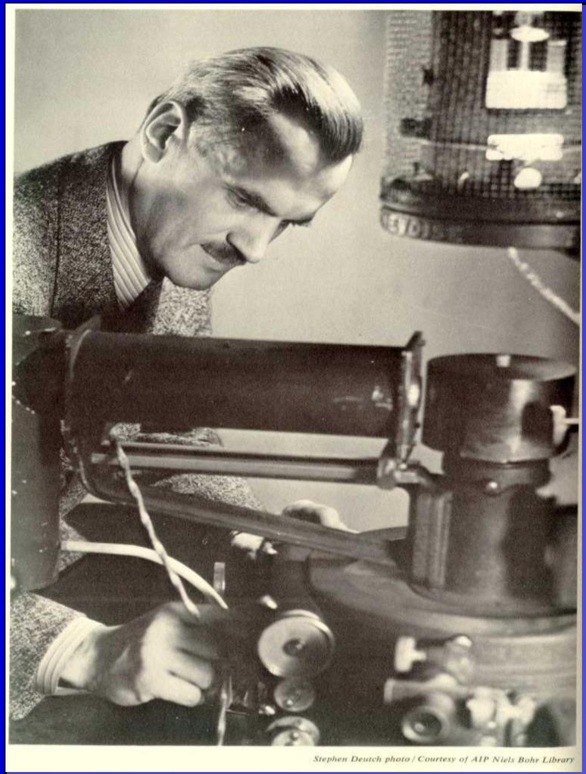
Visible
Ultraviolet
Stopping potential V_{stop} (V)
3.0
2.0
1.0
0
2
4
6
8
10
12
Frequency of incident light f (10^{14} Hz)
Cutoff frequency f_0
a
b
c

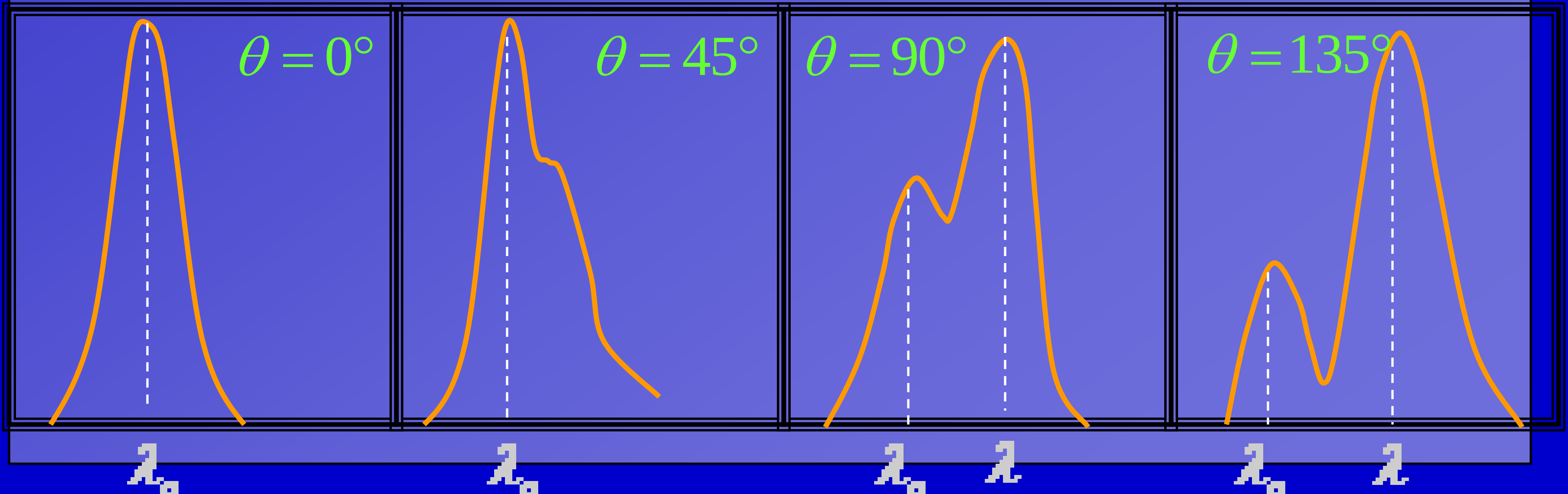
Compton effect（康普顿效应）

The apparatus for the experiment

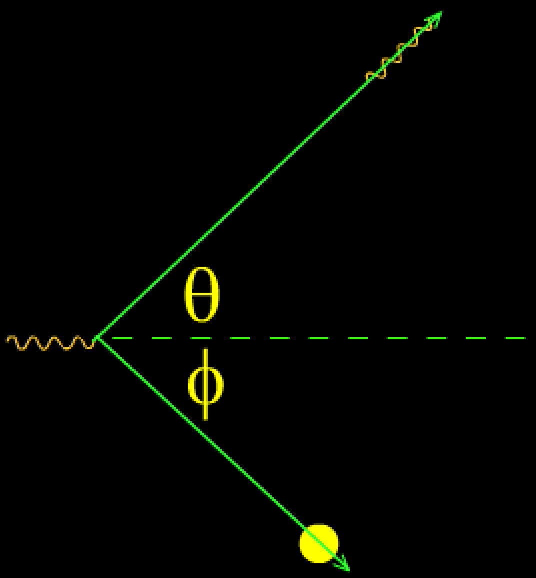


The results of experiment





康普顿效应



$$\lambda - \lambda_0 = \frac{2h}{m_0 c} Sin^2\frac{\theta}{2}$$

康普顿散射可看成是入射光子
与自由电子之间的弹性碰撞过程

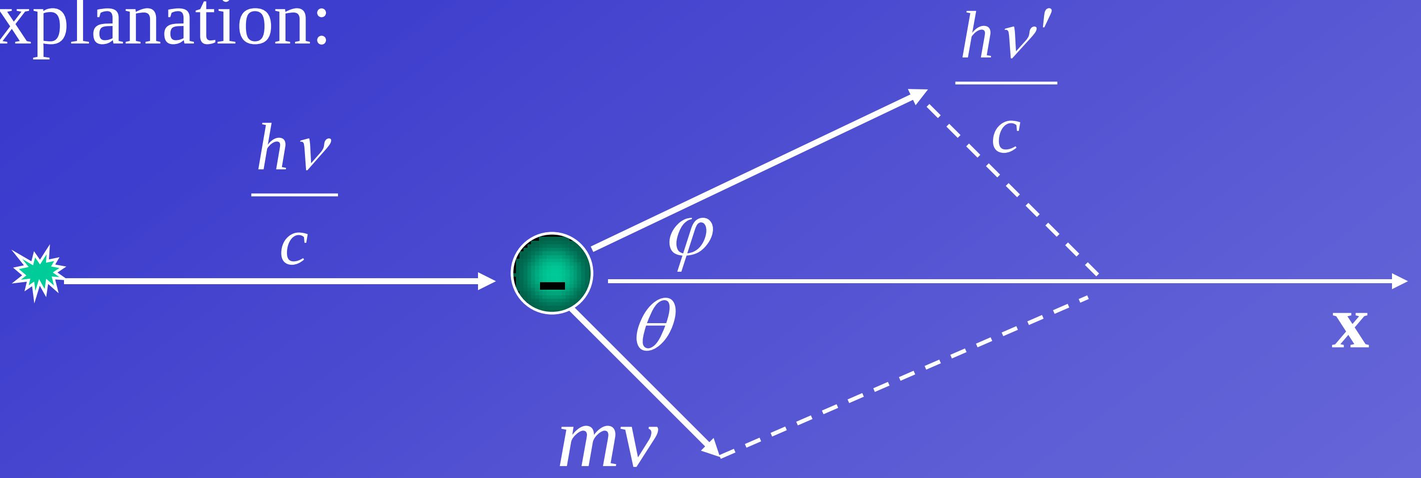
1. The shift in wavelength is determined by the scattering angler.

2. The effect is more significant with scatter object with small atom number.

3. The shift in wavelength does not change with different scatter object.

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_o c}(1 - \cos\varphi)$$

The explanation:



The conservation law of momentum

$$(mv)^2 = \left(\frac{h\nu}{c}\right)^2 + \left(\frac{h\nu'}{c}\right)^2 - 2\cdot\frac{h\nu}{c}\cdot\frac{h\nu'}{c}\cos\varphi$$

The conservation law of energy

$$h\nu + m_o c^2 = h\nu' + mc^2 \qquad m = \frac{m_o}{\sqrt{1 - v^2/c^2}}$$

$$\boxed{\Delta\lambda = \lambda' - \lambda = \frac{h}{m_o c}\left(1 - \cos\varphi\right)}$$

Compton wavelength $\frac{h}{m_o c} = 2.43 \times 10^{-12} m$