Chapter 45. The Nature of Light
(光的本质)

Prof. Fang Minghu

Department of Physics

Zhejiang Univeristy

Tel: 0571-87951913

Email: mhfang@zju.edu.cn

45-1 Introducing The Photon (光子概念的引入)

Interference (干涉), diffraction (衍射)……

wave-like

Black-body radiation (黑体辐射), Photoelectric Effect (光电效应), Compton Effect (康普顿效应)…..

Particle-like

Light is *both* a particle and a wave (**光既是粒子又是波**).

Light is neither a classical particle nor a classical wave.

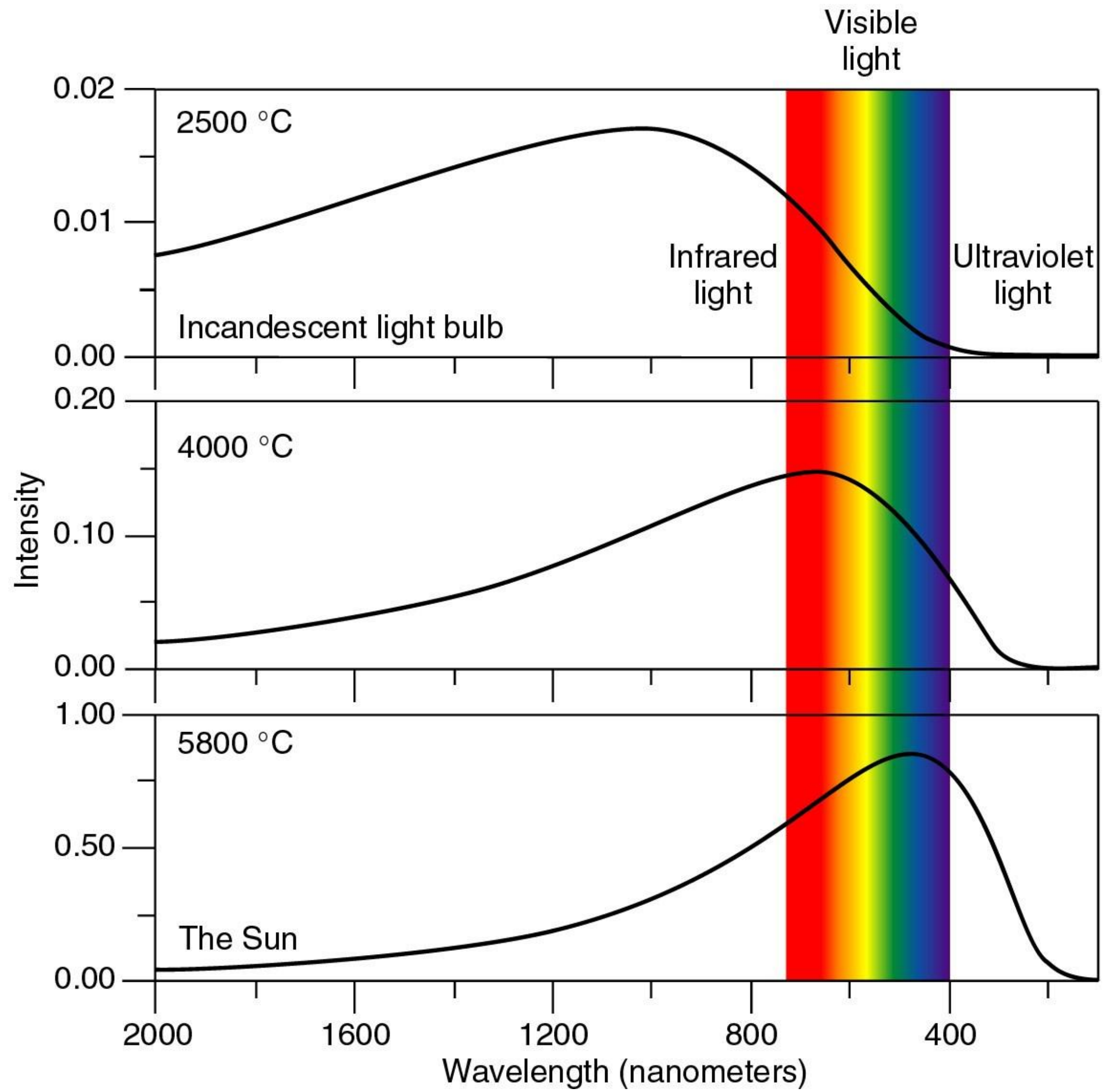
(既**不是传统的粒子也不是传统的波**)

Thermal radiation （热辐射）

—the sun light, incandescent (白炽灯)

普通灯泡, 炭火

(T>1000°C)



45-2 Black-Body Radiation (黑体辐射)

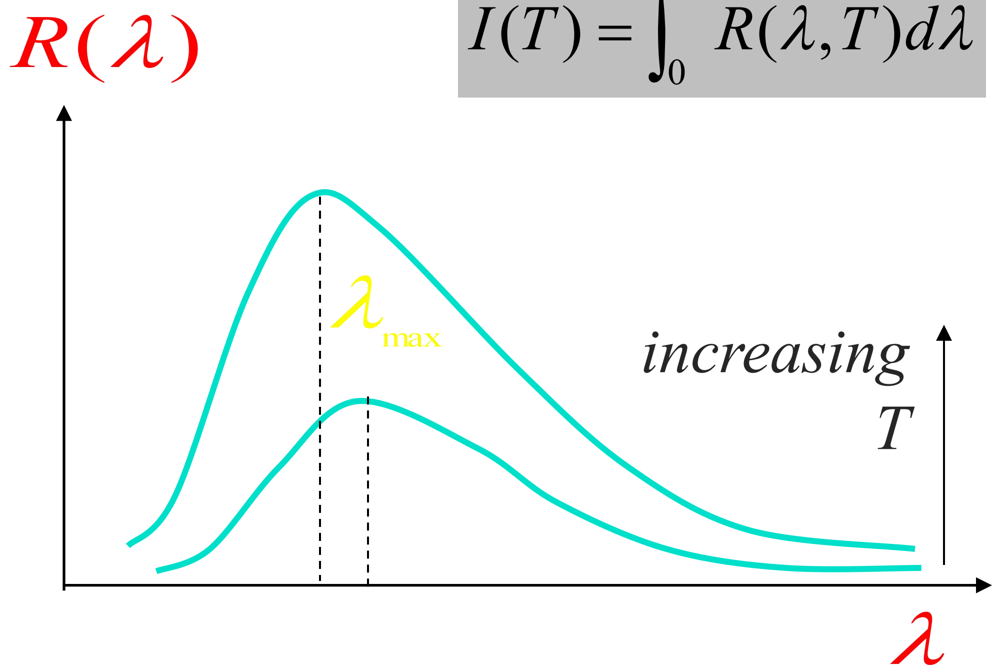
- **Stefan-Boltzmann law**
  —The total radiated energy per area:

$$R(\lambda,T)=\frac{dI}{d\lambda}$$

$$I(T)=\int_0^\infty R(\lambda,T)d\lambda$$

$$I(T)=\sigma T^4$$

$$\sigma=5.67\times10^{-8}\,\mathrm{W\cdot m^{-2}\cdot K^{-4}}$$



- **Wien displacement law:**

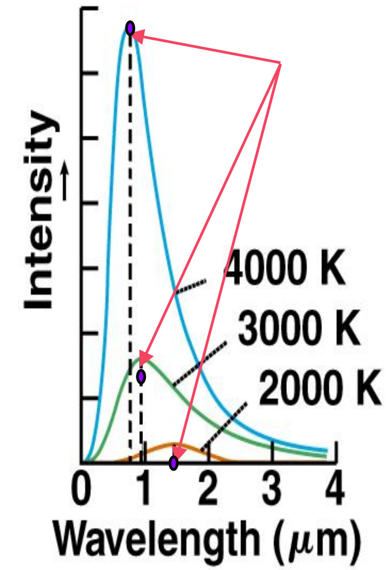
$$T\lambda_{\mathrm{m}}=b$$

$$b=2.898\times10^{-3}\,\mathrm{m\cdot K}$$

With a λ_m of 500 nm for sun radiation, the temperature of sun:

$$T_{sun}=b/\lambda_m\approx6000\,\mathrm{K}$$

Planck's Radiation Law (普朗克辐射定律)



- Wien's line at short wavelength:
- Reyleigh-Jeans line at long wavelengths:
- Planck's Law (1900):

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

$$h=6.63\times10^{-34}\,\mathrm{J\cdot s}$$

- Wien's Law:

$$T\lambda_{\mathrm{m}}=b \qquad \frac{h\nu}{kT}=\frac{\hbar\omega}{kT}=2.82$$

Born in 1858

Planck's function fits the observed data

Max Planck assumed energy of photon is quantized.

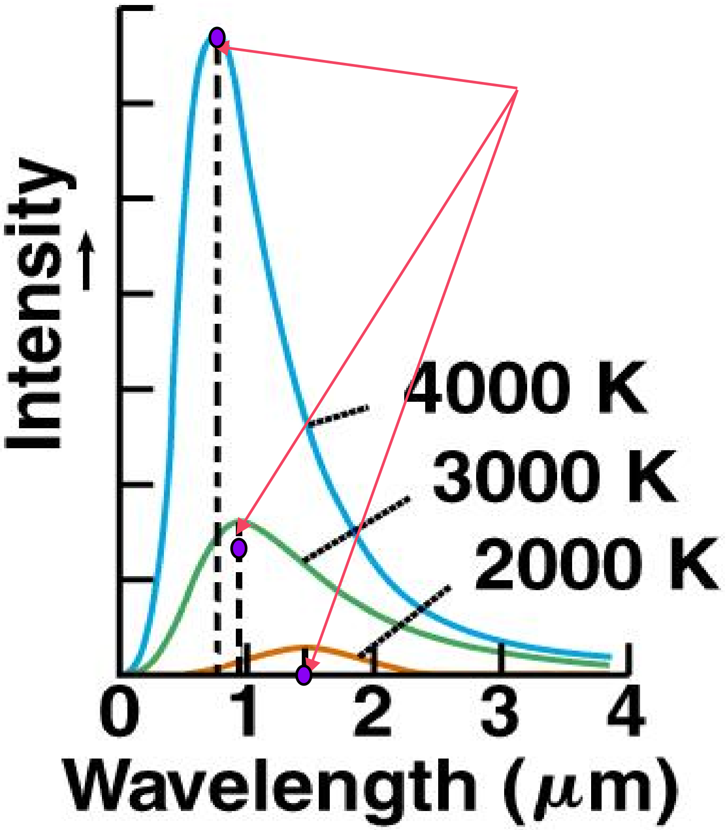
$$E = h\nu,$$

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

The beginning of quantum physics.

1905, Einstein introduced *the photon*

Planck(1918), Wien(1911) Noble Prize



Feature of Photon (光子的性质)

- **Wave feature of light:**

$$\vec{E} = \vec{E}_m \cos(\vec{k}\cdot\vec{r} - \omega t), \qquad \vec{E} = \vec{E}_m e^{i(\vec{k}\cdot\vec{r} - \omega t)}$$

$$k = \frac{2\pi}{\lambda}, \quad \text{wave vector,} \quad \omega \text{ frequency}$$

- **Photon—quantum of light:**

$$M_{\text{photon}} = 0$$

$$E = h\nu = \hbar\omega$$

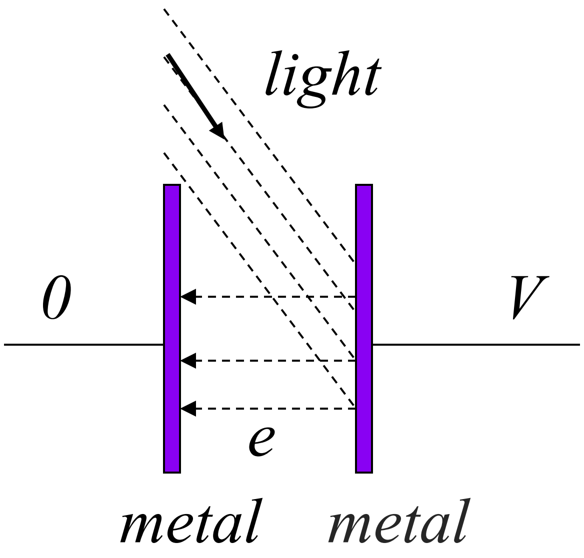
$$p = \frac{E}{c} = \frac{h}{\lambda} = \hbar k$$

45-3 Photoelectric Effect (光电效应)

- Kinetic energy:

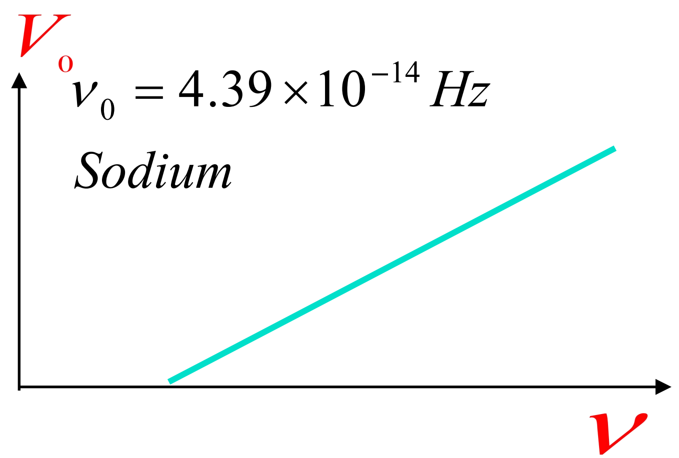
$$K = \frac{1}{2} m v^2 = eV_0$$

V_0 is stopping potential



- Problems facing to classical physics:

- **1. Intensity problem**
  2. Frequency problem
  3. Time delay problem



Einstein's Photon Theory (1921 Nobel Prize)

- **Quantum of light (later comes photon) was first introduced by Einstein**

$$h\nu = K + \phi = \frac{1}{2}mv^2 + \phi$$

ϕ is work function

- **Cutoff frequency:**

$$h\nu_o = \phi$$

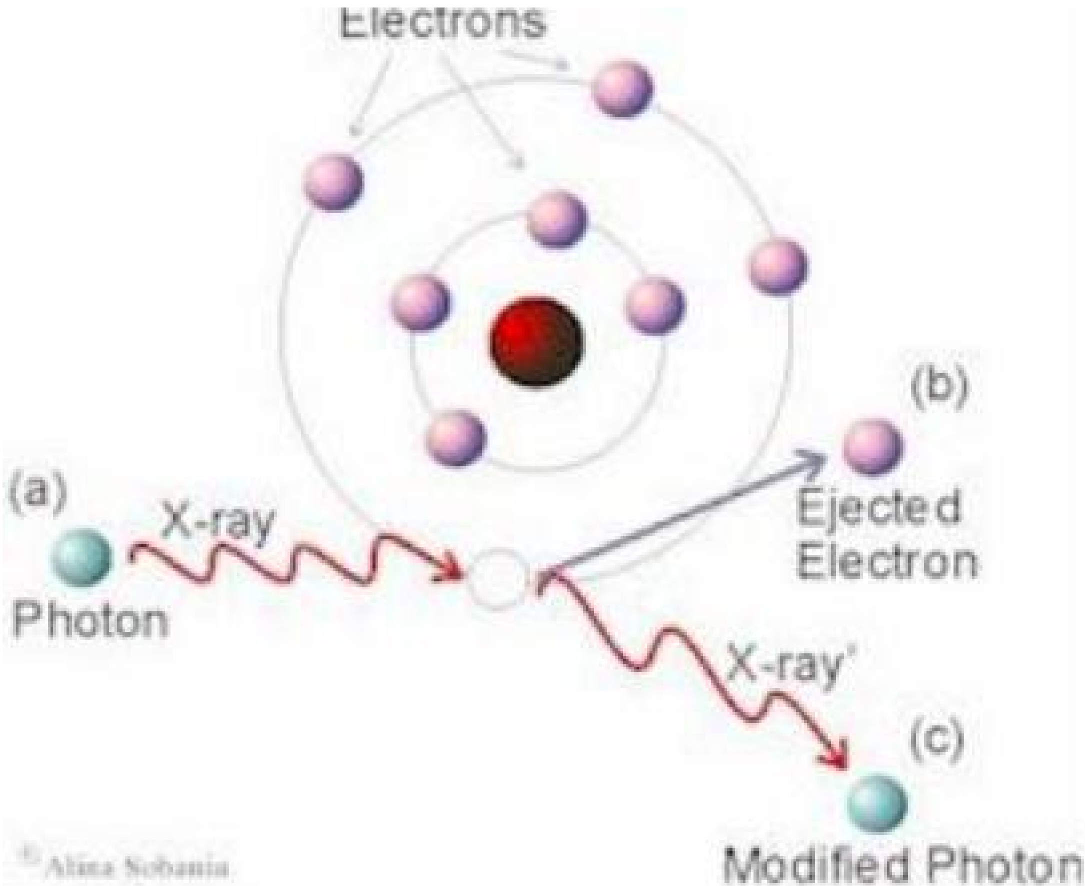
$$1\,\mathrm{eV} : \nu_{eV} = 2.4 \times 10^{14}\,Hz$$

- **Relation between stopping potential and frequency:**

$$V = \frac{h}{e}\nu - \frac{\phi}{e}$$

45-5 Compton Scattering (1923，康普顿散射)

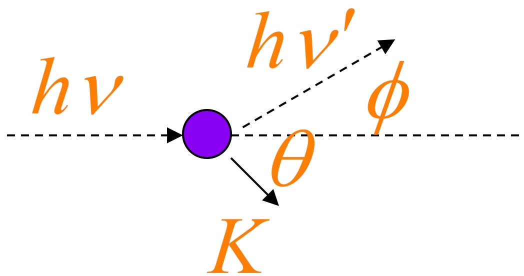
The 1927 Nobel Prize, see Page 1021



Explanation

Photon is already particle:

$$E = h\nu = \hbar\omega, \quad p = \frac{h}{\lambda} = \hbar k$$



- **Scattering by electron:**

$$h\nu + m_0c^2 = h\nu' + mc^2 \Rightarrow \quad \frac{hc}{\lambda_0} = \frac{hc}{\lambda'} + m_0c^2\left[\frac{1}{\sqrt{1-(v/c)^2}} - 1\right]$$

$$\frac{h}{\lambda_0} = \frac{h}{\lambda'}\cos\varphi + \frac{m_0 v}{\sqrt{1-(v/c)^2}}\cos\theta,$$

$$\frac{h}{\lambda_0}\sin\varphi = \frac{m_0 v}{\sqrt{1-(v/c)^2}}\sin\theta$$

$$\boxed{\begin{aligned}\Delta\lambda &= \lambda' - \lambda_0 = \frac{h}{m_0 c}(1-\cos\phi) \\ \textit{where} \quad \lambda_C &= \frac{h}{m_0 c} = 0.00243 \text{ nm}\end{aligned}}$$