Chapter 3: Quantum Physics

Blackbody Radiation

Photoelectric Effect

Compton Effect

P 5: The radius of our Sun is 6.96×10^8 m, and its total power output is 3.77×10^{26} W. (a) Assuming that the Sun's surface emits as a black body, calculate its surface temperature. (b) Using the result, find λ_{max} for the Sun.

Ans:

(a) From Stefans law, $P = Ae\,\sigma\,T^4$

$T = (P/\,A\,\sigma\,e)^{1/4}$ Surface area of Sphere, $A = 4\pi r^2$

$= \{(3.77 \times 10^{26} W)/[4\pi(6.96 \times 10^8 m)^2 \times 5.67 \times 10^{-8} W/m^2.K^4]\}^{1/4}$

$T = 5750$ K

(b) From Wien's Displacement Law, $\lambda_{max} T = 2.898 \times 10^{-3}$ m K,

$\lambda_{max} = (2.898 \times 10^{-3} \text{ m K})/\,T$

$= (2.898 \times 10^{-3} \text{ m K})/5750 \text{ K}$

$\lambda_{max} = 504$ nm

P 4: A blackbody at 7500 K consists of an opening of diameter 0.05 mm, looking into an oven. Find the number of photons per second escaping the hole and having wavelengths between 500 nm and 501 nm.

Ans:

- Power of e. m. radiation having wavelength λ is: $P = I(\lambda)A$
- Power of e. m. radiations in wavelength range λ and $\lambda + \Delta\lambda$ is

$$P = I(\lambda, T)\Delta\lambda\, A$$

Where $I(\lambda, T)\Delta\lambda$ is intensity of e. m. radiations having wavelengths in the range λ and $\lambda + \Delta\lambda$

From Planck's law:

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

Number of photons emitted per second,

$$n = \frac{P}{hf} = \frac{P}{(hc/\lambda)} = \frac{1}{(hc/\lambda)}\frac{2\pi hc^2}{\lambda^5(e^{hc/\lambda kT} - 1)}\Delta\lambda\, A$$

Take wavelength as the average wavelength

$$\lambda = \frac{\lambda_2 + \lambda_1}{2} = 500.5\, nm$$

And

- Wavelength range,

$$\Delta\lambda = \lambda_2 - \lambda_1 = 501\, nm - 500\, nm = 1\, nm$$

- Surface area,

$$A = \pi \left(\frac{d}{2}\right)^2 = \pi \left(0.05 \times \frac{10^{-3}}{2}\right)^2 = 1.963\ x\ 10^{-9}\, m^2$$

Substituting these we get

$$n = 1.3 \times 10^{15}/s$$

P 11: The stopping potential for photoelectrons released from a metal is 1.48V larger compared to that in another metal. If the threshold frequency for the first metal is 40% smaller than for the second metal, determine the work function for each metal.

$$KE_{max} = hf - \phi \qquad f_c = \frac{\phi}{h}$$

$$V_1 = V_2 + 1.48$$

$$e\,V_1 = e\,V_2 + 1.48\,e$$

$$K.E_1 = K.E_2 + 1.48\,e$$

$$hf - \phi_1 = hf - \phi_2 + 1.48\,e$$

$$\phi_2 - \phi_1 = 1.48\,e \qquad (1)$$

$$f_1 = f_2 - 0.4\,f_2 = 0.6\,f_2$$

$$\frac{\phi_1}{h} = 0.6\frac{\phi_2}{h}$$

$$\phi_1 = 0.6\,\phi_2 \qquad (2)$$

Equating (2) in (1):

$$\phi_2 - 0.6\,\phi_2 = 1.48\,e$$

$$\phi_2 = \frac{1.48\,e}{0.4} = 3.7\,eV$$

$$\phi_1 = 0.6\,\phi_2 = 0.6 \times 3.7 = 2.22\,eV$$

P 15: A 0.0016nm photon scatters from a free electron. For what photon scattering angle does the recoiling electron have kinetic energy equal to the energy of the scattered photon?

Given the kinetic energy (K) of the scattered electron is equal to the scattered photon energy (E').

$$K = E'$$

$$E_e - mc^2 = E' \qquad (1)$$

From the Compton scattering energy conservation equation:

$$E + mc^2 = E_e + E'$$

$$E_e - mc^2 = E - E' \qquad (2)$$

From equations (1) and (2), we get

$$E' = E - E'$$

$$E = 2E'$$

$$\frac{hc}{\lambda} = 2\,\frac{hc}{\lambda'}$$

$$\lambda' = 2\lambda \qquad (3)$$

From Compton formula:

$$\lambda' = \lambda + \frac{h}{mc}(1 - \cos\theta) \qquad (4)$$

From equation (3) and (4)

$$2\lambda = \lambda + \frac{h}{mc}(1 - \cos\theta)$$

Solving the above equation for θ, we get

$$\theta = 70^o$$