PHYS143
Physics for Engineers
Tutorial - Chapter 40 – Solutions

Question 1

The temperature of an electric heating element is 150°C. At what wavelength does the radiation emitted from the heating element reach its peak?

The absolute temperature of the heating element is

$$T = 150°\text{C} + 273 = 423 \text{ K}$$

The peak wavelength is

$$\lambda_{\max} T = 2.898 \times 10^{-3} \text{ m} \cdot \text{K}$$

$$\lambda_{\max} = \frac{2.898 \times 10^{-3} \text{ m} \cdot \text{K}}{T} = \frac{2.898 \times 10^{-3} \text{ m} \cdot \text{K}}{423 \text{ K}} = 6.85 \times 10^{-6} \text{ m}$$

or $\boxed{6.85\ \mu\text{m, which is in the infrared region of the spectrum.}}$

Question 2

The radius of our Sun is 6.96 × 10^8 m, and its total power output is 3.85 × 10^{26} W. (a) Assuming the Sun's surface emits as a black body, calculate its surface temperature. (b) Using the result of part (a), find λ_{max} for the Sun. (e = 1, $\sigma = 5.67 \times 10^{-8}$ W/m^2.K^4).

(a) From Stefan's law, $P = eA\sigma T^4$. If the sun emits as a black body, e = 1.

$$T = \left(\frac{P}{eA\sigma}\right)^{1/4}$$

$$= \left[\frac{3.85 \times 10^{26} \text{ W}}{1\left[4\pi\left(6.96 \times 10^8 \text{ m}\right)^2\right]\left(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4\right)}\right]^{1/4}$$

$$= \boxed{5.78 \times 10^3 \text{ K}}$$

(b)

$$\lambda_{\max} = \frac{2.898 \times 10^{-3} \text{ m} \cdot \text{K}}{T} = \frac{2.898 \times 10^{-3} \text{ m} \cdot \text{K}}{5.78 \times 10^3 \text{ K}}$$

$$= 5.01 \times 10^{-7} \text{ m} = \boxed{501 \text{ nm}}$$

Question 3

Molybdenum has a work function of 4.20 eV. (a) Find the cutoff wavelength and cutoff frequency for the photoelectric effect. (b) What is the stopping potential if the incident light has a wavelength of 180 nm? (c) If photons of energy 5.50 eV are incident on Molybdenum, what is the maximum kinetic energy of the ejected photoelectrons?

(a) The cutoff wavelength is given by:

$$\lambda_c = \frac{hc}{\phi} = \frac{(6.626\times10^{-34}\ \mathrm{J\cdot s})(2.998\times10^{8}\ \mathrm{m/s})}{(4.20\ \mathrm{eV})(1.602\times10^{-19}\ \mathrm{J/eV})} = \boxed{295\ \mathrm{nm}}$$

which corresponds to a frequency of

$$f_c = \frac{c}{\lambda_c} = \frac{2.998\times10^{8}\ \mathrm{m/s}}{295\times10^{-9}\ \mathrm{m}} = \boxed{1.02\times10^{15}\ \mathrm{Hz}}$$

(b) We find the stopping potential from $\frac{hc}{\lambda} = \phi + e\Delta V_S$:

$$\frac{(6.626\times10^{-34})(2.998\times10^{8})}{180\times10^{-9}} = (4.20\ \mathrm{eV})(1.602\times10^{-19}\ \mathrm{J/eV}) + (1.602\times10^{-19})\Delta V_S$$

Therefore, $\boxed{\Delta V_S = 2.69\ \mathrm{V}}$.

(c) The maximum kinetic energy is the difference between the energy of the photons and the work function:

$$K_{\max} = E - \phi = 5.50 - 4.2 = 1.3\ eV$$

Question 4

Two light sources are used in a photoelectric experiment to determine the work function for a particular metal surface. When green light from a mercury lamp (λ = 546.1 nm) is used, a stopping potential of 0.376 V reduces the photocurrent to zero. (a) Based on this measurement, what is the work function for this metal? (b) What stopping potential would be observed when using the yellow light from a helium discharge tube (λ = 587.5 nm)?

(a) Einstein's photoelectric effect equation is $K_{\max} = hf - \phi$ and the energy required to raise an electron through a 1-V potential is 1 eV, so that

$$K_{\max} = e\Delta V_s = 0.376\ \mathrm{eV}$$

The energy of a photon from the mercury lamp is:

$$hf = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\ \mathrm{J\cdot s})(2.998\times10^{8}\ \mathrm{m/s})}{546.1\times10^{-9}\ \mathrm{m}}\left(\frac{1\ \mathrm{eV}}{1.602\times10^{-19}\ \mathrm{J}}\right)$$

$$= \frac{1\ 240\ \mathrm{eV\cdot nm}}{546.1\ \mathrm{nm}} = 2.27\ \mathrm{eV}$$

Therefore, the work function for this metal is:

$$\phi = hf - K_{\max} = 2.27\ \mathrm{eV} - 0.376\ \mathrm{eV} = \boxed{1.89\ \mathrm{eV}}$$

(b) For the yellow light, $\lambda = 587.5$ nm and the photon energy is

$$hf = \frac{hc}{\lambda} = \frac{1\,240 \text{ eV}\cdot\text{nm}}{587.5 \text{ nm}} = 2.11 \text{ eV}$$

Therefore the maximum energy that can be given to an ejected electron is

$$K_{\max} = hf - \phi = 2.11 \text{ eV} - 1.89 \text{ eV} = 0.216 \text{ eV}$$

so the stopping voltage is

$$\Delta V_s = \boxed{0.216 \text{ V}}$$

Question 5

X-rays with a wavelength of 120.0 pm undergo Compton scattering. (a) Find the wavelengths of the photons scattered at an angle of 30.0°. (b) Find the energy of the scattered electron in each case.

(a) and (b) From $\Delta\lambda = \frac{h}{m_e c}(1-\cos\theta)$ we calculate the wavelength of the scattered photon. For example, at $\theta = 30°$ we have

$$\begin{aligned}\lambda_o + \Delta\lambda &= 120\times10^{-12} \text{ m} \\ &\quad + \frac{6.626\times10^{-34} \text{ J}\cdot\text{s}}{(9.11\times10^{-31} \text{ kg})(2.998\times10^{8} \text{ m/s})}(1-\cos 30.0°) \\ &= 120.3\times10^{-12} \text{ m}\end{aligned}$$

The electron carries off the energy the photon loses:

$$\begin{aligned}K_e &= \frac{hc}{\lambda_0} - \frac{hc}{\lambda'} \\ &= \frac{(6.626\times10^{-34} \text{ J}\cdot\text{s})\,(2.998\times10^{8} \text{ m/s})}{(1.602\times10^{-19} \text{ J/eV})} \\ &\qquad \times\left(\frac{1}{120\times10^{-12}\text{ m}} - \frac{1}{120.3\times10^{-12}\text{ m}}\right) \\ &= 27.9 \text{ eV}\end{aligned}$$

Question 6

After a 0.800-nm x-ray photon scatters from a free electron, the electron recoils at 1.40×10^{6} m/s. (a) What is the Compton shift in the photon's wavelength? (b) Through what angle is the photon scattered?

(a) To compute the Compton shift, we first determine the electron's kinetic energy:

$$\begin{aligned}K &= \frac{1}{2}m_e u^2 = \frac{1}{2}(9.11\times10^{-31} \text{ kg})(1.40\times10^{6} \text{ m/s})^2 \\ &= 8.93\times10^{-19} \text{ J} = 5.58 \text{ eV}\end{aligned}$$

Then,

$$E_0 = \frac{hc}{\lambda_0} = \frac{1\ 240\ \text{eV}\cdot\text{nm}}{0.800\ \text{nm}} = 1\ 550\ \text{eV}$$

$$E' = E_0 - K \quad \text{and} \quad \lambda' = \frac{hc}{E'} = \frac{1\ 240\ \text{eV}\cdot\text{nm}}{1\ 550\ \text{eV} - 5.58\ \text{eV}} = 0.803\ \text{nm}$$

and the Compton shift is

$$\Delta\lambda = \lambda' - \lambda_0 = 0.002\ 89\ \text{nm} = \boxed{2.89\ \text{pm}}$$

(b) $\Delta\lambda = \lambda_C\left(1 - \cos\theta\right)$

$$\cos\theta = 1 - \frac{\Delta\lambda}{\lambda_C} = 1 - \frac{0.002\ 89\ \text{nm}}{0.002\ 43\ \text{nm}} = -0.189 \quad \rightarrow \quad \boxed{\theta = 101^\circ}$$