1. The Sun's surface temperature is 5700 K.
(i) How much power is radiated by the Sun?
(ii) Given that the distance to Earth is about 200 Sun radii, what is the maximum power possible from one square kilometer solar energy installation?
(iii) What is the wavelength of maximum intensity of solar radiation?

Data:

$T = 5700K$

$power\ is\ radiated\ by\ sun\ = \frac{P}{A} = ?$

$P_{maximum} = ?$

$\lambda_{maximum} = ?$

SOLUTION:

$P = \sigma A T^4$

$\frac{P}{A} = \sigma\ T^4$

$P = (5.67 \times 10^{-8})\ (5700)^4$

$P = (5.67 \times 10^{-8})(1.055 \times 10^{15})$

$P = 5.98 \times 10^7\ W$

The intensity of radiation on Earth

$intensity = \frac{power}{area}$

$I = \frac{P}{(4\,\pi\,R'^2)} \qquad \{R'^2 = 200\ R_S\}$

$I = \frac{3.64 \times 10^{26}}{\{4\,\pi\ (200 \times 6.96 \times 10^8)^2\}}$

$I = 1.49 \times 10^3\ W/m^2$

The maximum power is given by

$P_{max} = intensity \times area\ of\ intalation$

$P_{max} = I \times (1\ km)^2$

$P_{max} = (1.49 \times 10^3) \times (1 \times 10^6)$

$P_{max} = 1.49 \times 10^9\ Watt$

The maximum wavelength is given by

$\lambda_{maximum}\ T = constant$

$\lambda_{maximum}\ 5700 = 2.897 \times 10^{-3}$

$\lambda_{maximum} = \frac{2.897 \times 10^{-3}}{5700}$

$\lambda_{maximum} = 5.08 \times 10^{-7}\ m$

2. The temperature of your skin is approximately 32 °C. What is the wavelength at which the peak occurs in the radiation emitted from your skin? (9.05×10^{-5} m).

Data: $T = 32\ ℃$ $T = 32 + 273 = 305\ K$ $\lambda_{maximum} = ?$ **SOLUTION:**	**The maximum wavelength is given by** $\lambda_{maximum}\, T = constant$ $\lambda_{maximum}\,(305) = 2.897 \times 10^{-3}$ $\lambda_{maximum} = \frac{2.897 \times 10^{-3}}{305}$ $\lambda_{maximum} = 9.49 \times 10^{-6}\, m$

3. An FM radio transmitter has a power output of 100 kW and operates at a frequency of 94 MHz, How many photons per second does the transmitter emit?

Data: $P = 100\ KW = 100000\ W$ $f = 94\ MHz = 94 \times 10^{6}\ Hz$ $\frac{n}{t} = ?$	**SOLUTION:** $P = \frac{E}{t}$ $\{E = n\, h\, f\}$ $P = \frac{n\, hf}{t}$ $\frac{n}{t} = \frac{P}{hf}$ $\frac{n}{t} = \frac{100\ 000}{(6.629 \times 10^{-34})(94 \times 10^{6})}$ $\frac{n}{t} = 1.605 \times 10^{30}\ photons/second$

4 **A light source of wavelength illuminates a metal and ejects photoelectrons with a maximum kinetic energy of 1.0 eV. A second light source with half the wavelength of the first ejects photoelectrons with a maximum kinetic energy of 4.0 eV. Determine the work function of the metal.**

Data:

$E_k = 1.0 \text{ eV}$

$E_k' = 4.0 \text{ eV}$

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

$\Phi = ?$

SOLUTION:

For the case of first light source

$$\frac{hc}{\lambda} = \Phi_0 + E_k$$

$$\frac{hc}{\lambda} = \Phi_0 + 1.0\ eV \quad \dots\dots\dots\dots..(i)$$

For the case of second light source

$$\frac{hc}{\lambda'} = \Phi_0 + E_k$$

$$\frac{hc}{\frac{\lambda}{2}} = \Phi_0 + 4.0\ eV$$

$$\frac{hc}{\lambda} \times 2 = \Phi_0 + 4.0\ eV$$

$$\frac{hc}{\lambda} = \frac{1}{2}(\Phi_0 + 4.0\ eV) \quad \dots\dots\dots\dots\dots\dots(ii)$$

Comparing equation (i) and (ii), we get

$$\Phi_0 + 1.0\ eV = \frac{1}{2}(\Phi_0 + 4.0\ eV)$$

$$2\,\Phi_0 + 2.0\ eV = \Phi_0 + 4.0\ eV$$

$$2\,\Phi_0 - \Phi_0 = 4.0\ eV - 2.0\ eV$$

$$\Phi_0 = 2.0\ eV$$

5. **A 430 nm violet light is an incident on a calcium photo electrode with a work function of 2.71 eV. Find the energy of the incident photons and the maximum kinetic energy of ejected electrons.**

Data:

$\lambda = 430 \text{ nm} = 430 \times 10^{-9}\ m$

$\Phi_0 = 2.71 \text{ eV}$

$E = ?\ ,\quad E_k = ?$

SOLUTION:

$$E = \frac{hc}{\lambda}$$

$$E = \frac{(6.626 \times 10^{-34})(3 \times 10^{8})}{430 \times 10^{-9}}$$

$$E = 4.6227 \times 10^{-19}\ J$$

$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

$$E = \frac{4.62\,27 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$\boldsymbol{E = 2.88\ eV}$$

$$E = \Phi_0 + E_k$$

$$2.88\ eV = 2.71\ eV + E_k$$

$$2.88\ eV - 2.71\ eV = E_k$$

$$\boldsymbol{0.17\ eV = E_k}$$

6. **Cut-off frequency for the photoelectric effect in some materials is 8x 10^{13}Hz. When the incident light has a frequency of l.2x 10^{14} Hz, the stopping potential is measured as 0.16 V. Estimate a value of Planck's constant from these data and determine the percentage error of your estimation.**

Data:

$f_0 = 8 \times 10^{13}\ Hz$

$f = 1.2 \times 10^{14}$

$V_0 = 0.16\ V$

$k = ?\ ,\quad percntage\ error\ (k)\ = ?$

SOLUTION:

$hf = hf_0 + e\,V_0$

$hf - hf_0 = e\,V_0$

$h\,(f - f_0) = e\,V_0$

$h\,(1.2 \times 10^{14} - 8 \times 10^{13}) = (1.6 \times 10^{-19})\,(0.16)$

$h \times 4 \times 10^{13} = 2.56 \times 10^{-20}$

$$h = \frac{2.56 \times 10^{-20}}{4 \times 10^{13}}$$

$h = 6.4 \times 10^{-34}\ Js$

Percentage error in Planck constant

$$Percentage\ error = \frac{|h - h_{caculated}|}{h}$$

$Percentage\ error$

$$= \frac{|6.626 \times 10^{-34} - 6.4 \times 10^{-34}|}{6.626 \times 10^{-34}} \times 100$$

$$Percentage\ error = \frac{|2.26 \times 10^{-34}|}{6.626 \times 10^{-34}} \times 100$$

$Percentage\ error = 3.4\ \%$

7. **The work function of some metals is listed below. The number of metals which will show photoelectric effect when light of 300 nm wavelength falls on the metal is:**

Metal	Li	Na	K	Mg	Cu	Ag	Fe	Pt	W
φ in eV	2.4	2.3	2.2	3.7	4.8	4.3	4.7	6.3	4.75

DATA

$\lambda_0 = 300\ \text{nm} = 300 \times 10^{-9}\ m$

$\Phi_0 = ?$

The work function is given by

$$\Phi_0 = \frac{h\,c}{\lambda_0}$$

$$\Phi_0 = \frac{(6.626 \times 10^{-34})\,(3 \times 10^{8})}{300 \times 10^{-9}}$$

$\Phi_0 = 6.626 \times 10^{-19}$

$$\Phi_0 = \frac{6.626 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$\Phi_0 = 4.14\ eV$

This is the value of the work function we have calculated (4.14 eV), so there are only five materials in the table whose work function is greater than 4.14eV, so they will produce the photoelectric effect.

Cu	Ag	Fe	Pt	W
4.8	4.3	4.7	6.3	4.75

8. **X-rays with an energy of 300 keV undergo Compton scattering with a target. If the scattered X-rays are detected at 30° relative to the incident X-rays, determine the Compton shift at this angle, the energy of the scattered X-rays, and the energy of the recoiling electron.**

DATA

$E_1 = 300\ \text{KeV} = 300 \times 10^3\ eV$

$E_1 = 300 \times 10^3 (1.6 \times 10^{-19})$

$E_1 = 4.8 \times 10^{-14}\ J$

$\theta = 30^0$

$\Delta\lambda = ?$

$\Delta\lambda = ?$

$E_2 = ?$

$E_k = ?$

The Compton shift is given by

$$\Delta\lambda = \frac{h}{m_0\, c}(1 - \cos\theta)$$

$$\Delta\lambda = \frac{(6.626 \times 10^{-34})}{(1.6 \times 10^{19})(3 \times 10^8)}(1 - \cos 30)$$

$$\Delta\lambda = \frac{(6.626 \times 10^{-34})}{(1.6 \times 10^{19})(3 \times 10^8)}(0.1339)$$

$$\Delta\lambda = 3.25 \times 10^{-13} m$$

Wavelength of incident photon

$$\lambda_1 = \frac{hc}{E_1}$$

$$\lambda_1 = \frac{(6.626 \times 10^{-34})(3 \times 10^8)}{4.8 \times 10^{-14}}$$

$$\lambda_1 = 4.14 \times 10^{-12}\ m$$

Wavelength of scattered photon

$$\Delta\lambda = \lambda_1 - \lambda_2$$

$$\lambda_2 = \Delta\lambda + \lambda_1$$

$$\lambda_2 = 3.25 \times 10^{-13} + 4.14 \times 10^{-12}$$

$$\lambda_2 = 4.465 \times 10^{-12} m$$

Energy of scattered photon

$$E_2 = \frac{hc}{\lambda_2}$$

$$E_2 = \frac{(6.626 \times 10^{-34})(3 \times 10^8)}{4.465 \times 10^{-12}}$$

$$E_2 = 4.45 \times 10^{-14}\ J$$

$$E_2 = \frac{4.45 \times 10^{-14}}{1.6 \times 10^{-19}}$$

$$E_2 = 278 \times 10^3\ eV$$

$$E_2 = 278\ KeV$$

energy of the recoiling electron

$$E = E_1 - E_2$$

$$E = 300\ \text{KeV} - 278\ KeV$$

$$E = 22\ \text{KeV}$$

9. A photon with a wavelength of 6.0x 10^{-12} m collides with an electron. After the collision the photon wavelength is found to have been changed by exactly one (Compton Wavelength is 2.43x 10^{-12} m).

(i) What is the photon's wavelength after collision?

(ii) Through what angle has been deflected in this collision?

(iii) What is the angle for the electron after the collision?

(iv) What is the electron's kinetic energy, in eV, after collision?

DATA

$\lambda_1 = 6.0 \times 10^{-12}\, m$

$\Delta\lambda = 2.43 \times 10^{-12}\, m$

$\lambda_2 = ?\quad \theta = ?\quad \Phi = ?\quad E_k = ?$

SOLUTION

The wavelength of the scattered photon

$$\Delta\lambda = \lambda_1 - \lambda_2$$

$$\lambda_2 = \Delta\lambda + \lambda_1$$

$$\lambda_2 = 2.43 \times 10^{-12} + 6.0 \times 10^{-12}$$

$$\lambda_2 = 8.43 \times 10^{-12} m$$

The Compton shift is given by

$$\Delta\lambda = \frac{h}{m_0\, c}(1 - \cos\theta)$$

$$2.43 \times 10^{-12} = \frac{(6.626 \times 10^{-34})}{(1.6 \times 10^{19})(3 \times 10^{8})}(1 - \cos\theta)$$

$$2.43 \times 10^{-12} = 2.43 \times 10^{-12}(1 - \cos\theta)$$

$$1 = 1 - \cos\theta$$

$$\cos\theta = 1 - 1$$

$$\theta = \cos^{-1}(0)$$

$$\theta = 90^0$$

For scattered angles of electron Φ

Law of conservation of momentum along x-axis

$$\frac{h}{\lambda_1}\cos(\theta) + 0 = \frac{h}{\lambda_2}\cos(\theta) + P\cos\Phi$$

$$\frac{h}{\lambda_1}\cos(0) + 0 = \frac{h}{\lambda_2}\cos(90) + P\cos\Phi$$

$$\frac{h}{\lambda_1} = \frac{h}{\lambda_2}(0) + P\cos\Phi$$

$$\frac{h}{\lambda_1} = P\cos\Phi \quad \ldots\ldots\ldots..(i)$$

Law of conservation of momentum along the y-axis

$$\frac{h}{\lambda_1}\sin(\theta) + 0 = \frac{h}{\lambda_2}\sin(\theta) - P\sin\Phi$$

$$\frac{h}{\lambda_1}\sin(0) + 0 = \frac{h}{\lambda_2}\sin(90) - P\,Cos\Phi$$

$$0 = \frac{h}{\lambda_2}(1) - P\sin\Phi$$

$$\frac{h}{\lambda_2} = P\sin\Phi \quad \ldots\ldots\ldots..(ii)$$

Dividing equation (ii) by (i)

$$\frac{\frac{h}{\lambda_2}}{\frac{h}{\lambda_1}} = \frac{P\sin\Phi}{P\cos\Phi}$$

$$\frac{\lambda_1}{\lambda_2} = \tan\Phi$$

$$\frac{6.0 \times 10^{-12}}{8.43 \times 10^{-12}} = \tan\Phi$$

$$0.711 = \tan\Phi$$

$$\Phi = \tan^{-1}(0.711)$$

$$\Phi = 35.41^0$$

$$\Phi = 35.45\,, \textit{which is smaller than } 90^0$$

Electron's kinetic energy after collision

$$E_k = E_1 - E_2$$

$$E_k = \frac{hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

$$E_k = hc\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) \{hc = 1.987 \times 10^{-25}\}$$

$$E_k = 1.987 \times 10^{-25}\left(\frac{1}{6.0 \times 10^{-12}} - \frac{1}{8.43 \times 10^{-12}}\right)$$

$$E_k = 9.55 \times 10^{-15} J$$

$$E_2 = \frac{9.55 \times 10^{-15}}{1.6 \times 10^{-19}}$$

$$E_2 = 5.96 \times 10^{4}\, eV$$

10. Find the de Broglie wavelength of an electron in the ground state of hydrogen.

DATA

$r = 0.53 \times 10^{-10}\ m$

$n = 1$

$\lambda = ?$

The angular momentum of electron is given by

$$mvr = \text{n}\left(\frac{\text{h}}{2\,\pi}\right)$$

$$mv = \frac{\text{nh}}{2\,\pi\,r}$$

$$mv = \frac{(1)(6.626 \times 10^{-34})}{2\,\pi\,(0.53 \times 10^{-10})}$$

$$mv = 1.9897 \times 10^{-24}\ kg\ m/s$$

The de Broglie wavelength is given by

$$\lambda = \frac{h}{mv}$$

$$\lambda = \frac{6.626 \times 10^{-34}}{1.9897 \times 10^{-24}}$$

$$\lambda = 3.33 \times 10^{-10}\ m$$

11. Determine the minimum uncertainties in the positions of the following objects if their speeds are known with a precision of l.0 x10^{-3} m/s: (a) an electron and (b) a bowling ball of mass 6.0 kg.

DATA

$\Delta x = ?$

$v = 1.0 \times 10^{-3}\ m/s$

According to the uncertainty principle

$$\Delta x\ \Delta P \geq \frac{\text{h}}{4\,\pi}$$

$$\Delta x \geq \frac{\text{h}}{4\,\pi\,\Delta P}$$

$$\Delta x \geq \frac{\text{h}}{4\,\pi\,m\,v}$$

$$\Delta x \geq \frac{6.626 \times 10^{-34}}{4\,\pi(9.1 \times 10^{-31})\,(1.0 \times 10^{-3})}$$

$$\Delta x \geq 0.0579\ \text{m}$$

$$\Delta x\ \Delta P \geq \frac{\text{h}}{4\,\pi}$$

$$\Delta x \geq \frac{\text{h}}{4\,\pi\,\Delta P}$$

$$\Delta x \geq \frac{\text{h}}{4\,\pi\,m\,v}$$

$$\Delta x \geq \frac{6.626 \times 10^{-34}}{4\,\pi(6.0)\,(1.0 \times 10^{-3})}$$

$$\Delta x \geq 8.78 \times 10^{-33}\ \text{m}$$