3-2 Assume that your skin can be considered a blackbody. One can then use Wien's displacement law, $\lambda_{max} T = 0.289\,8 \times 10^{-2}$ m·K with $T = 35\ ^0\text{C} = 308$ K to find

$$\lambda_{max} = \frac{0.289\,8 \times 10^{-2}\ \text{m}\cdot\text{K}}{308\ \text{K}} = 9.41 \times 10^{-6}\ \text{m} = 9\,410\ \text{nm}.$$

3-3 (a) The total energy of a simple harmonic oscillator having an amplitude A is $\frac{kA^2}{2}$, therefore, $E = \frac{kA^2}{2} = (25\ \text{N/m})\frac{(0.4\ \text{m})^2}{2} = 2.0\ \text{J}$. The frequency of oscillation will be $f = \left(\frac{1}{2\pi}\right)\left(\frac{k}{m}\right)^{1/2} = \left(\frac{1}{2\pi}\right)\left(\frac{25}{2}\right)^{1/2} = 0.56\ \text{Hz}$.

(b) If energy is quantized, it will be given by $E_n = nhf$ and from the result of (a) there follows $E_n = nhf = n(6.63 \times 10^{-34}\ \text{J s})(0.56\ \text{Hz}) = 2.0\ \text{J}$. Upon solving for n one obtains $n = 5.4 \times 10^{33}$.

(c) The energy carried away by one quantum of charge in energy will be $E = hf = (6.63 \times 10^{-34}\ \text{J s})(0.56\ \text{Hz}) = 3.7 \times 10^{-34}\ \text{J}$.

3-4 (a) From Stefan's law, one has $\frac{P}{A} = \sigma T^4$. Therefore,

$$\frac{P}{A} = (5.7 \times 10^{-8}\ \text{W/m}^2\text{K}^4)(3000\ \text{K})^4 = 4.62 \times 10^6\ \text{W/m}^2.$$

(b) $A = \frac{P}{4.62 \times 10^6\ \text{W/m}^2} = \frac{75\ \text{W}}{4.62 \times 10^6\ \text{W/m}^2} = 16.2\ \text{mm}^2$.

3-5 (a) Planck's radiation energy density law as a function of wavelength and temperature is given by $u(\lambda, T) = \frac{8\pi hc}{\lambda^5\left(e^{hc/\lambda_B T} - 1\right)}$. Using $\frac{\partial u}{\partial \lambda} = 0$ and setting $x = \frac{hc}{\lambda_{max} k_B T}$, yields an extremum in $u(\lambda, T)$ with respect to λ. The result is $0 = -5 + \left(\frac{hc}{\lambda_{max} k_B T}\right)\left(e^{hc/\lambda_{max} k_B T}\right)\left(e^{hc/\lambda_{max} k_B T} - 1\right)^{-1}$ or $x = 5\left(1 - e^{-x}\right)$.

(b) Solving for x by successive approximations, gives $x \cong 4.965$ or $\lambda_{max} T = \left(\frac{hc}{k_B}\right)(4.965) = 2.90 \times 10^{-3}\ \text{m}\cdot\text{K}$.

3-6 Planck length $= \left(\frac{hG}{c}\right)^{1/2} = 4.05 \times 10^{-35}$ m

Planck time $= \left(\frac{hG}{c^5}\right)^{1/2} = 1.35 \times 10^{-45}$ s

Planck mass $= \left(\frac{hG}{c}\right)^{1/2} = 5.46 \times 10^{-8}$ kg

3-10 The energy per photon, $E = hf$ and the total energy E transmitted in a time t is Pt where power $P = 100\text{ kW}$. Since $E = nhf$ where n is the total number of photons transmitted in the time t, and $f = 94\text{ MHz}$, there results $nhf = (100\text{ kW})t = (10^5\text{ W})t$, or

$$\frac{n}{t} = \frac{10^5\text{ W}}{hf} = \frac{10^5\text{ J/s}}{6.63\times10^{-34}\text{ J s}}(94\times10^6\text{ s}^{-1}) = 1.60\times10^{30}\text{ photons/s}.$$

3-11 Following the same reasoning as in Problem 3-9, one obtains

$$\frac{n}{t} = \frac{P}{hf} = \frac{P\lambda}{hc} = (3.74\times10^{26}\text{ J s})\frac{500\times10^{-9}\text{ s}^{-1}}{6.63\times10^{-34}\text{ J s}}(3\times10^8\text{ s}^{-1}) = 9.45\times10^{44}\text{ photons/s}.$$

3-12 As in Problems 3-9 and 3-10,

$$\frac{n}{t} = \frac{P}{hf} = \frac{P\lambda}{hc} = (10\text{ W})\frac{589\times10^{-9}\text{ m}}{1.99\times10^{-25}\text{ J m}} = 3.0\times10^{19}\text{ photons/s}.$$

3-13 $K = hf - \phi = \dfrac{hc}{\lambda - \phi}$

$$\phi = \frac{hc}{\lambda - K} = \frac{1\,240\text{ eV nm}}{250\text{ nm}} - 2.92\text{ eV} = 2.04\text{ eV}$$

3-14 (a) $K = hf - \phi = \dfrac{hc}{\lambda - \phi} = \dfrac{1\,240\text{ eV nm}}{350\text{ nm}} - 2.24\text{ eV} = 1.30\text{ eV}$

(b) At $\lambda = \lambda_c$, $K = 0$ and $\lambda = \dfrac{hc}{\phi} = \dfrac{1\,240\text{ eV nm}}{2.24\text{ eV}} = 554\text{ nm}$

3-15 (a) At the cut-off wavelength, $K = 0$ so $\dfrac{hc}{\lambda} - \phi = 0$, or $\lambda_{\text{cut-off}} = \dfrac{hc}{\phi} = \dfrac{1\,240\text{ eV nm}}{4.2\text{ eV}} = 300\text{ nm}$.

The threshold frequency, f_0 is given by

$$f_0 = \frac{c}{\lambda_{\text{cut-off}}} = \frac{3.0\times10^8\text{ m/s}}{3.0\times10^2\times10^{-9}\text{ m}} = 1.0\times10^{15}\text{ Hz}.$$

(b) $eV_s = K = hf - \phi = \dfrac{hc}{\lambda} - \phi$

$$V_s = \frac{hc}{\lambda e} - \frac{\phi}{e} = \frac{1\,240\text{ eV nm}}{200\text{ nm e}} = -4.2\text{ eV/e} = 2.0\text{ V}$$

3-16 (a) $\phi = \dfrac{hc}{\lambda} - K$, $\phi = \dfrac{1\,240\text{ eV nm}}{300\text{ nm}} - 2.23\text{ eV} = 1.90\text{ eV}$

(b) $V_s = \dfrac{1\,240\text{ eV nm}}{400\text{ nm e}} - 1.90\text{ eV/e} = 1.20\text{ V}$

3-17 The energy of one photon of light of wavelength $\lambda = 300$ nm is

$$E = \frac{hc}{\lambda} = \frac{1\,240 \text{ eV nm}}{300 \text{ nm}} = 4.13 \text{ eV}.$$

(a) As lithium and beryllium have work functions that are less than 4.13 eV, they will exhibit the photoelectric effect for incident light with this energy. However, mercury will not because its work function is greater than 4.13 eV.

(b) The maximum kinetic energy is given by $K = \frac{hc}{\lambda - \phi}$, so

$$K(\text{Li}) = \frac{1\,240 \text{ eV nm}}{300 \text{ nm}} - 2.3 \text{ eV} = 1.83 \text{ eV}, \text{ and } K(\text{Be}) = \frac{1\,240 \text{ eV nm}}{300 \text{ nm}} - 3.9 \text{ eV} = 0.23 \text{ eV}.$$

3-18 (a) $K_{\max} = eV_s = s(0.45 \text{ V}) = 0.45 \text{ eV}$

(b) $\phi = \frac{hc}{\lambda - K} = \frac{1\,240 \text{ eV nm}}{500 \text{ nm}} - 0.45 \text{ eV} = 2.03 \text{ eV}$

(c) $\lambda_c = \frac{hc}{\phi} = \frac{1\,240 \text{ eV nm}}{2.03 \text{ eV}} = 612 \text{ nm}$

3-19 $\phi = 2.00 \text{ eV}$, $K_{\max} = eV_0 = hf - \phi = \frac{hc}{\lambda} - \phi.$

$$\Rightarrow V_0 = \frac{\left(\frac{hc}{\lambda} - \phi\right)}{e} = \frac{\frac{(4.14\times10^{-15} \text{ eV s})(3\times10^{8} \text{ m/s})}{350\times10^{-9} \text{ m}} - 2.00 \text{ eV}}{e} = 1.55 \text{ V}.$$

3-20 $K_{\max} = hf - \phi = \frac{hc}{\lambda} - \phi \Rightarrow \phi = \frac{hc}{\lambda} - K_{\max};$

First Source: $\phi = \frac{hc}{\lambda} - 1.00 \text{ eV}.$

Second Source: $\phi = \frac{hc}{\frac{\lambda}{2}} - 4.00 \text{ eV} = \frac{2hc}{\lambda} - 4.00 \text{ eV}.$

As the work function is the same for both sources (a property of the metal),

$\frac{hc}{\lambda} - 100 \text{ eV} = \frac{2hc}{\lambda} - 4.00 \text{ eV} \Rightarrow \frac{hc}{\lambda} = 3.00 \text{ eV}$ and $\phi = \frac{hc}{\lambda} - 1.00 \text{ eV} = 3.00 \text{ eV} - 1.00 \text{ eV} = 2.00 \text{ eV}.$

3-21 $V_s = \left(\frac{h}{e}\right)\frac{f - \phi}{e}$. Choosing two points on the graph, one has $\left(\frac{h}{e}\right)(4\times10^{14} \text{ Hz}) - \frac{\phi}{e} = 0$ and $\left(\frac{h}{e}\right)(8\times10^{14} \text{ Hz}) - 1.7 \text{ eV}$. Combining these two expressions one obtains:

(a) $\phi = 1.6 \text{ eV}$

(b) $\frac{h}{e} = 4.0\times10^{-15} \text{ Vs}$

(c) For cut-off wavelength, $\lambda_c = \frac{hc}{\phi} = \frac{1\,240 \text{ eV nm}}{1.6\text{eV}} = 775 \text{ nm}.$

(d) Accepted $\frac{h}{e} = 4.14\times10^{-15} \text{ Vs}$, about a 3% difference.

3-22 The force acting on a charge moving perpendicular to a magnetic field has a magnitude given by qvB. For constant B and v the charge moves in a circle of radius r, and from Newton's second law we have $F = qvb = \frac{mv^2}{r}$, or $v = \frac{qBr}{m}$. Hence, one can express the kinetic energy of the charge q as $K = \frac{mv^2}{2} = \frac{(qBr)^2}{2m}$. Using the photoelectric equation $K = \frac{hc}{\lambda - \phi}$, there results $\phi = \frac{hc}{\lambda} - \frac{(qBr)^2}{2m}$. Substituting in the values $hc = 1\,240$ eV nm, $\lambda = 450$ nm, $B = 2\times10^{-5}$ T, $r = 0.2$ m, $q = 1.6\times10^{-19}$ C, and $m = 9.11\times10^{-31}$ kg, gives $\phi \cong 2.76\text{ eV} - 1.41\text{ eV} = 1.35\text{ eV}$.

3-23
$$E = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\text{ J s})(3\times10^{8}\text{ m/s})}{(5\times10^{-7}\text{ m})(1.6\times10^{-19}\text{ J/eV})} = 2.48\text{ eV}$$
$$p = \frac{h}{\lambda} = \frac{E}{c} = \frac{(2.48\text{ eV})(1.6\times10^{-19}\text{ J/eV})}{3\times10^{8}\text{ m/s}} = 1.32\times10^{-27}\text{ kg m/s}$$

3-24 (a) $\Delta\lambda = \frac{h}{m_e c}(1-\cos\theta) = (0.002\,43\text{ nm})(1-\cos\theta)$. When $\theta = 90°$, $\Delta\lambda = 0.002\,43$ nm.

(b) Conservation of energy requires that $\frac{hc}{\lambda_0} = \frac{hc}{\lambda' + K_e}$ or $K_e = hc\left(\frac{1}{\lambda_0} - \frac{1}{\lambda'}\right)$

$$K_e = \left[\frac{(6.625\times10^{-34}\text{ J s})(3\times10^{8}\text{ m/s})}{(1.6\times10^{-19}\text{ J/eV})}\right]\left[(2\times10^{-10}\text{ m})-1-(2.0243\times10^{-10}\text{ m})-1\right]$$
$$= 74.4\text{ eV}$$

3-25 $E = 300$ keV, $\theta = 30°$

(a) $\Delta\lambda = \lambda' - \lambda_0 = \frac{h}{m_e c}(1-\cos\theta) = (0.002\,43\text{ nm})[1-\cos(30°)] = 3.25\times10^{-13}$ m
$= 3.25\times10^{-4}$ nm

(b) $E = \frac{hc}{\lambda_0} \Rightarrow \lambda_0 = \frac{hc}{E_0} = \frac{(4.14\times10^{-15}\text{ eVs})(3\times10^{8}\text{ m/s})}{300\times10^{3}\text{ eV}} = 4.14\times10^{-12}$ m; thus,
$\lambda' = \lambda_0 + \Delta\lambda = 4.14\times10^{-12}\text{ m} + 0.325\times10^{-12}\text{ m} = 4.465\times10^{-12}$ m, and
$E' = \frac{hc}{\lambda'} \Rightarrow E' = \frac{(4.14\times10^{-15}\text{ eV s})(3\times10^{8}\text{ m/s})}{4.465\times10^{-12}\text{ m}} = 2.78\times10^{5}$ eV.

(c) $\frac{hc}{\lambda_0} = \frac{hc}{\lambda'} + K_e$, (conservation of energy)

$$K_e = hc\left(\frac{1}{\lambda_0} - \frac{1}{\lambda'}\right) = \frac{(4.14\times10^{-15}\text{ eV s})(3\times10^{8}\text{ m/s})}{\frac{1}{4.14\times10^{-12}} - \frac{1}{4.465\times10^{-12}}} = 22\text{ keV}$$

3-26 (a) $\Delta\lambda = \frac{h}{m_e c}(1-\cos\theta) = 2.426\times10^{-12}\text{ m}(1-\cos\theta)$

For $\theta = 30°$

$\Delta\lambda = 2.426\times10^{-12}\text{ m}(1-\cos 30°) = 3.25\times10^{-11}\text{ m}$; $\lambda' = \lambda_0 + \Delta\lambda$,

$\lambda' = 0.04\times10^{-9}\text{ m} + 3.25\times10^{-13}\text{ m} = 4.03\times10^{-11}\text{ m}$

(b) $\frac{hc}{\lambda_0} = \frac{hc}{\lambda' + K_e}$, $K_e hc\left(\frac{1}{\lambda_0} - \frac{1}{\lambda'}\right)$

For $\theta = 30°$

$$K_e = \frac{(6.63\times10^{-34}\text{ J s})(3\times10^8\text{ m/s})}{\frac{1}{0.04\times10^{-9}} - \frac{1}{4.03\times10^{-11}}} = (3.70\times10^{-17}\text{ J})\frac{1}{1.6\times10^{-19}\text{ J/eV}} = 231\text{ eV}.$$

The remaining calculations are similar and the following table summarizes the values to three significant figures

$\theta°$	$\Delta\lambda$ (nm)	λ' (nm)	K_e (eV)
30	0.000 325	0.040 3	231
60	0.001 21	0.041 2	905
90	0.002 43	0.042 4	1 760
120	0.003 64	0.043 6	2 570
150	0.004 53	0.044 5	3 140
180	0.004 85	0.044 8	3 330
210	0.004 53	0.044 5	3 140

(c) The electron which is backscattered corresponding to $\theta = 180°$ has the greatest energy.

3-27 Conservation of energy yields $hf = K_e + hf'$ (Equation A). Conservation of momentum yields $p_e^2 = p'2 + p^2 - 2pp'\cos\theta$. Using $p_{\text{photon}} = \frac{E}{c} = \frac{hf}{c}$ there results $p_e^2 = \left(\frac{hf'}{c}\right)^2 + \left(\frac{hf}{c}\right)^2 - 2\left(\frac{hf}{c}\right)\left(\frac{hf'}{c}\right)\cos\theta$ (Equation B). If the photon transfers all of its energy, $f' = 0$ and Equations A and B become $K_e = hf$ and $p_e^2\left(\frac{hf}{c}\right)^2$ respectively. Note that in general, $K_e = E_e - m_e c^2 = \left[p_e^2 c^2 + (m_e c^2)^2\right]^{1/2} - m_e c^2$. Finally, substituting $K_e = hf$ and $P_e^2 = \left(\frac{hf}{c}\right)^2$ into $K_e = \left[p_e^2 c^2 + (m_e c^2)^2\right]^{1/2} - m_e c^2$, yields $hf = \left[(hf)^2 + (m_e c^2)^2\right]^{1/2} - m_e c^2$ (Equation C). As Equation C is true only if h, or f, or m_e, or c is zero and all are non-zero this contradiction means that f' cannot equal zero and conserve both relativistic energy and momentum.

3-28 (a) From conservation of energy we have $E_0 = E' + K_e = 120\text{ keV} + 40\text{ keV} = 160\text{ keV}$. The photon energy can be written as $E_0 = \frac{hc}{\lambda_0}$. This gives

$$\lambda_0 = \frac{hc}{E_0} = \frac{1\,240\text{ nm eV}}{160\times10^3\text{ eV}} = 7.75\times10^{-3}\text{ nm} = 0.007\,75\text{ nm}.$$

(b) $\lambda' = \lambda_0 + \lambda_c(1 - \cos\theta)$

$$\lambda' = 0.001\,22 \text{ nm} + (0.002\,43 \text{ nm})[1 - \cos(41.5°)] = 0.001\,83 \text{ nm}$$

$$E = \frac{hc}{\lambda'} = \frac{1\,240 \text{ eV}\cdot\text{nm}}{0.001\,83 \text{ nm}} = 0.679 \text{ MeV}$$

3-30 Maximum energy transfer occurs when the scattering angle is 180 degrees. Assuming the electron is initially at rest, conservation of momentum gives

$$hf + hf' = p_e c = \sqrt{(m_e c^2 + K)^2 - m^2c^4} = \sqrt{(511 + 50)^2} = 178 \text{ keV}$$

while conservation of energy gives $hf - hf' = K = 30$ keV. Solving the two equations gives $E = hf = 104$ keV and $hf = 74$ keV. (The wavelength of the incoming photon is $\lambda = \frac{hc}{E} = 0.012\,0 \text{ nm}$.

3-31 (a) $E' = \frac{hc}{\lambda'}$, $\lambda' = \lambda_0 + \Delta\lambda$

$$\lambda_0 = \frac{hc}{E_0} = \frac{(6.63\times10^{-34} \text{ J}\cdot\text{s})(3\times10^8 \text{ m/s})}{0.1 \text{ MeV}} = 1.243\times10^{-11} \text{ m}$$

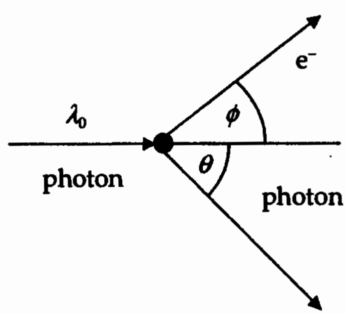
$$\Delta\lambda = \left(\frac{h}{m_e c}\right)(1 - \cos\theta) = \frac{(6.63\times10^{-34} \text{ J}\cdot\text{s})(1 - \cos 60°)}{(9.11\times10^{-34} \text{ kg})(3\times10^8 \text{ m/s})} = 1.215\times10^{-12} \text{ m}$$

$$\lambda' = \lambda_0 + \Delta\lambda = 1.364\times10^{-11} \text{ m}$$

$$E' = \frac{hc}{\lambda'} = \frac{(6.63\times10^{-34} \text{ J}\cdot\text{s})(3\times10^8 \text{ m/s})}{1.364\times10^{-11} \text{ m}} = 9.11\times10^4 \text{ eV}$$

(b) $\frac{hc}{\lambda_0} = \frac{hc}{\lambda'} + K_e$

$$K_e = 0.1 \text{ MeV} - 91.1 \text{ keV} = 8.90 \text{ keV}$$



Canceling and combining there results

$$\left(f'^2 + f_0^2 - 2f_0 f'\right) + \frac{2m_e c^2 (f_0 - f')}{h} = f'^2 + f_0^2 - 2f_0 f' \cos\theta$$

which reduces to $\frac{m_e c^2 (f_0 - f')}{h} = f_0 f'(1 - \cos\theta)$. Using $\lambda f = c$ one obtains $\lambda' - \lambda_0 = \frac{h(1-\cos\theta)}{m_e c}$, which is the Compton scattering or Compton shift relation.

3-34 Maximum energy transfer occurs when the scattering angle is 180 degrees. Assuming the electron is initially at rest, conservation of momentum gives

$$hf + hf' = p_e c = \sqrt{\left(m_e c^2 + K\right)^2 - m^2 c^4} = \sqrt{(511+50)^2} = 232 \text{ keV}$$

while conservation of energy gives $hf - hf' = K = 50$ keV. Solving the two equations gives $E = hf = 141$ keV. (The wavelength of the incoming photon is $\lambda = \frac{hc}{E} = 8.79$ pm.)

3-35 (a) The energy vs wavelength relation for a photon is $E = \frac{hc}{\lambda}$. For a photon of wavelength given by $\lambda_0 = 0.071\,1$ nm the photon's energy is

$$E = \frac{\left(6.626\times10^{-34}\text{ J}\cdot\text{s}\right)\left(3\times10^{8}\text{ m/s}\right)}{\left(0.071\,1\times10^{-9}\text{ m}\right)\left(1.602\times10^{-19}\text{ J/eV}\right)} = 17.4 \text{ keV}$$

(b) For the case of back scattering, $\theta = \pi$ the Compton scattering relation becomes $\lambda' - \lambda_0 = \left(\frac{2hc}{m_e c^2}\right)$. Setting $\lambda_0 = 0.071\,1$ nm we obtain

$$\lambda' = 0.711 \text{ nm} + \frac{2hc}{m_e c^2} = 7.60\times10^{-11}$$

or 0.076 0 nm.

(c) $E' = \frac{hc}{\lambda'} = \frac{\left(6.626\times10^{-34}\text{ J}\cdot\text{s}\right)\left(3\times10^{8}\text{ m/s}\right)}{\left(7.60\times10^{-11}\text{ m}\right)\left(1.602\times10^{-19}\text{ J/eV}\right)} = 16.3 \text{ keV}.$

(d) $\Delta E = 17.45 \text{ keV} - 16.33 \text{ keV} = 1.12 \text{ keV} \sim 1.1 \text{ keV}$.

3-36 A scattered photon has an energy of 80 keV and the recoiled electron has an energy of 25 keV.

(a) From conservation of energy we require that: $E_{\text{photon}} = 80 \text{ keV} = 25 \text{ keV} = 105 \text{ keV}$. As $E_0 = \frac{hc}{\lambda_0}$, we have $\lambda_0 = \frac{hc}{E_0} = \frac{\left(6.626\times10^{-34}\text{ J}\cdot\text{s}\right)\left(3\times10^{8}\text{ m/s}\right)}{\left(105\text{ keV}\right)\left(1.602\times10^{-19}\text{ J/eV}\right)} = 0.011\,8 \text{ nm}.$

(b) The incident photon energy is $E_0 = \frac{hc}{\lambda_0}$, and the energy of the scattered photon is $E' = \frac{hc}{\lambda'}$. One can then take their ratio,

$$\frac{E_0}{E'} = \frac{\lambda'}{\lambda_0} \Rightarrow \lambda' = \frac{\lambda_0 E_0}{E'} = 0.011\,8\text{ nm} \times \left(\frac{105\text{ keV}}{80\text{ keV}}\right) = 0.015\,4\text{ nm}.$$

Using the Compton scattering formula we have:

$$\lambda' - \lambda_0 = \left(\frac{h}{m_e c}\right)(1-\cos\theta) \Rightarrow (1-\cos\theta) = \left(\frac{m_e c}{h}\right)\Delta\lambda$$
$$= \frac{1}{0.002\,43\text{ nm}}(0.015\,4\text{ nm} - 0.011\,8\text{ nm}) = 1.487;\ \theta \approx 119°.$$

(c) The relations between p_e, p_1, p_2, f, and θ are given by $p_e^2 + p_1^2 + p_2^2 - 2p_1p_2' \cos\theta$ and $p_1 = p_e \cos\phi + p_2 \cos\theta$. (see the figure to solution 3-31). Substituting in the first of these equations we have

$$p_e = \left\{(6.626\times10^{-34}\text{ J/s})^2\left[\frac{1}{0.015\,4\text{ nm}} + \frac{1}{0.011\,8\text{ nm}} + \frac{2(-0.487)}{(0.015\,4\text{ nm})(0.011\,8\text{ nm})}\right]\right\}^{1/2}$$
$$= 8.58\times10^{-23}\text{ kg}\cdot\text{m/s}.$$

Now rearrange terms and substitute in the second equation:

$$\cos\phi = \frac{(p_1 - p_2)\cos\theta}{p_e} = (6.626\times10^{-34}\text{ J/s})\frac{1/(0.015\,4\text{ nm}) - 0.487/0.011\,8\text{ nm}}{8.58\times10^{-23}} = 0.819$$

and so $\phi = 35.0°$.

3-37 When waves are scattered between two adjacent planes of a single crystal, constructive wave interference will occur when the path length difference between such reflected waves is an integer multiple of wavelengths. This condition is expressed by the Bragg equation for constructive interference, $2d\sin\theta = n\lambda$ where d is the distance between adjacent crystalline planes, θ is the angle of incidence of the x-ray beam of photons, n is an integer for constructive interference, and λ is the wavelength of the photon beam which is in this case, 0.062 6 nm. Ignoring the incident beam that is not scattered, the first three angles for which maxima of x-ray intensities are found are $1\lambda = 2d\sin\theta_1$ or

$$\sin\theta_1 = \frac{\lambda}{2d} = \frac{0.626\times10^{-10}\text{ m}}{8\times10^{-10}\text{ m}}$$
$$\theta_1 = 0.078\,3\text{ radians} = 4.49°$$

$2\lambda = 2d\sin\theta_2$ or

$$\sin\theta_2 = \frac{\lambda}{d} = \frac{0.626\times10^{-10}\text{ m}}{4.0\times10^{-10}\text{ m}} = 0.156\,5,\ \theta = 9.00°$$