***28.1** (a) Using $\lambda_{\max}T = 2.898 \times 10^{-3}\ \text{m}\cdot\text{K}$

we get $$\lambda_{\max} = \frac{2.898 \times 10^{-3}\ \text{m}}{2900\ \text{K}} = 9.99 \times 10^{-7}\ \text{m} = \boxed{999\ \text{nm}}$$

(b) The $\boxed{\text{peak wavelength is in the infrared}}$ region of the electromagnetic spectrum, which is much wider than the visible region of the spectrum.

***28.2** (a) $\mathcal{P} = eA\sigma T^4$ so $$T = \left(\frac{\mathcal{P}}{eA\sigma}\right)^{1/4} = \left[\frac{3.77 \times 10^{26}\ \text{W}}{1\left[4\pi\left(6.96 \times 10^{8}\ \text{m}\right)^2\right]\left(5.67 \times 10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)}\right]^{1/4}$$

$$T = \boxed{5.75 \times 10^{3}\ \text{K}}$$

(b) $$\lambda_{\max} = \frac{2.898 \times 10^{-3}\ \text{m}\cdot\text{K}}{T} = \frac{2.898 \times 10^{-3}\ \text{m}\cdot\text{K}}{5.75 \times 10^{3}\ \text{K}} = 5.04 \times 10^{-7}\ \text{m} = \boxed{504\ \text{nm}}$$

28.4 Energy of a single 500-nm photon:

$$E_\gamma = hf = \frac{hc}{\lambda} = \frac{\left(6.626 \times 10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)}{\left(500 \times 10^{-9}\ \text{m}\right)} = 3.98 \times 10^{-19}\ \text{J}$$

The energy entering the eye each second

$$E = \mathcal{P}\Delta t = IA\Delta t = \left(4.00 \times 10^{-11}\ \text{W/m}^2\right)\left[\frac{\pi}{4}\left(8.50 \times 10^{-3}\ \text{m}\right)^2\right](1.00\ \text{s}) = 2.27 \times 10^{-15}\ \text{J}$$

The number of photons required to yield this energy

$$n = \frac{E}{E_\gamma} = \frac{2.27 \times 10^{-15}\ \text{J}}{3.98 \times 10^{-19}\ \text{J/photon}} = \boxed{5.71 \times 10^{3}\ \text{photons}}$$

28.7 (a) $$\lambda_c = \frac{hc}{\phi} = \frac{\left(6.626 \times 10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)}{(4.20\ \text{eV})\left(1.60 \times 10^{-19}\ \text{J/eV}\right)} = \boxed{296\ \text{nm}}$$

$$f_c = \frac{c}{\lambda_c} = \frac{3.00 \times 10^{8}\ \text{m/s}}{296 \times 10^{-9}\ \text{m}} = \boxed{1.01 \times 10^{15}\ \text{Hz}}$$

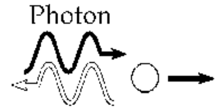
(b) $\frac{hc}{\lambda} = \phi + e\Delta V_S$: $$\frac{\left(6.626 \times 10^{-34}\right)\left(3.00 \times 10^{8}\right)}{180 \times 10^{-9}} = (4.20\ \text{eV})\left(1.60 \times 10^{-19}\ \text{J/eV}\right) + \left(1.60 \times 10^{-19}\right)\Delta V_S$$

Therefore, $\boxed{\Delta V_S = 2.71\ \text{V}}$

28.12 $E = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{700\times10^{-9}\ \text{m}} = 2.84\times10^{-19}\ \text{J} = \boxed{1.78\ \text{eV}}$

$p = \frac{h}{\lambda} = \frac{6.626\times10^{-34}\ \text{J}\cdot\text{s}}{700\times10^{-9}\ \text{m}} = \boxed{9.47\times10^{-28}\ \text{kg}\cdot\text{m/s}}$

28.14 This is Compton scattering through 180°:



$$E_0 = \frac{hc}{\lambda_0} = \frac{(6.626\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})}{(0.110\times10^{-9}\ \text{m})(1.60\times10^{-19}\ \text{J/eV})} = 11.3\ \text{keV}$$

$$\Delta\lambda = \frac{h}{m_e c}(1-\cos\theta) = (2.43\times10^{-12}\ \text{m})(1-\cos180°) = 4.86\times10^{-12}\ \text{m}$$

$\lambda' = \lambda_0 + \Delta\lambda = 0.115\ \text{nm}$ so $E' = \frac{hc}{\lambda'} = 10.8\ \text{keV}$

By conservation of momentum for the photon-electron system, $\frac{h}{\lambda_0}\mathbf{i} = \frac{h}{\lambda'}(-\mathbf{i}) + p_e\,\mathbf{i}$

and $p_e = h\left(\frac{1}{\lambda_0} - \frac{1}{\lambda'}\right)$

$$p_e = (6.626\times10^{-34}\ \text{J}\cdot\text{s})\left(\frac{(3.00\times10^{8}\ \text{m/s})/c}{1.60\times10^{-19}\ \text{J/eV}}\right)\left(\frac{1}{0.110\times10^{-9}\ \text{m}} + \frac{1}{0.115\times10^{-9}\ \text{m}}\right) = \boxed{22.1\ \text{keV}/c}$$

By conservation of system energy, $11.3\ \text{keV} = 10.8\ \text{keV} + K_e$

so that $\boxed{K_e = 478\ \text{eV}}$

Check: $E^2 = p^2c^2 + m_e{}^2c^4$ or $(m_ec^2 + K_e)^2 = (pc)^2 + (m_ec^2)^2$

$$(511\ \text{keV} + 0.478\ \text{keV})^2 = (22.1\ \text{keV})^2 + (511\ \text{keV})^2$$

$$2.62\times10^{11} = 2.62\times10^{11}$$

28.17 $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.626\times10^{-34}\ \text{J}\cdot\text{s}}{(1.67\times10^{-27}\ \text{kg})(1.00\times10^{6}\ \text{m/s})} = \boxed{3.97\times10^{-13}\ \text{m}}$

28.18 (a) Electron: $\lambda = \frac{h}{p}$ and $K = \frac{1}{2}m_e v^2 = \frac{m_e^2 v^2}{2m_e} = \frac{p^2}{2m_e}$ so $p = \sqrt{2m_e K}$

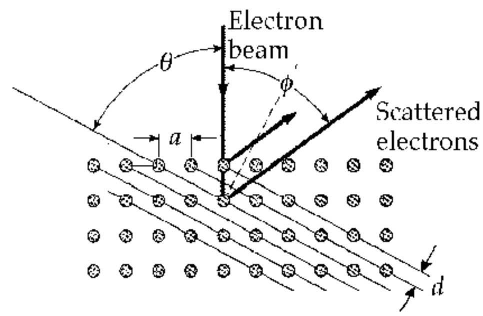
and $$\lambda = \frac{h}{\sqrt{2m_e K}} = \frac{6.626\times10^{-34}\ \text{J}\cdot\text{s}}{\sqrt{2\left(9.11\times10^{-31}\ \text{kg}\right)(3.00)\left(1.60\times10^{-19}\ \text{J}\right)}}$$

$$\lambda = 7.09\times10^{-10}\ \text{m} = \boxed{0.709\ \text{nm}}$$

(b) Photon: $\lambda = c/f$ and $E = hf$ so $f = E/h$

and $$\lambda = \frac{hc}{E} = \frac{\left(6.626\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00\times10^{8}\ \text{m/s}\right)}{3\left(1.60\times10^{-19}\ \text{J}\right)} = 4.14\times10^{-7}\ \text{m} = \boxed{414\ \text{nm}}$$

28.19 From the Bragg condition (Eq 27.18),



$$m\lambda = 2d\sin\theta = 2d\cos\left(\frac{\phi}{2}\right)$$

But $$d = a\sin\left(\frac{\phi}{2}\right)$$

where a is the lattice spacing.

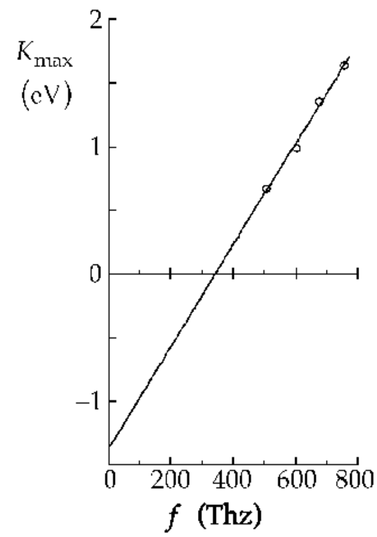
Thus, with $m = 1$, $$\lambda = 2a\sin\left(\frac{\phi}{2}\right)\cos\left(\frac{\phi}{2}\right) = a\sin\phi$$

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m_e K}} \qquad \lambda = \frac{6.626\times10^{-34}\ \text{J}\cdot\text{s}}{\sqrt{2\left(9.11\times10^{-31}\ \text{kg}\right)\left(54.0\times1.60\times10^{-19}\ \text{J}\right)}} = 1.67\times10^{-10}\ \text{m}$$

Therefore, the lattice spacing is $a = \frac{\lambda}{\sin\phi} = \frac{1.67\times10^{-10}\ \text{m}}{\sin 50.0^\circ} = 2.18\times10^{-10} = \boxed{0.218\ \text{nm}}$

28.51 We want an Einstein plot of K_{max} versus f

λ, nm	f, 10^{14} Hz	K_{max}, eV
588	5.10	0.67
505	5.94	0.98
445	6.74	1.35
399	7.52	1.63



(a) $\text{slope} = \dfrac{0.402 \text{ eV}}{10^{14} \text{ Hz}} \pm 8\%$

(b) $e\Delta V_S = hf - \phi$

$$h = (0.402)\left(\frac{1.60 \times 10^{-19} \text{ J}\cdot\text{s}}{10^{14}}\right) = \boxed{6.4 \times 10^{-34} \text{ J}\cdot\text{s} \pm 8\%}$$

(c) $K_{max} = 0$

at $f \approx 344 \times 10^{12}$ Hz

$$\phi = hf = 2.32 \times 10^{-19} \text{ J} = \boxed{1.4 \text{ eV}}$$

28.24 Consider the first bright band away from the center:

$d \sin\theta = m\lambda$ $\qquad$ $(6.00 \times 10^{-8} \text{ m})\sin\left(\tan^{-1}\left[\dfrac{0.400}{200}\right]\right) = (1)\lambda = 1.20 \times 10^{-10} \text{ m}$

$\lambda = \dfrac{h}{m_e v}$ so $\qquad$ $m_e v = \dfrac{h}{\lambda}$

and $\qquad$ $K = \frac{1}{2} m_e v^2 = \dfrac{m_e{}^2 v^2}{2m_e} = \dfrac{h^2}{2m_e\lambda^2} = e\Delta V$

$\Delta V = \dfrac{h^2}{2em_e\lambda^2}$ $\qquad$ $\Delta V = \dfrac{(6.626 \times 10^{-34} \text{ J}\cdot\text{s})^2}{2(1.60 \times 10^{-19} \text{ C})(9.11 \times 10^{-31} \text{ kg})(1.20 \times 10^{-10} \text{ m})^2} = \boxed{105 \text{ V}}$

28.25 (a) $\lambda = \dfrac{h}{mv} = \dfrac{6.626\times10^{-34}\ \text{J}\cdot\text{s}}{\left(1.67\times10^{-27}\ \text{kg}\right)(0.400\ \text{m/s})} = \boxed{9.92\times10^{-7}\ \text{m}}$

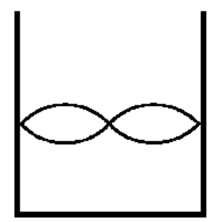
(b) For destructive interference in a multiple-slit experiment, $d\sin\theta = \left(m+\frac{1}{2}\right)\lambda$, with $m = 0$ for the first minimum.

Then, $\theta = \sin^{-1}\left(\dfrac{\lambda}{2d}\right) = 0.0284°$

so $\dfrac{y}{L} = \tan\theta$ $y = L\tan\theta = (10.0\ \text{m})(\tan 0.0284°) = \boxed{4.96\ \text{mm}}$

(c) We cannot say the neutron passed through one slit. We can only say it passed through the slits.

28.34 For an electron wave to "fit" into an infinitely deep potential well, an integral number of half-wavelengths must equal the width of the well.



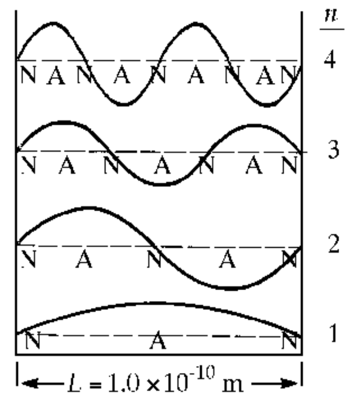
$$\frac{n\lambda}{2} = 1.00\times10^{-9}\ \text{m} \qquad \text{so} \qquad \lambda = \frac{2.00\times10^{-9}}{n} = \frac{h}{p}$$

(a) Since $K = \dfrac{p^2}{2m_e} = \dfrac{\left(h^2/\lambda^2\right)}{2m_e} = \dfrac{h^2}{2m_e}\dfrac{n^2}{\left(2\times10^{-9}\right)^2} = \left(0.377n^2\right)\text{eV}$

For $K \cong 6\ \text{eV}$, $\boxed{n = 4}$

(b) With $n = 4$, $\boxed{K = 6.03\ \text{eV}}$

28.35 (a) We can draw a diagram that parallels our treatment of standing mechanical waves. In each state, we measure the distance d from one node to another (N to N), and base our solution upon that:

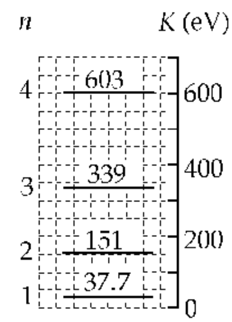


Since $d_{\text{N to N}} = \dfrac{\lambda}{2}$ and $\lambda = \dfrac{h}{p}$

$$p = \frac{h}{\lambda} = \frac{h}{2d}$$

Next, $K = \dfrac{p^2}{2m_e} = \dfrac{h^2}{8m_e d} = \dfrac{1}{d^2}\left[\dfrac{\left(6.626\times10^{-34}\ \text{J}\cdot\text{s}\right)^2}{8\left(9.11\times10^{-31}\ \text{kg}\right)}\right]$

Evaluating, $K = \dfrac{6.02\times10^{-38}\ \text{J}\cdot\text{m}^2}{d^2}$ $K = \dfrac{3.77\times10^{-19}\ \text{eV}\cdot\text{m}^2}{d^2}$



In state 1, $d = 1.00\times10^{-10}\ \text{m}$ $K_1 = 37.7\ \text{eV}$

In state 2, $d = 5.00\times10^{-11}\ \text{m}$ $K_2 = 151\ \text{eV}$

In state 3, $d = 3.33\times10^{-11}\ \text{m}$ $K_3 = 339\ \text{eV}$

In state 4, $d = 2.50\times10^{-11}\ \text{m}$ $K_4 = 603\ \text{eV}$

(b) When the electron falls from state 2 to state 1, it puts out energy

$$E = 151\ \text{eV} - 37.7\ \text{eV} = 113\ \text{eV} = hf = \frac{hc}{\lambda}$$

into emitting a photon of wavelength

$$\lambda = \frac{hc}{E} = \frac{\left(6.626\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00\times10^{8}\ \text{m/s}\right)}{\left(113\ \text{eV}\right)\left(1.60\times10^{-19}\ \text{J/eV}\right)} = 11.0\ \text{nm}$$

The wavelengths of the other spectral lines we find similarly:

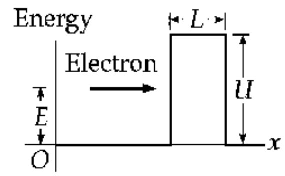
Transition	$4\to3$	$4\to2$	$4\to1$	$3\to2$	$3\to1$	$2\to1$
E(eV)	264	452	565	188	302	113
λ(nm)	4.71	2.75	2.20	6.60	4.12	11.0

***28.39** The desired probability is $P = \int_0^{L/4} |\psi|^2 dx = \frac{2}{L}\int_0^{L/4} \sin^2\left(\frac{2\pi x}{L}\right) dx$

where $\sin^2\theta = \frac{1-\cos 2\theta}{2}$

Thus, $P = \left(\frac{x}{L} - \frac{1}{4\pi}\sin\frac{4\pi x}{L}\right)\Big|_0^{L/4} = \left(\frac{1}{4} - 0 - 0 + 0\right) = \boxed{0.250}$

28.44

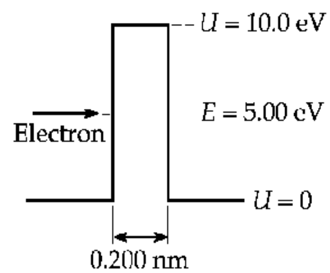


$$C = \frac{\sqrt{2(9.11\times10^{-31})(5.00-4.50)(1.60\times10^{-19})\ \text{kg}\cdot\text{m/s}}}{1.055\times10^{-34}\ \text{J}\cdot\text{s}} = 3.62\times10^{9}\ \text{m}^{-1}$$

$$T = e^{-2CL} = \exp\left[-2(3.62\times10^{9}\ \text{m}^{-1})(950\times10^{-12}\ \text{m})\right] = \exp(-6.88)$$

$$T = \boxed{1.03\times10^{-3}}$$

28.45 $T = e^{-2CL}$ (Use Equation 28.36)



$$2CL = \frac{2\sqrt{2(9.11\times10^{-31})(8.00\times10^{-19})}}{1.055\times10^{-34}}(2.00\times10^{-10}) = 4.58$$

(a) $T = e^{-4.58} = \boxed{0.0103}$, a 1% chance of transmission.

(b) $R = 1 - T = \boxed{0.990}$, a 99% chance of reflection.

28.53 $p = mv = \sqrt{2mE} = \sqrt{2(1.67\times10^{-27}\ \text{kg})(0.0400\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}$

$$\lambda = \frac{h}{mv} = 1.43\times10^{-10}\ \text{m} = \boxed{0.143\ \text{nm}}$$

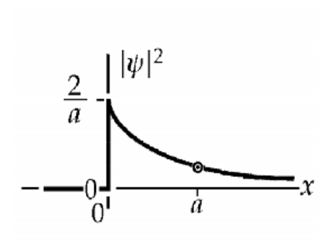
This is of the same order of magnitude as the spacing between atoms in a crystal so diffraction should appear.

28.54 (a) $\lambda = 2L = \boxed{2.00\times10^{-10}\ \text{m}}$

(b) $p = \frac{h}{\lambda} = \frac{6.626\times10^{-34}\ \text{J}\cdot\text{s}}{2.00\times10^{-10}\ \text{m}} = \boxed{3.31\times10^{-24}\ \text{kg}\cdot\text{m/s}}$

(c) $E = \frac{p^2}{2m} = \boxed{0.172\ \text{eV}}$

*28.59 For a particle with wave function



$$\psi(x) = \sqrt{\frac{2}{a}} e^{-x/a} \qquad \text{for } x > 0$$

and 0 for $x < 0$

(a) $|\psi(x)|^2 = 0,\ x < 0$ and $|\psi^2(x)| = \frac{2}{a} e^{-2x/a},\ x > 0$

(b) $\text{Prob}(x < 0) = \int_{-\infty}^{0} |\psi(x)|^2 dx = \int_{-\infty}^{0} (0) dx = \boxed{0}$

(c) Normalization $\int_{-\infty}^{\infty} |\psi(x)|^2 dx = \int_{-\infty}^{0} |\psi|^2 dx + \int_{0}^{\infty} |\psi|^2 dx = 1$

$$\int_{-\infty}^{0} 0\,dx + \int_{0}^{\infty} (2/a) e^{-2x/a} dx = 0 - e^{-2x/a}\Big|_0^{\infty} = -\left(e^{-\infty} - 1\right) = 1$$

$$\text{Prob}(0 < x < a) = \int_0^a |\psi|^2 dx = \int_0^a (2/a) e^{-2x/a} dx = -e^{-2x/a}\Big|_0^a = 1 - e^{-2} = \boxed{0.865}$$