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Chapter 1

Problem Solutions

1.1

(a) fcc: 8 corner atoms $\times 1/8 = 1$ atom
6 face atoms $\times 1/2 = 3$ atoms
Total of 4 atoms per unit cell

(b) bcc: 8 corner atoms $\times 1/8 = 1$ atom
1 enclosed atom $= 1$ atom
Total of 2 atoms per unit cell

(c) Diamond: 8 corner atoms $\times 1/8 = 1$ atom
6 face atoms $\times 1/2 = 3$ atoms
4 enclosed atoms $= 4$ atoms
Total of 8 atoms per unit cell

1.2

(a) Simple cubic lattice: $a = 2r$

Unit cell vol $= a^3 = (2r)^3 = 8r^3$

1 atom per cell, so atom vol $= (1)\left(\dfrac{4\pi r^3}{3}\right)$

Then

$$\text{Ratio} = \frac{\left(\dfrac{4\pi r^3}{3}\right)}{8r^3}\times 100\% = 52.4\%$$

(b) Face-centered cubic lattice

$$d = 4r = a\sqrt{2} \Rightarrow a = \frac{d}{\sqrt{2}} = 2\sqrt{2}\cdot r$$

Unit cell vol $= a^3 = \left(2\sqrt{2}\cdot r\right)^3 = 16\sqrt{2}\cdot r^3$

4 atoms per cell, so atom vol $= (4)\left(\dfrac{4\pi r^3}{3}\right)$

Then

$$\text{Ratio} = \frac{(4)\left(\dfrac{4\pi r^3}{3}\right)}{16\sqrt{2}\cdot r^3}\times 100\% = 74\%$$

(c) Body-centered cubic lattice

$$d = 4r = a\sqrt{3} \Rightarrow a = \frac{4}{\sqrt{3}}\cdot r$$

Unit cell vol $= a^3 = \left(\dfrac{4}{\sqrt{3}}\cdot r\right)^3$

2 atoms per cell, so atom vol $= (2)\left(\dfrac{4\pi r^3}{3}\right)$

Then

$$\text{Ratio} = \frac{(2)\left(\dfrac{4\pi r^3}{3}\right)}{\left(\dfrac{4r}{\sqrt{3}}\right)^3}\times 100\% = 68\%$$

(d) Diamond lattice

Body diagonal $= d = 8r = a\sqrt{3} \Rightarrow a = \dfrac{8}{\sqrt{3}}\cdot r$

Unit cell vol $= a^3 = \left(\dfrac{8r}{\sqrt{3}}\right)^3$

8 atoms per cell, so atom vol $= (8)\left(\dfrac{4\pi r^3}{3}\right)$

Then

$$\text{Ratio} = \frac{(8)\left(\dfrac{4\pi r^3}{3}\right)}{\left(\dfrac{8r}{\sqrt{3}}\right)^3}\times 100\% = 34\%$$

1.3

(a) $a = 5.43\ \overset{o}{A}$; From Problem 1.2d,

$$a = \frac{8}{\sqrt{3}}\cdot r$$

Then $r = \dfrac{a\sqrt{3}}{8} = \dfrac{(5.43)\sqrt{3}}{8} = 1.176\ \overset{o}{A}$

Center of one silicon atom to center of nearest neighbor $= 2r = 2.35\ \overset{o}{A}$

(b) Number density

$$= \frac{8}{\left(5.43\times 10^{-8}\right)^3} = 5\times 10^{22}\ \text{cm}^{-3}$$

(c) Mass density

$$= \rho = \frac{N(At.Wt.)}{N_A} = \frac{\left(5\times 10^{22}\right)(28.09)}{6.02\times 10^{23}}$$

$\Rightarrow \rho = 2.33\ \text{grams/cm}^3$

1.4

(a) 4 Ga atoms per unit cell

Number density $= \dfrac{4}{\left(5.65\times10^{-8}\right)^3}$

$\Rightarrow$ Density of Ga atoms $= 2.22\times10^{22}\ \text{cm}^{-3}$

4 As atoms per unit cell

$\Rightarrow$ Density of As atoms $= 2.22\times10^{22}\ \text{cm}^{-3}$

(b) 8 Ge atoms per unit cell

Number density $= \dfrac{8}{\left(5.65\times10^{-8}\right)^3}$

$\Rightarrow$ Density of Ge atoms $= 4.44\times10^{22}\ \text{cm}^{-3}$

1.5

From Figure 1.15

(a) $d = \left(\dfrac{a}{2}\right)\left(\dfrac{\sqrt{3}}{2}\right) = (0.4330)a$

$= (0.4330)(5.65) \Rightarrow d = 2.447\ \overset{o}{A}$

(b) $d = \left(\dfrac{a}{2}\right)\sqrt{2} = (0.7071)a$

$= (0.7071)(5.65) \Rightarrow d = 3.995\ \overset{o}{A}$

1.6

$$\sin\left(\frac{\theta}{2}\right) = \frac{\frac{a}{2}\sqrt{2}}{\frac{a}{2}\sqrt{3}} = \sqrt{\frac{2}{3}} \Rightarrow \frac{\theta}{2} = 54.74^\circ$$

$\Rightarrow \theta = 109.5^\circ$

1.7

(a) Simple cubic: $a = 2r = 3.9\ \overset{o}{A}$

(b) fcc: $a = \dfrac{4r}{\sqrt{2}} = 5.515\ \overset{o}{A}$

(c) bcc: $a = \dfrac{4r}{\sqrt{3}} = 4.503\ \overset{o}{A}$

(d) diamond: $a = \dfrac{2(4r)}{\sqrt{3}} = 9.007\ \overset{o}{A}$

1.8

(a) $2(1.035)\sqrt{2} = 2(1.035) + 2r_B$

$r_B = 0.4287\ \overset{o}{A}$

(b) $a = 2(1.035) = 2.07\ \overset{o}{A}$

(c) A-atoms: # of atoms $= 8\times\dfrac{1}{8} = 1$

Density $= \dfrac{1}{\left(2.07\times10^{-8}\right)^3}$

$= 1.13\times10^{23}\ \text{cm}^{-3}$

B-atoms: # of atoms $= 6\times\dfrac{1}{2} = 3$

Density $= \dfrac{3}{\left(2.07\times10^{-8}\right)^3}$

$= 3.38\times10^{23}\ \text{cm}^{-3}$

1.9

(a) $a = 2r = 4.5\ \overset{o}{A}$

# of atoms $= 8\times\dfrac{1}{8} = 1$

Number density $= \dfrac{1}{\left(4.5\times10^{-8}\right)^3}$

$= 1.097\times10^{22}\ \text{cm}^{-3}$

Mass density $= \rho = \dfrac{N(At.Wt.)}{N_A}$

$= \dfrac{\left(1.0974\times10^{22}\right)(12.5)}{6.02\times10^{23}}$

$= 0.228\ \text{gm/cm}^3$

(b) $a = \dfrac{4r}{\sqrt{3}} = 5.196\ \overset{o}{A}$

# of atoms $8\times\dfrac{1}{8} + 1 = 2$

Number density $= \dfrac{2}{\left(5.196\times10^{-8}\right)^3}$

$= 1.4257\times10^{22}\ \text{cm}^{-3}$

Mass density $= \rho = \dfrac{\left(1.4257\times10^{22}\right)(12.5)}{6.02\times10^{23}}$

$= 0.296\ \text{gm/cm}^3$

1.10

From Problem 1.2, percent volume of fcc atoms is 74%; Therefore after coffee is ground,

Volume = 0.74 cm^3

1.11

(b) $a = 1.8 + 1.0 = 2.8\ \mathring{A}$

(c) Na: Density $= \dfrac{(1/2)}{(2.8\times10^{-8})^3}$

$= 2.28\times10^{22}\ \text{cm}^{-3}$

Cl: Density $= 2.28\times10^{22}\ \text{cm}^{-3}$

(d) Na: At. Wt. = 22.99
Cl: At. Wt. = 35.45

So, mass per unit cell

$$= \frac{\left(\frac{1}{2}\right)(22.99) + \left(\frac{1}{2}\right)(35.45)}{6.02\times10^{23}} = 4.85\times10^{-23}$$

Then mass density

$$\rho = \frac{4.85\times10^{-23}}{(2.8\times10^{-8})^3} = 2.21\ \text{grams/cm}^3$$

1.12

(a) $a\sqrt{3} = 2(2.2) + 2(1.8) = 8\ \mathring{A}$

Then $a = 4.62\ \mathring{A}$

Density of A:

$$= \frac{1}{(4.62\times10^{-8})^3} = 1.01\times10^{22}\ \text{cm}^{-3}$$

Density of B:

$$= \frac{1}{(4.62\times10^{-8})^3} = 1.01\times10^{22}\ \text{cm}^{-3}$$

(b) Same as (a)
(c) Same material

1.13

$$a = \frac{2(2.2) + 2(1.8)}{\sqrt{3}} = 4.619\ \mathring{A}$$

(a) For 1.12(a), A-atoms

Surface density $= \dfrac{1}{a^2} = \dfrac{1}{(4.619\times10^{-8})^2}$

$= 4.687\times10^{14}\ \text{cm}^{-2}$

For 1.12(b), B-atoms: $a = 4.619\ \mathring{A}$

Surface density $= \dfrac{1}{a^2} = 4.687\times10^{14}\ \text{cm}^{-2}$

For 1.12(a) and (b), Same material

(b) For 1.12(a), A-atoms; $a = 4.619\ \mathring{A}$

Surface density

$$= \frac{1}{a^2\sqrt{2}} = 3.315\times10^{14}\ \text{cm}^{-2}$$

B-atoms;
Surface density

$$= \frac{1}{a^2\sqrt{2}} = 3.315\times10^{14}\ \text{cm}^{-2}$$

For 1.12(b), A-atoms; $a = 4.619\ \mathring{A}$

Surface density

$$= \frac{1}{a^2\sqrt{2}} = 3.315\times10^{14}\ \text{cm}^{-2}$$

B-atoms;
Surface density

$$= \frac{1}{a^2\sqrt{2}} = 3.315\times10^{14}\ \text{cm}^{-2}$$

For 1.12(a) and (b), Same material

1.14

(a) Vol. Density $= \dfrac{1}{a_o^3}$

Surface Density $= \dfrac{1}{a_o^2\sqrt{2}}$

(b) Same as (a)

1.15

(i) (110) plane
(see Figure 1.10(b))

(ii) (111) plane
(see Figure 1.10(c))

(iii) (220) plane $\Rightarrow \left(\frac{1}{2}, \frac{1}{2}, \infty\right) \Rightarrow (1,1,0)$

Same as (110) plane and [110] direction

(iv) (321) plane $\Rightarrow \left(\frac{1}{3}, \frac{1}{2}, \frac{1}{1}\right) \Rightarrow (2,3,6)$

Intercepts of plane at
$p = 2, q = 3, s = 6$

[321] direction is perpendicular to
(321) plane

1.16

(a)

$$\left(\frac{1}{1}, \frac{1}{3}, \frac{1}{1}\right) \Rightarrow (313)$$

(b)

$$\left(\frac{1}{4}, \frac{1}{2}, \frac{1}{4}\right) \Rightarrow (121)$$

1.17

Intercepts: 2, 4, 3 $\Rightarrow \left(\frac{1}{2}, \frac{1}{4}, \frac{1}{3}\right) \Rightarrow$

(634) plane

1.18

(a) $d = a = 5.28\ \overset{o}{A}$

(b) $d = \dfrac{a\sqrt{2}}{2} = 3.734\ \overset{o}{A}$

(c) $d = \dfrac{a\sqrt{3}}{3} = 3.048\ \overset{o}{A}$

1.19

(a) Simple cubic

(i) (100) plane:

$$\text{Surface density } = \frac{1}{a^2} = \frac{1}{\left(4.73\times10^{-8}\right)^2}$$

$$= 4.47\times10^{14}\ \text{cm}^{-2}$$

(ii) (110) plane:

$$\text{Surface density } = \frac{1}{a^2\sqrt{2}}$$

$$= 3.16\times10^{14}\ \text{cm}^{-2}$$

(iii) (111) plane:

$$\text{Area of plane } = \frac{1}{2}bh$$

where $b = a\sqrt{2} = 6.689\ \overset{o}{A}$

Now

$$h^2 = \left(a\sqrt{2}\right)^2 - \left(\frac{a\sqrt{2}}{2}\right)^2 = \frac{3}{4}\left(a\sqrt{2}\right)^2$$

So $h = \dfrac{\sqrt{6}}{2}(4.73) = 5.793\ \overset{o}{A}$

Area of plane

$$= \frac{1}{2}\left(6.68923\times10^{-8}\right)\left(5.79304\times10^{-8}\right)$$

$$= 19.3755\times10^{-16}\ \text{cm}^2$$

$$\text{Surface density } = \frac{3\times\frac{1}{6}}{19.3755\times10^{-16}}$$

$$= 2.58\times10^{14}\ \text{cm}^{-2}$$

(b) bcc

(i) (100) plane:

$$\text{Surface density } = \frac{1}{a^2} = 4.47\times10^{14}\ \text{cm}^{-2}$$

(ii) (110) plane:

$$\text{Surface density } = \frac{2}{a^2\sqrt{2}}$$

$$= 6.32\times10^{14}\ \text{cm}^{-2}$$

(iii) (111) plane:

$$\text{Surface density } = \frac{3\times\frac{1}{6}}{19.3755\times10^{-16}}$$

$$= 2.58\times10^{14}\ \text{cm}^{-2}$$

(c) fcc

(i) (100) plane:

$$\text{Surface density } = \frac{2}{a^2} = 8.94\times10^{14}\ \text{cm}^{-2}$$

(ii) (110) plane:

$$\text{Surface density } = \frac{2}{a^2\sqrt{2}}$$

$$= 6.32\times10^{14}\ \text{cm}^{-2}$$

(iii) (111) plane:

$$\text{Surface density } = \frac{3\times\frac{1}{6} + 3\times\frac{1}{2}}{19.3755\times10^{-16}}$$

$$= 1.03\times10^{15}\ \text{cm}^{-2}$$

1.20

(a) (100) plane: - similar to a fcc:

$$\text{Surface density } = \frac{2}{\left(5.43\times10^{-8}\right)^2}$$

$$= 6.78\times10^{14}\ \text{cm}^{-2}$$

(b) (110) plane:

$$\text{Surface density } = \frac{4}{\sqrt{2}\left(5.43\times10^{-8}\right)^2}$$

$$= 9.59\times10^{14}\ \text{cm}^{-2}$$

(c) (111) plane:

$$\text{Surface density } = \frac{2}{\left(\sqrt{3}/2\right)\left(5.43\times10^{-8}\right)^2}$$
$$= 7.83\times10^{14}\ \text{cm}^{-2}$$

1.21

$$a = \frac{4r}{\sqrt{2}} = \frac{4(2.37)}{\sqrt{2}} = 6.703\ \overset{o}{A}$$

(a) $$\#/\text{cm}^3 = \frac{8\times\frac{1}{8}+6\times\frac{1}{2}}{a^3} = \frac{4}{\left(6.703\times10^{-8}\right)^3}$$
$$= 1.328\times10^{22}\ \text{cm}^{-3}$$

(b) $$\#/\text{cm}^2 = \frac{4\times\frac{1}{4}+2\times\frac{1}{2}}{a^2\sqrt{2}}$$
$$= \frac{2}{\left(6.703\times10^{-8}\right)^2\sqrt{2}}$$
$$= 3.148\times10^{14}\ \text{cm}^{-2}$$

(c) $$d = \frac{a\sqrt{2}}{2} = \frac{(6.703)\sqrt{2}}{2} = 4.74\ \overset{o}{A}$$

(d) $$\#\text{ of atoms } = 3\times\frac{1}{6}+3\times\frac{1}{2} = 2$$

Area of plane: (see Problem 1.19)

$$b = a\sqrt{2} = 9.4786\ \overset{o}{A}$$
$$h = \frac{\sqrt{6}a}{2} = 8.2099\ \overset{o}{A}$$

Area

$$= \frac{1}{2}bh = \frac{1}{2}\left(9.4786\times10^{-8}\right)\left(8.2099\times10^{-8}\right)$$
$$= 3.8909\times10^{-15}\ \text{cm}^2$$

$$\#/\text{cm}^2 = \frac{2}{3.8909\times10^{-15}}$$
$$= 5.14\times10^{14}\ \text{cm}^{-2}$$

$$d = \frac{a\sqrt{3}}{3} = \frac{(6.703)\sqrt{3}}{3} = 3.87\ \overset{o}{A}$$

1.22

Density of silicon atoms $= 5\times10^{22}\ \text{cm}^{-3}$ and 4 valence electrons per atom, so

Density of valence electrons $= 2\times10^{23}\ \text{cm}^{-3}$

1.23

Density of GaAs atoms

$$= \frac{8}{\left(5.65\times10^{-8}\right)^3} = 4.44\times10^{22}\ \text{cm}^{-3}$$

An average of 4 valence electrons per atom,
So

Density of valence electrons

$$= 1.77\times10^{23}\ \text{cm}^{-3}$$

1.24

(a) $$\frac{5\times10^{17}}{5\times10^{22}}\times100\% = 10^{-3}\%$$

(b) $$\frac{2\times10^{15}}{5\times10^{22}}\times100\% = 4\times10^{-6}\%$$

1.25

(a) Fraction by weight

$$\cong \frac{\left(2\times10^{16}\right)(10.82)}{\left(5\times10^{22}\right)(28.06)} = 1.542\times10^{-7}$$

(b) Fraction by weight

$$\cong \frac{\left(10^{18}\right)(30.98)}{\left(5\times10^{22}\right)(28.06)} = 2.208\times10^{-5}$$

1.26

Volume density $= \frac{1}{d^3} = 2\times10^{16}\ \text{cm}^{-3}$

So $d = 3.684\times10^{-6}\ \text{cm} \Rightarrow d = 368.4\ \overset{o}{A}$

We have $a_o = 5.43\ \overset{o}{A}$

Then $\frac{d}{a_o} = \frac{368.4}{5.43} = 67.85$

1.27

Volume density $= \frac{1}{d^3} = 4\times10^{15}\ \text{cm}^{-3}$

So $d = 6.30\times10^{-6}\ \text{cm} \Rightarrow d = 630\ \overset{o}{A}$

We have $a_o = 5.43\ \overset{o}{A}$

Then $\frac{d}{a_o} = \frac{630}{5.43} = 116$

Chapter 2

2.1
Sketch

2.2
Sketch

2.3
Sketch

2.4

From Problem 2.2, phase $= \dfrac{2\pi x}{\lambda} - \omega t$
= constant

Then

$$\frac{2\pi}{\lambda} \cdot \frac{dx}{dt} - \omega = 0, \Rightarrow \frac{dx}{dt} = \upsilon_p = +\omega\left(\frac{\lambda}{2\pi}\right)$$

From Problem 2.3, phase $= \dfrac{2\pi x}{\lambda} + \omega t$
= constant

Then

$$\frac{2\pi}{\lambda} \cdot \frac{dx}{dt} + \omega = 0, \Rightarrow \frac{dx}{dt} = \upsilon_p = -\omega\left(\frac{\lambda}{2\pi}\right)$$

2.5

$$E = h\nu = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}$$

Gold: $E = 4.90 \text{ eV} = (4.90)(1.6\times10^{-19})$ J

So,

$$\lambda = \frac{(6.625\times10^{-34})(3\times10^{10})}{(4.90)(1.6\times10^{-19})} = 2.54\times10^{-5} \text{ cm}$$

or

$\lambda = 0.254\ \mu\text{m}$

Cesium: $E = 1.90 \text{ eV} = (1.90)(1.6\times10^{-19})$ J

So,

$$\lambda = \frac{(6.625\times10^{-34})(3\times10^{10})}{(1.90)(1.6\times10^{-19})} = 6.54\times10^{-5} \text{ cm}$$

or

$\lambda = 0.654\ \mu\text{m}$

2.6

(a) $p = \dfrac{h}{\lambda} = \dfrac{6.625\times10^{-34}}{550\times10^{-9}}$

$= 1.205\times10^{-27}$ kg-m/s

$$\upsilon = \frac{p}{m} = \frac{1.2045\times10^{-27}}{9.11\times10^{-31}} = 1.32\times10^{3} \text{ m/s}$$

or $\upsilon = 1.32\times10^{5}$ cm/s

(b) $p = \dfrac{h}{\lambda} = \dfrac{6.625\times10^{-34}}{440\times10^{-9}}$

$= 1.506\times10^{-27}$ kg-m/s

$$\upsilon = \frac{p}{m} = \frac{1.5057\times10^{-27}}{9.11\times10^{-31}} = 1.65\times10^{3} \text{ m/s}$$

or $\upsilon = 1.65\times10^{5}$ cm/s

(c) Yes

2.7

(a) (i)

$$p = \sqrt{2mE} = \sqrt{2(9.11\times10^{-31})(1.2)(1.6\times10^{-19})}$$

$= 5.915\times10^{-25}$ kg-m/s

$$\lambda = \frac{h}{p} = \frac{6.625\times10^{-34}}{5.915\times10^{-25}} = 1.12\times10^{-9} \text{ m}$$

or $\lambda = 11.2\ \overset{o}{A}$

(ii) $p = \sqrt{2(9.11\times10^{-31})(12)(1.6\times10^{-19})}$

$= 1.87\times10^{-24}$ kg-m/s

$$\lambda = \frac{6.625\times10^{-34}}{1.8704\times10^{-24}} = 3.54\times10^{-10} \text{ m}$$

or $\lambda = 3.54\ \overset{o}{A}$

(iii) $p = \sqrt{2(9.11\times10^{-31})(120)(1.6\times10^{-19})}$

$= 5.915\times10^{-24}$ kg-m/s

$$\lambda = \frac{6.625\times10^{-34}}{5.915\times10^{-24}} = 1.12\times10^{-10} \text{ m}$$

or $\lambda = 1.12\ \overset{o}{A}$

(b)

$$p = \sqrt{2(1.67\times10^{-27})(1.2)(1.6\times10^{-19})}$$

$$= 2.532\times10^{-23}\text{ kg-m/s}$$

$$\lambda = \frac{6.625\times10^{-34}}{2.532\times10^{-23}} = 2.62\times10^{-11}\text{ m}$$

or $\lambda = 0.262\ \overset{o}{A}$

2.8

$$E_{avg} = \frac{3}{2}kT = \left(\frac{3}{2}\right)(0.0259) = 0.03885\text{ eV}$$

Now

$$p_{avg} = \sqrt{2mE_{avg}}$$

$$= \sqrt{2(9.11\times10^{-31})(0.03885)(1.6\times10^{-19})}$$

or

$$p_{avg} = 1.064\times10^{-25}\text{ kg-m/s}$$

Now

$$\lambda = \frac{h}{p} = \frac{6.625\times10^{-34}}{1.064\times10^{-25}} = 6.225\times10^{-9}\text{ m}$$

or

$$\lambda = 62.25\ \overset{o}{A}$$

2.9

$$E_p = h\nu_p = \frac{hc}{\lambda_p}$$

Now

$$E_e = \frac{p_e^2}{2m} \text{ and } p_e = \frac{h}{\lambda_e} \Rightarrow E_e = \frac{1}{2m}\left(\frac{h}{\lambda_e}\right)^2$$

Set $E_p = E_e$ and $\lambda_p = 10\lambda_e$

Then

$$\frac{hc}{\lambda_p} = \frac{1}{2m}\left(\frac{h}{\lambda_e}\right)^2 = \frac{1}{2m}\left(\frac{10h}{\lambda_p}\right)^2$$

which yields

$$\lambda_p = \frac{100h}{2mc}$$

$$E_p = E = \frac{hc}{\lambda_p} = \frac{hc}{100h}\cdot 2mc = \frac{2mc^2}{100}$$

$$= \frac{2(9.11\times10^{-31})(3\times10^8)^2}{100}$$

$$= 1.64\times10^{-15}\text{ J} = 10.25\text{ keV}$$

2.10

(a) $p = \dfrac{h}{\lambda} = \dfrac{6.625\times10^{-34}}{85\times10^{-10}}$

$$= 7.794\times10^{-26}\text{ kg-m/s}$$

$$\upsilon = \frac{p}{m} = \frac{7.794\times10^{-26}}{9.11\times10^{-31}} = 8.56\times10^4\text{ m/s}$$

or $\upsilon = 8.56\times10^6$ cm/s

$$E = \frac{1}{2}m\upsilon^2 = \frac{1}{2}(9.11\times10^{-31})(8.56\times10^4)^2$$

$$= 3.33\times10^{-21}\text{ J}$$

or $E = \dfrac{3.334\times10^{-21}}{1.6\times10^{-19}} = 2.08\times10^{-2}$ eV

(b) $E = \dfrac{1}{2}(9.11\times10^{-31})(8\times10^3)^2$

$$= 2.915\times10^{-23}\text{ J}$$

or $E = \dfrac{2.915\times10^{-23}}{1.6\times10^{-19}} = 1.82\times10^{-4}$ eV

$$p = m\upsilon = (9.11\times10^{-31})(8\times10^3)$$

$$= 7.288\times10^{-27}\text{ kg-m/s}$$

$$\lambda = \frac{h}{p} = \frac{6.625\times10^{-35}}{7.288\times10^{-27}} - 9.09\times10^{-8}\text{ m}$$

or $\lambda = 909\ \overset{o}{A}$

2.11

(a) $E = h\nu = \dfrac{hc}{\lambda} = \dfrac{(6.625\times10^{-34})(3\times10^8)}{1\times10^{-10}}$

$$= 1.99\times10^{-15}\text{ J}$$

Now

$$E = e\cdot V \Rightarrow V = \frac{E}{e} = \frac{1.99\times10^{-15}}{1.6\times10^{-19}}$$

$$V = 1.24\times10^4\text{ V} = 12.4\text{ kV}$$

(b) $p = \sqrt{2mE} = \sqrt{2(9.11\times10^{-31})(1.99\times10^{-15})}$

$$= 6.02\times10^{-23}\text{ kg-m/s}$$

Then

$$\lambda = \frac{h}{p} = \frac{6.625\times10^{-34}}{6.02\times10^{-23}} = 1.10\times10^{-11}\text{ m}$$

or

$$\lambda = 0.11\ \overset{o}{A}$$

2.12

$$\Delta p = \frac{\hbar}{\Delta x} = \frac{1.054\times10^{-34}}{10^{-6}}$$
$$= 1.054\times10^{-28} \text{ kg-m/s}$$

2.13

(a) (i) $\Delta p \Delta x = \hbar$

$$\Delta p = \frac{1.054\times10^{-34}}{12\times10^{-10}} = 8.783\times10^{-26} \text{ kg-m/s}$$

(ii) $$\Delta E = \frac{dE}{dp}\cdot\Delta p = \frac{d}{dp}\left(\frac{p^2}{2m}\right)\cdot\Delta p$$
$$= \frac{2p}{2m}\cdot\Delta p = \frac{p\Delta p}{m}$$

Now $p = \sqrt{2mE}$
$$= \sqrt{2\left(9\times10^{-31}\right)(16)\left(1.6\times10^{-19}\right)}$$
$$= 2.147\times10^{-24} \text{ kg-m/s}$$

so $$\Delta E = \frac{\left(2.1466\times10^{-24}\right)\left(8.783\times10^{-26}\right)}{9\times10^{-31}}$$
$$= 2.095\times10^{-19} \text{ J}$$

or $$\Delta E = \frac{2.095\times10^{-19}}{1.6\times10^{-19}} = 1.31 \text{ eV}$$

(b) (i) $\Delta p = 8.783\times10^{-26}$ kg-m/s

(ii) $$p = \sqrt{2\left(5\times10^{-28}\right)(16)\left(1.6\times10^{-19}\right)}$$
$$= 5.06\times10^{-23} \text{ kg-m/s}$$
$$\Delta E = \frac{\left(5.06\times10^{-23}\right)\left(8.783\times10^{-26}\right)}{5\times10^{-28}}$$
$$= 8.888\times10^{-21} \text{ J}$$

or $$\Delta E = \frac{8.888\times10^{-21}}{1.6\times10^{-19}} = 5.55\times10^{-2} \text{ eV}$$

2.14

$$\Delta p = \frac{\hbar}{\Delta x} = \frac{1.054\times10^{-34}}{10^{-2}} = 1.054\times10^{-32} \text{ kg-m/s}$$
$$p = m\upsilon \Rightarrow \Delta\upsilon = \frac{\Delta p}{m} = \frac{1.054\times10^{-32}}{1500}$$
$$\Delta\upsilon = 7\times10^{-36} \text{ m/s}$$

2.15

(a) $\Delta E \Delta t = \hbar$

$$\Delta t = \frac{1.054\times10^{-34}}{(0.8)\left(1.6\times10^{-19}\right)} = 8.23\times10^{-16} \text{ s}$$

(b) $$\Delta p = \frac{\hbar}{\Delta x} = \frac{1.054\times10^{-34}}{1.5\times10^{-10}}$$
$$= 7.03\times10^{-25} \text{ kg-m/s}$$

2.16

(a) If $\Psi_1(x,t)$ and $\Psi_2(x,t)$ are solutions to Schrodinger's wave equation, then

$$\frac{-\hbar^2}{2m}\cdot\frac{\partial^2\Psi_1(x,t)}{\partial x^2} + V(x)\Psi_1(x,t) = j\hbar\frac{\partial\Psi_1(x,t)}{\partial t}$$

and

$$\frac{-\hbar^2}{2m}\cdot\frac{\partial^2\Psi_2(x,t)}{\partial x^2} + V(x)\Psi_2(x,t) = j\hbar\frac{\partial\Psi_2(x,t)}{\partial t}$$

Adding the two equations, we obtain

$$\frac{-\hbar^2}{2m}\cdot\frac{\partial^2}{\partial x^2}\left[\Psi_1(x,t) + \Psi_2(x,t)\right]$$
$$+V(x)\left[\Psi_1(x,t) + \Psi_2(x,t)\right]$$
$$= j\hbar\frac{\partial}{\partial t}\left[\Psi_1(x,t) + \Psi_2(x,t)\right]$$

which is Schrodinger's wave equation. So $\Psi_1(x,t) + \Psi_2(x,t)$ is also a solution.

(b) If $\Psi_1(x,t)\cdot\Psi_2(x,t)$ were a solution to Schrodinger's wave equation, then we could write

$$\frac{-\hbar^2}{2m}\cdot\frac{\partial^2}{\partial x^2}\left[\Psi_1\cdot\Psi_2\right] + V(x)\left[\Psi_1\cdot\Psi_2\right]$$
$$= j\hbar\frac{\partial}{\partial t}\left[\Psi_1\cdot\Psi_2\right]$$

which can be written as

$$\frac{-\hbar^2}{2m}\left[\Psi_1\frac{\partial^2\Psi_2}{\partial x^2} + \Psi_2\frac{\partial^2\Psi_1}{\partial x^2} + 2\frac{\partial\Psi_1}{\partial x}\cdot\frac{\partial\Psi_2}{\partial x}\right]$$
$$+V(x)\left[\Psi_1\cdot\Psi_2\right] = j\hbar\left[\Psi_1\frac{\partial\Psi_2}{\partial t} + \Psi_2\frac{\partial\Psi_1}{\partial t}\right]$$

Dividing by $\Psi_1\cdot\Psi_2$, we find

$$\frac{-\hbar^2}{2m}\left[\frac{1}{\Psi_2}\cdot\frac{\partial^2\Psi_2}{\partial x^2} + \frac{1}{\Psi_1}\cdot\frac{\partial^2\Psi_1}{\partial x^2} + \frac{2}{\Psi_1\Psi_2}\frac{\partial\Psi_1}{\partial x}\frac{\partial\Psi_2}{\partial x}\right]$$
$$+V(x) = j\hbar\left[\frac{1}{\Psi_2}\frac{\partial\Psi_2}{\partial t} + \frac{1}{\Psi_1}\frac{\partial\Psi_1}{\partial t}\right]$$

Since Ψ_1 is a solution, then

$$\frac{-\hbar^2}{2m}\cdot\frac{1}{\Psi_1}\cdot\frac{\partial^2\Psi_1}{\partial x^2}+V(x)=j\hbar\cdot\frac{1}{\Psi_1}\cdot\frac{\partial\Psi_1}{\partial t}$$

Subtracting these last two equations, we have

$$\frac{-\hbar^2}{2m}\left[\frac{1}{\Psi_2}\cdot\frac{\partial^2\Psi_2}{\partial x^2}+\frac{2}{\Psi_1\Psi_2}\frac{\partial\Psi_1}{\partial x}\frac{\partial\Psi_2}{\partial x}\right]$$

$$=j\hbar\cdot\frac{1}{\Psi_2}\cdot\frac{\partial\Psi_2}{\partial t}$$

Since Ψ_2 is also a solution, we have

$$\frac{-\hbar^2}{2m}\cdot\frac{1}{\Psi_2}\cdot\frac{\partial^2\Psi_2}{\partial x^2}+V(x)=j\hbar\cdot\frac{1}{\Psi_2}\cdot\frac{\partial\Psi_2}{\partial t}$$

Subtracting these last two equations, we obtain

$$\frac{-\hbar^2}{2m}\cdot\frac{2}{\Psi_1\Psi_2}\cdot\frac{\partial\Psi_1}{\partial x}\cdot\frac{\partial\Psi_2}{\partial x}-V(x)=0$$

This equation is not necessarily valid, which means that $\Psi_1\Psi_2$ is, in general, not a solution to Schrodinger's wave equation.

2.17

$$\int_{-1}^{+3}A^2\cos^2\left(\frac{\pi x}{2}\right)dx=1$$

$$A^2\left[\frac{x}{2}+\frac{\sin(\pi x)}{2\pi}\right]\Bigg|_{-1}^{+3}=1$$

$$A^2\left[\frac{3}{2}-\left(\frac{-1}{2}\right)\right]=1$$

so $A^2=\dfrac{1}{2}$

or $|A|=\dfrac{1}{\sqrt{2}}$

2.18

$$\int_{-1/2}^{+1/2}A^2\cos^2(n\pi x)dx=1$$

$$A^2\left[\frac{x}{2}+\frac{\sin(2n\pi x)}{4n\pi}\right]\Bigg|_{-1/2}^{+1/2}=1$$

$$A^2\left[\frac{1}{4}-\left(-\frac{1}{4}\right)\right]=1=A^2\left(\frac{1}{2}\right)$$

or $|A|=\sqrt{2}$

2.19

Note that $\int_0^\infty \Psi\cdot\Psi^* dx=1$

Function has been normalized.

(a) Now

$$P=\int_0^{a_o/4}\left[\sqrt{\frac{2}{a_o}}\exp\left(\frac{-x}{a_o}\right)\right]^2dx$$

$$=\frac{2}{a_o}\int_0^{a_o/4}\exp\left(\frac{-2x}{a_o}\right)dx$$

$$=\frac{2}{a_o}\left(\frac{-a_o}{2}\right)\exp\left(\frac{-2x}{a_o}\right)\Bigg|_0^{a_o/4}$$

or

$$P=(-1)\left[\exp\left(\frac{-2a_o}{4a_o}\right)-1\right]=1-\exp\left(\frac{-1}{2}\right)$$

which yields

$P=0.393$

(b)

$$P=\int_{a_o/4}^{a_o/2}\left[\sqrt{\frac{2}{a_o}}\exp\left(\frac{-x}{a_o}\right)\right]^2dx$$

$$=\frac{2}{a_o}\int_{a_o/4}^{a_o/2}\exp\left(\frac{-2x}{a_o}\right)dx$$

$$=\frac{2}{a_o}\left(\frac{-a_o}{2}\right)\exp\left(\frac{-2x}{a_o}\right)\Bigg|_{a_o/4}^{a_o/2}$$

or

$$P=(-1)\left[\exp(-1)-\exp\left(\frac{-1}{2}\right)\right]$$

which yields

$P=0.239$

(c)

$$P=\int_0^{a_o}\left[\sqrt{\frac{2}{a_o}}\exp\left(\frac{-x}{a_o}\right)\right]^2dx$$

$$=\frac{2}{a_o}\int_0^{a_o}\exp\left(\frac{-2x}{a_o}\right)dx$$

$$=\frac{2}{a_o}\left(\frac{-a_o}{2}\right)\exp\left(\frac{-2x}{a_o}\right)\Bigg|_0^{a_o}$$

$$=(-1)[\exp(-2)-1]$$

which yields

$P=0.865$

2.20

$$P=\int|\psi(x)|^2\,dx$$

(a) $\displaystyle\int_0^{a/4}\left(\frac{2}{a}\right)\cos^2\left(\frac{\pi x}{2}\right)dx$

$$=\left(\frac{2}{a}\right)\left[\frac{x}{2}+\frac{\sin\left(\frac{2\pi x}{a}\right)}{4\left(\frac{\pi}{a}\right)}\right]\Bigg|_0^{a/4}$$

$$=\left(\frac{2}{a}\right)\left[\frac{\left(\frac{a}{4}\right)}{2}+\frac{\sin\left(\frac{\pi}{2}\right)}{\left(\frac{4\pi}{a}\right)}\right]$$

$$=\left(\frac{2}{a}\right)\left[\frac{a}{8}+\frac{(1)(a)}{4\pi}\right]$$

or $P=0.409$

(b) $\displaystyle P=\int_{a/4}^{a/2}\left(\frac{2}{a}\right)\cos^2\left(\frac{\pi x}{a}\right)dx$

$$=\left(\frac{2}{a}\right)\left[\frac{x}{2}+\frac{\sin\left(\frac{2\pi x}{a}\right)}{4\left(\frac{\pi}{a}\right)}\right]\Bigg|_{a/4}^{a/2}$$

$$=\left(\frac{2}{a}\right)\left[\frac{a}{4}+\frac{\sin(\pi)}{\left(\frac{4\pi}{a}\right)}-\frac{a}{8}-\frac{\sin\left(\frac{\pi}{2}\right)}{\left(\frac{4\pi}{a}\right)}\right]$$

$$=2\left[\frac{1}{4}+0-\frac{1}{8}-\frac{1}{4\pi}\right]$$

or $P=0.0908$

(c) $\displaystyle P=\int_{-a/2}^{+a/2}\left(\frac{2}{a}\right)\cos^2\left(\frac{\pi x}{a}\right)dx$

$$=\left(\frac{2}{a}\right)\left[\frac{x}{2}+\frac{\sin\left(\frac{2\pi x}{a}\right)}{\left(\frac{4\pi}{a}\right)}\right]\Bigg|_{-a/2}^{+a/2}$$

$$=\left(\frac{2}{a}\right)\left[\frac{a}{4}+\frac{\sin(\pi)}{\left(\frac{4\pi}{a}\right)}-\left(\frac{-a}{4}\right)-\frac{\sin(-\pi)}{\left(\frac{4\pi}{a}\right)}\right]$$

or $P=1$

2.21

(a) $\displaystyle P=\int_0^{a/4}\left(\frac{2}{a}\right)\sin^2\left(\frac{2\pi x}{a}\right)dx$

$$=\left(\frac{2}{a}\right)\left[\frac{x}{2}-\frac{\sin\left(\frac{4\pi x}{a}\right)}{4\left(\frac{2\pi}{a}\right)}\right]\Bigg|_0^{a/4}$$

$$=\left(\frac{2}{a}\right)\left[\frac{a}{8}-\frac{\sin(\pi)}{\left(\frac{8\pi}{a}\right)}\right]$$

or $P=0.25$

(b) $\displaystyle P=\int_{a/4}^{a/2}\left(\frac{2}{a}\right)\sin^2\left(\frac{2\pi x}{a}\right)dx$

$$=\left(\frac{2}{a}\right)\left[\frac{x}{2}-\frac{\sin\left(\frac{4\pi x}{a}\right)}{4\left(\frac{2\pi}{a}\right)}\right]\Bigg|_{a/4}^{a/2}$$

$$=\left(\frac{2}{a}\right)\left[\frac{a}{4}-\frac{\sin(2\pi)}{\left(\frac{8\pi}{a}\right)}-\left(\frac{a}{8}\right)+\frac{\sin(\pi)}{\left(\frac{8\pi}{a}\right)}\right]$$

or $P=0.25$

(c) $\displaystyle P=\int_{-a/2}^{+a/2}\left(\frac{2}{a}\right)\sin^2\left(\frac{2\pi x}{a}\right)dx$

$$=\left(\frac{2}{a}\right)\left[\frac{x}{2}-\frac{\sin\left(\frac{4\pi x}{a}\right)}{4\left(\frac{2\pi}{a}\right)}\right]\Bigg|_{-a/2}^{+a/2}$$

$$=\left(\frac{2}{a}\right)\left[\frac{a}{4}-\frac{\sin(2\pi)}{\left(\frac{8\pi}{a}\right)}-\left(\frac{-a}{4}\right)+\frac{\sin(-2\pi)}{\left(\frac{8\pi}{a}\right)}\right]$$

or $P=1$

2.22

(a) (i) $\upsilon_p=\dfrac{\omega}{k}=\dfrac{8\times10^{12}}{8\times10^{8}}=10^4$ m/s

or $\upsilon_p=10^6$ cm/s

$$\lambda=\frac{2\pi}{k}=\frac{2\pi}{8\times10^8}=7.854\times10^{-9}\text{ m}$$