Introduction to Applied Modern Physics

First Edition

Instructor's Solutions Manual

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Chapter 1

Solutions to Problems

1.1 a. *The minimum photon energy is equal to the metal work function:*

$$\phi = 2.46ev(1.6\times10^{-19}\,J/ev) = 3.94\times10^{-19}\,J$$

b. $\lambda_c = \dfrac{hc}{\phi} = \dfrac{(3\times10^{8}\,m/s)(6.626\times10^{-34}\,J\cdot s}{3.94\times10^{-19}\,J} = 505nm$

c. Visible part of the electromagnetic spectrum.

1.2. *Planck's radiation law:* $I(\lambda,T) = 2\pi hc^2/[\lambda^5(e^{hc/\lambda K_b T}-1)]$

a. For large wavelength or high temperature:

$$e^{hc/\lambda k_b T} - 1 = 1 + \frac{hc}{\lambda k_b T} + ... - 1 \cong \frac{hc}{\lambda k_b T}$$

$$\therefore I(\lambda,T) = \frac{2\pi c k_b T}{\lambda^4}$$

b. For short wavelength or low temperature:

$$e^{hc/\lambda k_b T} - 1 \cong e^{hc/\lambda k_b T}$$

$$\therefore I(\lambda,T) = \frac{2\pi c^2 h}{\lambda^5} e^{-hc/\lambda k_b T}$$

c.

$$E_1 = hf \;\&\; E_2 = 2hf$$

$$\therefore \Delta E = E_2 - E_1 = hf$$

1.3 *a. Coulomb's and Newton's laws give:*

$$\frac{z\kappa q^2}{r^2} = \frac{m_e v^2}{r}$$
$$\frac{1}{2}m_e v^2 = \frac{z\kappa q^2}{2r} \; \& \; E = \frac{1}{2}m_e v^2 - z\kappa q^2 / r = -\frac{z\kappa q^2}{2r}$$

Angular momentum quantization gives:

$$m_e vr = n\hbar$$
$$v^2 = \frac{n^2\hbar^2}{m_e^2 r^2}$$
$$\therefore r_n = \frac{n^2\hbar^2}{zm_e\kappa q^2} = a_0 n^2 / z$$

b. $$E_n = \frac{13.6}{n^2} z^2 ev = 54.4ev$$

c.

$$\frac{1}{\lambda} = z^2 R_H (\frac{1}{n_f^2} - \frac{1}{n_i^2}) = \frac{3z^2 R_H}{4}$$
$$\therefore \lambda = 3.04\times10^{-8} m \; \& \; f = c/\lambda = \frac{3\times10^8 m/s}{3.04\times10^{-8} m} = 9.8\times10^{15} Hz$$

1.4. *a.*

$$\phi = hf - \frac{1}{2}m_e v^2$$
$$where \quad f = c/\lambda = \frac{3\times10^8 m/s}{600\times10^{-7} m} = 5\times10^{14} Hz$$
$$\therefore \phi =$$
$$(6.626\times10^{-34} J\cdot s)5\times10^{14} Hz - \frac{1}{2}(9.11\times10^{-31} kg)16\times10^{10} m^2/s^2 = 25.84\times10^{-20} J$$

b.

$$\lambda_c = \frac{hc}{\phi} = \frac{(6.626\times10^{-34} J\cdot s)3\times10^8 m/s}{25.84\times10^{-20} J} = 769nm$$

1.5.

$$\frac{1}{\lambda} = z^2 R_H (\frac{1}{n_f^2} - \frac{1}{n_i^2}) = 4(1.097\times10^7 m^{-1})(1-\frac{1}{9})$$
$$\therefore \lambda = 2.564\times10^{-8} m \; \& \; f = c/\lambda = \frac{3\times10^8 m/s}{2.56\times10^{-8} m} = 1.17\times10^{16} Hz$$

1.6. *a.*

$$\lambda_m = \frac{2.898\times10^{-3}\,m\cdot k}{T} = \frac{2.898\times10^{-3}\,m}{5800} = 0.5\mu m$$

b. Visible region.

1.7.

$$E = \frac{-13.606ev}{n^2} \;\&\; E = \frac{hc}{\lambda}$$

A: Absorption, where $\Delta E = 2.86ev$
B: Emission, where $\Delta E = -0.967ev$
C: Emission, where $\Delta E = -0.572ev$
D: Absorption, where $\Delta E = 0.572ev$

a. B
b. A
c. B & C

1.8.

Information a gives:

$$hf = q(\Delta V_{s1}) + \phi_1 \text{ and } hf = q(\Delta V_{s2}) + \phi_2,$$
$$\text{where } \Delta V_{s1} - \Delta V_{s2} = 4.48V$$
$$\therefore \phi_2 - \phi_1 = 4.48ev$$

Information a and b gives:

$$hf_{c1} = h(f_{c2} - 0.4 f_{c2}) = \phi_1$$
$$\phi_1 = 0.6\phi_2$$
$$\phi_2 - \phi_1 = \phi_2 - 0.6\phi_2 = 4.48ev$$
$$\therefore \phi_2 = 11.2ev \;\&\; \phi_1 = 6.72ev$$

1.9. *a. The total energy flux, power per unit area, is given by the **Stefan-Boltzmann law** (see example 1.2.2):*

$$P = A\sigma T^4 = 3.77\times 10^{26} W$$
$$where$$
$$A = 4\pi(6.96\times 10^8 m)^2$$
$$\sigma = 5.67\times 10^{-8} \frac{W}{m^2k^4}$$
$$\therefore T = (\frac{P}{A\sigma})^{1/4} = 5.75\times 10^3 k$$

b.

$$\lambda_m = \frac{2.898\times 10^{-3} m\cdot k}{T} = \frac{2.898\times 10^{-3} m\cdot k}{5.75\times 10^3 k} = 504nm$$

1.10. *For* ***Balmer series,*** *where* $n \geq 3$,

$$\frac{1}{\lambda} = R_H(\frac{1}{2^2} - \frac{1}{n^2})$$
$$\lambda = \frac{4n^2}{R_H(n^2-4)} = \frac{200n^2}{n^2-4}\times 10^{-9} m$$
$$\therefore 200nm \leq \lambda \leq 360nm$$

This is an ***ultraviolet*** *wavelength range.*

1.11. *Planck's radiation law:* $I(\lambda,T) = 2\pi hc^2/[\lambda^5(e^{hc/\lambda K_bT}-1)]$

$$\frac{dI}{d\lambda}|_{\lambda=\lambda_m} = 2\pi hc^2[-5\lambda^{-6}(e^{hc/\lambda k_bT}-1)^{-1} - \lambda^{-5}(e^{hc/\lambda k_bT}-1)^{-2}(\frac{-hce^{hc/\lambda k_bT}}{\lambda^2 k_bT})]|_{\lambda=\lambda_m} = 0$$
$$\frac{dI}{d\lambda}|_{\lambda=\lambda_m} = \frac{2\pi hc^2}{\lambda^6(e^{hc/\lambda k_bT}-1)}[-5 + \frac{hc}{\lambda k_bT}\frac{e^{hc/\lambda k_bT}}{(e^{hc/\lambda k_bT}-1)}]|_{\lambda=\lambda_m} = 0$$

Let $x = \frac{hc}{\lambda_m k_b T}$ *and solution of the above equation is*

$$\frac{xe^x}{e^x-1} = 5 \;\; where \;\; x = 4.965115$$
$$\therefore \lambda_m T = \frac{hc}{4.965115k_b} = 2.87755\times 10^{-3} m\cdot k$$

Chapter 2

Solutions to Problems

2.1. *a. Schrödinger equations for the three regions are given below.*

Region I:

$$\frac{d^2\psi_I}{dx^2} = \frac{-2m}{\hbar^2}E\psi_I$$

Region II:

$$\frac{d^2\psi_{II}}{dx^2} = \frac{-2m}{\hbar^2}(E-U)\psi_{II}$$

Region III:

$$\frac{d^2\psi_{III}}{dx^2} = \frac{-2m}{\hbar^2}E\psi_{III}$$

b.

$$T = \frac{1}{1+\dfrac{1}{\frac{E}{U}(1-\frac{E}{U})}\sinh^2(kL)} = \frac{1}{1+\frac{9}{2}\sinh^2(1.6)} \approx 0.0379$$

$$k = \frac{\sqrt{2m(U-E)}}{\hbar} = \frac{\sqrt{2\times 9.11\times 10^{-31}kg(10ev)1.6\times 10^{-19}J/ev}}{1.05\times 10^{-34}J\cdot s} = 16\times 10^{9}m^{-1}$$

c. R=1-T=0.96

2.2. *The first and second derivatives of the wave function are:*

$$\frac{d\psi}{dx} = -2k'A\sin(2k'x) + 2k'B\cos(2k'x)$$

$$\frac{d^2\psi}{dx^2} = -4k'^2 A\cos(2k'x) - 4k'^2 B\sin(2k'x) = -4k'^2\psi = -\frac{2m}{\hbar^2}E\psi$$

$$\therefore E = \frac{2\hbar^2 k'^2}{m}$$

2.3. *The first and second derivatives of the wave function are:*

$$\frac{d\psi}{dx} = Ae^{-bx^2} - 2bx^2 Ae^{-bx^2}$$

$$\frac{d^2\psi}{dx^2} = -6b\psi + 4b^2x^2\psi$$

Substituting the second derivative above into the Schrödinger equation gives:

$$-6b\psi + 4b^2x^2\psi = -(\frac{2mE}{\hbar^2})\psi + (\frac{mw}{\hbar})^2 x^2\psi$$

$$\textit{Therefore, } -6b = \frac{-2mE}{\hbar^2} \textit{ and } 4b^2 = (\frac{mw}{\hbar})^2.$$

b. *From part* a *above:*

$$4b^2 = (\frac{mw}{\hbar})^2$$

$$b = \frac{mw}{2\hbar}$$

$$\textit{and} \quad E = \frac{3\hbar^2}{m}b = \frac{3}{2}\hbar w$$

2.4. *a. The minimum uncertainty in determining the position of the particle is:*

$$\Delta x = \frac{\hbar}{2\Delta p} \textit{, where uncertainty of the momentum is:}$$

$$\Delta p = 9\times10^{-31}kg(0.01)m/s = 9\times10^{-33}kg\cdot m/s.$$

The momentum $p = 9\times10^{-31}kg(10^3 m/s) = 9\times10^{-28}kg\cdot m/s$

Therefore,

$$\Delta x = \frac{6.628\times10^{-34}J\cdot s}{4\pi(9\times10^{-33}kg\cdot m/s)} = 0.006m .$$

b. *The Bohr model of the hydrogen atom, an electron orbiting around a circular path, is not supported by the uncertainty principle. The uncertainty principle states that a particle confined to a region of space cannot have a unique single value of momentum. However, the Bohr model indicates that if we localized an electron at a distance r from the nucleus, we can exactly determine its velocity,*

$$v = \sqrt{\frac{\kappa q^2}{m_e r}},$$

which is a clear violation of the momentum and position uncertainty.

2.5. *a.* $1s^2 2s^2 2p^6$

b.

$$1s^2 \rightarrow \begin{cases} n & l & m_l & m_s \\ 1 & 0 & 0 & -1/2 \\ 1 & 0 & 0 & +1/2 \end{cases}$$

$$2s^2 \rightarrow \begin{cases} 2 & 0 & 0 & -1/2 \\ 2 & 0 & 0 & +1/2 \end{cases}$$

$$2p^6 \rightarrow \begin{cases} 2 & 1 & 1 & -1/2 \\ 2 & 1 & 0 & -1/2 \\ 2 & 1 & -1 & -1/2 \\ 2 & 1 & 1 & +1/2 \\ 2 & 1 & 0 & +1/2 \\ 2 & 1 & -1 & +1/2 \end{cases}$$

c. *The angular momentum* $L = \hbar\sqrt{l(l+1)} = \sqrt{2}\hbar$ *where l=1*

d. $L_z = m_l\hbar$ *=0,* $\hbar$, $-\hbar$ *where* m_l *=0, 1, -1*

$$\theta = \cos^{-1}\left(\frac{m_l}{\sqrt{l(l+1)}}\right) = \cos^{-1}(0),\ \cos^{-1}(1/\sqrt{2}),\ \cos^{-1}(-1/\sqrt{2}) = 90^0,\ 45^0,\ 135^0$$

2.6. *Quantum mechanics does not allow the ground state energy to be zero. If we assume that an electron has zero minimum energy and that we are able to locate its exact position, then automatically we know its momentum is zero. That is a clear violation of the uncertainty principle.*

2.7. *a.*

$$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}\,J\cdot s}{(50\times10^{-3}\,kg)(40m/s)} = 3.3\times10^{-34}\,m$$

b. *Conservation of energy states that the total kinetic energy is equal to the electric potential energy:*

$$\frac{1}{2}mv^2 = \frac{p^2}{2m} = qV,\ \text{where the momentum}\ p = \frac{h}{\lambda}$$

$$\therefore \lambda = \frac{h}{p} = \frac{h}{\sqrt{2mqV}}$$

2.8.

$$\int_{-a}^{a} |\psi|^2 dx = 1$$

$$\int_{-a}^{a} [A^2 \cos^2(\frac{\pi x}{2a}) + B^2 \sin^2(\frac{\pi x}{a}) + 2AB\cos(\frac{\pi x}{2a})\sin(\frac{\pi x}{a})]dx = 1$$

$$A^2 a + B^2 a + 0 = 1$$

$$\therefore A^2 + B^2 = 1/a$$

where sin 2θ=2sin θ cos θ & cos(2θ)=cos²(θ)- sin²(θ)

$$\sin^2\theta + \cos^2\theta - \cos(2\theta) = 1 - \cos(2\theta) = 2\sin^2\theta$$

$$1 - \cos(2\theta) = 2\sin^2\theta$$

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

$$\textit{Similarly, } \cos^2\theta = \frac{1}{2} + \frac{1}{2}\cos(2\theta)$$

2.9. *a. The energy equation can be rewritten using the uncertainty of position* $\Delta x \geq \hbar / 2\Delta p_x$ *and by taking the expectation values* $< x^2 >= (\Delta x)^2$, $< p_x^2 >= (\Delta p_x)^2$ *as*

$$E \geq \frac{p_x^2}{2m} + \frac{k\hbar^2}{8p_x^2}$$

b. Minimum energy of the harmonic oscillator:

$$\frac{dE}{dp_x^2}|_{p_x^2 = p_{x\min}^2} = \frac{1}{2m} - \frac{k\hbar^2}{8p_{x\min}^4} = 0$$

$$p_{x\min}^2 = \hbar\frac{\sqrt{mk}}{2}$$

$$\therefore E_{\min} = \frac{\hbar\sqrt{k/m}}{2} = \frac{\hbar w}{2}, \textit{ where } E \geq \frac{p_x^2}{2m} + \frac{k\hbar^2}{8p_x^2}.$$

2.10. *The probability density when only one slit is open is given by* $P_1 = |\psi_1|^2$ *or* $P_2 = |\psi_2|^2$, *where* ψ_1 *and* ψ_2 *are the wave functions of electron passing thru slit one and two respectively. If both slits are open, then:*

$$P = |\psi_1 + \psi_2|^2.$$

At the interference maximum, the wave functions are in phase and the probability is written as:

$$P_{\max} = (|\psi_1| + |\psi_2|)^2 .$$

At the interference minimum, the wave functions are out of phase and the probability is written as:

$$P_{\min} = (|\psi_1| - |\psi_2|)^2 .$$

Given: $\frac{P_1}{P_2} = \frac{|\psi_1|^2}{|\psi_2|^2} = 25 \Rightarrow |\psi_1| = 5|\psi_2|$

Thus,

$$\frac{P_{\max}}{P_{\min}} = \frac{(|\psi_1| + |\psi_2|)^2}{(|\psi_1| - |\psi_2|)^2} = \frac{(5|\psi_2| + |\psi_2|)^2}{(5|\psi_2| - |\psi_2|)^2} = \frac{36}{16} = 2.25 .$$

The probability density $P_{\max} > P_{\min}$ *(the destructive interference is not complete).*

Chapter 3

Solutions to Problems

3.1. $\psi(x) = A(1-\frac{x^2}{L^2})$

a. $\frac{d\psi}{dx} = -2\frac{Ax}{L^2}$ & $\frac{d^2\psi}{dx^2} = -2\frac{A}{L^2}$

Schrödinger equation:

$$\frac{d^2\psi}{dx^2} = \frac{-2m}{\hbar^2}(E-U)\psi \qquad \text{, where } U(x) = \frac{-\hbar^2 x^2}{mL^2(L^2-x^2)}.$$
$$\therefore E = \frac{\hbar^2}{L^2 m}$$

b. The probability of finding the particle between –L and L is given by

$$\int_{-L}^{L} |\psi|^2 \, dx = 1$$
$$A^2[x - \frac{2x^3}{3L^2} + \frac{x^5}{5L^4}]_{x=-L}^{x=+L} = A^2\frac{16L}{15} = 1$$
$$\therefore A = \sqrt{\frac{15}{16L}}$$

c.

$$P = \int_{-L/3}^{L/3} |\psi|^2 \, dx = 47/81 = 0.580$$

3.2.

$$f(E) = \frac{1}{e^{(E-E_f)/k_bT}+1}, \quad \text{where } E - E_f = 0.056ev \,\&\, k_bT = 0.026ev.$$
$$\therefore f(E) = 0.104$$

3.3. *If* $E >> k_bT$, $e^{(E-E_f)/k_bT} + 1 \cong e^{(E-E_f)/k_bT}$

$$\therefore f(E) = e^{-(E-E_f)/k_bT}$$ *(this is a Boltzmann distribution function).*

3.4. *a. The force at equilibrium position has to be zero:*

$$\left.\frac{dU}{dx}\right|_{x-x_0} = 0$$
$$-3A/x_0^4 + B/x_0^2 = 0$$
$$\therefore x_0 = \sqrt{3A/B} = 0.35nm$$

b. $U_0 = U(x_0) = A/x_0^3 - B/x_0 = -7.02ev$

c.

$$F = -\frac{dU}{dx} = 3A/x^4 - B/x^2$$
$$\left.\frac{dF}{dx}\right|_{x=x'} = 0$$
$$x' = \sqrt{6A/B} = 0.5nm$$
$$\therefore F_m = 3A/x'^4 - B/x'^2 = -7.52ev/nm$$

3.5. *a.*

$$hf = 0.66ev(1.6\times10^{-19}J/ev)$$
$$f = \frac{1.056\times10^{-19}J}{6.626\times10^{-34}J\cdot s} = 1.59\times10^{14}Hz$$

b.

$$\lambda = c/f = \frac{3\times10^8 m/s}{1.5\times10^{14}Hz} = 2\mu m$$

c. Infrared region.

3.6. *a. The Fermi-energy:* $E_f = \frac{h^2}{2m}[\frac{3(N/V)}{8\pi}]^{2/3}$

For sodium the electron density $\frac{N}{V} = 2.65\times10^{28}m^{-3}$

$$\therefore E_f = \frac{(6.626\times10^{-34}J\cdot s)^2}{2(9.11\times10^{-31}kg)}[\frac{3(2.65\times10^{28}m^{-3}}{8\pi}]^{2/3} = 5.1\times10^{-19}J = 3.2ev$$

b. $v_f = \sqrt{2E_f / m} = \sqrt{2 \times 5.1 \times 10^{-19} J / 9.11 \times 10^{-31} kg} = 1.1 \times 10^6 m/s$

c. $T_f = E_f / K_b = 5.1 \times 10^{-19} J / 1.38 \times 10^{-23} J/k = 3.7 \times 10^4 k$

3.7. *a. The angular momentum* $L = mvr = m\frac{2\pi r}{T} r = \sqrt{l(l+1)}\hbar$, *where the period* $T = 3.156 \times 10^7 s$ *and* $r = 1.496 \times 10^{11} m$ *is the average radius of the Earth's orbit around the Sun.*

$$\sqrt{l(l+1)} = \sqrt{l^2(1+\frac{1}{l})} = l(1+\frac{1}{2l} - \frac{1}{8l^2} + ...)$$

For large l, $\sqrt{l(l+1)} \cong l$ *and* $L = 5.98 \times 10^{24} kg \frac{2\pi(1.496 \times 10^{11} m)^2}{3.156 \times 10^7 s} = l\hbar$

$$\therefore l = 2.52 \times 10^{74}$$

b. The total energy $E = \frac{1}{2}mv^2 - G\frac{Mm}{r}$ *and Newton's second law gives*

$E = -G\frac{Mm}{2r} = -\frac{1}{2}mv^2$, *where* $G\frac{Mm}{r^2} = \frac{mv^2}{r}$

$$|E| = \frac{1}{2}mv^2 = \frac{1}{2}\frac{L^2}{mr^2} = \frac{1}{2}\frac{l^2\hbar^2}{mr^2}$$

$$\frac{d|E|}{dl} = 2E/l$$

$\therefore d|E| = 2.1 \times 10^{-41} J$, *where* $dl = 1$ *gives a very small changes of the Earth's total energy.*

3.8. *a.*

$$\int |\psi|^2 \, dV = 4\pi\int_0^\infty |\psi| r^2 dr = 4\pi(\frac{1}{\pi a_0^3})\int_0^\infty r^2 e^{-2r/a_0} dr = \frac{-2}{a_0^2}[e^{-2r/a_0}(r^2 + ra_0 + \frac{a_0^2}{2})]_{r=0}^{r=\infty} = 1$$

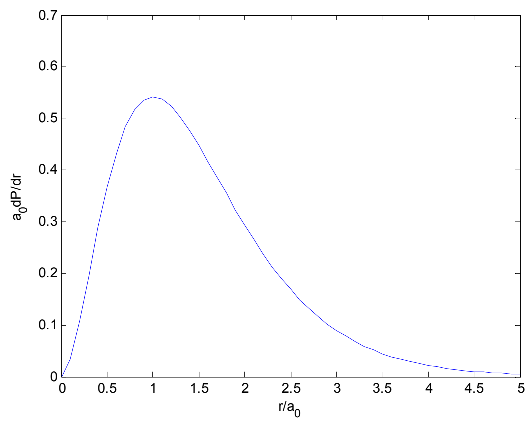
b. $P_{a_0/2 \to 3a_0/2} = 4\pi\int_{a_0/2}^{3a_0/2} |\psi|^2 \, r^2 dr = \frac{-2}{a_0^2}[e^{-2r/a_0}(r^2 + ra_0 + \frac{a_0^2}{2})]_{r=a_0/2}^{r=3a_0/2} = 0.497$

c.

The radial probability density for the hydrogen ground state is obtained by multiplying the square of the wave function by a spherical shell volume element.

$$dP = [\frac{1}{\sqrt{\pi} a_0^{3/2}} e^{-r/a_0}]^2 4\pi r^2 dr = \frac{4}{a_0^3} r^2 e^{-2r/a_0} dr ,$$

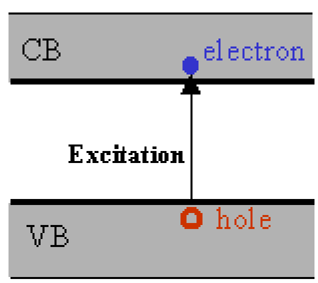
where the probability density is $\frac{dP}{dr}$.



The 1S radial probability is shown in the figure above and the maximum probability density occurs at $r = a_0$.

3.9

When radiation strikes a semiconductor, it will often excite an electron to the conduction band and consequently leave a hole in the valence band. This process is known as the creation of an ***electron-hole pair***.

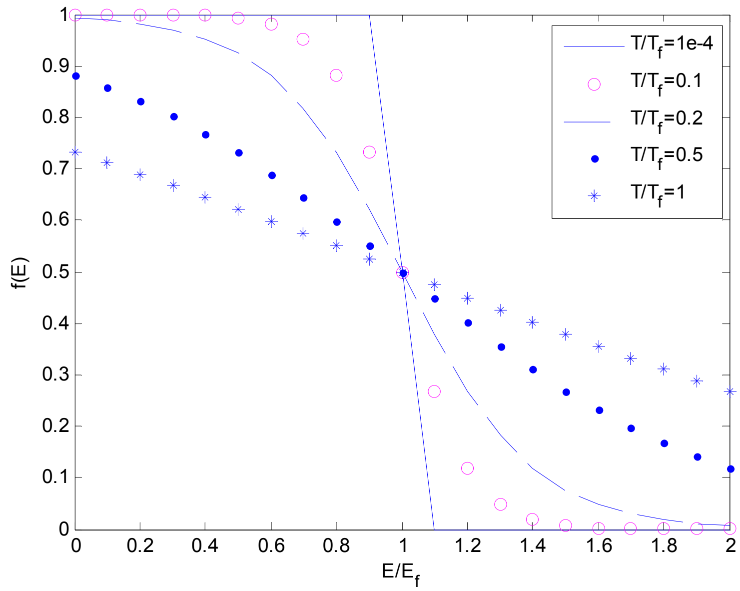


3.10.

The probability of finding an electron that has energy above the Fermi level increases dramatically when the temperature is very close to the Fermi temperature T_f*:*

$T/T_f =$ 0.1000 $E/E_f =$ 0 0.1000 0.2000	$T/T_f =$ 0.2000 $E/E_f =$ 0 0.1000 0.2000	$T/T_f =$ 0.5000 $E/E_f =$ 0 0.1000 0.2000

0.3000	*0.3000*	*0.3000*
0.4000	*0.4000*	*0.4000*
0.5000	*0.5000*	*0.5000*
0.6000	*0.6000*	*0.6000*
0.7000	*0.7000*	*0.7000*
0.8000	*0.8000*	*0.8000*
0.9000	*0.9000*	*0.9000*
1.0000	*1.0000*	*1.0000*
1.1000	*1.1000*	*1.1000*
1.2000	*1.2000*	*1.2000*
1.3000	*1.3000*	*1.3000*
1.4000	*1.4000*	*1.4000*
1.5000	*1.5000*	*1.5000*
1.6000	*1.6000*	*1.6000*
1.7000	*1.7000*	*1.7000*
1.8000	*1.8000*	*1.8000*
1.9000	*1.9000*	*1.9000*
2.0000	*2.0000*	*2.0000*
f(E) =	*f(E) =*	*f(E) =*
1.0000	*0.9933*	*0.8808*
0.9999	*0.9890*	*0.8581*
0.9997	*0.9820*	*0.8320*
0.9991	*0.9707*	*0.8022*
0.9975	*0.9526*	*0.7685*
0.9933	*0.9241*	*0.7311*
0.9820	*0.8808*	*0.6900*
0.9526	*0.8176*	*0.6457*
0.8808	*0.7311*	*0.5987*
0.7311	*0.6225*	*0.5498*
0.5000	*0.5000*	*0.5000*
0.2689	*0.3775*	*0.4502*
0.1192	*0.2689*	*0.4013*
0.0474	*0.1824*	*0.3543*
0.0180	*0.1192*	*0.3100*
0.0067	*0.0759*	*0.2689*
0.0025	*0.0474*	*0.2315*
0.0009	*0.0293*	*0.1978*
0.0003	*0.0180*	*0.1680*
0.0001	*0.0110*	*0.1419*
0.0000	*0.0067*	*0.1192*



T/T_f=1e-4
T/T_f=0.1
T/T_f=0.2
T/T_f=0.5
T/T_f=1
f(E)
E/E_f
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.2
1.4
1.6
1.8
2

Chapter 4

Solutions to Problems

4.1.

$$I_B = I_E - I_C$$
$$\frac{I_B}{I_C} = \frac{I_E}{I_C} - 1$$
$$\frac{1}{\beta} = \frac{1}{\alpha} - 1$$
$$\therefore \beta = \frac{\alpha}{1-\alpha} \ \& \ \alpha = \frac{\beta}{1+\beta}$$

where $\beta = I_C / I_B \ \& \ \alpha = I_C / I_E$.

4.2. *a. The channel current for V_{ds}=3V is:*

$$I_{ds} = \mu_0 \frac{\varepsilon_{ox} W}{2 t_{ox} L} (V_{gs} - V_T)^2$$
$$= 300 \times 10^{-4} \frac{m^2}{V \cdot s} \left(\frac{34.5 \times 10^{-12} F/m}{40 \times 10^{-9} m}\right)(10)(4V^2)$$
$$= 1.04 mA$$

b. The channel current for V_{ds}=1V is:

$$I_{ds} = \mu_0 \frac{\varepsilon_{ox} W}{t_{ox} L} [(V_{gs} - V_T) - V_{ds}/2] V_{ds}$$
$$= 300 \times 10^{-4} \frac{m^2}{V \cdot s} \left(\frac{34.5 \times 10^{-12} F/m}{20 \times 10^{-9} m}\right)(10)\left(\frac{3}{2} V^2\right)$$
$$= 0.78 mA$$

4.3.

a.

$$R = \frac{d(Vds)}{dI} = \frac{L}{\mu_0 C_{ox} W (Vgs - Vt)} =$$

$$\frac{1\times10^{-6}m}{(0.03m^2/v\cdot s)(\frac{34.5\times10^{-12}F/m}{10\times10^{-9}m})(20\times10^{-6}m)(3V-1.5V)} = 322.06\Omega$$

b.

$$2R = \frac{L}{\mu_0 C_{ox} W (Vgs^* - Vt)}$$

$$Vgs^* - Vt = \frac{L}{\mu_0 C_{ox} W (2R)} = \frac{3V - 1.5V}{2}$$

$$Vgs^* = 2.25V$$

4.4. *The DC output voltage can be approximated from the average of the input as:*

$$V_{dc} = \frac{\int_0^{\pi} V_m \sin(\tau) d(\tau)}{T} = \frac{2V_m}{2\pi} = V_m / \pi \ \ \textbf{\textit{where}}\ \tau = wt,\ w = \frac{2\pi}{T} = 1$$ *and the diode is reverse biased between t=π and 2π*

Ohm's law gives $V_{dc} = I_{dc} R_L = 20V$

$$\therefore V_m = V_{dc}\pi = 62.8V .$$

4.5. $R = \frac{d(Vd)}{dI} = \frac{k_b T / q}{I} = \frac{26mV}{260mA} = 0.1\Omega$

4.6. *The answers are given in section 4.1.*

4.7. *The answers are given in section 4.2 and 4.3.*

4.8. *The minimum photon energy is*:

$$E_{\min} = hf = hc/\lambda = \frac{(6.63\times10^{-34}J\cdot s)(3\times10^8 m/s)}{10^{-6}m}\left(\frac{1}{1.6\times10^{-19}J/ev}\right) = 1.243ev$$

$$\therefore E_g \le E_{\min}$$

Silicon is an appropriate material, since its E_g*=1.14ev.*

4.9. *The maximum photon energy we need is 5.5ev. If the photon energy is higher than 5.5ev, the diamond will start absorbing the photon.*

$$5.5ev = \frac{hc}{\lambda_{\min}} \Rightarrow \lambda_{\min} = \frac{(6.626\times 10^{-34}\,J\cdot s)(3\times 10^{8}\,m/s)}{5.5ev(1.6\times 10^{-19}\,J/eV)} = 226nm\,.$$