1. (1.10, text) \[ 1.12 \text{ eV} = E_0 \]

2. (1.11, text) a. Some \(10^{10} \text{ cm}^{-2}\)
   
b. Generation (thermal) and recombination balance

3. (1.12, text) Electron slows down, stops, and reverses direction. \( E_k \rightarrow 0 \) when \( E = E_p \). Force is in the direction of lower \( E_p \).

4. (1.21, text) a. No electronic states to go to.
   
b. Not many electrons in the conduction band. (relative to the number in the valence band)

5. (2.1, text) Right lower \( m_e^* \) (more curvature at \( E_c \))
   
   Left lower \( m_h^* \) (more curvature at \( E_v \))

6. (2.4, text) The large one. Most electrons are near \( E_c \)

7. (2.5, text) a. \( V/2 \mu = 0.5 \times 10^6 \text{ V/m} \), left.
   
b. \( F = qE = 1.6 \times 10^{-19} \times 0.5 \times 10^6 = 8 \times 10^{-14} \text{ N} \), right. (+x)
   
   c. Same, \( 8 \times 10^{-14} \text{ N} \), left. (-x)

8. (2.6, text) GaAs - Electrons can move from filled states near \( E_c \) to empty states near \( E_v \).

9. (2.7, text) a. \( E_c \) or \( E_c + \) some constant.
   
b. 0.2 eV
   
c. \( E_v \) or \( E_v + \) some constant.
   
d. 0.1 eV
   
e. Down

10. (2.11, text) a. \( n \)-type, presumably. (2 extra electrons)
    
b. \( p \)-type, presumably. (missing 2 electrons)
    
c. Amphoteric (depends on which atom replaced)
    
d. Amphoteric
11. 2.13, Text:  
1. Find position of \( E_F \): Similar to example 2.4.
\[
E_i - E_{midsep} = \frac{3}{4} kT \ln \left( \frac{m_{\gamma}^\text{no}}{m_{\gamma}^\text{sec}} \right) = \frac{3}{4} (0.026) \ln \left( \frac{0.42}{0.067} \right)
\]
\[
E_i - E_{midsep} = 0.038 \text{ eV} \quad \Rightarrow \quad (\frac{3}{2} - 0.038)/kT
\]

2. \( F(E_i) = e^{-E_i - E_F/kT} \)
\[
= e^{-\frac{1.43}{2} - 0.038}/kT
\]

Probability \( = F(E_i) = 4.9 \times 10^{-12} \) !

12 2.15, Text:  
Here one might want to use the full Fermi function, but the Bethe approximation is ok.

Above: \( F(E-E_F) = e^{-0.11/kT} = 3.85 \)

Below \( F(E-E_F) = 1 - e^{-0.11/kT} = 1 - e^{-3.85} = 0.979 \)

13. (2.8) \( N_e \) is about 20 times smaller.

14. 2.22, Text:  
\[
\rho_0 \cong N_A = 4 \times 10^{17} \text{ cm}^{-3}
\]
\[
N_0 = \frac{N_i^2}{N_A} = \frac{(1.08 \times 10^{10})^2}{4 \times 10^{17}} = 2.92 \text{ cm}^{-3}
\]
\[
E_F - E_V = kT \ln \frac{N_i}{N_A} = 0.026 \ln \left( \frac{3.10 \times 10^{19}}{4 \times 10^{17}} \right)
\]
\[
E_F - E_V = 0.113 \text{ eV}
\]
15. \[ p_0 = N_A - N_D = 9 \times 10^{15} \]

\[ n_0 = n_i^2 / n_0 = (1.08 \times 10^{10})^2 / 9 \times 10^{15} = 1.30 \times 10^4 \text{ cm}^{-3} \]

16. \[ (2.29, \text{ text}) \quad \text{Degenerate} \iff E_C - E_F = 2.34 \times T = kT \ln \frac{N_C}{N_0} \]

\[ \Rightarrow \ln \frac{N_C}{N_0} = 2.5 \quad \text{or} \quad N_C = 10 N_0 \Rightarrow N_D = 2.8 \times 10^{18} \]

17. \[ (2.34, \text{ text}) \quad \text{"is occupied", I think.} \]

\[ n_0 = n_i^2 / n_0 = (1.08 \times 10^{10})^2 / 9 \times 10^{15} = 1.30 \times 10^4 \text{ cm}^{-3} \]

\[ N_C = \text{effective density of states at } E_C, \quad \text{so} \]

\[ N_0 = 10^{-4} \quad N_C = 2.8 \times 10^{15} \text{ cm}^{-3} \]

18. \[ (2.37, \text{ text}) \quad p_0 = N_0 - N_f = 9 \times 10^{15} \]

\[ n_i^2 + v_{37}^2 = \frac{N_F}{n_0} e^{-E_F/kT} \quad \text{so from } E_F 2.81 \text{ or } E_F 2.18 = 1.144 \text{ eV} \]

\[ E_F = 2.81 \times 10^{14} \text{ eV} \]

\[ n_i^2 = 1.35 \times 10^{12} \]

So \[ n_0 = \frac{1.35 \times 10^{12}}{9 \times 10^{15}} = 1.5 \times 10^{-4} \]

\[ n_i^2 + v_{37}^2 = 2 \times 10^{14} \text{ eV} \]

\[ n_0 = \frac{2.62 \times 10^{12}}{9 \times 10^{15}} = 2.9 \times 10^4 \text{ cm}^{-3} \quad \text{much larger but still } \ll p_0 \]
19. (2.44, text)

High $T$, so it may be necessary to use the high-$T$ expression:

$$P_0 = \frac{N_A - N_D}{2} + \left[ \left( \frac{N_A - N_D}{2} \right)^2 + n_i^2 \right]^{1/2}, \quad N_A - N_D = 9 \times 10^{19}$$

$$n_0 = \frac{n_i^2}{P_0}$$

$$n_i^2 = N_D N_V e^{-E_g/kT}$$

$$n_i^2 = (2.36 \times 10^{15}) (3.10 \times 10^{19}) \left( \frac{T}{300} \right)^5 e^{-E_g/kT}, \quad E_g = 1.120 - 2.73 \times 10^{-4} T \text{ eV (} T > 280 \text{ K)}$$

$$n_i^2 = (8.97 \times 10^{18}) \left( \frac{600}{300} \right)^3 e^{-E_g/kT}, \quad E_g = 1.04 \text{ eV @ 600 K}$$

$$n_i^2 = 1.34 \times 10^{17} \text{ cm}^{-2}$$

$$P_0 = 4.14 \times 10^{15} \text{ cm}^{-3}$$

$$n_0 = \frac{n_i^2}{P_0} = 3.23 \times 10^{15} \text{ cm}^{-3}$$

20. (518.2, text)

a. 45 meV
b. 147 meV
c. 105 meV (300K)
d. 70 meV (300K)
e. same as c. 105 meV (donor states present, but not much with acceptor states)
The temperature at which $E_F = E_p$.

However, $E_F$ changes with temperature and

$N_s$ changes with temperature, so iterate.

Start by guessing $80K$ (from Fig. 518.5), then calculate

\[ E_s - E_F = E_s - E_p = 0.057 \text{ eV} \]

\[ N = N_s e^{(E_s - E_F)/kT} \]

\[ N = 1.4 \times 10^{15} \text{ (too big, so go down in } T, \text{ guess 60K).} \]

Then $N = 2.5 \times 10^{18}$

\[ E_s - E_F = 0.052 \]

\[ N = 1.046 \times 10^{14} \]

Guess 55K

Then $N = 3.85 \times 10^{13}$ (close)

Guess 50.5K

Then $N = 5.4 \times 10^{15}$ (close enough) (about 1/2 in cond. band.)

This is lower than the text value for $N_s = 10^{16}$ by a surprising amount, considering the fact that the effective donor level does not change much from $N_s = 10^{16}$ to $N_s = 10^{14}$. I don't know why this is.

* Fig. 518.5 (a), about 100K.
22. (4.1, Perrot) \[ \psi(x,y) = A \sin k_x x \sin k_y y \]

\[ k^2 = k_x^2 + k_y^2 \]
\[ k_x = \frac{n_x \pi}{a}, \quad k_y = \frac{n_y \pi}{b} \]

Eliminating redundant solutions, \( x \) \& \( y \) spin \( \Rightarrow \)

Allowed energy state
\[ \frac{\text{Unit area in } k \text{-space}}{= \frac{ab}{2\pi^2}} \]

\# of states between \( k \) and \( k + dk \)
\[ = \# \text{ of states in annulus} \]
\[ = 2\pi \hbar dk \left( \frac{ab}{2\pi^2} \right) = \frac{abh \hbar dk}{\pi} \]

\[ dE, \text{ as before} = \frac{\hbar^2 k \hbar dk}{m} \]
\[ dh = \frac{1}{k} \sqrt{m \over 2} \frac{dE}{\hbar} \]
\[ h = \frac{\sqrt{2mE}}{\hbar} \]

\# of states between \( E \) and \( dE \)
\[ \frac{\text{Unit area}}{= \frac{ghk}{\pi} \frac{1}{2} \int \sqrt{m \over 2} \frac{dE}{\hbar} = \frac{m}{\pi \hbar^2} dE} \]

\[ \frac{g_{20}}{= \frac{m}{\pi \hbar^2}} \text{ = constant!} \]

23. (4.3, Perrot) \( a. \) The mathematical solution is the same, the difference is in the spacing between \( k_x \) values, which is very large compared to the spacing between \( k_x, k_y \) values.

\[ \begin{align*}
\text{b.} & \\
\text{C. i.} & \\
& \text{no solutions exist for } |k| < \frac{\pi}{T}, \text{ then the density of states is due to the first plane of } k \text{-space solutions along, until } \\
& k = 2\pi / T, \text{ when 2 planes continue, etc.} \\
& \text{ii.} E = \frac{\hbar^2}{2m} \left( k_x^2 + k_y^2 + k_z^2 \right) = \frac{\hbar^2 k_x^2}{2m} + \frac{\hbar^2 k_y^2}{2m} + \hbar^2 k_z^2
\end{align*} \]

\[ k = k_x^2 + k_y^2 \]
\[ E = \frac{\hbar^2 k^2}{2m} + \frac{\hbar^2 k^2}{2m} \]

\[ dE = \frac{x^2}{m^2} \frac{d\theta}{\pi} \]  
(for \( E_1 < E < E_2 \))

\[ d\theta = \frac{m dE}{\hbar^2} \]

by analogy with problem 1. \# of states in annulus in the \( k_2 = \frac{\pi}{\ell} \) plane = \( \frac{\alpha \hbar}{\pi} \theta \)

\[ = \frac{\alpha \hbar}{\pi} \frac{(m dE)}{\hbar^2} = \frac{\alpha b m dE}{\pi \hbar^2} \]

\# of states (unit energy, unit volume) = \( \frac{m}{\pi \hbar^2} \)  
(volume = \( abc \))

So, for \( 0 \leq E < E_1 \), \( g(E) = 0 \) (no states correspond to \( k_2 = 0 \))

\( E_1 \leq E < E_2 \)

\( g(E) = \frac{m}{\pi \hbar^2} \)  
(still have first plane, add second)

\( E_2 \leq E < E_3 \)

\( g(E) = \frac{2m}{\pi \hbar^2} \)

\( E_3 \leq E < E_4 \)

\( g(E) = \frac{3m}{\pi \hbar^2} \)

\( E_4 \leq E \)

\( g(E) = \frac{4m}{\pi \hbar^2} \)

\[ E_n = \hbar^2 \left( \frac{\pi^2 \ell^2}{2m} \right) \]

\( g(E) \propto \sqrt{E} \) as in the 3-dimensional case!

large \( \ell \)

\[ g(E) = \frac{\alpha b m}{\pi \hbar^2} \)  
(continuous now)

\[ n = \frac{E}{\hbar^2} \int_0^{2\pi} \Rightarrow g(E) = \frac{m \sqrt{2mE}}{\pi \hbar^2} \]