$$\mathbf{R} = n_1\mathbf{a}_1 + n_2\mathbf{a}_2 + n_3\mathbf{a}_3 \tag{1-6}$$

$$\begin{aligned} \mathbf{R} &= a\hat{\mathbf{i}} && \text{or} \quad [100], \\ \mathbf{R} &= a\hat{\mathbf{i}} + a\hat{\mathbf{j}} && \text{or} \quad [110], \\ \mathbf{R} &= a\hat{\mathbf{i}} + a\hat{\mathbf{j}} + a\hat{\mathbf{k}} && \text{or} \quad [111]. \end{aligned} \tag{1-7}$$

$$\begin{aligned} \mathbf{a}_1 &= -\tfrac{1}{2}a\hat{\mathbf{i}} + \tfrac{1}{2}a\hat{\mathbf{j}} + \tfrac{1}{2}a\hat{\mathbf{k}}, \\ \mathbf{a}_2 &= \tfrac{1}{2}a\hat{\mathbf{i}} - \tfrac{1}{2}a\hat{\mathbf{j}} + \tfrac{1}{2}a\hat{\mathbf{k}}, \\ \mathbf{a}_3 &= \tfrac{1}{2}a\hat{\mathbf{i}} + \tfrac{1}{2}a\hat{\mathbf{j}} - \tfrac{1}{2}a\hat{\mathbf{k}}. \end{aligned} \tag{1-8}$$

$$\begin{aligned} \mathbf{a}_1 &= \tfrac{1}{2}a\hat{\mathbf{j}} + \tfrac{1}{2}a\hat{\mathbf{k}}, \\ \mathbf{a}_2 &= \tfrac{1}{2}a\hat{\mathbf{i}} + \tfrac{1}{2}a\hat{\mathbf{k}}, \\ \mathbf{a}_3 &= \tfrac{1}{2}a\hat{\mathbf{i}} + \tfrac{1}{2}a\hat{\mathbf{j}}. \end{aligned} \tag{1-9}$$

$$F = -\frac{e^2}{4\pi\epsilon_0 r^2} \tag{1-10}$$

$$F = Be^{-r/R},$$

$$y = A\sin(kx - \omega t) \tag{2-1}$$

$$k = 2\pi/\lambda \tag{2-2}$$

$$T = 1/f \tag{2-3}$$

$$\omega = 2\pi f \tag{2-4}$$

$$v = \lambda f \tag{2-5}$$

$$\omega = vk \tag{2-6}$$

$$x_2 - x_1 = n\lambda \tag{2-7}$$

$$x_2 - x_1 = (n + \tfrac{1}{2})\lambda \tag{2-8}$$

$$d\sin\theta = n\lambda \tag{2-9}$$

$$2d\sin\theta = n\lambda \tag{2-10}$$

$$\Delta x = R\cos\theta_1 + R\cos\theta_2 \tag{2-11}$$

$$R\cos\theta_1 + R\cos\theta_2 = n\lambda \tag{2-12}$$

$$\mathbf{R}\cdot\mathbf{k}_1 = Rk\cos(\pi - \theta_1) = -Rk\cos\theta_1 \tag{2-13}$$

$$\mathbf{R}\cdot\mathbf{k}_2 = Rk\cos\theta_2 \tag{2-14}$$

$$\mathbf{R}\cdot(\mathbf{k}_2 - \mathbf{k}_1) = nk\lambda = 2\pi n \tag{2-15}$$

$$\mathbf{R}\cdot\mathbf{G} = 2\pi n, \tag{2-16}$$

$$\mathbf{G} = \mathbf{k}_2 - \mathbf{k}_1 \tag{2-17}$$

$$\mathbf{R} = n_1\mathbf{a}_1 + n_2\mathbf{a}_2 + n_3\mathbf{a}_3 \tag{2-18}$$

$$\begin{aligned} \mathbf{a}_1\cdot\mathbf{G} &= 2\pi m_1, \\ \mathbf{a}_2\cdot\mathbf{G} &= 2\pi m_2, \\ \mathbf{a}_3\cdot\mathbf{G} &= 2\pi m_3, \end{aligned} \tag{2-19}$$

$$\mathbf{a}_1 = a\hat{\mathbf{i}},\ \mathbf{a}_2 = a\hat{\mathbf{j}},\ \mathbf{a}_3 = a\hat{\mathbf{k}} \tag{2-20}$$

$$\begin{aligned} &G_x = m_1(2\pi/a),\ G_y = m_2(2\pi/a), \\ &G_z = m_3(2\pi/a) \end{aligned} \tag{2-21}$$

$$\mathbf{G} = m_1\frac{2\pi}{a}\hat{\mathbf{i}} + m_2\frac{2\pi}{a}\hat{\mathbf{j}} + m_3\frac{2\pi}{a}\hat{\mathbf{k}} \tag{2-22}$$

$$\begin{aligned} \mathbf{b}_1 &= (2\pi/a)\hat{\mathbf{i}}, \\ \mathbf{b}_2 &= (2\pi/a)\hat{\mathbf{j}}, \\ \mathbf{b}_3 &= (2\pi/a)\hat{\mathbf{k}}, \end{aligned} \tag{2-23}$$

$$\mathbf{G} = m_1\mathbf{b}_1 + m_2\mathbf{b}_2 + m_3\mathbf{b}_3 \tag{2-24}$$

$$\mathbf{b}_i = \frac{2\pi\mathbf{a}_j\times\mathbf{a}_k}{\mathbf{a}_i\cdot(\mathbf{a}_j\times\mathbf{a}_k)} \tag{2-25}$$

$$G = 2k\sin\theta \tag{2-26}$$

$$\sin\theta = G/2k \tag{2-27}$$

$$F = -\alpha(r - r_0) \tag{3-1}$$

$$r = r_0 + A\sin\omega t \tag{3-2}$$

$$x_n = na \tag{3-3}$$

$$F_n = -\alpha(2u_n - u_{n+1} - u_{n-1}) \tag{3-4}$$

$$a_n = \frac{d^2u_n}{dt^2} \tag{3-5}$$

$$-\alpha(2u_n - u_{n+1} - u_{n-1}) = m\frac{d^2u_n}{dt^2} \tag{3-6}$$

$$u_n = A\sin(kx_n - \omega t) \tag{3-7}$$

$$\omega^2 = \omega_m^2\sin^2(ka/2) \tag{3-8}$$

$$\omega = \omega_m|\sin(ka/2)| \tag{3-9}$$

$$\omega_m = \sqrt{4\alpha/m} \tag{3-10}$$

$$\omega = vk \tag{3-11}$$

$$\omega \approx (\omega_m a/2)|k| \tag{3-12}$$

$$v = \omega_m a/2 \tag{3-13}$$

$$-\alpha(2u_{2n} - u_{2n+1} - u_{2n-1}) = m_1\frac{d^2u_{2n}}{dt^2} \tag{3-14}$$

$$-\alpha(2u_{2n+1} - u_{2n+2} - u_{2n}) = m_2\frac{d^2u_{2n+1}}{dt^2}. \tag{3-15}$$

$$u_{2n} = A_1\sin(kx_{2n} - \omega t) \tag{3-16}$$

$$u_{2n+1} = A_2\sin(kx_{2n+1} - \omega t) \tag{3-17}$$

$$\begin{aligned} \omega^2 =& \alpha\left(\frac{1}{m_1} + \frac{1}{m_2}\right) \\ &\pm \alpha\sqrt{\left(\frac{1}{m_1} + \frac{1}{m_2}\right)^2 - \frac{4\sin^2(ka/2)}{m_1 m_2}}. \end{aligned} \tag{3-18}$$

$$A_2 = A_1(1 - m_1\omega^2/2\alpha)\sec(ka/2) \tag{3-19}$$

$$\omega \approx ka\sqrt{\frac{\alpha}{2(m_1 + m_2)}} \tag{3-20}$$

$$\omega \approx \sqrt{2\alpha\left(\frac{1}{m_1} + \frac{1}{m_2}\right)}. \tag{3-21}$$

$$v = a\sqrt{\frac{\alpha}{2(m_1 + m_2)}} \tag{3-22}$$

$$\omega = \sqrt{2\alpha/m_1} \quad \text{(acoustic branch)} \tag{3-23}$$

$$\omega = \sqrt{2\alpha/m_2} \quad \text{(optical branch)} \tag{3-24}$$

$$\mathbf{u}_n = \mathbf{A}\sin(\mathbf{k}\cdot\mathbf{r}_n - \omega t) \tag{3-25}$$

$$U = -\int_{r_0}^{r} F\,dr \tag{3-26}$$

$$U = \tfrac{1}{2}\alpha(r - r_0)^2 \tag{3-27}$$

$$\mathbf{F} = -e\boldsymbol{\mathcal{E}} \tag{4-1}$$

$$\mathbf{a} = -(e/m)\boldsymbol{\mathcal{E}} \tag{4-2}$$

$$\mathbf{r} = \tfrac{1}{2}\mathbf{a}t^2 + \mathbf{v}_0 t \tag{4-3}$$

$$\langle\mathbf{r}\rangle = \tfrac{1}{2}\mathbf{a}\langle t^2\rangle \tag{4-4}$$

$$\mathbf{v}_d = \tfrac{1}{2}\mathbf{a}\langle t^2\rangle/\tau \tag{4-5}$$

$$\mathbf{v}_d = -(e\tau/m)\boldsymbol{\mathcal{E}} \tag{4-6}$$

$$\mathbf{J} = -ne\mathbf{v}_d \tag{4-7}$$

$$\mathbf{J} = (ne^2\tau/m)\boldsymbol{\mathcal{E}} \tag{4-8}$$

$$\mathbf{J} = \sigma\boldsymbol{\mathcal{E}} \tag{4-9}$$

$$\sigma = ne^2\tau/m \tag{4-10}$$

$$V = IR \tag{4-11}$$

$$R = L/A\sigma \tag{4-12}$$

$$\mathcal{E} = V/L$$

$$\mathbf{F} = -e\mathbf{v}_d\times\mathbf{B} \tag{4-13}$$

$$\mathbf{F} = -e(\mathbf{v}_d\times\mathbf{B}) - e\boldsymbol{\mathcal{E}}_H \tag{4-14}$$

$$\boldsymbol{\mathcal{E}}_H = -\mathbf{v}_d\times\mathbf{B} \tag{4-15}$$

$$\boldsymbol{\mathcal{E}}_H = \frac{1}{ne}\mathbf{J}\times\mathbf{B} \tag{4-16}$$

$$\boldsymbol{\mathcal{E}}_H = -R_H\mathbf{J}\times\mathbf{B} \tag{4-17}$$

$$R_H = -1/ne \tag{4-18}$$

$$\mathbf{F} = -e\mathbf{v}\times\mathbf{B} \tag{4-19}$$

$$evB = mv^2/r \tag{4-20}$$

$$\omega = eB/m \tag{4-21}$$

$$E = hf \tag{5-1}$$

$$p = h/\lambda \tag{5-2}$$

$$E = \hbar\omega \tag{5-3}$$

$$\mathbf{p} = \hbar\mathbf{k} \tag{5-4}$$

$$\hbar\omega_i = \hbar\omega_f + E \tag{5-5}$$

$$\hbar\mathbf{k}_i = \hbar\mathbf{k}_f + \mathbf{p} \tag{5-6}$$

$$E_f = E_i + \hbar\omega \tag{5-7}$$

$$\mathbf{p}_f = \mathbf{p}_i + \hbar\mathbf{k} \tag{5-8}$$

$$E_f = E_i - \hbar\omega \tag{5-9}$$

$$\mathbf{p}_f = \mathbf{p}_i - \hbar\mathbf{k} \tag{5-10}$$

$$\omega_f = \omega_i + \omega \tag{5-11}$$

$$\mathbf{k}_f = \mathbf{k}_i + \mathbf{k} \tag{5-12}$$

$$\omega_f = \omega_i - \omega \tag{5-13}$$

$$\mathbf{k}_f = \mathbf{k}_i - \mathbf{k} \tag{5-14}$$

$$k = k_i\sqrt{2} \tag{5-15}$$

$$\lambda = h/p \tag{5-16}$$

$$|z| = \sqrt{x^2 + y^2} \tag{6-1}$$

$$\begin{aligned} \exp(ix) &= 1 + (ix) + \tfrac{1}{2}(ix)^2 + \tfrac{1}{6}(ix)^3 + \cdots \\ &= \sum_{n=0}^{\infty}\frac{1}{n!}(ix)^n. \end{aligned} \tag{6-2}$$

$$\begin{aligned} \exp(ix) &= (1 - \tfrac{1}{2}x^2 + \cdots) + i(x - \tfrac{1}{6}x^3 + \cdots) \\ &= \cos x + i\sin x. \end{aligned} \tag{6-3}$$

$$|\exp(ix)| = 1 \tag{6-4}$$

$$\psi = A\exp(ikx - i\omega t) \tag{6-5}$$

$$\psi = A\cos(kx - \omega t) + iA\sin(kx - \omega t) \tag{6-6}$$

$$-i\hbar\frac{\partial\psi}{\partial x} = p\psi, \tag{6-7}$$

$$i\hbar\frac{\partial\psi}{\partial t} = E\psi. \tag{6-8}$$

$$-\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} = i\hbar\frac{\partial\psi}{\partial t} \tag{6-9}$$

$$-\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + U\psi = i\hbar\frac{\partial\psi}{\partial t} \tag{6-10}$$

$$|\psi|^2 = A^2 \tag{6-11}$$

$$\psi = A\int_{k_1}^{k_2} \exp(ikx - i\omega t)dk \tag{6-12}$$

$$\omega(k) \approx \omega(\bar{k}) + \left.\frac{d\omega}{dk}\right|_{k=\bar{k}}(k-\bar{k}) \tag{6-13}$$

$$\bar{k} = \tfrac{1}{2}(k_1 + k_2) \tag{6-14}$$

$$\bar{\omega} = \omega(\bar{k}) \tag{6-15}$$

$$v_g = \left.\frac{d\omega}{dk}\right|_{k=\bar{k}} \tag{6-16}$$

$$\omega = \bar{\omega} + (k-\bar{k})v_g \tag{6-17}$$

$$\psi = 2A\frac{\sin\left[(x-v_g t)\Delta k/2\right]}{x - v_g t}\exp(i\bar{k}x - i\bar{\omega}t) \tag{6-18}$$

$$\Delta k = k_2 - k_1 \tag{6-19}$$

$$|\psi|^2 = 4A^2\frac{\sin^2\left[(x-v_g t)\Delta k/2\right]}{(x-v_g t)^2} \tag{6-20}$$

$$\omega = \frac{\hbar}{2m}k^2 \tag{6-21}$$

$$v_g = \frac{d\omega}{dk} = \frac{d}{dk}\left(\frac{\hbar}{2m}k^2\right) = \frac{\hbar k}{m} = v \tag{6-22}$$

$$\text{Re }\ \psi = 2A\frac{\sin\left[(x-v_g t)\Delta k/2\right]}{x - v_g t}\cos(\bar{k}x - \bar{\omega}t) \tag{6-23}$$

$$\Delta x\Delta p \approx \hbar \tag{6-24}$$

$$\psi = A\exp(ikx - i\omega t) - A\exp(-ikx - i\omega t) \tag{6-25}$$

$$\psi(x,t) = 2iA\sin(kx)\exp(-i\omega t) \tag{6-26}$$

$$k = n(\pi/L) \tag{6-27}$$

$$\psi = \begin{cases} 2iA\sin(n\pi x/L)\exp(-i\omega t), & 0 \le x \le L, \\ 0, & x \le 0 \text{ or } x \ge L. \end{cases} \tag{6-28}$$

$$|\psi|^2 = 4A^2\sin^2(n\pi x/L) \tag{6-29}$$

$$\hbar^2k^2/2m + U = \hbar\omega \tag{6-30}$$

$$k = \sqrt{\frac{2m(E-U)}{\hbar^2}} \tag{6-31}$$

$$k = i\alpha \tag{6-32}$$

$$\alpha = \sqrt{\frac{2m(U-E)}{\hbar^2}} \tag{6-33}$$

$$\psi = A\exp(-\alpha x)\exp(-i\omega t) \tag{6-34}$$

$$|\psi|^2 = A^2\exp(-2\alpha x) \tag{6-35}$$

$$-\frac{\hbar^2}{2m}\left(\frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2}\right) + U\psi = i\hbar\frac{\partial\psi}{\partial t} \tag{6-36}$$

$$\psi = A\exp(i\mathbf{k}\cdot\mathbf{r} - i\omega t) \tag{6-37}$$

$$\mathbf{r} = x\hat{\mathbf{i}} + y\hat{\mathbf{j}} + z\hat{\mathbf{k}} \tag{6-38}$$

$$\mathbf{k} = k_x\hat{\mathbf{i}} + k_y\hat{\mathbf{j}} + k_z\hat{\mathbf{k}} \tag{6-39}$$

$$\mathbf{v}_g = \frac{\partial\omega}{\partial k_x}\hat{\mathbf{i}} + \frac{\partial\omega}{\partial k_y}\hat{\mathbf{j}} + \frac{\partial\omega}{\partial k_z}\hat{\mathbf{k}} \tag{6-40}$$

$$\psi(x,y,z,t) = A\sin(k_x x)\sin(k_y y)\sin(k_z z)\exp(-i\omega t), \tag{7-2}$$

$$\mathbf{k} = k_x\hat{\mathbf{i}} + k_y\hat{\mathbf{j}} + k_z\hat{\mathbf{k}} \tag{7-3}$$

$$\begin{aligned} k_x &= n_x(\pi/L), \\ k_y &= n_y(\pi/L), \\ k_z &= n_z(\pi/L), \end{aligned} \tag{7-4}$$

$$\begin{aligned} \psi(x+L,y,z,t) &= \psi(x,y,z,t), \\ \psi(x,y+L,z,t) &= \psi(x,y,z,t), \\ \psi(x,y,z+L,t) &= \psi(x,y,z,t). \end{aligned} \tag{7-5}$$

$$\psi(x,y,z,t) = A\exp(ik_x x + ik_y y + ik_z z - i\omega t) \tag{7-6}$$

$$\begin{aligned} k_x &= n_x(2\pi/L), \\ k_y &= n_y(2\pi/L), \\ k_z &= n_z(2\pi/L). \end{aligned} \tag{7-7}$$

$$\mathbf{k} = (2\pi/L)(n_x\hat{\mathbf{i}} + n_y\hat{\mathbf{j}} + n_z\hat{\mathbf{k}}) \tag{7-8}$$

$$g(\mathbf{k}) = 2V/(2\pi)^3 \tag{7-9}$$

$$E = p^2/2m = \hbar^2k^2/2m \tag{7-10}$$

$$k = \sqrt{2mE/\hbar^2} \tag{7-11}$$

$$V_k = \tfrac{4}{3}\pi k^3 = \tfrac{4}{3}\pi(2mE/\hbar^2)^{3/2} \tag{7-12}$$

$$N(E) = V_k\ g(\mathbf{k}) = (V/3\pi^2)(2mE/\hbar^2)^{3/2} \tag{7-13}$$

$$N(E) = \int_0^E g(E)\ dE \tag{7-14}$$

$$g(E) = \frac{dN(E)}{dE} \tag{7-15}$$

$$g(E) = (V/2\pi^2)(2m/\hbar^2)^{3/2}E^{1/2} \tag{7-16}$$

$$N = V_k\ g(\mathbf{k}) = (V/3\pi^2)(2mE_F/\hbar^2)^{3/2}. \tag{7-17}$$

$$E_F = (\hbar^2/2m)(3\pi^2 n)^{2/3} \tag{7-18}$$

$$W_{21} = W_{12}\exp\left(\frac{E_2 - E_1}{k_B T}\right) \tag{7-19}$$

$$W'_{12} = W_{12}P_1(1-P_2) \tag{7-20}$$

$$W'_{21} = W_{21}P_2(1-P_1) \tag{7-21}$$

$$W_{12}P_1(1-P_2) = W_{21}P_2(1-P_1) \tag{7-22}$$

$$\frac{P_1}{1-P_1}\exp(E_1/k_B T) = \frac{P_2}{1-P_2}\exp(E_2/k_B T). \tag{7-23}$$

$$\frac{P_n}{1-P_n}\exp(E_n/k_B T) = \text{constant} \tag{7-24}$$

$$\text{constant} = \exp(E_F/k_B T) \tag{7-25}$$

$$P_n = \frac{1}{\exp\left(\frac{E_n - E_F}{k_B T}\right) + 1} \tag{7-26}$$

$$f_D(E) = \frac{1}{\exp\left(\frac{E - E_F}{k_B T}\right) + 1} \tag{7-27}$$

$$f_D(E) = \begin{cases} 1, & E < E_F, \\ 0, & E > E_F. \end{cases} \tag{7-28}$$

$$N = \int_0^\infty f_D(E)g(E)\ dE \tag{7-29}$$

$$\Delta\mathbf{k} = (1/\hbar)\Delta\mathbf{p} = (m/\hbar)\mathbf{v}_d \tag{7-30}$$

$$J \approx (nv_d/v_F)ev_F = nev_d \tag{7-31}$$

$$v_d = e\tau_F\mathcal{E}/m \tag{7-32}$$

$$\sigma = ne^2\tau_F/m \tag{7-33}$$

$$\ell = v_F\tau_F \tag{7-34}$$

$$E = (\hbar^2/2m)k^2 \tag{8-1}$$

$$\psi = A\exp(\pm i\pi x/a - i\omega t) \tag{8-2}$$

$$\begin{aligned} \psi_1 &= 2A\cos(\pi x/a)\exp(-i\omega t) \\ \psi_2 &= 2iA\sin(\pi x/a)\exp(-i\omega t) \end{aligned} \tag{8-3}$$

$$\begin{aligned} |\psi_1|^2 &= 4A^2\cos^2(\pi x/a) \\ |\psi_2|^2 &= 4A^2\sin^2(\pi x/a) \end{aligned} \tag{8-4}$$

$$\psi = u_k(x)\exp(ikx - i\omega t) \tag{8-5}$$

$$u_k(x+a) = u_k(x) \tag{8-6}$$

$$\psi = u_{k'}(x)\exp(ik'x - i\omega t) \tag{8-7}$$

$$\psi = u_{n,k}(x)\exp(ikx - i\omega t) \tag{8-8}$$

$$u_{n,k}(x) = u_{k'}(x)\exp(-i2\pi nx/a) \tag{8-9}$$

$$\psi = u_{\mathbf{k}}(\mathbf{r})\exp(i\mathbf{k}\cdot\mathbf{r} - i\omega t), \tag{8-10}$$

$$\mathbf{r} = x\hat{\mathbf{i}} + y\hat{\mathbf{j}} + z\hat{\mathbf{k}} \tag{8-11}$$

$$\mathbf{k} = k_x\hat{\mathbf{i}} + k_y\hat{\mathbf{j}} + k_z\hat{\mathbf{k}} \tag{8-12}$$

$$u_{\mathbf{k}}(\mathbf{r} + \mathbf{R}) = u_{\mathbf{k}}(\mathbf{r}) \tag{8-13}$$

$$V_k = (2\pi)^3/V_c \tag{8-14}$$

$$V_k\ g(\mathbf{k}) = \left[(2\pi)^3/V_c\right]\ \left[2V/(2\pi)^3\right] = 2V/V_c \tag{8-15}$$

$$v = \frac{d\omega}{dk} = \frac{1}{\hbar}\frac{dE}{dk} \tag{9-1}$$

$$dE = F_{\text{ext}}dx \tag{9-2}$$

$$dE = F_{\text{ext}}vdt \tag{9-3}$$

$$\frac{dE}{dt} = F_{\text{ext}}v \tag{9-4}$$

$$\frac{dE}{dt} = F_{\text{ext}}\frac{1}{\hbar}\frac{dE}{dk} \tag{9-5}$$

$$F_{\text{ext}} = \hbar\frac{dk}{dt} \tag{9-6}$$

$$F = \frac{d(\hbar k)}{dt} = \frac{dp}{dt} = m\frac{dv}{dt} = ma. \tag{9-7}$$

$$\mathbf{F}_{\text{ext}} = \hbar\frac{d\mathbf{k}}{dt} \tag{9-8}$$

$$\frac{d\mathbf{k}}{dt} = -(e/\hbar)\boldsymbol{\mathcal{E}} \tag{9-9}$$

$$a = \frac{dv}{dt} = \frac{dv}{dk}\frac{dk}{dt} \tag{9-10}$$

$$a = \left(\frac{1}{\hbar}\frac{d^2E}{dk^2}\right)\left(\frac{1}{\hbar}F_{\text{ext}}\right) \tag{9-11}$$

$$m^* = \left(\frac{1}{\hbar^2}\frac{d^2E}{dk^2}\right)^{-1} \tag{9-12}$$

$$a = F_{\text{ext}}/m^* \tag{9-13}$$

$$E_p = -E_n \tag{9-14}$$

$$\mathbf{k}_p = -\mathbf{k}_n \tag{9-15}$$

$$q_p = -q_n = +e \tag{9-16}$$

$$\mathbf{a} = \mathbf{F}_{\text{ext}}/m_p^* \tag{9-17}$$

$$m_p^* = \left(\frac{1}{\hbar^2}\frac{d^2E_p}{dk_p^2}\right)^{-1}. \tag{9-18}$$

$$m_p^* = -m_n^* \tag{9-19}$$

$$\boldsymbol{\mathcal{E}}_H = -R_H \mathbf{J}\times\mathbf{B} \tag{9-20}$$

$$R_H = -1/ne \tag{9-21}$$

$$R_H = +1/pe \tag{9-22}$$

$$\omega = eB/m^* \tag{9-23}$$

$$E_g = E_c - E_v \tag{10-1}$$

$$E(k) = E(0) + \left.\frac{dE}{dk}\right|_{k=0} k + \tfrac{1}{2}\left.\frac{d^2E}{dk^2}\right|_{k=0} k^2 + \cdots \tag{10-2}$$

$$E = E_c + \frac{\hbar^2}{2m_n^*}k^2 \tag{10-3}$$

$$E = E_v - \frac{\hbar^2}{2m_p^*}k^2 \tag{10-4}$$

$$g(E) = \frac{V}{2\pi^2}(2m_n^*/\hbar^2)^{3/2}(E-E_c)^{1/2}. \tag{10-5}$$

$$g(E) = \frac{V}{2\pi^2}(2m_p^*/\hbar^2)^{3/2}(E_v-E)^{1/2}. \tag{10-6}$$

$$f_D(E) = \frac{1}{\exp\left(\dfrac{E-E_F}{k_BT}\right)+1} \tag{10-7}$$

$$N = \int_{E_c}^{\infty} f_D(E)g(E)\,dE \tag{10-8}$$

$$n = \frac{1}{V}\int_{E_c}^{\infty} f_D(E)g(E)\,dE \tag{10-9}$$

$$f_D(E) \approx \exp\left(-\frac{E-E_F}{k_BT}\right) \tag{10-10}$$

$$n = N_c \exp\left(-\frac{E_c-E_F}{k_BT}\right) \tag{10-11}$$

$$N_c = 2\left(\frac{m_n^* k_B T}{2\pi\hbar^2}\right)^{3/2}. \tag{10-12}$$

$$\int_0^\infty \sqrt{x}e^{-x}\,dx = \tfrac{1}{2}\sqrt{\pi},$$

$$p = \frac{1}{V}\int_{-\infty}^{E_v}[1-f_D(E)]g(E)\,dE \tag{10-13}$$

$$1 - f_D(E) \approx \exp\left(-\frac{E_F-E}{k_BT}\right) \tag{10-14}$$

$$p = N_v \exp\left(-\frac{E_F-E_v}{k_BT}\right) \tag{10-15}$$

$$N_v = 2\left(\frac{m_p^* k_B T}{2\pi\hbar^2}\right)^{3/2}. \tag{10-16}$$

$$E_F = \tfrac{1}{2}(E_c+E_v) + \tfrac{1}{2}k_BT\ln(N_v/N_c) \tag{10-17}$$

$$n_i = p_i = \sqrt{N_cN_v}\exp\left(-\frac{E_g}{2k_BT}\right). \tag{10-18}$$

$$np = N_cN_v\exp\left(-\frac{E_g}{k_BT}\right) \tag{10-19}$$

$$np = n_ip_i = n_i^2 \tag{10-20}$$

$$\begin{aligned} n &\approx N_d, \\ p &\approx n_i^2/N_d. \end{aligned} \tag{10-21}$$

$$\begin{aligned} p &\approx N_a, \\ n &\approx n_i^2/N_a. \end{aligned} \tag{10-22}$$

$$\sigma_n = ne^2\tau_n/m_n^* \tag{10-23}$$

$$\mathbf{J} = \sigma_n \boldsymbol{\mathcal{E}} \tag{10-24}$$

$$\mathbf{J} = -ne\mathbf{v}_d \tag{10-25}$$

$$\mathbf{v}_d = -\frac{\sigma_n}{ne}\boldsymbol{\mathcal{E}} = -\frac{e\tau_n}{m_n^*}\boldsymbol{\mathcal{E}} \tag{10-26}$$

$$\mu_n = e\tau_n/m_n^* \tag{10-27}$$

$$\mathbf{v}_d = -\mu_n\boldsymbol{\mathcal{E}} \tag{10-28}$$

$$\sigma_n = ne\mu_n \tag{10-29}$$

$$\sigma_p = pe^2\tau_p/m_p^* \tag{10-30}$$

$$\mu_p = e\tau_p/m_p^* \tag{10-31}$$

$$\mathbf{v}_d = \mu_p\boldsymbol{\mathcal{E}} \tag{10-32}$$

$$\sigma_p = pe\mu_p \tag{10-33}$$

$$\sigma = \sigma_n + \sigma_p \tag{10-34}$$

$$\boldsymbol{\mathcal{E}}_H = -R_H\mathbf{J}\times\mathbf{B} \tag{10-35}$$

$$R_H = -1/ne \tag{10-36}$$

$$R_H = +1/pe \tag{10-37}$$

$$\mu_n = -\sigma R_H \tag{10-38}$$

$$\mu_p = \sigma R_H \tag{10-39}$$

$$E_F = \tfrac{1}{2}(E_c+E_v) + \tfrac{1}{2}k_BT\ln\left[(N_v/N_c)^{1/2}(N_d/n_i)\right] \tag{11-1}$$

$$E_F = \tfrac{1}{2}(E_{cn}+E_{vn}) + \tfrac{1}{2}k_BT\ln\left[(N_v/N_c)^{1/2}(N_d/n_i)\right] \tag{11-2}$$

$$E_F = \tfrac{1}{2}(E_{cp}+E_{vp}) - \tfrac{1}{2}k_BT\ln\left[(N_c/N_v)^{1/2}(N_a/n_i)\right] \tag{11-3}$$

$$E_{vp} - E_{vn} = k_BT\ln(N_dN_a/n_i^2) \tag{11-4}$$

$$e\phi = E_{vp} - E_{vn} \tag{11-5}$$

$$\phi = (k_BT/e)\ln(N_dN_a/n_i^2) \tag{11-6}$$

$$\oint \boldsymbol{\mathcal{E}}\cdot d\mathbf{S} = Q/\epsilon \tag{11-7}$$

$$\epsilon = \epsilon_r\epsilon_0 \tag{11-8}$$

$$\boldsymbol{\mathcal{E}} = \mathcal{E}\,\hat{\mathbf{i}} \tag{11-9}$$

$$\frac{d\mathcal{E}}{dx} = \frac{\rho}{\epsilon_r\epsilon_0} \tag{11-10}$$

$$\mathcal{E} = \frac{1}{\epsilon_r\epsilon_0}\int_{-\infty}^{x}\rho\,dx. \tag{11-11}$$

$$\mathcal{E} = \begin{cases} -(eN_d/\epsilon_r\epsilon_0)(\frac{1}{2}x_d + x), & -\frac{1}{2}x_d \le x \le 0, \\ -(eN_d/\epsilon_r\epsilon_0)(\frac{1}{2}x_d - x), & 0 \le x \le \frac{1}{2}x_d, \\ 0, & \text{otherwise.} \end{cases} \tag{11-12}$$

$$\mathcal{E}_{\max} = eN_dx_d/2\epsilon_r\epsilon_0 \tag{11-13}$$

$$\Delta U = -\int_{-\infty}^{\infty} F\,dx \tag{11-14}$$

$$\Delta U = e\int_{-x_d/2}^{x_d/2}\mathcal{E}\,dx \tag{11-15}$$

$$\Delta U = -e^2N_dx_d^2/4\epsilon_r\epsilon_0 \tag{11-16}$$

$$\phi = eN_dx_d^2/4\epsilon_r\epsilon_0 \tag{11-17}$$

$$x_d = \sqrt{4\epsilon_r\epsilon_0\phi/eN_d} \tag{11-18}$$

$$\mathcal{E}_{\max} = \sqrt{eN_d\phi/\epsilon_r\epsilon_0} \tag{11-19}$$

$$I_{nr0} = I_{ng0} \tag{11-20}$$

$$I_{pr0} = I_{pg0} \tag{11-21}$$

$$E_{cp} = E_{vn} + E_g + e(\phi - V_a) \tag{11-22}$$

$$n(V_a) = \frac{1}{V}\int_{E_{cp}}^{\infty} f_D(E)g(E)\,dE \tag{11-23}$$

$$n(V_a) = N_c\exp\left(-\frac{E_{cp}-E_F}{k_BT}\right) \tag{11-24}$$

$$n(V_a) = N_c\times \exp\left(-\frac{E_{vn}+E_g+e(\phi-V_a)-E_F}{k_BT}\right) \tag{11-25}$$

$$n(V_a) = n(0)\exp(eV_a/k_BT) \tag{11-26}$$

$$I_{nr} = I_{nr0}\exp(eV_a/k_BT) \tag{11-27}$$

$$I_{pr} = I_{pr0}\exp(eV_a/k_BT) \tag{11-28}$$

$$I_{ng} = I_{ng0} \tag{11-29}$$

$$I_{pg} = I_{pg0} \tag{11-30}$$

$$I = I_{nr} - I_{ng} + I_{pr} - I_{pg} \tag{11-31}$$

$$I = I_0\left[\exp(eV_a/k_BT) - 1\right] \tag{11-32}$$

$$I_0 = I_{ng0} + I_{pg0} \tag{11-33}$$

$$x_d = \sqrt{4\epsilon_r\epsilon_0(\phi - V_a)/eN_d} \tag{11-34}$$

$$\mathcal{E}_{\max} = \sqrt{eN_d(\phi - V_a)/\epsilon_r\epsilon_0}. \tag{11-35}$$

$$C = \frac{\epsilon_r\epsilon_0 A}{x_d} \tag{11-36}$$

$$C = A\sqrt{eN_d\epsilon_r\epsilon_0/4(\phi - V_a)} \tag{11-37}$$

$$p = mv = \frac{m}{\hbar}\frac{dE}{dk} \tag{12-1}$$

$$\oint \boldsymbol{\mathcal{E}}\cdot d\boldsymbol{\ell} = -d\Phi_B/dt \tag{13-1}$$

$$\mathbf{B} = \mathbf{B}_0\exp(-x/\lambda) \tag{13-2}$$

$$\lambda = \frac{\lambda_0}{\sqrt{1-(T/T_c)^4}} \tag{13-3}$$

$$B_c(T) = B_c(0)\left[1-(T/T_c)^2\right] \tag{13-4}$$

$$B = \mu_0 I/2\pi R \tag{13-5}$$

$$I_c = 2\pi r B_c/\mu_0 \tag{13-6}$$

$$\mathbf{k}_{1f} = \mathbf{k}_{1i} - \mathbf{k}$$

$$\mathbf{k}_{2f} = \mathbf{k}_{2i} + \mathbf{k} \tag{13-7}$$

$$\mathbf{k}_{1f} + \mathbf{k}_{2f} = \mathbf{k}_{1i} + \mathbf{k}_{2i} \tag{13-8}$$

$$\mathbf{k}_1 + \mathbf{k}_2 = \text{constant} \tag{13-9}$$

$$\psi = \sum_{i,j} A_{ij}\psi_1(\mathbf{k}_i)\psi_2(\mathbf{k}_j) \tag{13-10}$$

$$2\Delta \approx 3.5k_BT_c \tag{13-11}$$

$$\mathbf{k}_1 + \mathbf{k}_2 = \Delta\mathbf{k} \tag{13-12}$$

The Periodic Table of the Elements

1st line: atomic number
2nd line: atomic symbol
3rd line: atomic mass

1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.0	89 Ac 227.0	104 Rf (261)	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									

58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np 237.0	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

89	Ac	actinium	68	Er	erbium	101	Md
13	Al	aluminum	63	Eu	europium	80	Hg
95	Am	americium	100	Fm	fermium	42	Mo
51	Sb	antimony	9	F	fluorine	60	Nd
18	Ar	argon	87	Fr	francium	10	Ne
33	As	arsenic	64	Gd	gadolinium	93	Np
85	At	astatine	31	Ga	gallium	28	Ni
56	Ba	barium	32	Ge	germanium	41	Nb
97	Bk	berkelium	79	Au	gold	7	N
4	Be	beryllium	72	Hf	hafnium	102	No
83	Bi	bismuth	108	Hs	hassium	76	Os
107	Bh	bohrium	2	He	helium	8	O
5	B	boron	67	Ho	holmium	46	Pd
35	Br	bromine	1	H	hydrogen	15	P
48	Cd	cadmium	49	In	indium	78	Pt
20	Ca	calcium	53	I	iodine	94	Pu
98	Cf	californium	77	Ir	iridium	84	Po
6	C	carbon	26	Fe	iron	19	K
58	Ce	cerium	36	Kr	krypton	59	Pr
55	Cs	cesium	57	La	lanthanum	61	Pm
17	Cl	chlorine	103	Lr	lawrencium	91	Pa
24	Cr	chromium	82	Pb	lead	88	Ra
27	Co	cobalt	3	Li	lithium	86	Rn
29	Cu	copper	71	Lu	lutetium	75	Re
96	Cm	curium	12	Mg	magnesium	45	Rh
105	Db	dubnium	25	Mn	manganese	37	Rb
66	Dy	dysprosium	109	Mt	meitnerium	44	Ru
99	Es	einsteinium					

101	Md	mendelevium	104	Rf	rutherfordium
80	Hg	mercury	62	Sm	samarium
42	Mo	molybdenum	21	Sc	scandium
60	Nd	neodymium	106	Sg	seaborgium
10	Ne	neon	34	Se	selenium
93	Np	neptunium	14	Si	silicon
28	Ni	nickel	47	Ag	silver
41	Nb	niobium	11	Na	sodium
7	N	nitrogen	38	Sr	strontium
102	No	nobelium	16	S	sulfur
76	Os	osmium	73	Ta	tantalum
8	O	oxygen	43	Tc	technetium
46	Pd	palladium	52	Te	tellurium
15	P	phosphorus	65	Tb	terbium
78	Pt	platinum	81	Tl	thallium
94	Pu	plutonium	90	Th	thorium
84	Po	polonium	69	Tm	thulium
19	K	potassium	50	Sn	tin
59	Pr	praseodymium	22	Ti	titanium
61	Pm	promethium	74	W	tungsten
91	Pa	protactinium	92	U	uranium
88	Ra	radium	23	V	vanadium
86	Rn	radon	54	Xe	xenon
75	Re	rhenium	70	Yb	ytterbium
45	Rh	rhodium	39	Y	yttrium
37	Rb	rubidium	30	Zn	zinc
44	Ru	ruthenium	40	Zr	zirconium

Listed below are the crystal structures of various elements and compounds. The lattice parameters a in units of Å are also given.

Elements with a bcc lattice

Li	3.50	Ba	5.02	Mo	3.14
Na	4.30	V	3.04	W	3.15
K	5.20	Nb	3.30	Fe	2.86
Rb	5.59	Ta	3.32	Eu	4.58
Cs	6.50	Cr	2.87		

Elements with an fcc lattice

Ca	5.56	Pd	3.87	Al	4.04
Sr	6.08	Pt	3.90	Pb	4.93
Ac	5.31	Cu	3.61	Ce	5.12
Rh	3.80	Ag	4.07	Yb	5.48
Ir	3.82	Au	4.07	Th	5.08
Ni	3.52				

Elements with the diamond structure

C	3.56	Ge	5.65	Sn	6.46
Si	5.42				

Compounds with the cesium chloride structure

CsCl	4.11	TlI	4.18	CuPd	2.99
CsBr	4.28	TlSb	3.85	AgZn	3.16
CsI	4.56	TlBi	3.90	AuZn	3.15
TlCl	3.84	CuZn	2.95	AlNi	2.82
TlBr	3.97				

Compounds with the sodium chloride structure

LiF	4.02	RbI	7.32	BaTe	6.99
LiCl	5.14	CsF	6.00	MnO	4.43
LiBr	5.49	MgO	4.20	MnS	5.21
LiI	6.00	MgS	5.19	MnSe	5.45
NaF	4.61	MgSe	5.45	FeO	4.28
NaCl	5.63	CaO	4.80	CoO	4.25
NaBr	5.96	CaS	5.68	NiO	4.17
NaI	6.46	CaSe	5.91	AgF	4.92
KF	5.36	CaTe	6.34	AgCl	5.54
KCl	6.27	SrO	5.15	AgBr	5.76
KBr	6.58	SrS	6.01	CdO	4.70
KI	7.05	SrSe	6.23	SnTe	6.28
RbF	5.63	SrTe	6.65	PbS	5.93
RbCl	6.53	BaO	5.53	PbSe	6.14
RbBr	6.85	BaSe	6.59	PbTe	6.44

Compounds with the zincblende structure

BeS	4.86	ZnTe	6.09	GaP	5.44
CuCl	5.41	CdTe	6.46	GaAs	5.64
CuBr	5.68	AlP	5.45	GaSb	6.09
CuI	6.05	AlAs	5.63	InSb	6.45
ZnS	5.42	AlSb	6.10	SnSb	6.13
ZnSe	5.66				

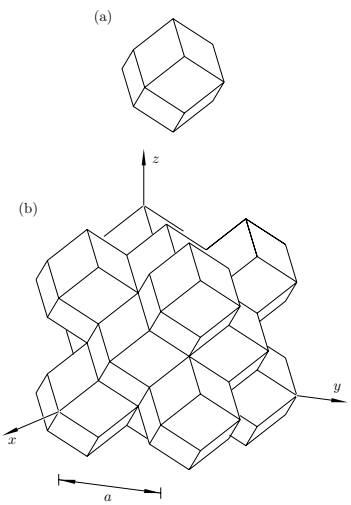


Fig. 1-19. (a) The Wigner-Seitz cell for the fcc lattice. (b) These cells fit together to fill all space.

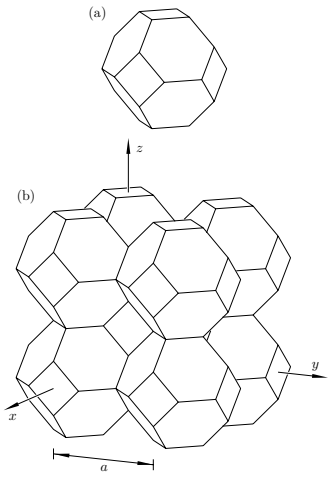


Fig. 1-16. (a) The Wigner-Seitz cell for the bcc lattice. (b) These cells fit together to fill all space.

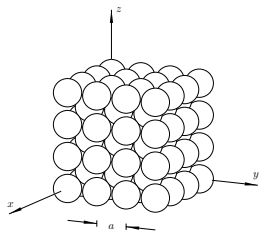


Fig. 1-12. Body-centered cubic arrangement of atoms.

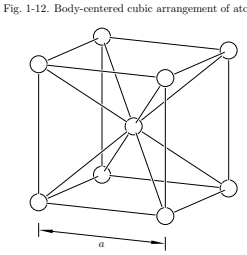


Fig. 1-13. The conventional unit cell of the bcc lattice.

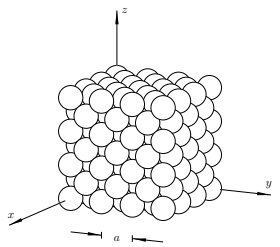


Fig. 1-17. Face-centered cubic arrangement of atoms.

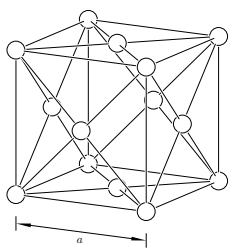


Fig. 1-18. The conventional unit cell of the fcc lattice.

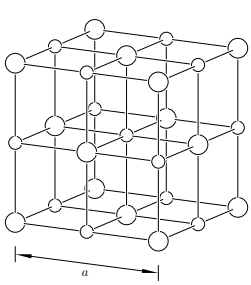


Fig. 1-21. The conventional unit cell for the sodium chloride structure. The large and small spheres represent two different types of atoms.

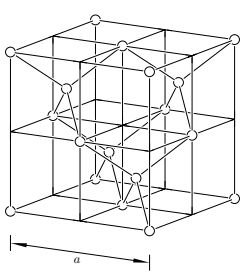


Fig. 1-27. The conventional unit cell of the diamond structure. All atoms are identical.

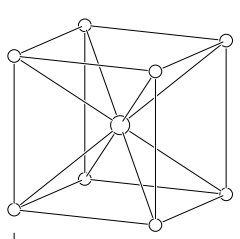


Fig. 1-25. The conventional unit cell of the cesium chloride structure. The large and small spheres represent two different types of atoms.

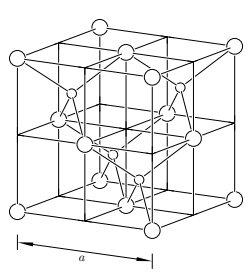


Fig. 1-26. The conventional unit cell for the zincblende structure. The large and small spheres represent two different types of atoms.

UNITS

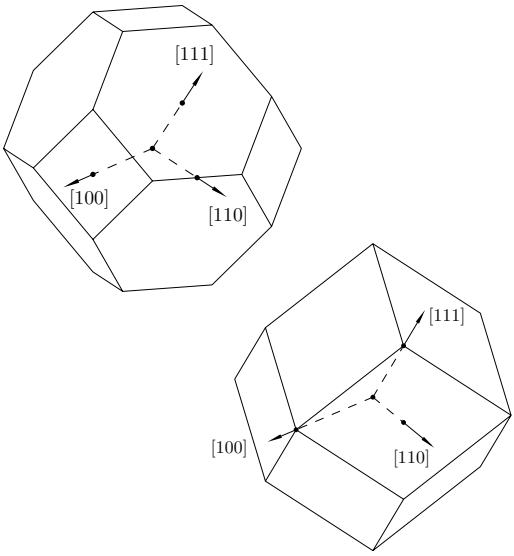
The SI units are given in parentheses. Other commonly used units are given in terms of the SI units. Symbols conform with the recommendations of the American National Standards Institute (ANSI) and the American Institute of Physics (AIP).

Commonly used multiples of SI units:

prefix	symbol	factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

length: meter (m)		
angstrom	1 Å	$= 10^{-10}$ m
inch	1 in.	$= 2.54 \times 10^{-2}$ m
foot	1 ft	= 0.3048 m
mile	1 mi	= 1609 m
mass: kilogram (kg)		
atomic mass unit	1 u	$= 1.661 \times 10^{-27}$ kg
slug	1 slug	= 14.59 kg
force: newton ($N = kg \cdot m/s^2$)		
dyne	1 dyn	$= 10^{-5}$ N
pound	1 lb	= 4.448 N
pressure: pascal ($Pa = kg/m \cdot s^2$)		
atmosphere	1 atm	$= 1.013 \times 10^{5}$ Pa
pounds/square inch	1 psi	= 6895 Pa
cm of mercury	1 cm Hg	= 1333 Pa
bar	1 bar	$= 1.000 \times 10^{5}$ Pa
torr	1 torr	= 133.3 Pa

time: second (s)		
minute	1 min	= 60 s
hour	1 h	= 3600 s
frequency: hertz ($Hz = s^{-1}$)		
radians/second	1 rad/s	$= 1/2\pi$ Hz
energy: joule ($J = kg \cdot m^2/s^2$)		
erg	1 erg	$= 10^{-7}$ J
electron volt	1 eV	$= 1.602 \times 10^{-19}$ J
calorie	1 cal	= 4.187 J
kilowatt-hour	1 kW·h	$= 3.6 \times 10^{6}$ J
British thermal unit	1 Btu	= 1055 J
power: watt ($W = kg \cdot m^2/s^3$)		
horsepower	1 hp	= 745.7 W
charge: coulomb ($C = A \cdot s$)		
electric potential: volt ($V = kg \cdot m^2/s^3 \cdot A$)		
current: ampere (A)		
resistance: ohm ($\Omega = kg \cdot m^2/s^3 \cdot A^2$)		
capacitance: farad ($F = s^4 \cdot A^2/kg \cdot m^2$)		
magnetic field: tesla ($T = kg/s^2 \cdot A$)		
gauss	1 G	$= 10^{-4}$ T
magnetic flux: weber ($Wb = kg \cdot m^2/s^2 \cdot A$)		
maxwell	1 Mx	$= 10^{-8}$ Wb
magnetic inductance: henry ($H = kg \cdot m^2/s^2 \cdot A^2$)		
temperature: kelvin (K)		
degrees Celsius	0°C	= 273.15 K
angle: radian (rad)		
degree	1°	$= \pi/180$ rad
revolution	1 rev	$= 2\pi$ rad



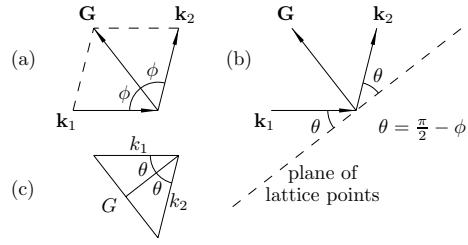


Fig. 2-14. (a) Diagram showing the relation, $\mathbf{G} = \mathbf{k}_2 - \mathbf{k}_1$. (b) $\mathbf{G}$ is perpendicular to planes of lattice points in real space. (c) Diagram showing the relation between G, k, and θ.

IMPURITY LEVELS IN SILICON AND GERMANIUM

All values are given for room temperature (300 K).

Donors	E_d in Si	E_d in Ge
P	0.044 eV	0.0120 eV
As	0.049	0.0127
Sb	0.039	0.0096
Bi	0.069	
Acceptors	E_a in Si	E_a in Ge
B	0.046 eV	0.0104 eV
Al	0.057	0.0102
Ga	0.065	0.0108
In	0.16	0.0112
Tl	0.26	0.01

SOME PHYSICAL CONSTANTS

electron charge	e	1.602×10^{-19} C
electron mass		9.11×10^{-31} kg
proton mass		1.673×10^{-27} kg
neutron mass		1.675×10^{-27} kg
Planck's constant	h	6.626×10^{-34} J·s
	$\hbar$	1.055×10^{-34} J·s
Boltzmann's constant	k_B	1.380×10^{-23} J/K
permittivity constant	ϵ_0	8.854×10^{-12} F/m
permeability constant	μ_0	1.257×10^{-6} H/m
speed of light	c	3.00×10^{8} m/s
Avogadro's number		6.022×10^{23} /mol
Bohr magneton	μ_B	9.27×10^{-24} J/T