Corrections 2

Quantum Mechanics: Concepts and Applications

by Nouredine Zettili

(Modified last on March 20, 2007)

Note: This list of corrections pertain to the book's re-prints that were produced **after 2001**.

Physical Constants

- Back page of the front cover. Replace the proton Compton wavelength "1.321×10^{-17} m" by "1.321×10^{-15} m".

Chapter 1

- Page 5, Caption of Figure 1.1, replace $T_1 < T_2 < T_3$ by $T_1 > T_2 > T_3$.
- Page 8, remove the second tilde in Eq. (1.11); i.e., replace Eq. (1.11) by

$$\tilde{u}(\lambda, T) = u(\nu, T) \left| \frac{d\nu}{d\lambda} \right| = \frac{8\pi hc}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}.$$

- Page 8, replace Eq. (1.13) by

$$\frac{\alpha}{\lambda} = 5 \left(1 - e^{-\alpha/\lambda} \right).$$

- Page 12, replace Example 1.2 by:

Example 1.2 When two ultraviolet beams of wavelengths $\lambda_1 = 80$nm and $\lambda_2 = 110$nm fall on a lead surface, they produce photoelectrons with maximum energies 11.390 eV and 7.154 eV, respectively.

(a) Estimate the numerical value of the Planck constant.

(b) Calculate the work function and the cutoff frequency of lead

Solution

(a) From (1.21) we can write the kinetic energies of the emitted electrons as $K_1 = hc/\lambda_1 - W$ and $K_2 = hc/\lambda_2 - W$; the difference between these two expressions is given by $K_1 - K_2 = hc(\lambda_2 - \lambda_1)/(\lambda_1\lambda_2)$, hence

$$h = \frac{K_1 - K_2}{c} \frac{\lambda_1 \lambda_2}{\lambda_2 - \lambda_1}. \tag{1}$$

Since $1\,\text{eV} = 1.6 \times 10^{-19}\,\text{J}$, the numerical value of h follows at once:

$$h = \frac{(11.390 - 7.154) \times 1.6 \times 10^{-19}\,\text{J}}{3 \times 10^8\text{m}\,\text{s}^{-1}} \times \frac{(80 \times 10^{-9}\,\text{m})(110 \times 10^{-9}\,\text{m})}{110 \times 10^{-9}\,\text{m} - 80 \times 10^{-9}\,\text{m}} \simeq 6.627 \times 10^{-34}\,\text{J}\,\text{s}. \tag{2}$$

This is a very accurate result indeed.

(b) The work function of the metal can be obtained from either one of the two data

$$\begin{aligned} W = \frac{hc}{\lambda_1} - K_1 &= \frac{6.627 \times 10^{-34}\,\text{J}\,\text{s} \times 3 \times 10^8\,\text{m}\,\text{s}^{-1}}{80 \times 10^{-9}\,\text{m}} - 11.390 \times 1.6 \times 10^{-19}\,\text{J} \\ &= 6.627 \times 10^{-19}\,\text{J} = 4.14\,\text{eV}. \end{aligned} \tag{3}$$

The cutoff frequency of the metal is

$$\nu_0 = \frac{W}{h} = \frac{6.627 \times 10^{-19}\,\text{J}}{6.627 \times 10^{-34}\text{J}\,\text{s}} = 1.0 \times 10^{15}\ \text{Hz}. \tag{4}$$

- Page 15, first line of solution to part (c), replace $E = 15\,\text{MeV}$ by $E = 150\,\text{MeV}$.
- Page 18, replace 75 eV by 54 eV in line 10 from bottom.
- Page 19, replace $d = 9.1$nm by $d = 0.091$nm in line 8 from top.
- Page 19, replace Eq. (1.47) by

$$\lambda = \frac{2d}{n} \sin\phi = \frac{2d}{n} \cos \frac{1}{2}\theta = \frac{2 \times 0.091\,\text{nm}}{1} \cos 25 = 0.165\,\text{nm}.$$

- Page 19, two lines above Eq. (1.48), replace $\hbar c \simeq 19732.8\,\text{eV}\,\text{nm}$ by $\hbar c \simeq 197.33\,\text{eV}\,\text{nm}$.
- Page 19, replace Eq. (1.48) by

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m_e K}} = \frac{2\pi\hbar c}{\sqrt{2m_e c^2 K}} = 0.167\,\text{nm},$$

- Page 20, Footnote 12, replace $m_e/m_b \simeq 10^{-30}$ by $m_e/m_b \simeq 10^{-29}$.
- Page 21, Eq. (1.51), replace 0.01 kg by 0.1 kg, and 7.4×10^{-34} m by 7.4×10^{-36} m.
- Page 21, line after Eq. (1.51), replace 2.2×10^{-19} m by 2.2×10^{-21} m.
- Page 32, first line, replace $a_0 = 5.3\,\text{nm}$ by $a_0 = 0.053\,\text{nm}$.
- Page 35, line after Eq. (1.82), replace $a_0 = 4\pi\varepsilon_0\hbar^2/(m_e e^2) = 5.3\,\text{nm}$ by $a_0 = 4\pi\varepsilon_0\hbar^2/(m_e e^2) = 0.053\,\text{nm}$.
- Page 35, part (b) in the solution of Example 1.7, replace $r_1 = 2a_0 = 10.6\,\text{nm}$, $r_2 = 8a_0 = 42.4\,\text{nm}$ and $r_3 = 18a_0 = 95.4\,\text{nm}$ by $r_1 = 2a_0 = 0.106\,\text{nm}$, $r_2 = 8a_0 = 0.424\,\text{nm}$ and $r_3 = 18a_0 = 0.954\,\text{nm}$.

- Page 59, replace the final result of Eq. (1.188) (i.e., 2.3 eV) by 2.3 MeV.
- Page 68, replace Eq. (1.233) by

$$r_0 = \frac{4\pi\varepsilon_0\hbar^2}{m_e e^2} = 0.053\,\text{nm}.$$

- Page 61, replace Eq. (1.193) by

$$r_{n_C} = \frac{a_0}{6}n^2, \qquad E_{n_C} = -\frac{36\mathcal{R}}{n^2}$$

- Page 65, replace the solution to Problem 1.14 by

  Using the relation $\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$, we can write the superposition of $\psi_1(y,t)$ and $\psi_2(y,t)$ as follows:

$$\begin{aligned} \psi(y,t) &= \psi_1(y,t) + \psi_2(y,t) = 5y\cos 7t - 5y\cos 9t \\ &= 5y(\cos 8t\cos t + \sin 8t\sin t) - 5y(\cos 8t\cos t - \sin 8t\sin t) \\ &= 10y\sin t\sin 8t. \end{aligned}$$

  The periods of $10y\sin t$ and $\sin(8t)$ are given by 2π and $2\pi/8$, respectively. Since the period of $10y\sin t$ is larger than that of $\sin 8t$, $10y\sin t$ must be the modulating function and $\sin 8t$ the modulated function. As depicted in Figure 1.18, we see that $\sin 8t$ is modulated by $10y\sin t$.

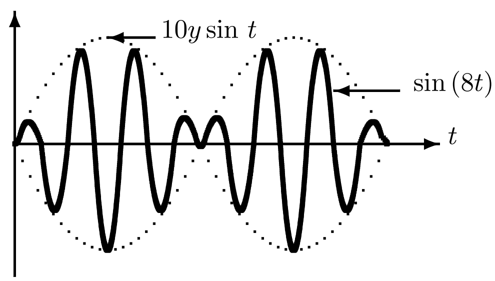


Figure 1: Shape of the wave packet $\psi(y,t) = 10y\sin t\sin 8t$. The function $\sin 8t$, the solid curve, is modulated by $10y\sin t$, the dashed curve.

- Page 69, replace the final result (i.e., 1.2×10^{-21} s) of Eq.(1.235) by 3.2×10^{-21} s.
- Page 70, replace Eq.(1.245) by

$$\omega_{nm} = \frac{E_n - E_m}{\hbar} = \frac{3}{2}\left(\frac{k^2}{\mu\hbar}\right)^{1/3}\left(n^{2/3} - m^{2/3}\right).$$

- Page 70, replace the final result (i.e., 0.733 fm) of Eq.(1.247) by 0.427 fm.
- Page 72, Exercise 1.13, replace 3.9 eV by 1.9 eV.

- Page 72, Exercise 1.15, replace 12 V by 1.2 V.
- Page 73, Exercise 1.24, replace 0.8nm and 17nm by 0.0008nm and 0.0017nm, respectively.
- Page 74, Exercise 1.25, replace 0.05 MeV by 0.5 MeV.
- Page 75, Problem 1.34, replace 5.3nm by 0.053 nm.

Chapter 2

- Page 82, replace Eq.(2.13) by

$$-a_1 + a_2 - a_3 = 0, \qquad a_1 + a_2 + a_3 = 0, \qquad 3a_1 + 9a_2 + 27a_3 = 0$$

- Page 83, replace Eq.(2.15) by

$$3a_1 = 0, \qquad -2a_2 = 0, \qquad -a_3 = 0,$$

- Page 83, Line after Eq.(2.16), replace $a_1 = -3a_2$ by $a_1 = a_2/3$
- Page 87, replace Eq.(2.39) by

$$\begin{aligned} \mid \psi + \chi\rangle &= \mid \psi\rangle + \mid \chi\rangle = (3i \mid \phi_1\rangle \; - \; 7i \mid \phi_2\rangle) + (- \mid \phi_1\rangle \; + \; 2i \mid \phi_2\rangle) \\ &= (-1 + 3i) \mid \phi_1\rangle \; - \; 5i \mid \phi_2\rangle. \end{aligned}$$

- Page 91, replace $f(\hat{A})$ in part (b) of Example 2.4 by $f(\hat{A}) = (1 + i\hat{A} + 3\hat{A}^2)(1 - 2i\hat{A} - 9i\hat{A}^2)/(5 + 7\hat{A})$.
- Page 93, replace Eq. (2.86) by

$$[\hat{A},\ \hat{B}^n] = \sum_{j=0}^{n-1} \hat{B}^j [\hat{A},\ \hat{B}] \hat{B}^{n-j-1}$$

- Page 93, replace Eq. (2.87) by

$$[\hat{A}^n,\ \hat{B}] = \sum_{j=0}^{n-1} \hat{A}^{n-j-1} [\hat{A},\ \hat{B}] \hat{A}^j$$

- Page 93, replace Eq. (2.90) by

$$\begin{aligned} [\hat{A},\ [\hat{B},\ \hat{C}]\hat{D}] &= [\hat{B},\ \hat{C}][\hat{A},\ \hat{D}] + [\hat{A},\ [\hat{B},\ \hat{C}]]\hat{D} \\ &= (\hat{B}\hat{C} - \hat{C}\hat{B})(\hat{A}\hat{D} - \hat{D}\hat{A}) + \hat{A}(\hat{B}\hat{C} - \hat{C}\hat{B})\hat{D} - (\hat{B}\hat{C} - \hat{C}\hat{B})\hat{A}\hat{D} \\ &= \hat{C}\hat{B}\hat{D}\hat{A} - \hat{B}\hat{C}\hat{D}\hat{A} + \hat{A}\hat{B}\hat{C}\hat{D} - \hat{A}\hat{C}\hat{B}\hat{D}. \end{aligned}$$

- Page 95, replace Eq. (2.103) by

$$e^{a\hat{A}} = \sum_{n=0}^{\infty} \frac{a^n}{n!} \hat{A}^n = \hat{I} + a\hat{A} + \frac{a^2}{2!}\hat{A}^2 + \frac{a^3}{3!}\hat{A}^3 + \cdots.$$

- Page 102, replace Eq. (2.157) by

$$\hat{U}_\alpha(\hat{G}) = \lim_{N\to\infty} \prod_{k=1}^{N} \left(1 + i\frac{\alpha}{N}\hat{G}\right) = \lim_{N\to+\infty} \left(1 + i\frac{\alpha}{N}\hat{G}\right)^N = e^{i\alpha\hat{G}},$$

- Page 104, replace Eq. (2.165) by

$$\begin{aligned} \langle\psi \mid \longrightarrow & \ (\langle\psi \mid \phi_1\rangle \ \ \langle\psi \mid \phi_2\rangle \ \ \cdots \ \ \langle\psi \mid \phi_n\rangle \ \ \cdots) \\ &= (\langle\phi_1 \mid \psi\rangle^* \ \ \langle\phi_2 \mid \psi\rangle^* \ \ \cdots \ \ \langle\phi_n \mid \psi\rangle^* \ \ \cdots) \\ &= (a_1^* \ \ a_2^* \ \ \cdots \ \ a_n^* \ \ \cdots). \end{aligned}$$

- Page 105, replace the statement "So a square matrix A is symmetric if it is equal to its transpose, $A^T = -A$" right after Eq. (2.172) by "So a square matrix A is symmetric if it is equal to its transpose, $A^T = A$". (i.e., the minus sign in $A^T = -A$ should be tossed).
- Page 106, replace the term B_{32} in Eq. (2.184) by

$$B_{32} = (-1)^5 \begin{vmatrix} 2 & 0 \\ 3 & 5 \end{vmatrix} = -10.$$

- Page 118, replace Eq. (2.263) by

$$\mid \psi\rangle \quad \longrightarrow \quad \begin{pmatrix} \vdots \\ \langle\chi_k \mid \psi\rangle \\ \vdots \end{pmatrix}.$$

- Page 118, replace Eq. (2.264) by

$$\langle\psi \mid \longrightarrow (\cdots\cdots \qquad \langle\psi \mid \chi_k\rangle \qquad \cdots\cdots).$$

- Page 119, replace Eq. (2.269) by

$$\delta(\vec{r} - \vec{r}\,') = \frac{1}{(2\pi)^3} \int d^3k\, e^{i\vec{k}\cdot(\vec{r}-\vec{r}\,')}.$$

- Page 136, replace Eq. (2.387) by

$$AB = \begin{pmatrix} 7 & 0 & 21 \\ 1 & 2i & -5 \\ -i & -2 & 5i \end{pmatrix}, \quad BA = \begin{pmatrix} 7 & 3i & -3 \\ 0 & 2i & 2 \\ 7i & 5 & 5i \end{pmatrix},$$

- Pages 140-141, replace the product AB in equations (2.410)–(2.413) by

$$AB = \begin{pmatrix} 0 & 1 & -2i \\ 3 & 1 & 5 \\ -2i & 1 & 0 \end{pmatrix}$$

- Page 141, replace Eq. (2.421) by

$$\begin{aligned} e^{xA} &= I\cosh x + A\sinh x = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \cosh x + \begin{pmatrix} 0 & 0 & i \\ 0 & 1 & 0 \\ -i & 0 & 0 \end{pmatrix} \sinh x \\ &= \begin{pmatrix} \cosh x & 0 & i\sinh x \\ 0 & \cosh x + \sinh x & 0 \\ -i\sinh x & 0 & \cosh x \end{pmatrix}. \end{aligned}$$

- Page 142, in the statement of Problem 2.11, replace $A' = U^\dagger A U$ by $A' = UAU^\dagger$.
- Page 144, replace Eq. (2.441) by

$$\begin{aligned} A' &= UAU^\dagger = \frac{1}{4}\begin{pmatrix} -\sqrt{2} & 1 & 1 \\ 0 & \sqrt{2} & -\sqrt{2} \\ \sqrt{2} & 1 & 1 \end{pmatrix} \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} -\sqrt{2} & 0 & \sqrt{2} \\ 1 & \sqrt{2} & 1 \\ 1 & -\sqrt{2} & 1 \end{pmatrix} \\ &= \frac{1}{2}\begin{pmatrix} 1-\sqrt{2} & -1 & 1 \\ -1 & -2 & 1 \\ 1 & 1 & 1+\sqrt{2} \end{pmatrix}. \end{aligned}$$

- Page 144, replace the last line of Eq. (2.442) by

$$\alpha^2 \left(|\, \phi_1\rangle\langle\phi_2 \,| + |\, \phi_2\rangle\langle\phi_1 \,| \right).$$

- Page 145, replace the first line of Eq. (2.443) by

$$\left(|\, \phi_1\rangle\langle\phi_2 \,| + |\, \phi_2\rangle\langle\phi_1 \,| \right)\left(|\, \phi_1\rangle\langle\phi_2 \,| + |\, \phi_2\rangle\langle\phi_1 \,| \right).$$

Chapter 3

- Page 160, replace "probability density" by "probability" in the two lines following Eq. (3.9) and in the line following Eq. (3.10).
- Page 167, replace in the upper line of Eq. (3.43) the term $E = \frac{\langle\psi|\hat{H}|\psi\rangle}{\langle\psi|\hat{H}|\psi\rangle}$ by

$$E = \frac{\langle\psi|\hat{H}|\psi\rangle}{\langle\psi|\psi\rangle}$$

- Page 179, replace the last term of Eq. (3.114) by

$$\{q_j, p_k\} = \delta_{jk}.$$

- Page 181, replace Eq. (3.129) by

$$[\hat{\vec{P}}, \hat{V}(\hat{\vec{R}}, t)] = -i\hbar\vec{\nabla}\hat{V}(\vec{R}, t),$$

- Page 181, replace Eq. (3.130) by

$$\frac{d}{dt}\langle\hat{\vec{P}}\rangle = \frac{1}{i\hbar}\langle[\hat{\vec{P}}, \hat{V}(\hat{\vec{R}}, t)]\rangle = -\langle\vec{\nabla}\hat{V}(\hat{\vec{R}}, t)\rangle$$

- Last line of Page 183, replace "and so do $\hat{L}_x$, $\hat{L}_y$ and $\hat{L}_z$," by "and so do $\hat{P}_x$, $\hat{P}_y$ and $\hat{P}_z$,".
- Page 185, line after Eq. (3.153), replace $\exp(-iE_5t/\hbar)$ by $\exp(iE_5t/\hbar)$.
- Page 196, replace Eq. (3.220) by

$$|\psi(0)\rangle = \frac{1}{5}\begin{pmatrix} 3 \\ 0 \\ 4 \end{pmatrix} = \frac{2\sqrt{2}}{5}|\phi_1\rangle + \frac{3}{5}|\phi_2\rangle + \frac{2\sqrt{2}}{5}|\phi_3\rangle,$$

- Page 186, replace the first line of Eq. (3.158) by

$$\rho(x,t) = \frac{3}{10}\phi_3^2(x) + \frac{\sqrt{3}}{5}\phi_3(x)\phi_5(x)\cos\left(\frac{16E_1t}{\hbar}\right) + \frac{1}{10}\phi_5^2(x).$$

- Page 186, replace equations (3.160) and (3.161) by

$$\begin{aligned}\frac{d\psi(x,t)}{dx} &= \frac{3\pi}{a}\sqrt{\frac{3}{5a}}\cos\left(\frac{3\pi x}{a}\right)e^{-iE_3t/\hbar} + \frac{5\pi}{a}\frac{1}{\sqrt{5a}}\cos\left(\frac{5\pi x}{a}\right)e^{-iE_5t/\hbar}, \\ \frac{d\psi^*(x,t)}{dx} &= \frac{3\pi}{a}\sqrt{\frac{3}{5a}}\cos\left(\frac{3\pi x}{a}\right)e^{iE_3t/\hbar} + \frac{5\pi}{a}\frac{1}{\sqrt{5a}}\cos\left(\frac{5\pi x}{a}\right)e^{iE_5t/\hbar}.\end{aligned}$$

- Page 187, replace Eq. (3.162) by

$$\begin{aligned}\psi\frac{d\psi^*}{dx} - \psi^*\frac{d\psi}{dx} = &-2i\pi\frac{\sqrt{3}}{5a^2}\left[5\sin\left(\frac{3\pi x}{a}\right)\cos\left(\frac{5\pi x}{a}\right) - 3\sin\left(\frac{5\pi x}{a}\right)\cos\left(\frac{3\pi x}{a}\right)\right] \\ &\times\ \sin\left(\frac{E_3 - E_5}{\hbar}t\right).\end{aligned}$$

- Page 193, replace Eq. (3.202) by

$$P(a_1) = \frac{|\langle a_1|\psi(t)\rangle|^2}{\langle\psi(t)|\psi(t)\rangle} = \frac{36}{17}\left|\frac{1}{\sqrt{2}}\frac{1}{6}\begin{pmatrix} 0 & i & 1 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \\ 4 \end{pmatrix}\right|^2 = \frac{8}{17},$$

- Page 196, replace Eq. (3.220) by

$$|\psi(0)\rangle = \frac{1}{5}\begin{pmatrix} 3 \\ 0 \\ 4 \end{pmatrix} = \frac{2\sqrt{2}}{5}|\phi_1\rangle + \frac{3}{5}|\phi_2\rangle + \frac{2\sqrt{2}}{5}|\phi_3\rangle,$$

- Page 196, replace Eq. (3.221) by

$$|\psi(t)\rangle = \frac{2\sqrt{2}}{5}e^{-iE_1 t}|\phi_1\rangle + \frac{3}{5}e^{-iE_2 t}|\phi_2\rangle + \frac{2\sqrt{2}}{5}e^{-iE_3 t}|\phi_3\rangle = \frac{1}{5}\begin{pmatrix} 3e^{-3it} \\ -4i\sin 5t \\ 4\cos 5t \end{pmatrix}.$$

- Page 197, replace Eq. (3.222) by

$$\begin{aligned} E(0) = \langle\psi(0)|\hat{H}|\psi(0)\rangle &= \frac{8}{25}\langle\phi_1|\hat{H}|\phi_1\rangle + \frac{9}{25}\langle\phi_2|\hat{H}|\phi_2\rangle + \frac{8}{25}\langle\phi_3|\hat{H}|\phi_3\rangle \\ &= \frac{8}{25}(-5) + \frac{9}{25}(3) + \frac{8}{25}(5) = \frac{27}{25}. \end{aligned}$$

- Page 197, replace Eq. (3.225) by

$$\begin{aligned} E(t) = \langle\psi(t)|\hat{H}|\psi(t)\rangle &= \frac{8}{25}e^{iE_1 t}e^{-iE_1 t}\langle\phi_1|\hat{H}|\phi_1\rangle + \frac{9}{25}e^{iE_2 t}e^{-iE_2 t}\langle\phi_2|\hat{H}|\phi_2\rangle \\ &+ \frac{8}{25}e^{iE_3 t}e^{-iE_3 t}\langle\phi_3|\hat{H}|\phi_3\rangle = \frac{8}{25}(-5) + \frac{9}{25}(3) + \frac{8}{25}(5) = \frac{27}{25} = E(0). \end{aligned}$$

- Page 198, Problem 3.14, in the first line of part(a) solution, replace $d\langle\hat{P}\rangle/dt = i\langle[\hat{P}, \hat{V}(x,t)]\rangle/i\hbar$ by $d\langle\hat{P}\rangle/dt = \langle[\hat{P}, \hat{V}(x,t)]\rangle/i\hbar$.
- Page 198, replace Eq. (3.233) by

$$\langle\hat{X}\rangle(t) = \frac{p_0}{m}t + x_0.$$

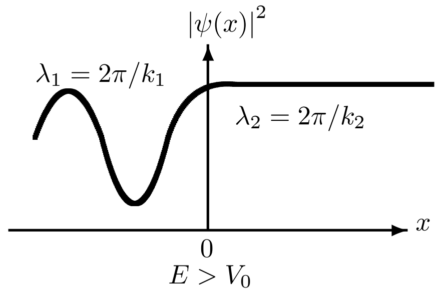
- Page 201, replace the equations of Exercise 3.7 by

$$\langle\phi_1|\psi_i\rangle = \frac{i}{\sqrt{3}}, \quad \langle\phi_2|\psi_i\rangle = \sqrt{\frac{2}{3}}, \quad \langle\phi_3|\psi_i\rangle = 0.$$

$$\langle\phi_1|\psi_f\rangle = \frac{1+i}{\sqrt{3}}, \quad \langle\phi_2|\psi_f\rangle = \frac{1}{\sqrt{6}}, \quad \langle\phi_3|\psi_f\rangle = \frac{1}{\sqrt{6}}.$$

Chapter 4

- Page 209, third line below Eq. (4.8), replace $E_\pm = \hbar k^2/2m$ by $E_\pm = \hbar^2 k^2/2m$.
- Page 211, replace the left lower plot of Fig. 4.2 by the following figure

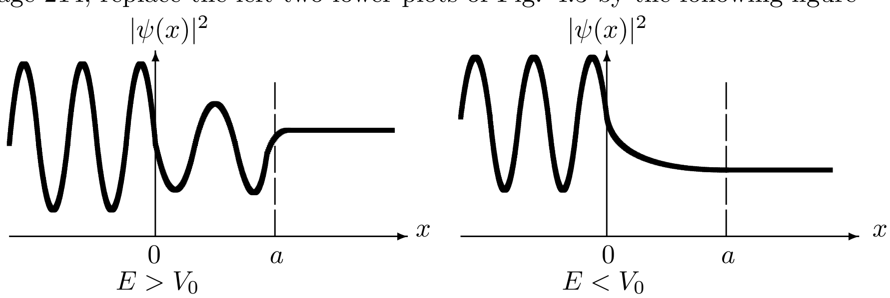


because the probability density $|\psi(x)|^2$ shown in the lower left plot of (Figure 4.2) must be a straight line for $x > 0$, since $|\psi_2(x)|^2 = |C \exp i(k_2 x)|^2 = |C|^2$.

- Page 213, replace $x < a$ in Eq. (4.35) by $x > a$, so that Eq. (4.35) should now read

$$V(x) = \begin{cases} 0 & x < 0 \\ V_0 & 0 \leq x \leq a \\ 0 & x > a. \end{cases}$$

- Page 214, replace the left two lower plots of Fig. 4.3 by the following figure



because the probability density $|\psi(x)|^2$ shown in the lower plots of (Figure 4.3) must be straight lines for $x > a$, since $|\psi_3(x)|^2 = |E \exp i(k_1 x)|^2 = |E|^2$.

- Page 232, replace Eq. (4.149) by

$$\langle x \mid 2 \rangle = \frac{1}{\sqrt{2!}} \langle x | \left(a^\dagger\right)^2 \mid 0 \rangle = \frac{1}{\sqrt{2!}} \left(\frac{1}{\sqrt{2} x_0} \right)^2 \left(x - x_0^2 \frac{d}{dx} \right)^2 \psi_0(x),$$

- Page 233, replace Eq. (4.153) by

$$e^{-x^2/2} \left(x - \frac{d}{dx} \right) e^{x^2/2} = -\frac{d}{dx}, \quad \text{or} \quad e^{-x^2/2x_0^2} \left(x - x_0^2 \frac{d}{dx} \right) e^{x^2/2x_0^2} = -x_0^2 \frac{d}{dx},$$

- Page 235, Eq. (4.167), replace $\left(\hat{a}^2 + \hat{a}^{\dagger 2} - 2\hat{a}^\dagger \hat{a} + 1\right)$ by $\left(\hat{a}^2 + \hat{a}^{\dagger 2} - 2\hat{a}^\dagger \hat{a} - 1\right)$.

- Page 238, replace the final result of Eq. (4.180) by $7.66 \times 10^{-4}\,\text{fm}^{-3}$.
- Page 241, replace the line before last in Eq. (4.189)

$$\frac{a^2}{3} + \frac{1}{2n\pi} x^2 \sin^2\left(\frac{2n\pi x}{a}\right)\Big|_{x=0}^{x=a} + \frac{a}{n\pi}\int_0^a x \sin\left(\frac{2n\pi x}{a}\right) dx,$$

by

$$\frac{a^2}{3} - \frac{1}{2n\pi} x^2 \sin\left(\frac{2n\pi x}{a}\right)\Big|_{x=0}^{x=a} + \frac{1}{n\pi}\int_0^a x \sin\left(\frac{2n\pi x}{a}\right) dx.$$

- Page 241, replace Eq. (4.193) by

$$\frac{1}{T}\int_0^T x^2(t)\,dt = \frac{v^2}{T}\int_0^T t^2 dt = \frac{1}{3}v^2T^2 = \frac{a^2}{3}.$$

- Page 241, replace the line after Eq. (4.193) by: "where T is half of the period of the motion, with $a = vT$.".
- Pages 242-243, replace the energies in Eqs. (4.199), (4.200), (4.203) by: $E_1 = \frac{\pi^2\hbar^2}{2ma^2}$, $E_1' = \frac{\pi^2\hbar^2}{2m(4a)^2} = \frac{\pi^2\hbar^2}{32ma^2}$, and $E_2' = \frac{\pi^2\hbar^2}{8ma^2}$.
- Page 251, replace Eq. (4.251) by

$$-2kA\sinh\, ka - 2kA\cosh\, ka + (2A)\frac{2mV_0}{\hbar^2}\sinh\, ka = 0.$$

- Page 254, replace Eq. (4.270) by

$$v \sim \frac{\hbar c}{mc^2 a}c \sim \frac{200\,\text{MeV fm}}{0.5\,\text{MeV} \times 10^5\,\text{fm}}c \simeq 4 \times 10^{-3}c = 1.2 \times 10^6 \text{m s}^{-1}$$

- Page 255, replace the left-hand side of Eq. (4.275) by $\frac{\hat{P}^2}{2m} + \frac{1}{2}m\omega^2\hat{X}^2$
- Page 258, replace Eq. (4.293) by

$$n\pi - \frac{\pi}{2} < \frac{\sqrt{2mV_0}}{\hbar}a < n\pi + \frac{\pi}{2} \quad \Longrightarrow \quad \text{there are } n \text{ bound states}$$

- Page 266, Exercise 4.16, the expression of $\psi(x, 0)$, replace the second constant $\sqrt{\frac{3}{7a}}$ by $\sqrt{\frac{6}{7a}}$.

Chapter 5

- Page 274, third line after Eq. (5.47), remove the '0' from −5/2, −3/2, −1/2, 0, 1/2, 3/2, 5/2; that is, replace "−5/2, −3/2, −1/2, 0, 1/2, 3/2, 5/2" by "−5/2, −3/2, −1/2, 1/2, 3/2, 5/2".

- Page 287, before Eq. (5.127), replace $\langle l,\ m\rangle$ by $\mid l,\ m\rangle$
- Page 290, replace the expression of $P_3^1(\cos\theta)$ in Table 5.1 by $P_3^1(\cos\theta) = 3\sin\theta(5\cos^2\theta - 1)/2$.
- Page 291, replace Eq. (5.168) by

$$\frac{1}{\Theta_{ll}}\frac{\partial\Theta_{ll}(\theta)}{\partial\theta} = l\cot\theta.$$

- Page 292, first line of Eq. (5.135), replace "$>$" by "$\rangle$".
- Page 293, replace the expression of $Y_{2,\pm 2}(x,y,z)$ in Table 5.2 by $Y_{2,\pm 2}(x,y,z) = \sqrt{\frac{15}{32\pi}}\,\frac{x^2-y^2\pm 2ixy}{r^2}$.
- Page 295, replace "$\hat{L}_+Y_{30}$" by "$\hat{L}_-Y_{30}$" in Eqs. (5.195) and (5.197).
- Page 295, Problem 2.1 Part (b), replace $\Delta J_x\Delta J_y \ \geq\ (\hbar/2)\ |\langle\hat{J}_z\rangle| = \hbar/2m$ by $\Delta J_x\Delta J_y \ \geq\ (\hbar/2)\ |\langle\hat{J}_z\rangle| = \hbar^2 m/2$.
- Page 295, replace Eq. (5.200) by

$$\langle\hat{J}_y^2\rangle = \frac{1}{4}\langle(\hat{J}_+ - \hat{J}_-)^2\rangle = -\frac{1}{4}\langle\hat{J}_+^2 - \hat{J}_+\hat{J}_- - \hat{J}_-\hat{J}_+ + J_-^2\rangle.$$

- Page 297, replace Eq. (5.209) by

$$\hat{H}\psi(\theta,\varphi) = \frac{\hat{\vec{L}}^2}{2I}\psi(\theta,\varphi) = E\psi(\theta,\varphi).$$

- Page 298, between Eqs. (5.221) and (5.225), replace $\lambda = \pm\hbar/2$ by $\lambda = \pm 1$.
- Page 300, between Eqs. (5.233) and (5.239), replace $\lambda = \pm\hbar/2$ by $\lambda = \pm 1$.
- Page 300, replace Eqs. (5.243) and (5.244) by

$$\begin{aligned} |\lambda_+(t)\rangle &= e^{-iE_+t/\hbar}\cos\frac{1}{2}\theta\left|\frac{1}{2},\ \frac{1}{2}\right\rangle + e^{i(\varphi - E_-t/\hbar)}\sin\frac{1}{2}\theta\left|\frac{1}{2},\ -\frac{1}{2}\right\rangle, \\ |\lambda_-(t)\rangle &= -e^{-iE_+t/\hbar}\sin\frac{1}{2}\theta\left|\frac{1}{2},\ \frac{1}{2}\right\rangle + e^{i(\varphi - E_-t/\hbar)}\cos\frac{1}{2}\theta\left|\frac{1}{2},\ -\frac{1}{2}\right\rangle, \end{aligned}$$

  where $E_\pm$ are the energy eigenvalues corresponding to the spin-up and spin-down states, respectively.
- Page 304, last term of Eq. (5.271), replace "$\frac{2\sqrt{3}}{5}\hbar$" by "$\frac{2\sqrt{6}}{5}\hbar$".
- Page 305, first line from top, replace "$\langle 10|\hat{L}_+\mid 1,\ -1\rangle = \langle 11|\hat{L}_+\mid 10\rangle = \sqrt{2}$" by "$\langle 10|\hat{L}_+\mid 1,\ -1\rangle = \langle 11|\hat{L}_+\mid 10\rangle = \sqrt{2}\hbar$".

- Page 309, replace Eq. (5.308) by

$$P\left(\frac{\pi}{3},\frac{\pi}{2}\right)=\left[\frac{1}{4\sqrt{\pi}}\left(3\cos^2\frac{\pi}{3}-1\right)+0\right]^2(0.03)^2\sin\frac{\pi}{3}=9.7\times10^{-7}.$$

- Page 310, replace (c) including equation (5.316) at bottom of Page 310 by: Since the initial state $|\,\psi_0\rangle$ can be written in terms of the eigenvectors (5.316) as follows

$$|\,\psi_0\rangle=\begin{pmatrix}1\\0\\0\\0\end{pmatrix}=-\frac{\sqrt{3}}{2}\,|\,1\rangle+\frac{1}{2}\,|\,3\rangle,$$

the eigenfunction at a later time t is given by

$$\begin{aligned}|\,\psi(t)\rangle &= -\frac{\sqrt{3}}{2}\,|\,1\rangle e^{-iE_1t/\hbar}+\frac{1}{2}\,|\,3\rangle e^{-iE_3t/\hbar}\\ &= -\frac{\sqrt{3}}{4}\begin{pmatrix}-\sqrt{3}\\0\\1\\0\end{pmatrix}\exp\left[\frac{5i\varepsilon_0t}{2\hbar}\right]+\frac{1}{2\sqrt{12}}\begin{pmatrix}\sqrt{3}\\0\\3\\0\end{pmatrix}\exp\left[-\frac{3i\varepsilon_0t}{2\hbar}\right].\end{aligned}$$

Chapter 6

- Page 319, Eq. (6.19), replace $\Psi_{\vec{k}}(\vec{k},t)$ by $\Psi_{\vec{k}}(\vec{r},t)$
- Page 325, Eq. (6.52), replace $\psi_{nlm}(r,\theta,\psi)$ by $\psi_{nlm}(r,\theta,\varphi)$
- Page 327, replace Eq. (6.61) by

$$-\frac{\hbar^2}{2M}\frac{1}{r}\frac{d^2}{dr^2}\left(rR_{kl}(r)\right)+\frac{l(l+1)\hbar^2}{2Mr^2}R_{kl}(r)=E_kR_{kl}(r).$$

- Page 328, replace Eq. (6.65) by

$$j_l(\rho)\simeq\frac{2^l l!}{(2l+1)!}\rho^l,\qquad n_l(\rho)\simeq-\frac{(2l)!}{2^l l!}\rho^{-l-1}.$$

- Page 328, 3rd line above and 3rd line below "Remark", replace $E_k=\hbar k^2/(2M)$ by $E_k=\hbar^2k^2/(2M)$.
- Page 330, first line above and third line below Eq. (6.73), replace the arguments (k_2r) by (ik_2r).
- Page 330, replace Eq. (6.73) by

$$R_l(ik_2r)=B\left[j_l(ik_2r)\pm n_l(ik_2r)\right].$$

.

- Page 330, replace Eq. (6.76) by $-k_2 = k_1 \cot(k_1 a)$.
- Page 332, second line above Eq. (6.91), replace $r^{n'+2}$ by $r^{n'}$.
- Page 332, Eq. (6.95), replace r^{l+1} by r^l. That is, replace equation (6.95) by

$$\psi_{nlm}(r,\theta,\varphi) = R_{nl}(r)Y_{lm}(\theta,\varphi) = \frac{U_{nl}(r)}{r}Y_{lm}(\theta,\varphi) = r^l f(r)Y_{lm}(\theta,\varphi)e^{-M\omega r^2/2\hbar}.$$

- Page 336, remove the loose "t" at the beginning of the second line above Eq. (6.119).
- Page 338, second line from top, replace e^x by e^{2x}.
- Page 338, line after Eq. (6.136), replace $a_{N+1}, a_{N+2}, a_{N+3}, \ldots$ by $b_{N+1}, b_{N+2}, b_{N+3}, \ldots$.
- Page 338, line after Eq. (6.140), replace $a_0 = \hbar^2/(mue^2)$ by $a_0 = \hbar^2/(\mu e^2)$.
- Page 340, line after Eq. (6.146), replace $\int_0^\infty x^n e^{ax}\,dx$ by $\int_0^\infty x^n e^{-ax}\,dx$.
- Page 340, last fraction term in Eq. (6.147), replace $\frac{a_0^2}{4}$ by $\frac{a_0^3}{4}$.
- Page 340, line after Eq. (6.148), replace $n = 2 - 0 - 1 = 1$ by $N = 2 - 0 - 1 = 1$.
- Page 340, replace Eq. (6.149) by

$$R_{20}(r) = A_{20}e^{-r/2a_0}\sum_{k=0}^{1} b_k r^k = A_{20}(b_0 + b_1 r)e^{-r/2a_0}.$$

- Page 344, fifth line from bottom of page 344, replace "sing-particle" by "single-particle".
- Page 345, second line from bottom of page 345, replace $|\psi_{nlm}(r,\ \theta,\ \psi)|^2\,d^3r$ by $|\psi_{nlm}(r,\ \theta,\ \varphi)|^2\,d^3r$
- Page 347, replace Eq. (6.182) by

$$g_n = \sum_{l=0}^{n-1}(2l+1) = \sum_{l=0}^{n-1} 1 \ + \ \sum_{l=0}^{n-1} l = n + n(n-1) = n^2.$$

- Page 349, line above Eq. (6.197), replace $\psi_{nlm}(r,\theta,\varphi) = R_{nl}(r)Y_{lm}(\theta,\ \psi)$ by $\psi_{nlm}(r,\theta,\varphi) = R_{nl}(r)Y_{lm}(\theta,\ \varphi)$.
- Page 351, first equation of Problem 6.1, replace "$0 < x < a,\ 0 < y < b$" by "$0 < x < a,\ 0 < y < a$"
- Page 351, part (b) of Problem 6.1, replace $\hbar\omega > 5\pi^2\hbar^2/(ma^2)$ by $\hbar\omega > 3\pi^2\hbar^2/(2ma^2)$.
- Page 351, part (b) of Problem 6.1, replace $\hbar\omega > 5\pi^2\hbar^2/(ma^2)$ by $\hbar\omega > 3\pi^2\hbar^2/(2ma^2)$.
- Pages 352 and 353, in Eqs. (6.204) and (6.209), replace $\frac{5\pi^2\hbar^2}{ma^2}$ by $\frac{5\pi^2\hbar^2}{2ma^2}$.
- Pages 352, 2nd line below Eq. (6.204), replace $\hbar\omega > 5\pi^2\hbar^2/(ma^2)$ by $\hbar\omega > 3\pi^2\hbar^2/(2ma^2)$.
- Page 353, Eq. (6.209), replace $\frac{3\hbar\omega}{2}$ by $\frac{\hbar\omega}{2}$.

- Page 353, line line below Eq. (6.211), replace $E_n = \mu e^4/(2\hbar^2 n^2)$ by $E_n = -\mu e^4/(2\hbar^2 n^2)$.
- Page 355, replace k^2 in Eq. (6.226) by 4.
- Page 356, replace Eq. (6.233) by

$$-\frac{\hbar^2}{2m}\left[\frac{d^2U_{nl}(r)}{dr^2} - \frac{l(l+1)}{r^2}U_{nl}(r)\right] = EU_{nl}(r),$$

- Page 359, replace r^3 by r^3 inside the first integral sign of Eq. (6.259).
- Page 361, line above Eq. (6.272), replace $U_{n0}(r)$, $U_{n0_1}(a) = U_{n0_2}(r)(a)$ by $U_{n0}(r)$, $U_{n0_1}(a) = U_{n0_2}(a)$.
- Page 361, replace Eq. (6.275) by

$$-k\sinh\, ka - k\cosh\, ka + \frac{2mV_0}{\hbar^2}\sinh\, ka = 0,$$

- Page 362, replace the term $(1/r)e^{-kr}$ in Eq. (6.283) by $(1/r)\sinh(ka)e^{-k(r-a)}$.
- Page 368, second line above Exercise 6.2, replace "$|n\langle$" by "$|n\rangle$"
- Page 370, Exercise 6.8, replace $0 \le x \le a, \quad 0 < y \le b$ by $0 < x < a, \quad 0 < y < b$.
- Page 371, second line above Exercise 6.13, replace "From (b), find the degeneracy infer the general expression for the degeneracy g_n" by "From (b), infer a general expression for the degeneracy g_n".

Chapter 7

- Page 387, replace Eq. (7. 116) by

$$\hat{\vec{J}}_2^2 \mid j_1, j_2;\ j,\ m\rangle = j_2(j_2+1)\hbar^2 \mid j_1, j_2;\ j,\ m\rangle$$

- Page 401 second line after Eq. (7.219), replace $\langle j_1, j_2;\ m_1, m_2, m_3 | j_{12},\ m_{12}\rangle$ by $\langle j_1, j_2;\ m_1, m_2 | j_{12},\ m_{12}\rangle$.
- Page 425, last term of Eq. (7.397), replace $\frac{\sqrt{2}}{6}$ by $\frac{2}{\sqrt{6}}$.

.

Chapter 8

- Page 444, replace Eq. (8.36) by

$$V(\vec{r}_1, \vec{r}_2, \vec{r}_3, \cdots, \vec{r}_Z) = -\sum_{i=1}^{Z}\frac{Z\ e^2}{|\vec{r}_i - \vec{R}|} + \sum_{i>j}\frac{e^2}{|\vec{r}_i - \vec{r}_j|}$$

- Page 458, replace the last term of Eq. (8.82) by $\frac{3\pi^2\hbar^2}{ma^2}$.
- Page 458, replace the last term of Eq. (8.84) by $\frac{9\pi^2\hbar^2}{2ma^2}$.

.

Chapter 9

- Page 479, replace $\vec{r}$ in Eq. (9.65) by $\vec{v}$. So Eq. (9.65) becomes

$$\vec{B} = -\frac{1}{c}\vec{v} \times \vec{E} = -\frac{1}{m_e c}\vec{p} \times \vec{E} = \frac{1}{m_e c}\vec{E} \times \vec{p},$$

- Page 482, replace $\hat{T} = \sqrt{\hat{p}^2 c^2 - m_e^2 c^4} - m_e c^2$ by $\hat{T} = \sqrt{\hat{p}^2 c^2 + m_e^2 c^4} - m_e c^2$. Then replace Eq. (9.82) by

$$\sqrt{\hat{p}^2 c^2 + m_e^2 c^4} - m_e c^2 \simeq \frac{\hat{p}^2}{2m_e} - \frac{\hat{p}^4}{8m_e^3 c^2} + \cdots .$$

- Page 499, the exponential function is missing from Eq. (9.181). So, replace Eq. (9.181) by

$$\psi_{2_{WKB}}(x) = \frac{C_2'}{\sqrt{p(x)}} \exp\left[\frac{i}{\hbar}\int_x^{x_2} p(x')dx'\right] + \frac{C_2''}{\sqrt{p(x)}} \exp\left[-\frac{i}{\hbar}\int_x^{x_2} p(x')dx'\right], \quad x_1 < x < x_2;$$

.

Chapter 10

- Page 550, replace Eq. (10.3) by

$$\hat{U}(t, t_0) = e^{-i(t-t_0)\hat{H}/\hbar}.$$

- Page 563, replace in Eq. (10.77)

$$\psi_1'(x) = \sqrt{\frac{2}{a}} \sin\left(\frac{\pi x}{8a}\right) \qquad \text{by} \qquad \psi_1'(\mathrm{x}) = \sqrt{\frac{2}{8\mathrm{a}}} \sin\left(\frac{\pi \mathrm{x}}{8\mathrm{a}}\right)$$

- Page 581, second term of Eq. (10.195), replace ">" by "$\rangle$". So, Eq. (10.195) becomes

$$P_{1\to 2} = \frac{1}{\hbar^2}\left|\int_0^{+\infty} \langle\psi_2|\hat{V}(t)|\psi_1\rangle e^{i\omega_{21}t} dt\right|^2,$$

Chapter 11

- Page 612, replace the first line of Eq. (11.101) by

$$\sigma = \int \frac{d\sigma}{d\Omega} d\Omega = \int_0^{\pi} |f(\theta)|^2 \sin\theta \, d\theta \int_0^{2\pi} d\varphi = 2\pi \int_0^{\pi} |f(\theta)|^2 \sin\theta \, d\theta$$

Appendix A

- Page 629, replace Eq. (A.8) by

$$\frac{1}{2\pi}\int_{-\infty}^{+\infty} e^{ikx}dk = \frac{1}{2\pi}\lim_{\epsilon\to 0}\int_{-1/\epsilon}^{+1/\epsilon} e^{ikx}dk = \lim_{\epsilon\to 0}\frac{\sin(x/\epsilon)}{\pi x} = \delta(x).$$

- Page 631, replace Eq. (A.24) by

$$\delta(\vec{r}-\vec{r}\,') = \frac{1}{r^2\sin\theta}\delta(r-r')\delta(\theta-\theta')\delta(\varphi-\varphi').$$

Appendix B

- Page 633, replace Eq. (B.6) by

$$dy = \sin\theta\sin\varphi\, dr + r\cos\theta\sin\varphi\, d\theta + r\sin\theta\cos\varphi\, d\varphi.$$

- Page 634, replace Eq. (B.16) by

$$\frac{\partial}{\partial z} = \frac{\partial}{\partial r}\frac{\partial r}{\partial z} + \frac{\partial}{\partial \theta}\frac{\partial \theta}{\partial z} + \frac{\partial}{\partial \varphi}\frac{\partial \varphi}{\partial z} = \cos\theta\frac{\partial}{\partial r} - \frac{\sin\theta}{r}\frac{\partial}{\partial\theta}.$$

- Page 635, replace Eq. (B.29) by

$$\hat{L}_- = \hat{L}_x - i\hat{L}_y = -\hbar e^{-i\varphi}\left(\frac{\partial}{\partial\theta} - i\cot\theta\frac{\partial}{\partial\varphi}\right).$$