Principles of Laser Spectroscopy and Quantum Optics

Errata (as of 6/8/23)

1. On page 5, in Eq. (1.3), the exponent should be $-12$ instead of $-7$.

2. On page 11 in the first line of Eq. (1.28) the derivative of $A(R,t)$ should be a total rather than partial derivative.

3. In problem 1.11 on page 14, there is a factor of $1/m$ missing in the equation for $\gamma_2$ and a factor of $2/3$ missing in the equation for $\gamma_2/\omega$.

$$\gamma_2 = \frac{1}{4\pi e_0^2} \frac{2 e^2 \omega^2}{3 m^2 c^2}$$

$$\frac{\gamma_2}{\omega} = \frac{2}{3} \frac{\alpha_F S}{\hbar \omega}$$

4. On page 15, the reference to the book of S. Mukamel has some typos. The correct title is *Principles of Nonlinear Optical Spectroscopy* and the publication date is 1995, not 1955!

5. In the third line of Eq. (2.25) on page 20, replace $\psi_n(r)$ by $\psi_n^*(r)$.

6. In Eq. (2.31) on page 21, a factor $|n\rangle$ should be inside the summation.

7. On page 27 in Eq. (2.68) replace $\frac{d}{dt}$ by $\frac{d}{dt}$.

8. There is a tilde missing on the first $c$ in Eq. (2.96) on page 33. The correct equation is

$$a(t) = e^{i \omega \sigma_z t/2} \tilde{c}(t) = e^{i \omega \sigma_z t/2} c(t)$$

9. On page 46, in Eq. (2.171) the sign in the exponent should be negative.

10. On page 49, the + sign in Eq. (2.187) should be changed to $-$. 

11. On page 63, Eq. (3.45d), there is a missing factor of $i$ in the first term on the right hand side of the equation.

12. The state vector in problem 3.10 on page 81 should be

$$|\psi(t)\rangle = \sin (\theta/2) |\tilde{1}(t)\rangle + \cos (\theta/2) e^{-i\delta} |\tilde{2}(t)\rangle$$

13. On page 96, in Eqs. (4.59) and (4.60) there should be tildes on $\varphi_{12}$ and $\varphi_{21}$.

14. In Eq. (5.23) on page 104 the factor should be $(\gamma + i\delta)$ instead of $(\gamma - i\delta)$ and there should be no $v$ argument in Eq. (5.26).
15. In Eq. (5.38a) on page 106 and in Eq. (5.9a) on page 101 the last term should have $\theta_{22}$ instead of $\theta_{11}$.

16. The units for the Wigner function are $(\text{volume})^{-1}(\text{momentum})^{-3}$ or $\hbar^{-3}$ and not $(\text{volume})^{-3/2}(\text{momentum})^{-3/2}$ as stated incorrectly on page 113.

17. Following Eq. (5.87) we should have defined

$$O_{\alpha\alpha'}(\mathbf{R}, \mathbf{P}) = \int \Psi_\alpha^*(\mathbf{r}) \hat{O}(\mathbf{r}, \mathbf{R}, \mathbf{P}) \Psi_{\alpha'}(\mathbf{r}) d\mathbf{r}$$

and there should be a $^\wedge$ on the operator $\hat{O}$ in the integrand of Eq. (5.86). Equation (5.87) can be proved for a broad class of operators that can be expanded as Fourier transforms in coordinate and momentum space (that is, the condition that the operator be a symmetric function of $\mathbf{R}$ and $\mathbf{P}$ is sufficient, but not necessary) [for a proof, see the article DISTRIBUTION FUNCTIONS IN PHYSICS: FUNDAMENTALS by M. Hillery, R.F. O’Connell, M.O. Scully and E.P. Wigner in PHYSICS REPORTS (Review Section of Physics Letters) Vol. 106, No. 3 (1984) pps. 121—167, Sec. 2.2].

18. On page 117 in problem 5.18, $\psi_1(x)$ is not normalized. The normalized wave function is

$$\psi_1(x) = \left( \frac{2}{\pi a^2} \right)^{1/4} e^{ip_0 x/\hbar} e^{-x^2/a^2}$$

19. On page 118 in problem 21, the equation to be proved should have a factor of $i\hbar$ on the left hand side of the equation or no factor of $i\hbar$ on the right hand side.

20. On page 123, in the second line of Eq. (6.16), the final exponential should be inside the brackets. The correct second line is

$$= \mathcal{N} \left[ \mu_{21} \langle \hat{v}_{12}(Z, t) \rangle e^{-i(kZ-\omega t)} + \mu_{12} \langle \hat{v}_{21}(Z, t) \rangle e^{i(kZ-\omega t)} \right]$$

21. On page 124, in Eq. (6.19d), replace $P(Z, \omega)$ with $\hat{P}(Z, \omega)$.

22. On page 124, replace Eq. (6.21) by

$$\frac{\partial^2 \mathbf{E}^+(Z, t)}{\partial Z^2} - \frac{1}{c^2} \frac{\partial^2 \mathbf{E}^+(Z, t)}{\partial t^2} = \frac{1}{c^2 \epsilon_0} \frac{\partial^2 \mathbf{P}^+(Z, t)}{\partial t^2}$$  \hspace{1cm} (6.21)$$

23. On page 125, in the line after Eq. (6.24), replace (6.19b) by (6.19c).

24. On pages 132-133, there are several errors. The last term of the second line of Eq. (133) is missing a factor of $1/c^2$. In Eq. (6.56a) the first sign should be positive and the last line negative, and a term

$$- \frac{1}{2k\epsilon^2} \left[ \frac{\partial \phi(Z, t)}{\partial t} \right]^2$$
should be added in the brackets on the left hand side of the equation. In Eqs. (6.57a) and (6.59a) the first signs should be positive. In Eqs. (6.60a) and (6.62) the sign before \( \alpha_i \) should be negative. For convenience, the correct equations are listed below.

\[
\begin{align*}
- k \frac{\partial \phi(Z, t)}{\partial Z} |E(Z, t)| + i \left[ k + \frac{\partial \phi(Z, t)}{\partial Z} \right] \frac{\partial |E(Z, t)|}{\partial Z} - \frac{|E(Z, t)|}{2} \left( \frac{\partial \phi(Z, t)}{\partial Z} \right)^2 \\
+ \frac{k}{c} \frac{\partial \phi(Z, t)}{\partial t} |E(Z, t)| + \frac{i}{c} \left[ k - \frac{1}{c} \frac{\partial \phi(Z, t)}{\partial t} \right] \frac{\partial |E(Z, t)|}{\partial t} + \frac{|E(Z, t)|}{2c^2} \left( \frac{\partial \phi(Z, t)}{\partial t} \right)^2 \\
= - \frac{Nk^2(\mu_x)_{12}}{\epsilon_0} \left[ (u(Z, t) - i\langle v(Z, t) \rangle) - \frac{2ikNk^2(\mu_x)_{12}}{\epsilon_0 c} \frac{\partial [(u(Z, t) - i\langle v(Z, t) \rangle)]}{\partial Z} \right].
\end{align*}
\]

(6.55)

\[
\begin{align*}
\left[ \frac{1}{2k} \left( \frac{\partial \phi(Z, t)}{\partial Z} \right)^2 - \frac{1}{2kc^2} \left( \frac{\partial \phi(Z, t)}{\partial t} \right)^2 + \frac{\partial \phi(Z, t)}{\partial Z} - \frac{1}{c} \frac{\partial \phi(Z, t)}{\partial t} \right] |E(Z, t)| = \frac{Nk(\mu_x)_{12}}{\epsilon_0} \langle u(Z, t) \rangle \\
+ \frac{2N(\mu_x)_{12}}{\epsilon_0 c} \frac{\partial \langle v(Z, t) \rangle}{\partial t},
\end{align*}
\]

(6.56a)

\[
\begin{align*}
\beta^2 + \beta = \frac{N(\mu_x)_{12}}{2\epsilon_0} u(Z) = \frac{N(\mu_x)_{12}}{2\epsilon_0} \frac{\delta}{\gamma^2 + \delta^2} = - \frac{\alpha_i}{2k} \\
\beta = -1 + \sqrt{1 - \alpha_i/k}; \\
\beta = 1 + \sqrt{1 - \alpha_i/k}.
\end{align*}
\]

(6.59a)

(6.60a)

25. On page 135, replace \( \bar{\lambda} = 2\pi/\omega \) by \( \bar{\lambda} = c/\omega \) in the line after the equation for \( n(\omega) \).

26. A diagram is missing in the grating term in Fig. 7.1, in which \( \chi_1 \) acts first to produce \( \theta_{21} \), \( \chi_2 \) second to produce \( \theta_{22} \), and \( \chi_3 \) third to produce \( \theta_{12} \). The correct figure is shown in Fig. 1. For more details, see the Supplementary Notes on Field-Ordering in Chapter 7.

27. On page 138 in Eq. (7.4b) the minus sign in front of the sum should be deleted.

28. On page 139, in the line following Eq. (7.10), replace "is equal to the collision rate \( \Gamma \)" by "is equal to twice the collision rate, \( 2\Gamma \).

29. On page 141, in Eq. (7.22) replace the bracketed term by

\[
\left[ \frac{\chi_1 \chi_2 e^{-i(k_{12}R+\delta_{12}t)}}{(\gamma + i\delta_2)(\gamma - i\delta_1)} + \frac{\chi_2 \chi_1 e^{i(k_{12}R+\delta_{12}t)}}{(\gamma + i\delta_1)(\gamma - i\delta_2)} \right];
\]

that is, the signs in the denominators should be reversed.
Figure 1: Corrected Fig. 7.1. The saturation terms correspond to the $\mu = 1, \nu = 1, \sigma = 2$ term in Table 7.1 and the grating terms to the $\mu = 2, \nu = 1, \sigma = 1$ term in Table 7.1.
30. On page 148 in Eq. (7.46), the limits of integration are not indicated. They should be $-\infty$ to $\infty$.

31. On page 148, in the first paragraph of Sec. 7.3.2.1, replace the next to last sentence by "The second field interacts with these atoms only if $|kv_z + \delta| \lesssim \gamma$, or $|2\delta| \lesssim 2\gamma$.

32. On page 152, in Eq. (7.62e) change $c_{22}$ to $b_{22}$.

33. On page 155, in Eq. (7.72a) change $-\alpha_s^{(1)}$ to $+\alpha_s^{(1)}$.

34. On page 155 in the 4th line of the second paragraph the correct values are $(\mu, \nu, \sigma) = (2,3,1)$.

35. On page 155, in the 10th line of problem 7.3, replace $(\Delta = -\delta_1)$ by $(\Delta = \delta_1)$. As defined in the problem, $\Delta = -\delta_2 + \delta_1$ so if $\delta_2 = 0$, then $\Delta = \delta_1$.

36. On page 156, in problem 7.7-8, replace $\delta < 0$ by $\delta > 0$.

37. On page 160, in Fig. 8.1, for the $\Lambda$ scheme, it should be $\beta = 1$, $\beta' = -1$.

38. On page 170, in Eq. (8.45), replace $\eta kv_z$ by $\eta k' v_z$.

39. On page 173, in Eq. (8.59) $\tilde{g}_{21}(0)$ should be $\tilde{g}_{21}^{(0)}$. Also following Eq. (8.60), the sentence should start, "The $\Omega$ separation....."

40. On page 175, in Eq. (8.69), the first factor should be $\sin^2 \theta / \cos^2 \theta$ instead of $\cos^2 \theta / \sin^2 \theta$.

41. On Page 177, in each of Eqs. 8.78, the sign before the summation symbol should be $+$ rather than $-$.

42. On page 180, problem 8.6, the relaxation constants given are those for the cascade system. For the $\Lambda$ system, take $\gamma_3 = 0$, $\gamma_2,3 = \gamma_2,1 = 1/2$. Only if $\gamma_3 = 0$ and there are no collisions does the absorption vanish identically for the $\Lambda$ system at $\delta' = \delta$.

43. On page 180, problem 8.8, replace $\delta' = \delta$ by $\omega' = \omega$ and $k = -k' = -k\bar{z}$. In this problem the Doppler limit is for two-photon transitions from a single field, namely $2k u \gg \gamma$.

44. On page 181, problem 8.10, $\chi' \equiv \left[\chi'_{\beta=1}\right]$ for the $V$ scheme and $\chi' \equiv \left[\chi'_{\beta=-1}\right]^*$ for the $\Lambda$ scheme. In other words, the third sentence in problem 10 can be replaced by "Draw perturbation chains similar to those in Fig. 8.2 that lead to a contribution to probe absorption $\tilde{g}_{32}$ that is of order $|\chi|^2 \chi'_{\beta=1}$ for the $V$ scheme and $|\chi|^2 \left[\chi'_{\beta=-1}\right]$ for the $\Lambda$ scheme."
45. On page 185, replace Eq. (9.5) by

\[ |D(t)| = \frac{\chi' |\hat{I}(t)| - \chi |\hat{3}(t)|}{\sqrt{\chi'^2 + \chi^2}} , \]  

(9.5)

46. On page 186, in Eq. (9.12), in the first line, the derivatives refer only to the contribution from relaxation terms.

47. Corrections in Chap. 9

Equations (9.25) and (9.26) should be replaced by

\[ \alpha = \alpha_0^{21} \frac{\gamma_{12}^2 \delta^2}{(\chi'^2 - \delta^2)^2 + (\gamma_{12} \delta)^2} \]  

(9.25)

and

\[ n = 1 + \frac{\alpha_0^{21}}{2k} \frac{\gamma_{12} \delta (\delta^2 - \chi'^2)}{(\chi'^2 - \delta^2)^2 + (\gamma_{12} \delta)^2} \]  

(9.26)

where

\[ \alpha_0^{21} = \frac{\gamma_{2,1}}{\gamma_2} = \frac{3\lambda^2 N \gamma_{2,1}}{\gamma_{12}} \]

and \( \lambda \) is the probe field wavelength. The quantity \( \alpha_0 \) should be replaced by \( \alpha_0^{21} \) in section 9.5 and in Fig. 9.4. Also in Fig. 9.4, the \( x \)-axis label should be \(-\delta/\gamma_{12}\). Finally, Eqs. (9.30)-(9.31) should be replaced by

\[ \left( \frac{\partial}{\partial \zeta} + \frac{1}{c} \frac{\partial}{\partial t} \right) \chi = -i \kappa \tilde{\rho}_{21} ; \]  

(9.30a)

\[ \left( \frac{\partial}{\partial \zeta} + \frac{1}{c} \frac{\partial}{\partial t} \right) \chi' = -i \kappa' \tilde{\rho}_{23} ; \]  

(9.30b)

\[ \eta = 3\lambda^2 N \gamma_{2,1} / 8\pi ; \quad \eta' = 3\lambda^2 N \gamma_{2,3} / 8\pi . \]  

(9.31)

48. On page 198, in the last paragraph before section 9.5, the equation referred to should be (9.44b) rather than (9.44c).

49. On page 199, in the second paragraph, replace (9.46) by (9.47).

50. In Problem 9.4 on page 201, it is not stated explicitly, but you must take \( \Gamma_{13} = 0 \). In this way the steady-state is a dark state.

51. In Problem 9.9 on page 201, replace the equations by

\[ \dot{\vartheta}_{11} \approx -i \left( \frac{\chi' \chi}{\delta} \vartheta_{13} - \frac{\chi \chi'}{\delta} \vartheta_{31} \right) \]

\[ \dot{\vartheta}_{13} = i (\delta - \delta') \vartheta_{13} + i \left( \left| \chi \right|^2 - \frac{|\chi'|^2}{\delta} \right) \vartheta_{13} + i \left( \frac{\chi \chi'}{\delta} \vartheta_{33} - \frac{\chi \chi'}{\delta} \vartheta_{11} \right) \]

\[ \vartheta_{33} \approx 1 - \vartheta_{11} . \]
52. In Problem 9.12 on page 202, a subscript \( w \) is missing in the definition of \( W(\Delta) \). The correct distribution for \( W(\Delta) \) is

\[
W(\Delta) \approx \begin{cases} 
0 & -\Delta_0 \leq \Delta \leq \Delta_0 \\
\frac{1}{\Delta w} & -\Delta_w \leq \Delta \leq -\Delta_0 \\
\frac{1}{\Delta w} & \Delta_0 \leq \Delta \leq \Delta_w
\end{cases}
\]

Note that this is not normalized, since a hole has been burned in the distribution.

53. In Eq. (10.8) on page 208, the subscript \( j \) is missing on the \( T \)'s in the \( 1-3 \) and \( 2-3 \) matrix elements.

54. On pages 210-213, replace \( \gamma_2 \) by \( \gamma_{2,1} \) in Eqs. (10.17), (10.22), and (10.28).

55. In Eq. (10.43) on page 221, replace \( e^{-\gamma_2 T} \) by \( G(T) \).

56. On page 232 section 10.2.2 is referred to twice in the third paragraph. The correct section is 10.5.

57. In problem 6 on page 235, replace "section 10.2.1" by "section 10.4" .

58. In problem 10.12 on page 237, both signals are in the \( k_1 - 2k_2 \approx -k_1 \) direction.

59. On page 281 replace the first line of Eq. (12.6) by

\[
H = \epsilon_0 \sum_{j,j'} \int d^3R E_j E_{j'} \epsilon_j \epsilon_{j'} \left[ a_j e^{ik_j \cdot R} - a_j^{\dagger} e^{-ik_j \cdot R} \right] \left[ a_{j'} e^{-ik_{j'} \cdot R} - a_{j'}^{\dagger} e^{ik_{j'} \cdot R} \right]
\]

60. In Eq. (12.32) on page 285, change \( e^{-i\omega_{ij} t} \) to \( e^{i\omega_{ij} t} \).

61. In Eq. (12.34) on page 285, add a factor \( \frac{1}{(2\pi)^{3/2}} \) inside the absolute value symbols - that is, this factor multiplies the integral inside the absolute value symbols.

62. On page 286, Eqs. (12.36) are in error, as is some of the discussion in the
paragraph following these equations. It should be replaced by

\[ (E) = 0; \]  
\[ \langle E \cdot E \rangle = \left( \frac{\hbar \omega}{2 \epsilon_0 V} \right) (a^\dagger a + a^\dagger a) = \frac{\hbar \omega}{2 \epsilon_0 V} (2n + 1); \]  
\[ \langle (E \cdot E)^2 \rangle = \left( \frac{\hbar \omega}{2 \epsilon_0 V} \right)^2 \left\{ a^\dagger a^2 + a^2 a^\dagger + a^\dagger a^\dagger a + aa^\dagger a + aa^\dagger a + a^\dagger a^\dagger a \right\} 
= \left( \frac{\hbar \omega}{2 \epsilon_0 V} \right)^2 (6n^2 + 6n + 3); \]  
\[ \Delta (E \cdot E) = \frac{\hbar \omega}{2 \epsilon_0 V} \sqrt{2(n^2 + n + 1)}; \]  
\[ \frac{\Delta (E \cdot E)}{(E \cdot E)} = \frac{1}{\sqrt{2}} \sqrt{1 + \frac{3}{(2n + 1)^2}} \]  

where \( \Delta \) represents the standard deviation. The fact that \( (E) = 0 \) is related to an uncertainty in the phase of the field. Phase is discussed below, but for now we note that a pure \( n \) state has a phase that can be considered to be totally random. In some sense, the pure \( n \) state is similar to a field having having amplitude \( E_0 = \left[ \frac{\hbar \omega}{2 \epsilon_0 V} \right]^{1/2} \sqrt{(2n + 1)} \) and random phase \( \phi \), such that \( E = E_0 \cos(kZ - \Omega t + \phi) \), \( (E) = 0 \), \( (E^2) = E_0^2/2 = \left[ \frac{\hbar \omega}{2 \epsilon_0 V} \right] (2n + 1) \), \( (E^2) = 3E_0^4/8 = \left[ \frac{\hbar \omega}{2 \epsilon_0 V} \right]^2 (6n^2 + 6n + 3/2) \). The value of \( (E^2) \) was chosen to agree with the quantum result. With this choice, the value of \( (E^4) \) agrees with the quantum result for large \( n \).

63. In Eq. (12.43) on page 287, the second exponential should be \( e^{-i kR + \omega t} \).

64. On page 292 in Eq. (12.76) delete the \( i \).

65. On page 292 the unnumbered equation after Eq. (12.80) should be \( \Delta a_1 \Delta a_2 \geq 1/4 \).

66. On page 294, in Fig. 12.1 (b), the last distribution should be shifted as well as squeezed. Using Eq. (12.102) you can calculate the effect of the squeeze operator on a coherent state. For example, if \( \theta = 0 \), \( \mu \) and \( \nu \) are real and

\[ \langle z, \alpha|a_1|z, \alpha \rangle = \langle \alpha|U_L^\dagger(z) a_1 U_L(z)|\alpha \rangle = e^{-\tau} a_1 \]
\[ \langle z, \alpha|a_2|z, \alpha \rangle = \langle \alpha|U_L^\dagger(z) a_2 U_L(z)|\alpha \rangle = e^{\tau} a_2. \]

The center of the distribution is shifted as well as squeezed.

67. On page 296, following Eq. (12.108b), and on page 309, in Problem 4, the second \( \Delta A_1 \) should be \( \Delta A_2 \).

68. In Eqs. (12.126) on page 298, the \( a \)'s on the right hand side of the equations should be \( \alpha \)'s.
69. In problem 3 on page 336, in the last line of the problem replace "problem 1" by "problem 2".

70. In problem 5 on page 337, replace $e^{-t^2/2}$ by $e^{-t^2/2T^2}$.

71. On page 340, in Eq. (14.1) replace $P_1(t, \delta \tau)$ with $P_1(t + \tau, \delta \tau)$.

72. On page 341, following Eq. (14.9) replace $\hat{P}_m(t, 0) = 1$ with $\hat{P}_m(t, 0) = \delta_{m, 0}$.

73. In Sec. 14.1.2, it is assumed implicitly that $\xi \ll 1$, consistent with the assumption that the measurement process has a negligible back action on the fields.

74. On page 345 in Eq. (14.44), replace $e^{-\xi m}$ by $e^{-\xi \bar{n}}$.

75. There are some inconsistencies in Sec. 14.2. On page 347 the distances $d_1$ and $d_2$ in Fig. 14.1 and in the sentence following Eq. (14.51) should be replaced by $d_1/2$ and $d_2/2$, respectively. Equation (14.61) should be replaced by

$$\phi_r = \frac{\phi}{2} = k \Delta d.$$  \hspace{1cm} (14.61)

Thus the phase $\phi$ that appears in all subsequent equations actually corresponds to twice the optical path difference for the two arms of the interferometer. That is, a value of $\phi = \pi/2$ actually corresponds to an optical path difference of $\pi/4$, for which the signals in the $C$ and $D$ detectors are equal for a field incident from port $A$.

76. On page 349, the $|\psi_A(R)|^2$ factor should be deleted. The spatial factor appears only in the expressions for the fields.

77. On page 353, the last two signs in Eq. (14.91) should be $+$. 

78. On page 354, in the line after Eq. (14.93) the factor of 2 should be replaced by $1/2$.

79. In Eq. 15.16 on page 360, there should be no factor of $i\hbar$.

80. The first term on the right hand side of Eq. (15.20) on page 361 should be

$$\sum_{\alpha=1}^{N} \left[ TP_\alpha T^\dagger + eA(0) \right]^2$$

which, following Eq. (15.22) is equal to

$$\sum_{\alpha=1}^{N} \frac{p_\alpha^2}{2m}.$$ 

81. On page 365 in the second paragraph, second line, replace $g_n = g\alpha^2$ by $g_n = g\alpha$ and $\chi = 2ag$ by $\chi = a g$. 

9
82. On page 366, we require only that \( \sin^2 \Phi \) not depend on \( n \). Therefore Eq. (15.49) should be replaced by

\[
t \approx t_r = 2(m\pi)\sqrt{n}/|g| = 2(m\pi)\alpha/|g|
\]  

(15.49)

and Fig. 15.3 actually corresponds to the second revival, \( m = 2 \). The first revival is centered near \( |g| t = 94 \).

83. On page 384, change \((\epsilon_0)^*\) to \((\epsilon_{-q})^*\) in the first line of Eq. (16.40).

84. On page 393, a factor of \( 1/8 \pi \) is missing from the third line of Eq. (16.79); the first \( 6 \) symbol in Eq. (16.81) should be a Clebsch-Gordan coefficient; a factor of 3 is missing from the first line and a factor of \( 3/8 \pi \) is missing from the third line of Eq. (16.81); the factor of \( 1/(2G + 1) \) should be removed from Eq. (16.83).

85. On page 395, a minus sign should be added to Eq. (16.91) and the first two lines of Eq. (16.92).

86. On page 398, the line before Eq. (16.110) should have \( \epsilon > dP \) and the line before Eq. (16.111) should have \( \epsilon < dP \).

87. In problem 16.11 on page 400, replace \(|\psi(0)\rangle\) by \(|\psi(0)\rangle\) and \(|\psi(t)\rangle\) by \(|\psi(t)\rangle\).

88. In deriving Eq. (17.9) we use the fact that

\[
\begin{bmatrix}
H & 1 & G \\
q & m_H & m_G
\end{bmatrix} = (-1)^{H-G+q} \sqrt{\frac{2G+1}{2H+1}} \begin{bmatrix}
G & 1 & H \\
m_G & -q & m_H
\end{bmatrix}
\]

and

\[
\langle G|\mu^{(1)}|H\rangle = (-1)^{H-G}\langle H|\mu^{(1)}|G\rangle^* .
\]

89. In Eq. (17.23b) on page 408, the last factor should be \((\frac{1}{2})\) \((\frac{1}{2})\) instead of \((\frac{1}{2})\) \((\frac{1}{2})\).

90. On page 410, Eq. (17.32 should be \( \epsilon_q^{(x)} = (\delta_{q,-1} - \delta_{q,1})/\sqrt{2} \).

91. On page 412ff. in Sec 17.1.4.1 it is assumed implicitly that the Doppler shifts are smaller than the excited state decay rates, such that \( \delta(\nu) \) is replaced by \( \delta \) in these equations. The result for parallel polarized fields is unchanged if this assumption is not made, but the explicit form of the results in Sec. 17.1.4.1.2 are valid only in this limit.

92. On page 412, the reasoning leading to Eqs. (17.51) and (17.52) is wrong, even though the equations are correct. The allowed values of \( \tilde{K} \) in Eq. (17.29) are 0,1,2. As a consequence these values are also allowed in Eq. (17.50). However, since only \( Q = 0 \) or 2 enters into the polarization, it turns out that \( \tilde{\phi}_0^1(G) \) is coupled only to \( \tilde{\phi}_0^0(G) \) and \( \tilde{\phi}_0^0(G) = 1/\sqrt{2} \) and \( \tilde{\phi}_1^0(G) \) is coupled only to \( \tilde{\phi}_1^1(G) \) and \( \tilde{\phi}_1^1(G) = 0 \). Thus if we start from an unpolarized initial state, \( \tilde{\phi}_1^1(G) = \tilde{\phi}_1^0(G) = 0 \).
93. On page 417 Eqs. (17.67a) and (17.67b) should be
\[ \epsilon_q^{(x)} = (\delta_{q,-1} - \delta_{q,1})/\sqrt{2} \]
and
\[ \epsilon_q^{(x)} = -i(\delta_{q,-1} + \delta_{q,1})/\sqrt{2}. \]

94. On page 418 Eqs. (17.69e), the coefficient in front of \( \delta_{K,1} \) should be \(-1\) instead of 1.

95. On page 420, Problem 1, in the first equation replace \( D_{Q' Q} \) by \( D_{Q Q'} \).

96. On page 433, the factor of 1/2 should be deleted from Eq. (18.56). Alternatively, Eqs. (18.57) and (18.59) could be multiplied by 2.

97. In Eq. (18.59) on page 433, the first factor of \( \sqrt{2} \) in the next to last line of the equation should be deleted.

98. In Eq. (19.8d) on page 455 there should be no \( a \) in the first term on the right hand side of the equation.

99. On page 456 in Eq. (19.15), factors of \( \alpha \) are missing from the last two terms in the equation and \( g_{21} \) should be changed to \( g_{11} \) in Eq. (19.17b).

100. On pages 464 and 465, in Eqs. (19.64) and (19.66) the \( R \)'s in the denominators should be replaced by \( |R - R_j| \). In the radiation zone, \( |R - R_j| \approx R \).

101. On page 468, in Eq. (19.79), \( e^{i k_j \cdot R} \) should be replaced by \( e^{i k_j \cdot R_j} \).

102. On page 469, in the equation above Eq. (19.80), \( \omega_s R / c \) should be replaced by \( \omega_s R / c \) and in Eq. (19.80), \( e^{i k \cdot R} \) should be replaced by \( e^{i k \cdot R} \).

103. On pages 469 and 470, the signs in Eqs. (19.84) and (19.85) should be +, and the sign of the second term in Eq. 19.87 should be minus.

104. On pages 496 and 497, before and after Eq. (21.21). This is a tricky point. The quantization procedure includes all \( k_j \) with \( \omega_j = |k_j| c \). In this problem, we are considering media for which the index of refraction is very close to unity, so we can neglect any reflected wave at the interface and take \( \omega_j = k_j c \) since all the \( k_j \) of interest are positive. Thus can take \( \omega_k = k c \) for both positive and negative \( k \) since the negative values of \( k \) contribute negligibly. Thus the phrase following Eq. (21.21), "and extended the \( k \) integral to \(-\infty \), since the major contributions from both \( k \) and \( k' \) are in the vicinity of \( k_0\)," can be replaced by "and set \( \omega_k = k c \) even for negative values of \( k \), since the major contributions from both \( k \) and \( k' \) are in the vicinity of \( k_0 \)."

105. On page 497, the lower limit of the last integral in Eq. (21.27) should be 0 rather than \(-ct\).