Atomic Physics. Exploration through problems and solutions

We would be greatly indebted to our readers for informing us of errors and misprints in the book by sending an e-mail to: budker@berkeley.edu. The Errata are listed at `http://socrates.berkeley.edu/~budker`. We will do our best to correct problems in subsequent printings of the book.

Here is a list of issues identified so far.

Comments and Errata

- Acknowledgements. Chih-Hao Li's name is misspelled, sorry.

- Problems 1.1 and 1.2. As kindly pointed to us by Prof. G. A. Brooker, we have overextended the applicability of the Hund's rules in these two problems. The rules, strictly speaking, are only good for determining the lowest-energy term of the ground-state configuration, and only when there is a single unfilled shell. This said, all final answers appear correct.

- Problem 3.1 Two-level system under periodic perturbation; **pp. 117-118**. Equation (3.16) should read

$$\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}}(|2\rangle - |1\rangle) \ ,$$

  while Eqs.(3.17-3.19) should read

$$\begin{aligned} b(t) &= \frac{1}{2}(-\langle 1| + \langle 2|)\big(e^{iV_0 t}|1\rangle + e^{-iV_0 t}|2\rangle\big) \\ &= \frac{1}{2}\big(-e^{iV_0 t} + e^{-iV_0 t}\big) \\ &= -i\sin(V_0 t) \ . \end{aligned}$$

- Problem 3.3 Emission of light by atoms; **pp. 135-137**. Complex conjugation was lost in going from the left- to the right-hand side of Eq. (3.105). The problem is fixed by replacing in Eqs. (3.105-3.109) $\epsilon_{-q} \to (-1)^q \epsilon_q$ (this is because $(\epsilon^*)_{-q} = (-1)^q \epsilon_q$). This substitution eliminates $(-1)^q$ in each of these equations (and switches $\epsilon_{-q} \to \epsilon_q$).

  In Eq. (3.112), the final summation should be over the values of M_J.

- Problem 3.9 Change in absorption due to optical pumping; **p. 157**. In the $1 \to 1$ case on Fig. 3.13, there should be no vertical squiggly line connecting the $M = 0$ sublevels because the corresponding Clebsch-Gordan coefficient is zero (see Problem 9.5).

- Problem 3.10 Optical pumping and density matrix; **p. 163**. Equation (3.215) should read:

$$\rho = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} . \tag{1.1}$$

Thanks to Andrew Dawes (Duke University) for pointing this out.

- Problem 4.5 Stark-induced transition; **pp. 203-207**. In Eqs. (4.61-4.64), the denominators $E_p - E_m$ should all be replaced with $E_m - E_p$ (the $E_n - E_p$ denominators are correct).

Equation (4.68) should read

$$T_q^\kappa = \sum_{q_1, q_2} \langle 1, q_1, 1, q_2 | \kappa, q \rangle \mathbb{E}_{q_1} \mathcal{E}_{q_2} .$$

The sentence following Eq. (4.68) should be eliminated.

There should be a comma at the end of Eq. (4.69), and a period at the end of Eq. (4.70).

Equation (4.72) should read

$$\boxed{T_0^0 = -\frac{1}{\sqrt{3}} \vec{\mathbb{E}} \cdot \vec{\mathcal{E}} .}$$

Additionally, "where a is a constant" should be eliminated.

Equation (4.75) should read

$$\boxed{T_q^1 = \frac{i}{\sqrt{2}} \left(\vec{\mathbb{E}} \times \vec{\mathcal{E}} \right)_q .}$$

Additionally, "where b is a constant" should be eliminated.

Equation (4.76) should read

$$\boxed{T_q^2 = \left(\mathbb{E}^1 \otimes \mathcal{E}^1 \right)_q^2 .}$$

Equation (4.82) should read

$$A_s = -\frac{1}{\sqrt{3}} \left(\vec{\mathbb{E}} \cdot \vec{\mathcal{E}} \right) \langle m | U_0^0 | n \rangle + \sum_q \frac{i}{\sqrt{2}} (-1)^q \left(\vec{\mathbb{E}} \times \vec{\mathcal{E}} \right)_q \langle m | U_{-q}^1 | n \rangle$$
$$+ \sum_q (-1)^q \left(\mathbb{E}^1 \otimes \mathcal{E}^1 \right)_q^2 \langle m | U_{-q}^2 | n \rangle .$$

Equations (4.83-4.84) and the discussion between them should read:

$$A_s = -\frac{1}{\sqrt{3}}\left(\vec{\mathbb{E}}\cdot\vec{\mathcal{E}}\right)\frac{\langle m, F'||U^0||n, F\rangle}{\sqrt{2F'+1}}\langle F, M, 0, 0|F', M'\rangle$$
$$+\frac{i}{\sqrt{2}}(-1)^{M-M'}\left(\vec{\mathbb{E}}\times\vec{\mathcal{E}}\right)_{q=M-M'}\frac{\langle m, F'||U^1||n, F\rangle}{\sqrt{2F'+1}}\langle F, M, 1, M'-M|F', M'\rangle$$
$$+(-1)^{M-M'}\left(\mathbb{E}^1\otimes\mathcal{E}^1\right)_{q=M-M'}^{\kappa=2}\frac{\langle m, F'||U^2||n, F\rangle}{\sqrt{2F'+1}}\langle F, M, 2, M'-M|F', M'\rangle \ .$$

In the literature [see, for example, Bouchiat and Bouchiat (1975); Drell and Commins (1985); Bowers *et al.* (1999); Bennett and Wieman (1999)], the Stark-induced amplitude is defined in terms of the real parameters α, β, and γ, known as the *scalar*, *vector*, and *tensor transition polarizabilities*, respectively. These parameters correspond to the three terms in the above expression. Unfortunately, there does not seem to be a universal convention on how to normalize these parameters. In cases where the γ term is zero (see part **(d)**), α characterizes the Stark-induced amplitude for collinear static electric field and light polarization, while β characterizes the amplitude when the light polarization is orthogonal to the static field. In the case of transitions between $s_{1/2}$ states (for example, the $6s_{1/2}\rightarrow 7s_{1/2}$ transition in Cs where parity-violation experiments have been carried out), the Stark-induced transition amplitude between states with total angular momenta F and F' can be conveniently written as

$$A_s = \alpha\,\vec{\mathbb{E}}\cdot\vec{\mathcal{E}}\,\delta_{F,F'}\delta_{M,M'} + i\beta\left(\vec{\mathbb{E}}\times\vec{\mathcal{E}}\right)\cdot\langle F'M'|\vec{\sigma}|FM\rangle \ ,$$

where σ is the Pauli spin operator.

- Problem 5.4 Basic concepts in spin exchange; **p. 239**. Following Eq. (5.29), the second of the two $V_t(r)$ should be $V_s(r)$.

- Problem 7.1 Amplitude of molecular vibrations; **p. 291**. The final formula in the second footnote should read

$$D_e - D_0 \approx \frac{\omega_e}{2} \ .$$

- Problem 7.4 Relative densities of atoms and molecules in a vapor; **pp. 298-301**. Equation (7.38) should read

$$F(T; D_e, B_e, \omega_e) = e^{\frac{D_e}{k_B T}}\frac{e^{\frac{-\omega_e}{2k_B T}}}{1 - e^{-\frac{\omega_e}{k_B T}}}(2I+1)$$
$$\times\left(I\sum_{\mathcal{J}=0}^{\infty}(2\mathcal{J}+1)e^{-\frac{B_e\mathcal{J}(\mathcal{J}+1)}{k_B T}} + \sum_{\mathcal{J}'=0}^{\infty}(4\mathcal{J}'+3)e^{-\frac{B_e(2\mathcal{J}'+1)(2\mathcal{J}'+3)}{k_B T}}\right) \ .$$

Equation (7.41) should read

$$\frac{e^{\frac{-\omega_e}{2k_B T}}}{1 - e^{-\omega_e/(k_B T)}} \approx \frac{k_B T}{\omega_e} \ .$$

Equations (7.46) and (7.47) should read

$$F(T; D_e, B_e, \omega_e) \approx e^{\frac{D_e}{k_B T}} \left(\frac{k_B T}{\omega_e}\right)(2I + 1)\left(I\frac{k_B T}{B_e} + \frac{1}{2}\frac{k_B T}{B_e}\right)$$

$$= e^{\frac{D_e}{k_B T}}\frac{k_B T}{\omega_e}\frac{k_B T}{B_e}\frac{(2I + 1)^2}{2}.$$

Equation (7.48) should read

$$\boxed{\frac{N_{Cs_2}}{N_{Cs}} \approx \frac{n_{Cs}}{2\sqrt{2}}\left(\frac{h}{\sqrt{2\pi m k_B T}}\right)^3 e^{\frac{D_e}{k_B T}}\left(\frac{k_B T}{\omega_e}\right)\left(\frac{k_B T}{B_e}\right).}$$

Equation (7.52) should read

$$P[\text{CGS}] \approx 1.33 \times 10^3 \ P[\text{torr}],$$

and the following equation should read

$$P(T) \approx 1.8 \text{ torr} \approx 2.4 \times 10^3 [\text{CGS}] \ .$$

Finally, Eqn. (7.54) should read

$$\boxed{\frac{N_{Cs_2}}{N_{Cs}}(T = 22^\circ\text{C}) \approx 6.5 \times 10^{-5} \ .}$$

The final paragraph should state:

The difference in molecular abundance between these two temperatures is strongly affected by the difference in atomic Cs pressure; at room temperature this is only $P \approx 1 \times 10^{-6}$ torr, six orders of magnitude less than at $T = 300^\circ\text{C}$.

- Problem 7.7 Scalar coupling of nuclear spins in molecules; **p. 312**. Equation (7.101) should read:

$$|g\rangle = \psi_{1s}(\vec{r}_1)\psi_{1s}(\vec{r}_2)\frac{1}{\sqrt{2}}(|\alpha_1\beta_2\rangle - |\beta_1\alpha_2\rangle)|\uparrow\rangle \ .$$

- Problem 8.6 Transmission through a light guide; **p. 325**. We have neglected light reflection at the entrance. This may not be a realistic approximation, particularly, for large incidence angles α. See, for example, a discussion of the Fresnel' formulae (and the corresponding plots of the reflection and transmission coefficients) in Ch. 3 of K. D. Möller's book *Optics*, University Science Books, Mill Valey, California (1988).

- Problem 8.14 Matter-wave vs. optical Sagnac gyroscopes; **pp. 343, 346**. The units of the gyroscope's sensitivity should be $\frac{\text{rad/s}}{\sqrt{t(\text{s})}}$, where $t(\text{s})$ is the duration of the measurement in seconds.

- Problem 8.16 Magnetic field fluctuations due to random thermal currents; **pp. 352**. The inequality after Eq. (8.106) should read $1 \leq C \leq 2\pi$.

- References. Here are the corrected references.

  Budker, D., Hollberg, L., Kimball, D. F., Kitching, J., Pustelny, S., and Yashchuk, V. V. (2003). Investigation of microwave transitions and nonlinear magneto-optical rotation in anti-relaxation-coated cells. *Physical Review A*, **71**, 012903.

  Happer, W., Walker, T., and Bonin, K. (2003). *Optical pumping: principles and applications*. Springer-Verlag, Berlin. This book has not been published as yet (January 2006).

  Haroche, S. (1976). Quantum beats and time-resolved fluorescence spectroscopy, in *High-resolution laser spectroscopy*, K. Shimoda, Ed. Springer-Verlag, Berlin.