

Bernstein Fishbane and Gasiorowicz “Modern Physics” Corrections and clarifications.

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2006-May-11 (updated 2012-May-30)

Page Correction

- 0 Inside front cover:
- (a) The value of $\hbar c$ in SI units is misprinted as 3.162×10^{-28} Jm. Using the values given above for \hbar and c , the correct value is 3.142×10^{-26} Jm: note that this differs from the value in the book in both mantissa and exponent.
 - (b) Compton wavelength of the electron is misprinted as $\hbar/(m_e c)$, and the wrong numerical value 3.816×10^{-13} m is given. The correct definition (p114) is $h/(m_e c) \approx 2.4 \times 10^{-12}$ m
 - (c) The Bohr magneton is misprinted as $e\hbar/(2m_e c)$, when it should be $e\hbar/(2m_e)$.
- 109 Spelling. Caption to Fig 4-4, lines 2-3: “photomultpler”.
- 115 Fig 4-10. Vertical axis should be Intensity not Energy. It would be helpful if somewhere in the caption or on the axis label it said that this plot is the observed intensity at an angle of 90° .
- 167 Figure 6-8: since $u_1(x)$ is approximately linear near its zeros at $x = 0$ and L , $|u_1(x)|^2$ should behave like a parabola, not a straight line, near those points.
- 181 Different definitions of Δp are used in sections 7-2 and 7-3. This tends to confuse the students. In 7-2, Δp is the full width of a momentum space wave packet. In 7-3, Δp is the standard deviation. If you want to use Δp generically, it would be good to have a specific notation (e.g. “ δp ” or “ σ_p ”) for the standard deviation.
- 183 Discussion after eqn (7-20) of how Δx depends on Δp . If you use the definition (7-25) of Δx in the wavefunction eqn (7-17) then you find $\Delta x = \infty$. This wavepacket is not truly localized.
- 185 The sentence before equation (7-35) should read “we define Δx , the width in x , to be the square root of the variance of the space distribution”, not “the square root of the standard deviation in the space distribution”. Equation (7-25) should read $(\Delta x)^2 = \sigma(x)^2 = \langle x^2 \rangle - \langle x \rangle^2$. Analogous changes are required for equation (7-26) and the sentence before it. [pointed out by Alessandro Cuttin, Univ. of Trieste].
- 193 In equation (7-35), the quantity d is not defined. Actually it is the distance from the slits to the screen. This is particularly confusing because in the original discussion of the 2-slit experiment (Fig 1-12), d was the distance between the slits.

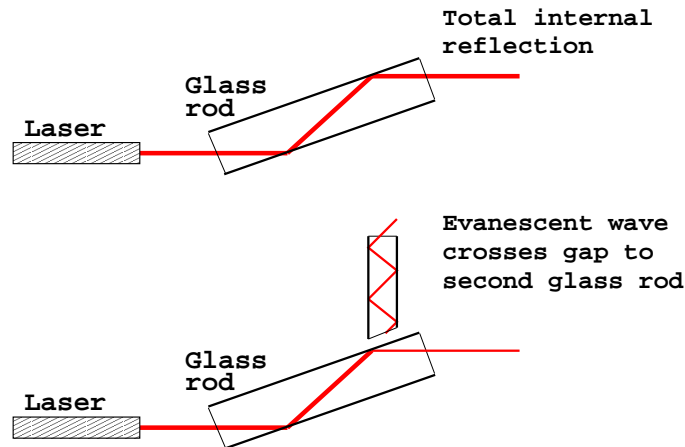


Figure 1: Alternate version of Fig 8-4.

- 195 Second-to-last line on the page, the inline equation should be $\Delta f = \Delta E/h$, not $\Delta f = \Delta E/\hbar$.
- 205 Fig 8-4 was very confusing to students. Just looking at the figure, it seems that light cannot jump the air gap: the second panel shows no “stolen” beam. Then in the third panel, where there is a stolen beam, it looks as if that’s because the two glass rods are in contact. Reading the labels does not help: students then get the impression that the evanescent beam can only go through glycerine, not air. To make the essential point requires only two panels (see Fig. 1 in these notes). It is true that the evanescent wave drops exponentially over one-wavelength distance scales, so Fig. 1 does not depict an easily performed demonstration, but it makes the essential point in a clean way.
- 211 The un-numbered equation for P_i at the top of the page is wrong by a factor of 2. It should read $P_i = F_i \exp(-2\kappa_i \Delta x_i)$. It is obtained from (8-18) using the fact that $\Delta x = 2a$.
- 213 The un-numbered reaction equation at the bottom of the page is misprinted. The final state should contain ${}^3\text{He}$, not ${}^3\text{H}$ (charge conservation).
- 216 Fig 8-15: If ψ_L and ψ_R are as depicted in the left panel, both being negligibly small at $x = 0$, then their sum cannot be as depicted in the middle panel: $\psi_L + \psi_R$ should drop to zero at $x = 0$.
- 217 Example 8-3, solution, part (b). First equation: the numerical value is closer to 1.15×10^{10} than 1.1×10^{10} . Third equation: should be -77 not -73 . Final line: should be $\exp(-77) \approx 3.6 \times 10^{-34}$.
- 223 Fig 8-22. The second panel in the figure is displaced down from the axis: the wavefunction should tend to zero at large $|x|$ just as in all the other panels. Panels three and four are badly drawn because inside the well the wavefunction should simply be a cosine with equally spaced nodes: the curves in those panels look

nothing like that.

Actually, the whole sequence is misleading since it is not clear that for the stronger values of V_0 it is only showing one of the energy eigenfunctions. Students will be expecting a figure like Fig 6-7 (which shows the lowest few eigenstates of the infinite well). The corresponding figure for a square well with three bound states is given in Fig. 2 in these notes.

- 232 Equation (9-10) is misprinted: the final term should be $-\frac{m^2}{\sin^2 \theta} F$.
- 234 After eqn (9-16): the integral over θ runs from 0 to π , not $-\pi$ to π .
- 235 Table 9-1, bottom line: The spherical harmonics with negative m are given by $Y_{\ell,-m} = (-1)^\ell Y_{\ell,m}^*$, not $(-1)^\ell Y_{\ell,m}$.
- 248 Equation (9-42) is technically correct because it is about magnitudes, but invites misinterpretation because the underlying vector equation contains a minus sign: $\vec{\mu} = -\frac{e}{2m_e} \vec{L}$. This seems to have led to errors later in the section. It would be good to display the vector equation with equal prominence, eg by converting q to $-e$ in Equation (9-43), whose generality is unnecessary and (as far as I can see) never used.
- 249 Equations (9-46) and (9-47) both have the wrong sign, perhaps obtained from a naive reading of eqn (9-42). The in-line equation four lines above eqn (9-46) also has the wrong sign: it should read $\vec{\mu} = -e/(2m_e) \vec{L}$. This leads to the error in Fig. 9-11.
- 250 Figure 9-11. (a) In the right-hand panel, all the $l=2 \rightarrow l=1$ transition lines start at $m = -2$, when they should start at various different values of m . (b) In the right-hand panel, the ordering of values of m is wrong. It should go from large positive m at the top to large negative m at the bottom, as in Fig 9-15. (c) In the left-hand panel, it would be more helpful to label the states by n, l rather than n_r, l . n_r is not used in the classification of states, and the students find it simpler to think in terms of one principal quantum number, n .
- 254 Fig. 9-15 is very misleading. Because the gyromagnetic ratio is approximately 2, the spin splittings are of the same size as the orbital splittings, not smaller as shown in the figure. The correct figure looks like Fig. 3 in these notes.
- 255 In discussing modern measurement of the g -factor, why not give the measured value, with its error? Seeing it is more impressive to the students than being told about it. I suggest writing it as $g_e = 2(1 + 1.159652188(4) \times 10^{-3})$, which makes the overall value and the precision very clear.
- 257 Equation (9.62) is too small by a factor of 2. It should contain $\vec{L} \cdot \vec{S}/(2m_e^2 c^2)$ instead of $\vec{L} \cdot \vec{S}/(4m_e^2 c^2)$. This can be seen by comparing it with eqn (6.60) in Griffiths "Introduction to QM", or by substituting in numbers and comparing with Fig. (9-17).
- 259 The gyromagnetic ratio of the proton is 5.586, not 5.56.

Square well wavefunctions

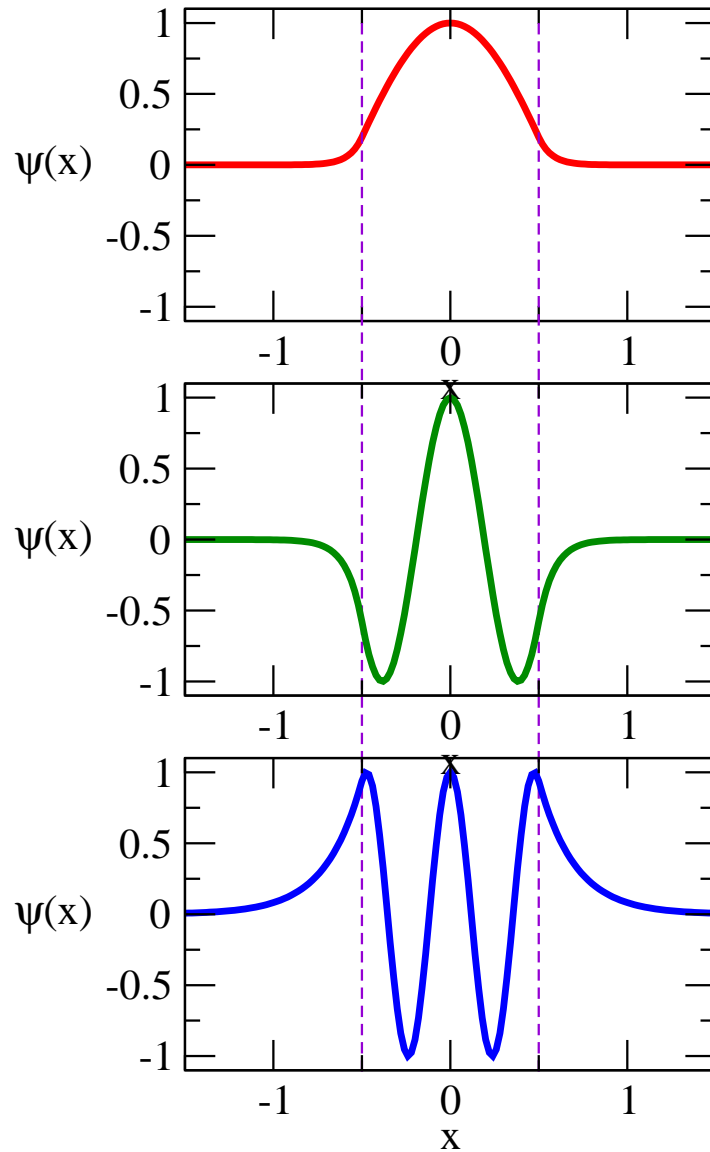


Figure 2: Alternate version of Fig 8-22, showing the energy eigenstate wavefunctions for a square well that is deep enough to have three bound states in it. They have been arbitrarily normalized so that each has a maximum value of 1.

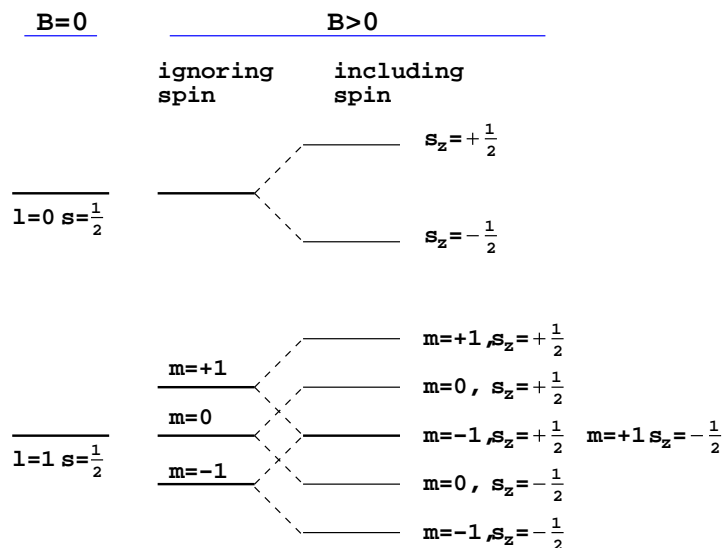


Figure 3: Alternate version of Fig 9-15.

259 The paragraph after eqn (9-64), arguing that only $l = 0$ states have a hyperfine splitting, is hard to understand. The text says that the hyperfine spin-spin interaction has a $1/r^3$ term, like the spin-orbit interaction that gave fine structure. But it then says that only $l = 0$ states of the electron feel the interaction because they are the only ones for which the electron wavefunction at the origin is non-zero. This is confusing: why didn't the same reasoning apply to the fine structure, if an interaction of the the same $1/r^3$ form is involved in both cases? The physics is explained properly in Gasiorowicz's textbook "Quantum Physics", near the end of chapter 17. The spin-spin interaction has a $1/r^3$ term which ends up with zero coefficient, and *also* a δ -function term which only contributes when the spins are at the same point, i.e. for $l = 0$ states.

260 It would be helpful if the un-numbered equation in the middle of the page for the hyperfine splitting gave the energy as well as the frequency: $\Delta E_{\text{hfs}} = 6 \times 10^{-6}$ eV. But then this brings out an apparent contradiction, because at the bottom of p259 it was stated that hyperfine splittings are typically 1/2000 of fine-structure splittings, and you can see in Fig 9-17 that the fine structure is $\Delta E_{\text{fs}} \approx 3 \times 10^{-5}$ eV. So ΔE_{hfs} is only 5 times smaller than ΔE_{fs} .

The explanation is that the expression for ΔE_{fs} happens to contain additional numerical factors that suppress it by a factor of about 300, so actually ΔE_{hfs} is of the expected size, but ΔE_{fs} is anomalously small.

261 NMR explanation.

(a) Halfway down the page, "as long as \vec{B} is unchanging, I_z remains the same; that is. . .the energy remains fixed." But elsewhere we have always assumed that higher energy states can decay into lower energy states by emitting a photon. Why is

this an exception?

(b) A few lines further on, “the spin vector will precess around the direction of the new field \vec{B}' ,...”. But the new field is $\vec{B} + \vec{B}'$.

(c) The whole presentation is confusing, intermingling classical and quantum pictures. It would be simpler to go straight to the splitting of the proton spin levels in a magnetic field, obtain the energy difference and corresponding photon frequency, and *then* give the classical argument that shows there is precession and identifies the photon frequency with the spin precession frequency.

262 It should be mentioned that the crucial point about MRI is that it finds a way to use radio waves, which can easily penetrate the human body, to “see” inside the body. The cleverness of the method is that it uses a magnetic field to make hydrogen atoms absorb the radio waves, so that different tissues (with different amounts of hydrogen) have different opaqueness to the radio waves. Thus a “radio image” of the body carries useful diagnostic information.

286 First equation of solution to Example 10-6: factor of 2 missing. It should read $E = pc = 2(\hbar c\pi/L)\sqrt{n_1^2 + n_2^2 + n_3^2}$.

290 Equation (10-69) contains a misprint. First factor should be $\left(\frac{81\pi^2}{512}\right)^{1/3}$, not $\left(\frac{81\pi^2}{128}\right)^{1/3}$.

295 Chapter 10, problem 23: the measured bulk modulus of Copper is given as $1.34 \times 10^{13} \text{N/m}^2$; actually it is $1.40 \times 10^{11} \text{N/m}^2$. The calculated value from electron degeneracy pressure is $0.63 \times 10^{11} \text{N/m}^2$, which is only smaller by a factor of 2. Are we meant to conclude that the bulk modulus of the ionic lattice is about the same as the contribution from electron degeneracy pressure?

301 Above equation (11-5), the reference to equation (9-17) is incorrect. Perhaps it should be equation (9-33).

307 Discussion of atoms with $Z > 10$. One third of the way down the page, we find “The $3d$ states have (slightly) higher energy than the $4s$ states.” This seems to imply that the $3d$ states are at larger r : more screened, less bound, higher energy. But two-thirds of the way down, we find “the probability distribution of the $4s$ electrons is weighted at larger values of r than that of the $3d$ electrons.” So why do the $4s$ have lower energy, then?

310 In discussing Fig 11-4, it would be good to give the fitted value of b , with its standard error of estimate, so the reader can see how close it is to 1.

312 Fig 11-5 could benefit from some additional explanation. Why is there such a large non-zero background intensity of electrons? And why does each Auger signal consist of a positive spike in intensity immediately followed by a negative spike, or in one case (Ga) just a negative spike? The discussion in the text would have led us to expect a low background with large positive spikes at specific energies.

314 The discussion of symmetry and antisymmetry of wavefunctions (second paragraph of “The H_2 molecule and valence bonds”) appears to confuse two different concepts.

1) Reflection transformation properties. Wavefunctions can be symmetric or antisymmetric “in space”, i.e. under $x \rightarrow -x, y \rightarrow y, z \rightarrow z$.

2) Particle exchange properties. Wavefunctions for multiple particles can be symmetric or antisymmetric under exchange of those particles.

The text first states that the ground-state two-electron wavefunction of H_2 has an exchange-symmetric space part, multiplying an exchange-antisymmetric spin part, so it is overall exchange-antisymmetric, as a two-fermion wavefunction should be. The next part, beginning “A spatial wavefunction that is antisymmetric about the plane. . .” appears to be trying to justify the claim that this is the ground state. But its discussion of the energy of a reflection-symmetric vs a reflection-antisymmetric spatial state does not explain why the ground state has an *exchange*-symmetric space wavefunction.

315 In the middle of the page, the text states “we have an additional negative contribution to the energy that is on the order of the ionization potential itself”. The vagueness of this statement undercuts the precision of the rest of the section, where the ionization energy of Sodium is given as 5.1 eV and the electron affinity of Fluorine as 3.5 eV. To present a unified quantitative story to the students, we need to know the precise value of the attraction energy.

317 After eqn (11-12) there is a reference to Eq. (1-6), but that equation does not seem relevant.

319 Rotations of molecules: it would be helpful to at least mention the other possible rotational mode, around the axis of the bond, and explain why we do not study it. Also, in the second line of Example 11-5, the molecule should be HBr, not Hbr.

321 The argument for even/odd l only mentions the azimuthal angle φ . But exchanging the two nuclei corresponds to $\theta \rightarrow \pi - \theta$ as well as $\varphi \rightarrow \varphi + \pi$. One can show that the θ -dependence of the wavefunction is not affected by the exchange, by aligning the coordinate system so that $m = l$, so the angular wavefunction is $Y_l(\theta, \varphi) \propto \sin^l(\theta)e^{il\varphi}$.

Also, the text says “for nuclei that are identical bosons the phase factor must be plus one . . . and ℓ must be even.” But the two objects in question are ions, not nuclei. The electrons in the ions contribute to the phase as well. In ions, there is an even number of electrons (a closed shell), so actually the electron contribution is +1.

322 Second-to-last bullet point, last line: the electronic, vibrational, and rotational energy levels are in the ratio $1 : 10^{-2} : 10^{-4}$, not $1 : 10^2 : 10^4$.

399 The explanation of why the Fermi velocity of the electrons is the correct one to use in the Drude formula assumes at the outset that the electrons are in a large box, ie a square well potential like the one shown in Fig 8-19. But the picture of the potential on the next page (Fig 14-4) looks nothing like a square well. Really one already needs Bloch’s theorem at this point, to argue that the states are indexed by a wavenumber k even though they are not plane wave states.

- 400 After the unnumbered equation for \bar{v} at the top of the page, it should be noted that, as well as being larger than the classical version, this \bar{v} is independent of temperature.
- 403 In the solution to example 14-2, when numbers are substituted in to the expression for ρ , the first term in the denominator should be $(1.6 \times 10^{-19} \text{ C})^2$, not just $(1.6 \times 10^{-19} \text{ C})$.
- 409 (a) Fig 14-15: vertical axis should be labeled $\cos(ka)$ as in the caption, not ka .
 (b) First line of page 409: the factor that multiplies ξ in eqn (14-21) has the dimensions of energy \times length, not dimensions of energy.
 (c) The line after eqn (14-22): it would be helpful to remind the reader what k is, by referring to (14-12).
- 413 In the line below eqn (14-28), the inline equation should read $\exp(-15) \approx 3 \times 10^{-7}$, not 3×10^{-6} .
- 418 In the section on intrinsic and extrinsic semiconductors, it would be helpful to explain why, in a doped semiconductor, the hole in the donor level does not count as a p -carrier. Otherwise the promotion of an electron from a donor level to the conduction band (extrinsic semiconductor) looks essentially the same as the promotion of an electron from the valence band to the conduction band (intrinsic semiconductor). The reason is that the impurities are so spread out that their orbitals have very little overlap with each other, and the hole cannot jump from impurity to impurity: a hole in the donor level is *not* a p -carrier.
- 430 Fig 14-38: horizontal axis should be labeled T_c/T (as stated in the caption) not “ T ”.
- 431 Last paragraph: the discussion of superconductivity says that in a superconductor the energy required to change the current is huge. This begs the question: how did you get a current to flow in the first place, if the energy cost of changing the current is prohibitive?
- 486 The discussion of virtual particles based on the energy-time uncertainty relation $\Delta E \Delta t \geq \hbar/2$ is found in many textbooks, but it has major problems. Firstly, it implies that conservation laws can be broken by quantum mechanics, which is not true. (Students ask: why can't you violate charge or quark number in a similar way?). Secondly, the uncertainty relation is an inequality, which indicates that $\Delta t \geq \hbar/(2\Delta E)$ so you can “borrow” energy for as long as you like. (It is noticeable that the uncertainty relation (7-40) has been converted into an approximate equality on p485 to gloss over this point).
 The truth is that all conservation laws are exactly conserved at all vertices, and that the essential feature of virtual particles is that they disobey $E^2 = p^2 + m^2$: they are “off-shell”. I don't know a clean heuristic argument (other than dimensions) for relating their mass to the range of the force.
- 487 Fig 16-4 is confusing because the caption says that time flows upwards, so panel (c) appears to show a photon standing still. (Similar problem in panel (f) and (g)).

- 571 Table A-1, second line: electron charge should be 1.602×10^{-19} C, not $\times 10^{19}$ C.
- 577 (a) “Some simple integrals”: the integral of x^n is $\frac{x^{n+1}}{n+1}$, not $\frac{x^{n+1}}{n}$.
(b) “Some special integrals”: in the second equation, the middle term should be $-\frac{dI}{dA}$, not $\frac{dI}{dA}$.
- 584 Chapter 9, problem 13: should read $\langle V \rangle = \frac{me}{16\epsilon_0^2 h^2}$. 15(a) should be 6.7×10^{-15} (?).