Quantum Mechanics 4th Edition
Alastair I M Rae
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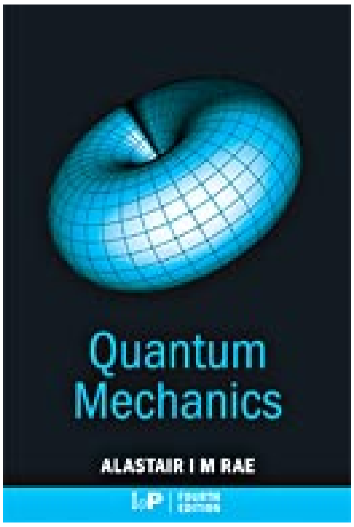
Supporting Material



Contents

Chapter 1

Some of the Figures in Colour

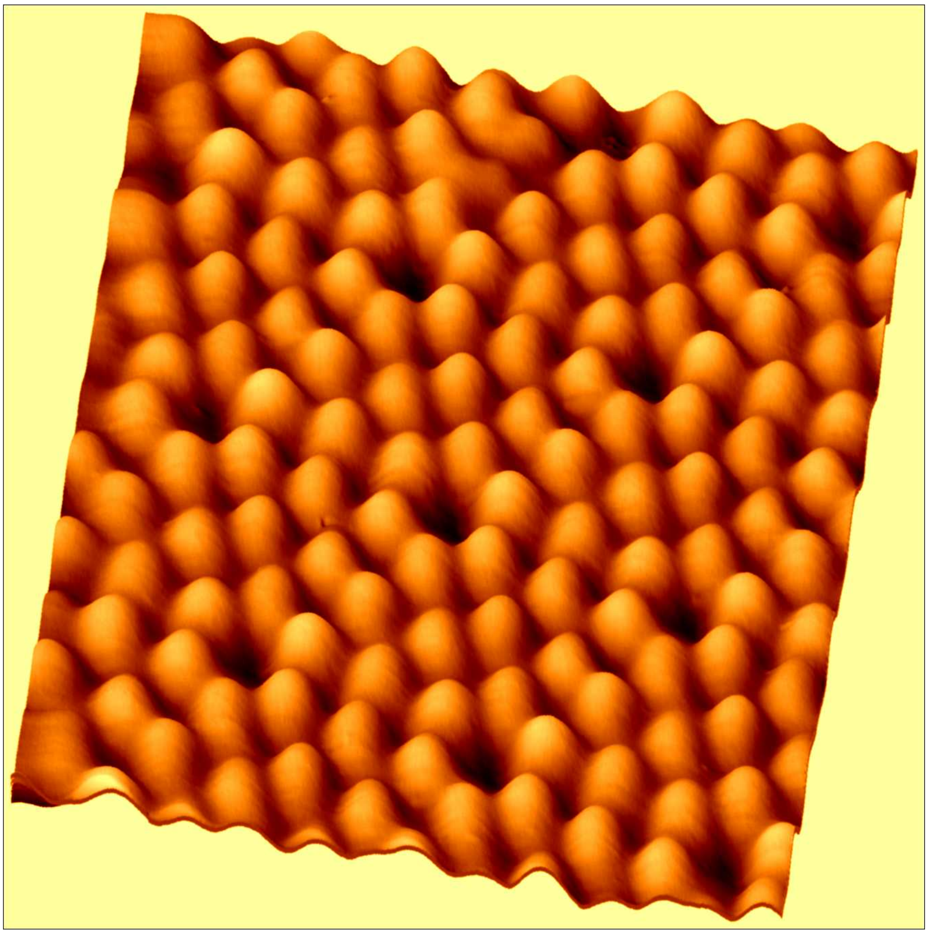


Figure 2.6. An image of the (111) surface of silicon obtained by scanning tunnelling microscopy. The bright peaks correspond to silicon atoms. The hexagonal symmetry is a characteristic feature of this surface. (Supplied by P. A. Sloan and R. E. Palmer of the Nanoscale Physics Research Laboratory in the University of Birmingham.)

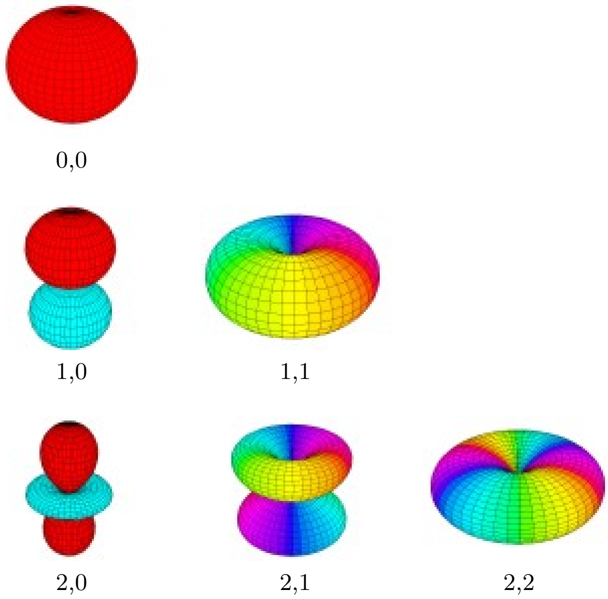


Figure 3.3. Representations of the shapes of the spherical harmonics with quantum numbers l, $|m|$, where $l < 3$ and the z axis is vertical. In the case of $m = 0$, the red and blue regions have opposite sign; when m is non-zero, the function is complex and the changing colour corresponds to the phase changing by $2m\pi$ during a complete circuit of the z axis. The images are taken, with permission, from the web page of Jim Smith (http://odin.math.nau.edu/%7Ejws/dpgraph/Yellm.html) at the Arizona National University. This site contains illustrations of other spherical harmonics and alternative representations are readily located by entering ‘spherical harmonics’ into a web search engine.

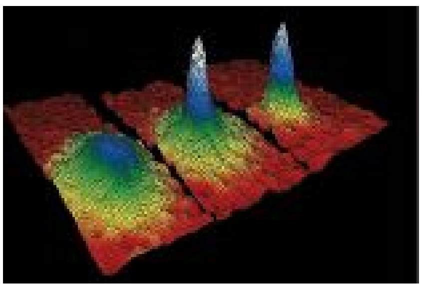


Figure 10.1. The distribution of atomic velocities in a collection of rubidium atoms held in a trap for three temperatures that span the Bose condensation temperature of 170nK.

Chapter 2

Corrections

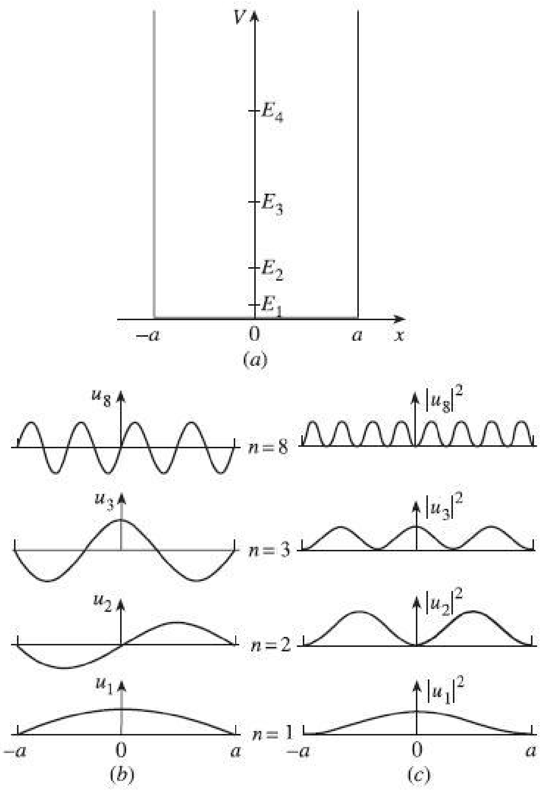
This section contains an updated list of corrections to known misprints in the text. If you detect any misprints or mistakes that are not listed here, please let us know by e-mailing john.navas@informa.com.

Chapter 1

Figure 1.3, Page 11 The symbol for the angle should be a greek 'alpha' (α) rather than 'x'.

Chapter 2

Figure 2.1, Page 21 The labels $n = 1, n = 2$ and $n = 3$ are presented in reverse order. The correct figure is shown below.



Chapter 4

Equation 4.37, Page 72 It should read $\exp(-\mathrm{i}kx)$ not $\exp(\mathrm{i}kx)$; i.e.,

$$a(k) = (2\pi)^{(-1/2)} \int \psi(x) \exp(-\mathrm{i}kx)\mathrm{d}x. \qquad (4.37)$$

Equation 4.90, Page 91 It should read;

$$P(k_z) = \frac{8a_0}{3\pi} \frac{1}{[1 + (a_0^2 k_z^2)]^3}. \qquad (4.90)$$

Chapter 5

Equation 5.52, Page 107 The term $\hbar$ should be squared, i.e.,

$$\begin{aligned} \int \phi_{m+1}\phi_{m+1}^* \mathrm{d}\tau &= \int (\hat{L}_+\phi_m)\hat{L}_+^*\phi_m^* \mathrm{d}\tau \\ &= \int \phi_m^* \hat{L}_-\hat{L}_+\phi_m \mathrm{d}\tau = [l(l+1) - m(m+1)]\hbar^2. \qquad (5.52) \end{aligned}$$

Equations following (5.51), Page 107 The term '$= \int g\hat{L}_-^* f\, d\tau$' should be added at the end of the line, i.e.,

$$\int f\hat{L}_+ g\, d\tau = \int f(\hat{L}_x + i\hat{L}_y) g\, d\tau = \int g(\hat{L}_x^* + i\hat{L}_y^*) f\, d\tau = \int g(\hat{L}_x - i\hat{L}_y)^* f\, d\tau = \int g\hat{L}_-^* f\, d\tau.$$

Chapter 6

Equation 6.29, Page 118 There should be a 'dagger' after the term $[a_1]$, i.e.

$$Q_{12} = [a_1^\dagger][Q][a_2]. \qquad (6.29)$$

Equations 6.37 to 6.38, Page 120 replace V by U to avoid possible confusion.

If the potential U associated with the field $\mathcal{E}$ is spherically symmetric (as in a one-electron atom) we have

$$\mathcal{E} = -\frac{\partial U}{\partial r}\frac{\mathbf{r}}{r} \qquad (6.37)$$

and hence

$$\begin{aligned} \mathbf{B} &= \frac{\mathbf{v} \times \mathbf{r}}{rc^2}\frac{\partial U}{\partial r} \\ &= -\frac{1}{m_e c^2 r}\frac{\partial U}{\partial r}\mathbf{l}. \qquad (6.38) \end{aligned}$$

Equation 6.43, Page 121 Should read:

$$\hat{H}' = f(r)(\hat{J}^2 - \hat{L}^2 - \hat{S}^2) + \frac{eB_0}{2m_e}(\hat{L}_z + 2\hat{S}_z) \qquad (6.43)$$

Equation 6.44, Page 121 Should read:

$$f(r) = \frac{\mu_0 Z e^2}{16\pi m_e^2 r^3} = \frac{-e}{4m_e^2 c^2 r}\frac{\partial V}{\partial r}. \qquad (6.44)$$

Page 126 Correct text shortly after equation (6.54) to read:

…the operators $\hat{J}^2$, $\hat{J}_z$, $\hat{L}^2$ and $\hat{S}^2$ possess a common set of eigenstates.

Equations 6.64 to 6.68, Pages 129–130

$$\begin{aligned}\hat{H}' &\equiv \hat{H}'^{(1)} + \hat{H}'^{(2)} \\ &= \langle f(r)\rangle(\hat{J}^2 - \hat{L}^2 - \hat{S}^2) + \frac{eB_0}{2m_e}(\hat{L}_z + 2\hat{S}_z) \qquad (6.64)\end{aligned}$$

the expectation value being taken over the radial co-ordinate only. Using the states $|j, m_j\rangle$ as a basis, we calculate the matrix elements

$$\begin{aligned}H'_{(j,m_j),(j',m'_j)} &= H'^{(1)}_{(j,m_j),(j',m'_j)} + H'^{(2)}_{(j,m_j),(j',m'_j)} \\ &= \langle f(r)\rangle \langle j, m_j| (\hat{J}^2 - \hat{L}^2 - \hat{S}^2) |j', m'_j\rangle \\ &+ \frac{eB_0}{2m_e} \langle j, m_j| (\hat{L}_z + 2\hat{S}_z) |j', m'_j\rangle \qquad (6.65)\end{aligned}$$

$$\begin{aligned}H'^{(2)}_{(j,m_j),(j',m'_j)} &= -\frac{eB}{2m_e} \sum_{m_l,m_s} C^*_{(j,m_j)(m_l,m_s)} \langle m_s| \langle m_l| (\hat{L}_z + 2\hat{S}_z) \\ &\times \sum_{m'_l,m'_s} C_{(j',m'_j)(m'_l,m'_s)} |m'_l\rangle |m'_s\rangle \\ &= \frac{eB}{2m_e} \sum_{(m_l,m_s)(m'_l,m'_s)} C^*_{(j,m_j)(m_l,m_s)} C_{(j',m'_j)(m'_l,m'_s)} \\ &\times \langle m_l| \langle m_s| (\hat{L}_z + 2\hat{S}_z) |m'_l\rangle |m'_s\rangle \qquad (6.67)\end{aligned}$$

We can now use the fact that $|m_l\rangle$ and $|m_s\rangle$ are eigenstates of $\hat{L}_z$ and $\hat{S}_z$ respectively, along with orthogonality to get

$$H'^{(2)}_{(j,m_j),(j',m'_j)} = \frac{e\hbar B}{2m_e} \sum_{m_l,m_s} C^*_{(j,m_j)(m_l,m_s)} C_{(j',m'_j)(m_l,m_s)} (m_l + 2m_s) \qquad (6.68)$$

Table 6.3, Page 130 Should appear as:

Table 6.3. The matrix representing $\hat{H}'$ in the case where $l = 1$ and $s = \frac{1}{2}$. $\epsilon = \langle f(r)\rangle\hbar^2$ and $\mu_B = e\hbar/2m_e$.

	(j, m_j)					
(j, m_j)	$(\frac{3}{2},\frac{3}{2})$	$(\frac{3}{2},-\frac{1}{2})$	$(\frac{3}{2},-\frac{1}{2})$	$(\frac{3}{2},-\frac{3}{2})$	$(\frac{1}{2},\frac{1}{2})$	$(\frac{1}{2},-\frac{1}{2})$
$(\frac{3}{2},\frac{3}{2})$	$\epsilon + 2\mu_B B$	0	0	0	0	0
$(\frac{3}{2},\frac{1}{2})$	0	$\epsilon + \frac{2}{3}\mu_B B$	0	0	$-\frac{\sqrt{2}}{3}\mu_B B$	0
$(\frac{3}{2},-\frac{1}{2})$	0	0	$\epsilon - \frac{2}{3}\mu_B B$	0	0	$-\frac{\sqrt{2}}{3}\mu_B B$
$(\frac{3}{2},-\frac{3}{2})$	0	0	0	$\epsilon - 2\mu_B B$	0	0
$(\frac{1}{2},\frac{1}{2})$	0	$-\frac{\sqrt{2}}{3}\mu_B B$	0	0	$-2\epsilon + \frac{1}{3}\mu_B B$	0
$(\frac{1}{2},-\frac{1}{2})$	0	0	$-\frac{\sqrt{2}}{3}\mu_B B$	0	0	$-2\epsilon - \frac{1}{3}\mu_B B$

Figure 6.5, Page 131 The symbols i to the left of the y axis should be j

Problem 6.1, Page 132 Matrix $[P]$ should read,

$$[P] = \left(\frac{1}{2}m\omega\hbar\right)^{1/2} \begin{bmatrix} 0 & -i & 0 & 0 & \dots \\ i & 0 & -i\sqrt{2} & 0 & \dots \\ 0 & i\sqrt{2} & 0 & -i\sqrt{3} & \dots \\ \vdots & \vdots & \vdots & \vdots & \dots \\ \vdots & \vdots & \vdots & \vdots & \dots \end{bmatrix}.$$

Chapter 7

Equation 7.56, Page 148 The equation should read,

$$E = \frac{\hbar^2}{4m_e}\left[k^2 + (k - \frac{2\pi}{a})^2\right] \pm \frac{1}{2}\left[\left(\frac{\hbar^2}{2m_e}[k^2 - (k - \frac{2\pi}{a})^2]\right)^2 + V_0^2\right]^{\frac{1}{2}} \tag{7.56}$$

Chapter 13

Figure 13.9, Page 282 The legend should read: 'According to GRW theory, there is a finite probability of a particle collapsing into a localized state at any time. The leftmost picture represents a macroscopic body delocalized between two positions. When one of the atoms collapses, one of its possible positions is left empty, while the other is 'over-full' (central picture). To avoid the inevitable increase in energy, the whole object must collapse around the atom (picture on right).'

Pages 265 and 266 $n(2_+, 3_-)$ should be $n(2_-, 3_+)$ in equation (13.19) and the preceding unnumbered equation.

Figure 13.3b, Page 266 To be consistent with the legend and the text, the graph should be reflected through a vertical line at $\theta = 45$ degrees, so that the negative section comes between $\theta = 60$ degrees and $\theta = 90$ degrees.

Chapter 3

Further Reading

Earlier editions of Quantum Mechanics contained a Bibliography. During the last twenty years, not only have many of the references in it become out of date, but the amount of relevant published material has exploded to the point where there is a great danger that important works will be left out. Moreover, the availability of web searches and other data retrieving tools means that readers can much more easily build up their own databases of relevant material. Nevertheless, I would like to build up a database of useful references here. If you have any suggestions to offer, please let me know by e-mailing john.navas@informa.com.

In the meantime here is the bibliography published with the third edition.

References to the literature relating to particular points are made on occasions throughout the text. A guide to more general reading is given below.

Background

A more extensive treatment of the experimental evidence for the need for quantum mechanics than is given in Chapter 1 is contained in many textbooks on atomic physics, of which the following are good examples.

Eisberg, R. M., and Resnick, R., *Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles*, Wiley, New York, 1974.

Enge, H. A., Wehr, M. R., and Richards, J. A., *Introduction to Atomic Physics*, Addison-Wesley, Reading, Massachusetts, 1972.

Richtmeyer, F. K., Kennard, E. H., and Cooper, J. H., *Introduction to Modern Physics* (6th edn.), McGraw-Hill, New York, 1969.

A general familiarity with mathematical techniques, particularly calculus and elementary matrix algebra, up to a level typical of that of a first-year undergraduate physics course, is assumed; suitable textbooks covering this material are

Arfken, G., *Mathematical Methods for Physicists*, Academic, New York, 1985.

Boas, M. L., *Mathematical Methods in the Physical Sciences* (2nd ed.), Wiley, New York, 1984.

Complementary

Some of the textbooks on quantum mechanics which treat the subject at approximately the same level as the present volume are listed below with short comments.

Bohm, D., *Quantum Theory*, Prentice-Hall, New York, 1951. This thorough, discursive test is one of the few at this level to attempt a detailed discussion of the conceptual problems of the subject. It is of course rather out of date by now.

Dicke, R. H., and Wittke, J. R., *Introduction to Quantum Mechanics*, Addison-Wesley, Reading, Massachusetts, 1960. In many ways the approach of this book is rather similar to that adopted in the present work, but it relies on a more detailed understanding of formal classical mechanics and uses rather complex mathematical arguments at times.

Feynman, R. P., Leighton, R. B., and Sands, M., *The Feynman Lectures in Physics* (vol. III, *Quantum Mechanics*), Addison-Wesley, Reading, Massachusetts, 1965. This book contains many physical insights and is written in an attractive informal style. However, from the start it uses an abstract, matrix formulation which some students find difficult.

French, A. P., and Taylor, E. F., *An Introduction to Quantum Physics*, Nelson, Middlesex, 1978. This book describes the physical principles behind many quantum processes in considerable detail, and this discussion is illustrated by a large number of examples. However, detailed mathematical arguments are avoided, which somewhat limits its scope.

Mathews, P. T., *Introduction to Quantum Mechanics* (3rd ed.), McGraw-Hill, London, 1974. This book contains a rather condensed and mathematically based treatment of the basic ideas of quantum mechanics and their application to a number of physical problems.

Sillito, R. M., *Non-Relativistic Quantum Mechanics* (2nd ed.), University Press, Edinburgh, 1967. A good reliable text, if a little over detailed and mathematical in places, by the person who taught the subject to the present author.

Advances

The following is a small selection of the many books on quantum mechanics which treat the subject at a more advanced level.

Dirac, P. A. M., *Quantum Mechanics* (4th ed.), Oxford University Press, London, 1967. This classic text describes the formal, rigorous version of quantum mechanics that was first developed by its author.

Gillespie, D. T., *A Quantum-Mechanics Primer*, International Textbook Company, 1970. This short book contains a clear, simplified description of formal theory and is an excellent introduction to the book by Dirac (see above).

Landau, L., and Lifschitz, E. M., *Quantum Mechanics, Non-Relativistic Theory* (2nd ed.) (trans. J. B. Sykes and J. S. Bell), Addison-Wesley, Reading, Massachusetts, 1965. A long book which discusses a number of advanced topics in some detail.

Ziman, J. M., *Elements of Advanced Quantum Theory*, University Press, Cambridge, 1969. A good introduction to more advanced topics, particularly quantum field theory and the many-body problem.

The conceptual problems of quantum mechanics

The following constitute a selection of some publications on the topics discussed in Chapter 11. They all contain references to further published work.

Bellinfante, F. J., *Measurement and Time Reversal in Objective Quantum Theory*, Pergamon, Oxford, 1978. This book argues forcibly for quantum mechanics being an objective theory and for the importance of an 'indelible record' as part of any measurement.

Clauser, J. F., and Shimony, A., 'Bell's theorem: experimental tests and implications', *Reports on Progress in Physics*, vol. 41, pp. 1881–1927, 1978. This review article contains a thorough discussion of Bell's theorem and carefully analyses the various experiments that have been performed to test it.

D'Espagnat, B., *Conceptual Foundations of Quantum Mechanics*, Benjamin, Massachusetts, 1976. This is probably the nearest there is to an authoritative reference work on this subject. It reviews and analyses the whole field, including non-separability, measurement theories, and the associated philosophical problems.

Hughes, R. I. G., *The Structure and Interpretation of Quantum Mechanics*, Harvard University Press, 1989. This book contains a thorough discussion of the whole field at a moderately advanced level.

Prigogine, I., *From Being to Becoming*, Freeman, San Francisco, 1980. This book develops Prigogine's ideas referred to in Chapter 11.

Rae, A. I. M., *Quantum Physics, Illusion or Reality*, University Press, Cambridge, 1986. This book discusses the conceptual problems of quantum mechanics at greater length, although at a somewhat less advanced level than is done in Chapter 11.

Applications

The applications of quantum mechanics discussed in this book are mainly, if not entirely, drawn from the fields of atomic, nuclear, particle, and solid-state physics. More detailed discussion of these subjects can be found in a number of textbooks of which the following are typical examples.

Corney, A., *Atomic and Laser Spectroscopy*, Oxford University Press, London, 1977.

Kuhn, H., *Atomic Spectra* (2nd ed.), Longman, Harlow. 1970.

Woodgate, G. K., *Elementary Atomic Structure* (2nd ed.), Oxford University Press, London, 1980.

Burcham, W. E., *Nuclear Physics: An Introduction* (2nd ed.), Longman, Harlow, 1973.

Cohen, B. L., *Concepts of Nuclear Physics*, McGraw-Hill, New York, 1971.

Perkins, D. H., *Introduction to High-Energy Physics*, Addison-Wesley, Reading, Massachusetts, 1972.

Hook, J. R., and Hall, H. E., *Solid State Physics*, Wiley, 1991.

Kittel, C., *Introduction to Solid State Physics* (5th ed.), Wiley, New York, 1976.