Physics 310: QUANTUM MECHANICS FACT SHEET Fall Term, 2003

INSTRUCTOR: David M. Cook, Y-107, 832-6721, `david.m.cook@lawrence.edu`

OFFICE HOURS: 7:00–9:00 PM most Sundays; 2:30–4:00 PM Mondays, 9:30–11:00 AM Thursdays; and by appointment.

REQUIRED MATERIALS: The following materials are required for this course:

- September, 2003, version of *Non-Relativistic Quantum Mechanics* (*NRQM*), which is available from DMC. Note that this volume contains not only the text for the course but also several appendices dealing with a variety of mathematical topics, including linear equations, determinants, and matrix algebra; binomial and Taylor expansions; complex variable theory and Fourier analysis; and vector calculus (gradient, divergence, curl, Laplacian, Stokes' theorem, divergence theorem)—all topics that you have met before but with respect to which you may need a handy reference.

  While considerably less costly than a commercially published text, these notes none the less must be bought. Before too long into the term, your student account will be billed $17.50 (plus 5% state sales tax) to cover the costs of printing and binding these materials.

- The *Local Guide* (*LG*), that provides orientation to the CPL. While some edits have been made since the version used last winter in Physics 225 was printed, that version is still in the main applicable, and I assume you still have your copy. Two copies of the most recent version are in three-ring notebooks in the CPL for your reference.

- Appropriate portions of *Computation and Problem Solving in Undergraduate Physics* (*CPSUP*), all of which were included in the materials for Physics 225 last winter term—though minor edits have been made in the most recent printings. Two copies of the most recent printing of the *entire* book are in three-ring notebooks in the CPL for your reference. I assume, however, that you still have the materials from last winter.

READINGS: The bulk of the readings in this course will be assigned in *NRQM*. Most assignments will also identify parallel readings in other standard texts (see reserve list below), and you are urged to look regularly at those supplementary materials. Occasionally, readings in texts other than *NRQM* will be required, especially for those few topics that have not yet found their way into *NRQM*. All supplementary texts will be on reserve in the main library and some of them will be available also in Y-104 or Y-138.

BOOKS ON RESERVE:

- [QC23/qF47] Richard Feynman *et. al.*, *The Feynman Lectures on Physics* Volume III
- [QC174.12/G75] David Griffiths, *Introduction to Quantum Mechanics*
- [QC174.12/G37] Stephen Gasiorowicz, *Quantum Physics*, Second Edition
- [QC174.1/S289] David Saxon, *Elementary Quantum Mechanics*
- [QC174/12/L52] Richard Liboff, *Introductory Quantum Mechanics*
- [QC174.1/S34] Leonard Schiff, *Quantum Mechanics*
- [QC174.3/D5] Paul A. M. Dirac, *Quantum Mechanics*
- [QC174.12/S52] Ramamurti Shankar, *Principles of Quantum Mechanics*
- [personal copy] David Park, *Introduction to the Quantum Theory*
- [QC174.12/C35] Anton Z. Capri, *Non-Relativistic Quantum Mechanics*

- [QC174.12/S25] J. J. Sakurai, *Modern Quantum Mechanics*
- [QC174.12/F73] A. P. French/E. F. Taylor, *Introduction to Quantum Physics*
- [QC174.12/C6313v1] Claude Cohen Tannoudji, *Quantum Mechanics* Volume 1
- [QC174.12/C6313v2] Claude Cohen Tannoudji, *Quantum Mechanics* Volume 2
- [QC174.1/M36] Eugen Merzbacher, *Quantum Mechanics*
- [QC174.1/B6] David Bohm, *Quantum Theory*
- [QC174.12/J36] Max Jammer, *Conceptual Development of Quantum Mechanics*
- [QC173.98/J35] Max Jammer, *The Philosophy of Quantum Mechanics*

RECOMMENDED SUPPLEMENTARY TEXT: R. Shankar, *Basic Training in Mathematics: A Fitness Program for Science Students* [Plenum Press, New York, 1995; ISBN 0-306-45036-4 (paper)]. Taking a physicist's perspective, this book reviews a lot of mathematics, most of which you already know at some level. The Department has agreed that the book is a worthwhile addition to your personal library, and you may already have acquired it in response to that recommendation. If you haven't, I urge you to acquire it this year. Assignments in Physics 310 may occasionally direct your attention to portions of the book as supplementary reading. I think it would be worthwhile for you pick the book up and read a few pages every once in awhile, simply to help you develop increased familiarity with the mathematics pertinent to physics. Treat it as a source of bedtime entertainment.

SCHEDULE: Physics 310 will meet three times a week. The topics on which each class will focus are identified in the accompanying schedule. On most days, we will meet for lecture/discussion on the topic indicated in the schedule. I will expect you to come to class having made a first pass at the proper reading assignment and a first pass at doing the problems associated with that assignment. I intend to begin each class by sketching the general development of the topic at hand, and I will expect you to interrupt that sketch by asking questions along the way. My hope is that we will thus focus class sessions on the parts of the reading and problems that you have already identified as troublesome, confusing, mysterious, or unfathomable. I am going to try to resist the temptation to engage in lengthy lecturing (though we all know I may not be particularly successful in that endeavor).

DISCUSSION AND REVIEW SESSIONS: Five times during the term, no specific new topic is identified for the class session. On those occasions, the class will meet in two groups, one at 8:30 AM and the other at another time later on the same day. At each of these sessions, two or more students will be asked to present solutions to previously designated problems and further discussion of the current material will be in order.

CPL WORKSHOP: Once during the term the class will meet for a tutorial workshop in the CPL. For that session, the class will be divided in the same way that it is divided for the discussion and review sessions.

PROBLEMS: Beyond identifying the required readings in *NRQM* and optional readings in various texts, the schedule identifies several problems. Some—those in the group labeled 'Try'—relate to the material of the day and should be started as you read the material of the assignment; they may help you sharpen the questions you want to ask in the upcoming class session. Others—those in the group labeled 'Hand in'—are drawn from the group labeled 'Try' on previous day and are to be written out to be handed in at the beginning of the class.

The assigned problems provide a test that you understand the material covered by the assignment. *All problems to be handed in are to be written out neatly, including a careful explanation of your method of solution.* When there is computer output included, it should be carefully edit-

ted and incorporated smoothly into the narrative accompanying your solution. In the interests of your keeping abreast of the course and of my efficient grading, I ask that you turn in at each due date whatever of the assignment you have completed; do not withhold an entire assignment solely because you have not completed some of the problems.

COMPUTER: On several occasions during the term, you will find software available in the CPL to be a useful aid. Do not hesitate on your own initiative to use IDL, MAPLE, or any other computational tool whenever it seems appropriate. Some assignments will draw specific attention to one or another computational resource and expect you to use that resource in addressing the assignment.

All of you have accounts in the CPL and your access card has been configured to allow you to enter the CPL any time you wish. Sometime in the next couple of weeks, please spend a couple of hours either reviewing or learning for the first time (as the case may be) something about how to log in, do a few simple things, and log out. Copies of the Lawrence *Local Guide*, which describes how accounts are set up and includes a tutorial introduction to the UNIX operating system, are included in the materials used in Physics 225 last winter. There are also a couple of copies of the most recent printing of the *Local Guide* in notebooks in the CPL. A quick way to review your knowledge or start building it would be to work your way through Sections 1, 2.1, 2.2, 2.3 (if you wish), 2.4, 3, and 4.2 of the *Local Guide*.

In addition, you might find it valuable to review the basic capabilities of IDL and MAPLE by working your way through Chapter 2 (IDL) and Chapter 5 (MAPLE) in *CPSUP*. In Chapter 2, Sections 2.1, 2.2, 2.3, 2.8, and 2.10 would be particularly worth your attention. In Chapter 5, I would direct your attention first to Sections 5.1, 5.2, 5.3, 5.4,5 5.5, 5.6, 5.7, and 5.8.

All of this computer material was introduced in Physics 225, but a review could well be in order. I will leave you to your own initiative to refresh your understanding of our local computational resources *before* our first in-class use (which will be on Monday, 6 October).

EXAMINATIONS: There will be two closed-book hour examinations and a closed-book final examination in this course.

GRADING: Your grade in this course will be determined largely by your performance on the examinations, by your diligence and success in working the assigned problems, and by your attentiveness to the work of the class sessions. In particular, a final grade of A will be recorded only for those students who do exceptionally well on all three examinations and who *in addition* complete a substantial fraction (at least 90%) of the assigned problems successfully. Failure to complete some reasonable fraction (say 60-70%) of the assigned problems may depress whatever grade is earned on the examinations alone by as much as a full letter grade.

HONOR SYSTEM: Each of you is expected to present only his or her own work on the hour examinations and the final examination. In contrast, you are encouraged to work together on the assignments. Each of you is expected to write up your own assignments, but working together to solve the problems can be a valuable learning aid. I establish only two ground rules: (1) Working together will be most effective if all individuals contribute more or less equally to the group effort; you should be wary if you are always on the receiving end in such effort, for ultimately you will be expected to perform on your own. At the very least, once you have finished solving an exercise in a group, make sure that you could solve a similar exercise on your own. (2) Where substantial help has been received through conversation with another, I ask that you follow common scientific courtesy and acknowledge that help briefly in your submitted work.

PHYSICS 310: SCHEDULE FALL TERM, 2003

We 24 Sep The Nature of the Microscopic World
READ: *NRQM*, Chapter 1; Park, Chapter 1;
Griffiths, Preface (which is *really* good);
Gasiorowicz, Chapter 1; Feynman, Vol III, Lectures 1, 2

Fr 26 Sep The Quantum Mechanical Free Particle
READ: *NRQM*, Chapter 2, Sections 1–4;[1] Gasiorowicz, pp. 27, 41–48;
Griffiths, Chapter 1
(If you need help with complex numbers, look at Appendix C
in *NRQM* and try problem P1.15. Shankar's Chapter 5
also treats the basic ideas of complex numbers.)
PROBLEMS: Try: P2.1, P2.3, P2.4, P2.7, P2.10, P2.19
Hand in[01]:[2] P1.7, P1.11, P1.14, P1.18, P1.20

Mo 29 Sep Free Particle Wave Packets and Uncertainties
READ: Cook Chapter 2, Section 5; Gasiorowicz, Chapter 2;
Griffiths, Chapter pp. 44–50
PROBLEMS: Try: P2.8, P2.11, P2.12, P2.14, P2.15, P2.16
Hand in[02]: P2.3, P2.7, P2.10

We 1 Oct Discussion and Review
Note: Class will be divided. One half will come at 8:30 AM,
the other half at a time to be determined.
PROBLEMS: Try: P2.1, P2.4, P2.11, P2.12, P2.15, P2.16, P2.19
Hand in: None

Fr 3 Oct Particles That Aren't Free
READ: Cook Chapter 3, Sections 1–5; Gasiorowicz, pp. 49–70;
Griffiths, pp. 20–31
PROBLEMS: Try: P3.1, P3.4, P3.8, P3.10
Hand in[03]: (P2.11 or P2.14—your choice), P2.12, P2.15

Mo 6 Oct Bound States in One-Dimension
NOTE: This class session will be held in the CPL.
Note: Class will be divided. One half will come at 8:30 AM,
the other half at a time to be determined.
READ: *NRQM*, Chapter 3, Sections 6, 7; Saxon, pp. 121–131;
Schiff (3rd Edition), pp. 37–44, 66–74; Park, pp. 105–109;
Gasiorowicz, pp. 89–108; Griffiths pp. 31–44, 50–66
PROBLEMS: Try: P3.11, P3.12, P3.13, P3.16
Hand in[04]: P3.4, P3.10

[1]Readings in *NRQM* are required. Unless otherwise noted, the remaining readings are suggested supplements.
[2]The numbers in square brackets simply count the assignments.

We 8 Oct Discussion and Review
Note: Class will be divided. One half will come at 8:30 AM, the other half at a time to be determined.
PROBLEMS: Try: P3.17, P3.19, P3.21, P3.22, P3.25, P3.27
Hand in[05]: P3.11, P3.13, P3.16

Fr 10 Oct Scattering and Tunneling in One-Dimension
READ: *NRQM*, Chapter 4; Gasiorowicz, pp. 74–89; Griffiths, pp. 66–68; Solution to *CPSUP* Exercise 5.7
PROBLEMS: Try: P4.1, P4.3, P4.7, P4.11, P4.12
Hand in[06]: P3.21, P3.22, (P3.25 or P3.27—your choice)

Mo 13 Oct Quantum States and Representations
READ: *NRQM*, Chapter 5; Feynman, Vol III, Lecture 3; Griffiths, pp. 75–80; Shankar, pp. 229–247
PROBLEMS: Try: P5.1, P5.5, P5.7, P5.12, P5.13
Hand in[07]: P4.3, P4.7, P4.12

We 15 Oct Linear Operators: Eigenvalues, Observables, Expectation Values
READ: *NRQM*, Chapter 6, Sections 1–12; Griffiths, pp. 80–95, 104-108; Shankar, pp. 247–266
PROBLEMS: Try: P6.5, P6.6, P6.9, P6.10, P6.12, P6.13, P6.15, P6.17
Hand in[08]: P5.5, P5.7, P5.12

Fr 17 Oct Uncertainty, Degeneracy, Parity
READ: *NRQM*, Chapter 6, Sections 13–17; Appendix D Griffiths, pp. 108–112
PROBLEMS: Try: P6.11, P6.18, P6.21, P6.35, P6.36, P6.37
Hand in[09]: P6.5, P6.10, P6.12, P6.15

Mo 20 Oct Discussion and Review
Note: Class will be divided. One half will come at 8:30 AM, the other half at a time to be determined.
PROBLEMS: Try: Review previously identified problems in Chapter 6
Hand in[10]: P6.11, P6.18, P6.21, P6.35, P6.37

Tu 21 Oct (7:00–9:00 PM) DMC available in Y-107 for questions.

We 22 Oct HOUR EXAMINATION

Fr 24 Oct Systems with a Finite Number of States
READ: *NRQM*, Chapter 7; Feynman, Vol III, Lecture 5
PROBLEMS: Try: P7.1, P7.2, P7.3, P7.4, P7.5

Mo 27 Oct The Harmonic Oscillator (Operator Approach)
READ: *NRQM*, Chapter 8; Gasiorowicz, pp. 130–139
PROBLEMS: Try: P8.1, P8.2, P8.3, P8.4, P8.5, P8.6
Hand in[11]: P7.2, P7.5

We 29 Oct Extension to Three Dimensions; Coordinate Transformations
READ: *NRQM*, Chapter 9; Appendix G, Sections 1, 2
Gasiorowicz, Chapter 9
PROBLEMS: Try: P9.3, P9.8, P9.9, P9.14, B.2, B.6
Hand in[12]: P8.2, P8.3, P8.5

Fr 31 Oct Quantum Dynamics
READ: *NRQM*, Chapter 10, Sections 1, 2, 3, 4;
Griffiths, pp. 112–115
PROBLEMS: Try: P10.2, P10.3, P10.5, P10.6, P10.7
Hand in[13]: P9.8, P9.14*
* This one is a real bear, but everyone must do it once in a lifetime.

Mo 3 Nov Quantum Dynamics (continued)
READ: *NRQM*, Chapter 10, Sections 5, 6; Appendix B, Section 3
Feynman, Lecture 8, Gasiorowicz, pp. 139–141
PROBLEMS: Try: P10.10, P10.12, P10.13, B.8, B.10
Hand in[14]: P10.2, P10.3, P10.6

We 5 Nov Discussion and Review
Note: Class will be divided. One half will come at 8:30 AM, the other half at a time to be determined.
PROBLEMS: Try: P10.11, P10.14
Hand in[15]: P10.12, P10.13, B.10

Fr 7 Nov MID-TERM READING PERIOD (No Class)

Note: DMC will be available for questions and discussion on most of Thursday and Friday during this reading period. Firming up your grasp of Chapter 10 and getting a head start on Chapter 11 would be valuable activities.

Mo 10 Nov Angular Momentum Eigenvalues; Spin-1/2
READ: *NRQM*, Chapter 11, Sections 1,2; Griffiths, pp. 145–165;
Gasiorowicz, pages 168–175, Chapter 11, Chapter 14;
Feynman, Lecture 6, 7-5
PROBLEMS: Try: P11.3, P11.4, P11.6, P11.7, P11.9, P11.10, P11.12
Hand in[16]: P10.14

We 12 Nov Addition of Angular Momentum
READ: *NRQM*, Chapter 11, Section 3; Gasiorowicz, Chapter 15; Griffiths, pp. 165–170
PROBLEMS: Try: P11.18, P11.20, P11.21, P11.23, P11.24, P11.25
Hand in[17]: P11.6, P11.9, P11.10, P11.12

Fr 14 Nov Bound States in Spherically Symmetric Potentials
READ: *NRQM*, Chapter 12, Sections 1–6; Griffiths, pp. 121–133; Gasiorowicz, pp. 175–188
PROBLEMS: Try: P12.3, P12.5, P12.6, P12.20
Hand in[18]: P11.18, P11.21, P11.25

Mo 17 Nov The Hydrogen Atom
READ: *NRQM*, Chapter 12, Sections 7–11; Park, Chapter 14; Gasiorowicz, Chapters 12 and 17; Griffiths, pp. 133–144;[3] Shankar, pp. 318–329
PROBLEMS: Try: P12.13, P12.15, P12.16, P12.21, P12.22, P12.24, P12.25
Hand in[19]: P12.5, P12.20

We 19 Nov Discussion and Review
Note: Class will be divided. One half will come at 8:30 AM, the other half at a time to be determined.
PROBLEMS: Try: Review previously identified problems in Chapters 7–12
Hand in[20: P12.13, P12.15, P12.25

Th 20 Nov (7:00–9:00 PM) DMC available in Y-107 for questions.

Fr 21 Nov HOUR EXAMINATION

Mo 24 Nov Time-Independent Perturbation Theory
READ: *NRQM*, Chapter 13, Sections 1–4; Gasiorowicz, Chapter 16; Griffiths, Chapter 6
PROBLEMS: Try: P13.2, P13.3, P13.10

We 26 Nov NO CLASS – THANKSGIVING HOLIDAY

Fr 28 Nov NO CLASS – THANKSGIVING HOLIDAY

Mo 1 Dec Time-Independent Perturbation Theory
READ: Material identified for 24 Nov. This also might be a good time to read Griffiths *Afterword*, pp. 374–385.
PROBLEMS: Try: P13.12, P13.21, P13.22
Hand in[21]: P13.2, P13.10

[3] At least some of the readings in Gasiorowicz, Chapter 17, and Park are required. These texts deal with assorted corrections to the simple Schrödinger solution for the hydrogen atom and take into account various relativistic effects, mass corrections, and spin-orbit interactions.

We 3 Dec Time-Dependent Perturbation Theory
READ: *NRQM*, Chapter 13, Sections 6, 8–11; Griffiths, Chapter 9; Gasiorowicz, pp. 341–345, 352–362
PROBLEMS: Try: P13.20, P13.23, P13.25
Hand in[22]: P13.21, P13.22

Fr 5 Dec Systems of Particles[4]
READ: *NRQM*, Chapter 14; Gasiorowicz, Chapter 8; Feynman, Lecture 4; Griffiths, Chapter 5, especially pp. 177–193
PROBLEMS: Try: P14.1, P14.2, P14.4, P14.5
Hand in[23]: P13.20, P13.23

Sa 6 Dec PROBLEMS: Hand in at 12:00 noon[24]: P14.2, P14.4, P14.5

Mo 8 Dec (7:00–9:00 PM) DMC available in Y-107 for questions.

Tu 9 Dec (1:30 PM) FINAL EXAMINATION

[4]If the presidential search progresses according to the anticipated schedule, DMC will be out of town to interview candidates on 5 and 6 December. Should that schedule become reality, some adjustment—either rescheduling or a substitute instructor—of the class on 5 December will be necessary. Stay tuned for further announcements.