

**General Information (corrected, updated)**

**Instructor:** John Collins  
Office: 303K Osmond  
Phone: 3-0783  
E-mail: [collins@phys.psu.edu](mailto:collins@phys.psu.edu)  
Course web-site: <http://www.phys.psu.edu/~collins/563/>

**Lecture times:** MWF 12:20–1:10 pm in 116 Osmond, (First class is Monday Aug. 24.) My slides are usually *outlines* of the lectures, together with graphs (etc) and some key formulae.

**Discussion period:** Tuesdays 5:00pm–6:00pm, in 339 Davey, starting Sep. 1.

**Office hours:** Friday 10:00–11:00 am.

**Exam times:** Final: Take-home exam due Wed. Dec. 16.

**Course Objectives for Phys. 563 and 564:** To understand the principles of relativistic quantum field theory, including all the main tools needed for work on the standard model that encompasses strong, electromagnetic and weak interactions. The level of understanding is that of a future physics professional in elementary particle theory and related fields, although the course should be accessible to elementary particle experimentalists and many other physicists. You will have the tools necessary to carry out further study and research.

Starting on page 6 is the list of topics that are planned to be covered in this course and the continuation course Phys. 564.

**Homework:** As usual in physics courses, it is essential to work problems on the course material. You do not fully understand the principles of an area of physics until you can apply them. Since the object of the homework is to help you learn quantum field theory, I have assigned a minority of the course grade to homework. This of course does not reflect the importance of doing the homework or the time involved. If you find difficulties, the homework and my comments on it will assist you in learning. It is on the exam(s) that you have to get it right.

I will post solutions to all the homework problems on the course website and in a folder in the library. The library folder may be borrowed for short periods. You will be able to check your solutions against mine, particularly for any problems I choose not to grade. If you have questions, please feel free to discuss them with me.

For those of you who find this useful, I encourage you to discuss the *homework* (not the exam(s)) together and even to work on it together. This is normally

best in small groups. You may well find, for example, that the effort of explaining the course material to others will assist your own learning. However, unless I suggest otherwise for specific assignments, *you should write up the homework separately* from others in your group to ensure you have your own personal understanding of the material.

**Discussion session:** I will continue the practice of holding a weekly discussion session at a time that is maximally convenient to the participants in the class. The time slot I listed above is based on previous year's experiences as the least likely to cause a conflict.

While participation in the discussion session is strictly optional, and you are always welcome to consult me at other times, e.g., my office hour, many students in previous years have found the discussion session very helpful. The style is quite informal, and participants can feel free to raise all kinds of issue, e.g., from conceptual difficulties to problems with the homework.

I have also found the discussion session useful to help me to adjust the pedagogy of the course to the actual needs. Sometimes issues have been worked out and clarified in a discussion session and then have found their way into a more formal presentation in the next lecture.

**Grading:** 45% homework  
55% final exam

I may assign an essay during the semester. If so, I will assign a part of the numerical course grade to it and reduce the percentages for one or both exams.

The meanings of the letter grades, with the *approximate* boundary lines in the numerical grades, are:

A = "Excellent", full understanding of quantum field theory, as appropriate for a professional physicist. A and A-: above about 82%;  
B = "Good". B-, B, and B+: about 62-81%;  
C = "Acceptable but substandard". C: about 50-61%.

(The quoted definitions are those made by Penn State University.) I will adjust the boundaries that relate letter grades and numerical scores depending on my judgment of the difficulty of the examinations.

The final exam will be open book and open notes; it will also be a take-home exam.

**Collaboration:** Examinations are to be the individual work of the students in the course, and collaboration or copying is not allowed.

However, to a certain extent, collaboration on the homework assignments is allowed and even encouraged in this course—see the comments above.

## Books

### OFFICIAL TEXTBOOK FOR COURSE

The books marked by ‘\*\*’ are on reserve in the library in Davey Lab. The catalog numbers in the library are indicated (e.g., “QC174.45.P465 1995”).

- \*\* M. Srednicki, “Quantum Field Theory” (Cambridge University Press, 2007). ISBN 978-0-521-86449-7. This is a very good book, mostly very compatible with the way I teach this course, much more so than any other book. For errata, see <http://www.physics.ucsb.edu>

Note: The space-time metric is opposite to that often used in high-energy physics, and therefore in many textbooks, but it should agree with the one used in the general relativity course.

### OTHER SOURCES OF INFORMATION ON ELEMENTARY PARTICLE PHYSICS

- Particle Data Group: <http://pdg.lbl.gov/>
- SPIRES database for articles: <http://www.slac.stanford.edu/spires/hep/>
- E-print archive: <http://arxiv.org/>, especially the categories hep-ph, hep-th, hep-exp, and hep-lat.

### OTHER IMPORTANT BOOKS ON QUANTUM FIELD THEORY

- \*\* M.E. Peskin and D.V. Schroeder, “An Introduction to Quantum Field Theory” (Addison-Wesley, 1995). ISBN 0-201-50397-2. QC174.45.P465 1995. An useful book, with broader coverage than Serman of physics topics. It also contains a helpful introduction.
- \*\* G. Serman, “Quantum Field Theory” (Cambridge University Press, 1993) ISBN 0-521-31132-2 (pbk). QC174.45.S78 1993. It is solid and reliable, but rather biased towards QCD.
- \*\* S. Weinberg, “The Quantum Theory of Fields”: “Volume I Foundations” (Cambridge, 1995) ISBN 0-521-55001-7. QC174.45.W45 1995 v.1. “Volume II Modern Applications” (Cambridge, 1996) ISBN 0-521-55002-5. QC174.45.W45 1995 v.2. These are the first two volumes of a three volume set. They are good and comprehensive. But they are probably too big and sophisticated for a first learning of the subject.  
Volume III of the series is about supersymmetry, a topic we will probably have no time to cover in these courses.
- \*\* L.S. Brown, “Quantum Field Theory” (Cambridge University Press, 1994). ISBN 0-521-46946-5 (pbk). QC174.45.B79 1994  
This is an excellent book pedagogically. It includes some material not easily available elsewhere, including non-relativistic quantum field theory and its relation to many-body theory. It doesn’t go to the more advanced topics (e.g., non-abelian gauge theories).

- M. Stone, “The Physics of Quantum Fields” (Springer, 2000) ISBN 0–387–98909–9. QC174.45.S66 2000. This is a small but masterful book that shows how quantum fields work in both elementary particle physics and condensed matter physics. *For condensed matter physicists taking Phys. 563 and 564, this book is probably essential reading.* However it does not cover many of the topics that are needed for the standard model, and must be supplemented by another text.  
It also includes material on the Schrödinger field, in Ch. 10.
- M. Maggiore, “A modern introduction to quantum field theory” (Oxford University Press, 2005) ISBN: 0198520735 QC174.45.M24 2005.
- C. Itzykson and J.-B. Zuber, “Quantum Field Theory”. QC174.45.I77. This is excellent and encyclopedic, but intimidating. Once you are acquainted with this subject, it is a useful reference. But it does not treat all the physical applications in an up-to-date fashion—it was published in 1980. Even so, it is still in print.
- I. Aitchison and A.J. Hey, “Gauge Theories in Particle Physics” (2nd ed.) QC793.3.F5A34 1989. This is a useful book on elementary particle phenomenology. Students who possess this book will find it helpful.
- J.D. Bjorken and S.D. Drell: “Relativistic Quantum Mechanics”, QC174.1.B52. “Relativistic Quantum Fields”, QC174.1.B52 These classics are old (mid 1960s), so the physics is pre-Standard-Model. But their treatment of the principles is excellent, for the most part. Their treatment of renormalization is extremely difficult to read.
- F. Halzen and A. Martin, “Quarks and Leptons, an Introductory Course in Modern Particle Physics”, QC793.5.Q2522H34 1984. A useful introduction to the phenomenology of the standard model.
- F. Mandl and G. Shaw, “Quantum Field Theory” (Wiley 1984) QC174.45.M32 1984. This is an excellent book, with plenty of problems. Unfortunately it provides no coverage of QCD, even though it was published in 1984.
- S. Pokorski, “Gauge field theories” (Cambridge University Press, 1987) QC793.3.F5P65 1987 A useful book particularly for nonabelian gauge theories, which we will mostly cover in 564.
- P. Ramond, “Field Theory: A Modern Primer” (2nd ed.). QC174.45.R35 1989. This provides a nice treatment of functional methods. But it is rather unbalanced: in the 1st edition at least, it was hard to work out from the book how to compute a cross section!
- L. Ryder, “Quantum Field Theory”. QC793.3.S9R9. Good, especially for the functional integral formulation. But it does some things badly wrong.

## OTHER BOOKS

- J.C. Collins, “Renormalization” (Cambridge). QC174.17.R46C65. This is a commercial.
- A. Pais, “Inward Bound” (Oxford, 1986). QC21.2.P35 This is a nice historical account of the development of elementary particle physics starting from the nineteenth century. It includes an account of the discovery (or invention) of quantum field theory.
- \*\* B.L. van der Waerden, “Sources of quantum mechanics” (Dover, 1968) QC174.1.W3. Contains some of the founding papers of quantum mechanics, translated into English when the original is in German. These are useful to understand why the textbook rules of quantum mechanics are what they are, and what leeway we have for setting up quantum field theory. But the all important section on quantum electromagnetism of the Born-Jordan paper is missing in the translation. I have a translation: [http://www.phys.psu.edu/~collins/563/born\\_jordan.pdf](http://www.phys.psu.edu/~collins/563/born_jordan.pdf).
- J. Ziman, “Elements of Advanced Quantum Theory”, (Cambridge UP, 1969). QC174.1.Z49. Useful introduction to the basics of field quantization and many body theory from the point of view of a solid-state physicist.
- D. Lurie, “Particles and Fields” (Interscience, 1969). QC721.L98. Excellent treatment of scattering theory, but very pre-Standard-Model. I don’t like the imaginary time metric used. Out of print.
- R.F. Streater and A. Wightman, “PCT, Spin and Statistics and All That” (Benjamin, 1964). 530.12St83p. A good book on axiomatic field theory.
- R.J. Rivers, “Path Integral Methods in Quantum Field Theory” (Cambridge University Press, 1987). QC174.52.P37R58
- A.L. Fetter and J.D. Walecka, “Quantum theory of many-particle systems” (McGraw-Hill, 1971). QC174.5.F47  
Application of QFT to (non-relativistic) many-body systems: condensed matter and nuclear physics. Includes good treatment of Schrödinger field.

## List of topics to be covered this semester (approximately)

- Background, motivation, history
- Relativistic fields:
  - Klein-Gordon,
  - Mention Maxwell field. But this and other relativistic fields are to be treated in detail later.
- Lagrangians and Hamiltonians for field theories
- Quantization of field theories
- Non-relativistic fields: Schrödinger field
- Fermionic version
- Noether's theorem: Symmetries and conservation laws
- Lorentz and Poincaré groups
- Representations of Poincaré group
- Perturbation theory, Wick's theorem, and Feynman rules for Green functions, both relativistic and nonrelativistic
- Functional integrals
- Relation between Lagrangian and Feynman rules
- Scattering and LSZ reduction.
- Cross sections

Mathematical topics that are used in the subject, and will be reviewed as needed include:

- Complex analysis
- Group theory
- Theory of distributions/generalized functions

## List of topics to be covered in Phys. 564 next semester (approximately)

- Renormalization
- Renormalization group
- Representations of Lorentz group
- Dirac field
- Yukawa theory
- Discrete symmetries: C, P and T
- Abelian gauge fields: Maxwell field
- QED
- Infra-red divergences
- Non-abelian gauge fields (Yang-Mills fields)
- Spontaneous symmetry breaking: Goldstone and Higgs mechanisms
- Standard model of particle physics: QCD and Weinberg-Salam.
- Possibly: Operator product expansion
- *Possibly*: It would be nice to have something on nonperturbative phenomena and on bound states.