PHYS 40602 RELATIVISTIC QUANTUM PHYSICS

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This course draws together two of the key ideas from 20th century physics: special relativity and quantum mechanics. Combining these provides a framework for describing the interactions of particles at high energies or short distances. This framework, quantum field theory, underpins all our current theories of particle physics as well as much of nuclear and atomic physics.

As well as having a very wide scope, relativistic quantum mechanics is, as we shall see, much more complicated than the familiar nonrelativistic version. A first course like this has to be very selective. In it we shall focus on the general features of the framework, using simple examples to illustrate the range of physics which it can describe. The aim is to give you a flavour of the power of the principles of relativity and quantum mechanics when they are combined into quantum field theory. (This is not a course on the "nuts and bolts" of calculations in field theory nor on "stamp collecting" of particles and forces.)

Prerequisites

The only prerequisites for this course are the quantum mechanics courses (PHYS 30101, 30602)[1] and introductory relativity. Some background in classical relativistic field theory, from electrodynamics (PHYS 30642), would be helpful but is not essential. Ideas and techniques from the other "theory" courses—Lagrangian dynamics (PHYS 20401), mathematical methods (PHYS 30672) and complex variables (MATH 20612)—will not be required, although you will find them useful if you wish to learn more about quantum field theory beyond the level of this course. Good mathematical skills are essential.

Recommended books

There are two good books which cover the material for the course:

F. Gross, *Relativistic quantum mechanics and field theory* (Wiley, 1993)

I. J. R. Aitchison and A. J. G. Hey, *Gauge theories in particle physics, Volume 1: From relativistic quantum mechanics to QED*, 3rd edition (IOP, 2003)

Other useful books are listed in the handout on textbook references.

[1]In previous years, PHYS 40401 was also listed as a prerequisite but that course no longer exists. However the only crucial concepts needed from it were those of creation and annihilation operators and these were also covered in PHYS 30602. In any case you should try the "revision" questions on Examples 1 as soon as possible. If you find that you have problems with these you should study the relevant chapters of Gasiorowicz (3, 4, 7, 13, 14), or a similar book on quantum mechanics. If you are not familar with the idea of a scattering cross section, you should also look at Chapter 24 of Gasiorowicz.

Examples sheets

The six examples sheets form an integral part of this course. The questions are largely extensions or variations of the topics discussed in the lectures. The examination will consist of similar questions and so model answers will not be issued. Bottom-line answers (and in some cases important intermediate results) will be given either in the questions or in the lectures. More details can often be found in textbooks and so you should make full use of a range of these. You are encouraged to work together on the problems and to build up your own set of "model answers".

Assessment

Undergraduate students: Assessment is by a 1.5 hour exam in May/June.

Postgraduate students: In addition to the same exam, there is an element of coursework. This consists of question 6 on Examples 3, question 4 on Examples 4, and question 4 on Examples 6. The final marks on the exam and course work will be combined with a weighting of 2:1. Deadlines for handing in work will be specified nearer the time.

Webpage

I have set up a webpage with links to copies of the examples sheets and other documents for the course. This can be found at:
`http://theory.physics.manchester.ac.uk/~mikeb/lecture/phys40602/`

Course outline

1. Relativistic wave equations

Klein-Gordon equation

Dirac equation

Positive- and negative energy solutions

Conserved currents

Interactions with EM fields

Particle in a spherical potential

The MIT bag model

2. Quantum fields and their dynamics

Klein-Gordon field

Dirac field

Antiparticles

Feynman propagator

Interaction picture and the S-matrix

Covariant perturbation theory

Feynman diagrams and rules

Decay processes

3. Scattering processes

Exchange of virtual particles

Cross sections

Scattering of charged particles

e^-e^+ annihilation

High-energy scattering

Form factors

Deep-inelastic scattering and partons

Mike Birse (January 2010)