PHYS 30121 INTRODUCTION TO NUCLEAR AND PARTICLE PHYSICS

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Overview

In previous courses, we have seen how quantum mechanics governs the structures of atoms and solids, and hence the properties of matter as we know it. In this course, we shall look inwards to the hearts of atoms – nuclei – and beyond, to the basic constituents of matter and the forces between them.

These involve distance scales that we cannot experience, even indirectly. Instead we have to rely on rare natural processes – radioactivity – or beams of particles from accelerators – from the first cyclotrons less than 1 m across to the 27 km of superconducting magnets in the LHC. Detecting these phenomena also requires special devices: originally photographic plates and gold-leaf electroscopes, and now giant barrels filled with arrays of radiation detectors as in ATLAS and CMS.

A full description of physics on these scales requires both quantum mechanics and special relativity. These can be combined into the framework of quantum field theory, probably the most complex type of theory we have that describes nature. Even if we treat nucleons as nonrelativistic, solving the Schrödinger equation is challenging when we have three strongly interacting particles, let alone 238 of them. New phenomena – collective motions, breaking of symmetries, confinement – can emerge from seemingly simple interactions in these systems of fields and particles. In this course, we shall not attempt to describe them from first principles but instead we shall look at the patterns that are observed, and what these can tell us about the underlying physics.

Despite their small sizes, these subatomic systems have important consequences for physics at much larger distances. Nuclear reactions power the Sun and all other stars, and hence are responsible for the origin of elements that we are formed of. Quarks, leptons and their interactions have played key roles in the evolution of the Universe from an unimaginably hot Big Bang to the form we see today. Closer to home, unstable nuclei or nuclear reactions are central to cancer treatment, to imaging techniques in medicine, to archeological and geological dating, and to the production of energy without burning fossil fuels.

The boundary between nuclear and particle physics is a fuzzy one, not suprisingly since nuclei are only a few times larger than protons. In fact the distinction is more about sociology than physics. Originally there was just "subatomic" physics. Then, as the range of energies that could be probed grew, a split developed between people focussed on discovering the fundamental laws of nature and people working on the complicated dynamics that emerges from them. More recently the two subfields have come together in work on topics such as the determination of neutrino masses and the hunt for dark matter.

Textbooks

There are several good books that cover both nuclear and particle physics at this level:

- B. R. Martin, *Nuclear and particle physics: an introduction*, 2nd ed (Wiley, 2008)
- E. M. Henley and A. Garcia, *Subatomic physics*, (World Scientific, 2007)
- B. Povh, K. Rith, C. Scholz and F. Zetsch, *Particles and nuclei*, 6th ed (Springer, 2008)

Of these Martin's book is the one I recommend particularly, as it is closest to the the approach I take, and it does most to link the two areas.

There are also more specialised books on each of these which will be useful for the courses next semester or in fourth year:

- K. S. Krane, *Introductory nuclear physics*, (Wiley, 1988)
- S. S. M. Wong, *Introductory nuclear physics*, 2nd ed (Wiley, 1998)
- B. R. Martin and G. Shaw, *Particle physics*, 3rd ed (Wiley, 2008)
- D. H. Perkins, *Introduction to High Energy Physics*, 4th ed (CUP, 2000)

I may dip into these from time to time for more details of some of the phenomena we shall be studying.

Examples

I know you've heard this before, but the only way to become familiar with physical techniques is to *use* them. This is particularly true of this course, where the skills required are a bit different from other courses you have taken so far. You need to recognise patterns and apply logical reasoning, rather than follow mathematical derivations. Without those patterns, the subject could seem like a mountain of facts to be remembered separately.

I will provide examples sheets to give you some practice on the ideas and methods from each section of the course. There will be four examples classes devoted to this course, which will give you opportunities to get help with these examples and to work on them with other students, or to ask any questions you may have about the course. More examples can be found in the recommended textbooks.

Webpage

I have set up webpages for the course at:
`http://theory.physics.manchester.ac.uk/~mikeb/lecture/phys30121/`
I will post my lecture summaries, handouts, examples and solutions there. Other material for the course can be found on Blackboard: `https://online.manchester.ac.uk/`

Mike Birse (September 2018)