Part II Particle and Nuclear Physics 2024

1 Prerequisites

This course assumes familiarity with many of the topics in the "Advanced Quantum Physics" course.

2 Learning Outcomes and Assessment

At the end of the course, the students should be familiar with the following features of Particle Physics:

- how forces arise from virtual particle exchange (in outline only);
- the particle content and interactions of The Standard Model, together with an understanding of how to apply (spinless) Feynman Diagrams to make order-of-magnitude estimates for rates and signatures of allowed/disallowed Standard Model processes;
- the types of evidence upon which the three key parts of The Standard Model (i.e. electromagnetic, strong and weak), are founded;
- how to determine which hadron decays would or would not be consistent with the quark content of the Standard Model, with parity violation/conservation, with energy-momentum conservation, etc.

and with the following aspects of Nuclear Physics:

- the structure of nuclei, and simple nuclear models such as the liquid drop model and the shell model;
- techniques in scattering theory which are relevant in nuclear physics – partial waves, Born approximation and compound nucleus formation;
- the main types of nuclear decays, and with models for calculating these and the associated selection rules;
- the key features of nuclear fission and fusion and their applications;

3 Synopsis

INTRODUCTION
Matter and Forces: Matter and generations. Leptons, quarks, hadrons and nuclei. Forces and gauge bosons.
Kinematics, Decays and Reactions: Natural units. Relativistic kinematics (Four-vectors, invariant mass, colliders and $\sqrt{s}$). Particle properties (mass, spin parity, decays, scattering). Particle decays and transition rates. Resonances and partial decay widths. Reactions and cross sections. Scattering.

PARTICLE PHYSICS

The Standard Model: Summary of the Standard Model of particle physics. Theoretical framework. Klein-Gordon and Dirac equations. Antimatter. Interaction via particle exchange. Yukawa potential. Virtual particles. Feynman diagrams. Colliders and detectors

Electromagnetic Interaction: QED. Gauge invariance. Electromagnetic interaction vertices. Scattering in QED. Discovery of quarks. Drell-Yan process. Experimental tests of QED. Higher orders and running of α.

Strong interaction: QCD. Strong interaction vertices. Gluons, colour and self-interactions, colour factors. QCD potential, confinement and jets. Jets. Running of the strong coupling. Scattering in QCD. Experimental evidence for gluons, colour, self-interactions and the running of α_{s}.

Quark Model of Hadrons: Hadron wavefunctions and parity. Light quark mesons and masses. Baryons, baryon masses and magnetic moments. Hadron decays. Discovery of the J/Ψ. Charmonium. Charmed Hadrons. Discovery of the Υ. Bottomonium and bottom hadrons.

Weak Interaction: Bosons and self-interactions. Weak charged current ($\mathrm{W}^{\pm}$ boson). Parity violation. Weak charged current lepton vertices. μ and τ decay. Lepton universality. Weak charged current interactions of quarks. Cabibbo suppression and the CKM matrix. Weak charged current quark vertices

Electroweak Unification: Neutral currents (Z^0 boson). Electroweak Unification and the Glashow-Weinberg-Salam Model. Weak neutral current vertices and couplings. Summary of Standard Model vertices and drawing Feynman diagrams. Precision tests of the Standard Model at the Large Electron Positron collider (LEP). The top quark. The Higgs mechanism and the Higgs boson.

The Standard Model and Beyond: Incompleteness of the Standard Model. Neutrino oscillations. Beyond the Standard Model - supersymmetry.

NUCLEAR PHYSICS

Basic Nuclear Properties: Stable nuclei. Binding energy. Nuclear mass (Semi-Empirical Mass Formula). Spin and parity. Nuclear size. Nuclear moments.

The Nuclear Force: General features. The deuteron. Nucleon-nucleon scattering.

Nuclear Structure: Magic numbers, the Nuclear Shell Model and its predictions, excited states of nuclei (vibrations and rotations).

Nuclear Decay: Radioactivity and dating. α decay. β decay, Fermi theory of β decay. γ decay.

Nuclear Fission and Fusion: Nuclear fission. Reactors. Nuclear fusion. Nucleosynthesis. Solar Neutrinos.

BOOKS

Nuclear physics books (Krane is closest to the course):

Introductory Nuclear Physics, Krane K S (Wiley 1988).

Basic Ideas and Concepts in Nuclear Physics, Heyde K (3rd edn CRC Press 2004).

Fundamentals of Nuclear Physics, Jelley N (CUP 1990).

Particle physics books (Perkins is closest to the course; Thomson or Griffiths are good if you want to go beyond):

Introduction to High Energy Physics, Perkins D H (4th edn CUP 2000).
Particle Physics, Martin B R & Shaw G (3rd edn Wiley 2008).
Introduction to Elementary Particles, Griffiths D J (2nd edn Wiley 2009).
Modern Particle Physics, Thomson, M A (CUP 2013)

Introductory books that cover the whole course, (at a lower level generally):

Nuclear and Particle Physics, Martin B R (2nd edn Wiley 2009).
The Physics of Nuclei and Particles, Dunlap P A (Thomson Brooks/Cole 2003).