Nuclear Physics and Astrophysics

PHY-302

Dr. E. Rizvi

Lecture 1 - Introduction

Queen Mary
University of London

Introduction

- Course Organiser: Dr E. Rizvi (room 401)
  Deputy: Prof. J. Emerson

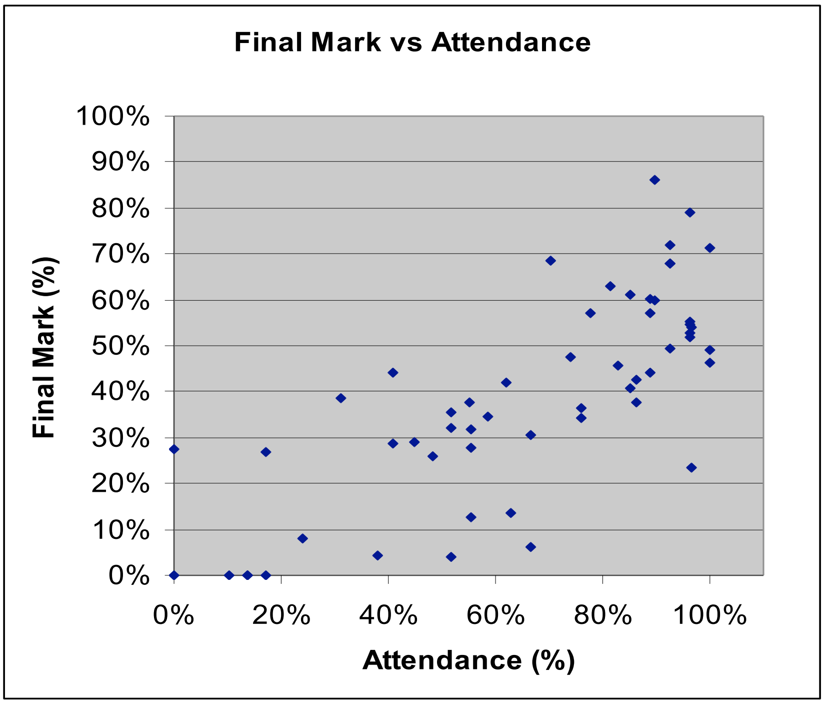
- My Office hours 10^{00} – 11^{00} Thursday

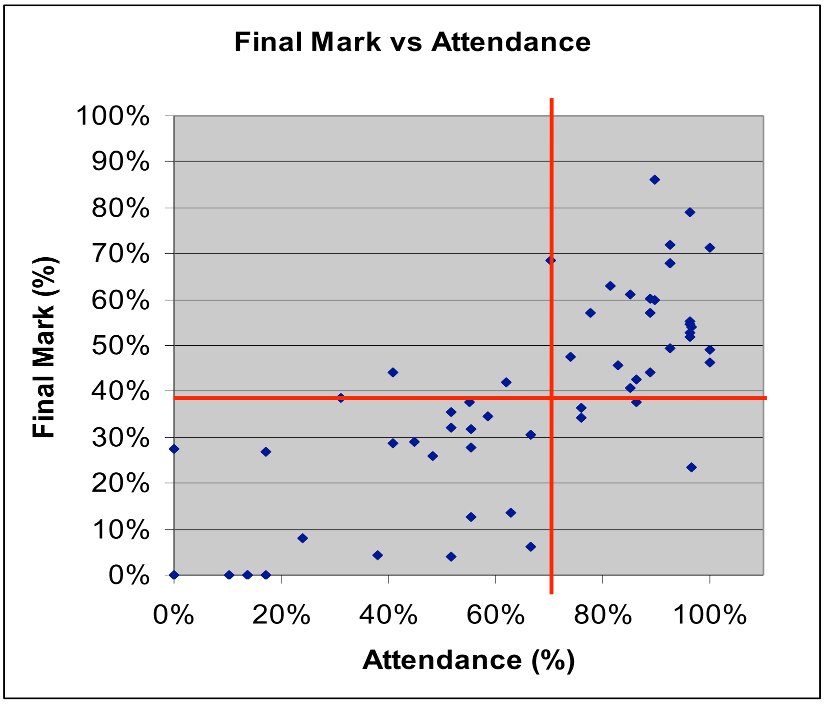
- 3 lecture slots per week

Thursday	09^{00} - 10^{00}	Francis Bancroft - David Sizer Lecture Theatre
Thursday	12^{00} - 13^{00}	Arts One Lecture Theatre
Friday	13^{00} – 14^{00}	Peoples Palace 2

Good news:
There are only ~3 homework sets for this module

Exercise classes will begin on Monday 2pm, 3pm, 4pm
Please sign up to one group at today's pm lecture





You have a much better chance of passing this course if you attend lectures!

Assessment

- Final Examination 70% of final mark
- Midterm exam 10% of final mark
- Homework 10% of final mark
- In-class debate 10% of final mark

Midterm exam will take place in week 8 - after reading week

<u>In-class debate</u>
We will discuss and fundamental concepts of nuclear physics in class
I will test your understanding in class using electronic voting
Each of you must collect a "clicker" from Pete/Saqib in 2nd floor lab
Pay £10 deposit - returned at end of this semester
Answer multiple choice questions in class

Some questions will be "formative" i.e. not marked at all
Other questions will be "summative" i.e. test understanding:
- You get 1 mark for participating in the discussion around each question
- You get 4 marks for a correct answer

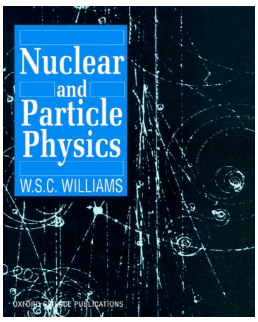
To facilitate this you are **required** to read through the online lecture notes **before** each lecture
Prepare a list of questions you do not understand
Read the relevant sections of the text books

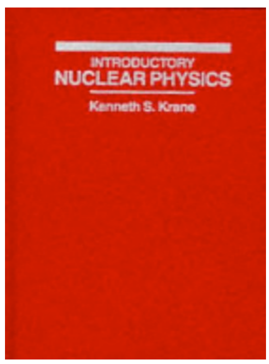
Introduction

Course Information available on web at:
http://ph.qmul.ac.uk/course/phy-302
will be continuously updated during course

Recommended books for the Nuclear Physics Course

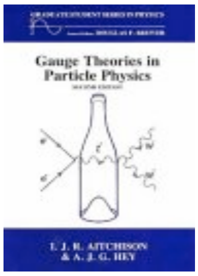
Nuclear and Particle Physics
W. S. C. Williams
Paperback - Clarendon Press;
ISBN: 0198520468



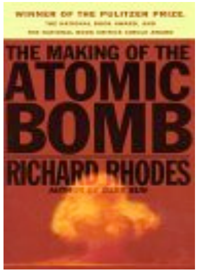


Introductory Nuclear Physics
K. S. Krane
Hardcover - John Wiley and Sons
ISBN: 047180553X

Nuclear Physics – Advanced Further Reading



Particle Physics
Gauge theories in Particle Physics
I.J.R. Aitchison, A.J.G. Hey
ISBN: 0852743289



Atomic Bomb
The Making of the Atomic Bomb
Richard Rhodes
ISBN: 0684813785

Medical Nuclear Physics
Physics for Diagnostic Radiology
P.P. Dendy, B. Heaton
ISBN: 0750305916

What is Nuclear Physics ?

It is the study of the phenomena of the atomic nucleus

Understand:

- composition - what is it made of?
- properties - size, mass, charge, angular momentum
- structure - do nuclei have internal structure?
- interactions - how do nuclei interact with everything else?
- decays - how and why do some nuclei decay

Why Study Nuclear Physics ?

Plays an important part in our lives

Nuclear Fission : Source of energy from reactors / weapons

Nuclear Fusion : Maintains (nearly) all life

Creation of all the heavy elements – Nucleosynthesis

Possible future source of low pollution energy

Radioactive Decay: carbon dating, smoke alarms

Isotope Abundances: isotope ratios ⇒ paleoclimate temp. proxies !

Medical Applications: Diagnostic Uses Imaging

Therapeutic uses for cancer treatment

An understanding of nuclear physics will enable you to make an informed contribution to the debate on the the use of nuclear materials and science and to understand their limitations and their benefits

What We Know About Nuclear Physics

- Early Nuclear Experiments (How we know what we know!)
- Nuclear Sizes (scales, ranges)
- Application of Quantum Mechanics to Nuclear Phenomena
- Nuclear Forces (magnitude of the forces, mechanisms)
- Nuclear Models (A very brief introduction to the types)

Borrow ideas from atomic physics

nucleus is a complex quantum system

exact calculations not really possible

use several simplified models to describe different phenomena

NUCLEAR SIZE AND SHAPE
Experimental determination of the size and shape of atomic nuclei
Rutherford scattering.

RADIOACTIVE DECAY
Introduction to radioactive decay and the exponential decay law
Implications for isotope production and use in archaeological dating.

NUCLEAR MODELS
Derivation of the masses, binding energies and spin of atomic nuclei from simple models general conditions on the stability of nuclei and nuclear disintegration via radioactive decay and spontaneous fission.

NUCLEAR REACTIONS
Nuclei-Nuclei collisions as a probe of nuclear properties and reaction kinematics.

ALPHA DECAY
Alpha decay as a tunnelling process.

BETA DECAY
The weak interaction and beta decay. Introduction to the neutrino and a discussion of symmetry principles in physics

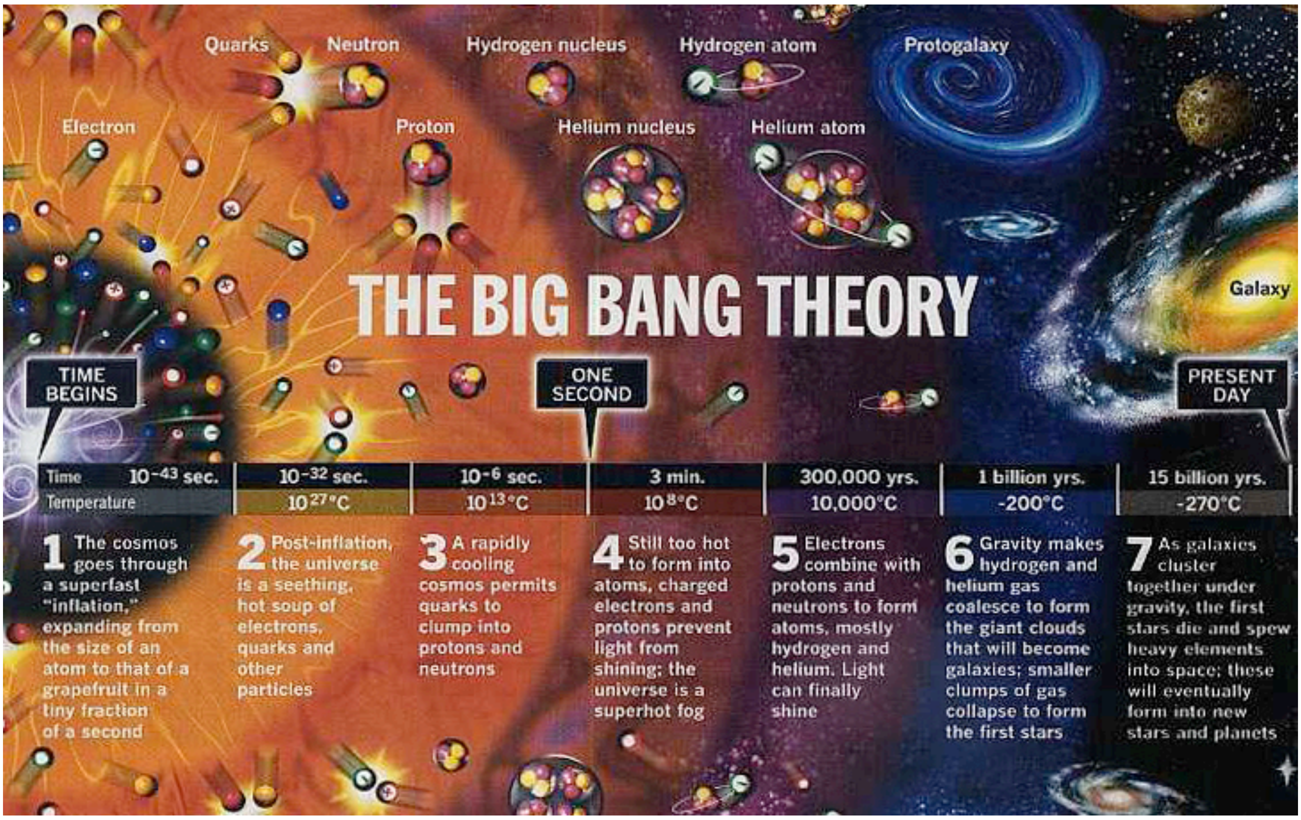
GAMMA DECAY
De-excitations of nuclei via photon emission

NEUTRONS AND URANIUM
The study of neutron induced reactions and specific attention to the uranium system and fission reactions.

FUSION AND NUCLEOSYNTHESIS
Fusion in light nuclei and the solar cycle. Synthesis of heavy elements in stars and in stellar explosions.
Primordial nucleosynthesis just after the Big Bang.

PARTICLE PHYSICS AND COSMOLOGY
We examine the Standard Model of particle physics and its relation to the structure of the universe.

MEDICAL APPLICATIONS AND OTHER APPLICATIONS
The use of radioisotopes and radiation beams in medical diagnosis and treatment.



1895 The discovery of X-rays by Wilhelm Röntgen from discharge tubes & fluorescent plates

1896 Henri Becquerel investigated fluorescence in uranium salts. His photographic plates were fully exposed <u>before</u> coming close to discharge tubes: discovery of radioactivity

1897 Investigations into radioactivity in radium by Marie & Pierre Curie. First woman to win Nobel Prize

1911 Discovery of the atomic nucleus by Rutherford

1913 Bohr model of atom

1914 Determination of nuclear charge

1919 Rutherford discovers the proton by producing hydrogen from alpha bombardment of Nitrogen

1926 Quantum mechanics takes off - Schrödinger equation

1931 Pauli theory of the neutrino in beta decay

1932 discovery of the neutron – Chadwick

1934 Fission observed – Fermi / Hahn

1941 Start of the Manhattan Project

1942 First Reactor – Fermi

1945 The Atomic Bomb, Oppenheimer

1948 Nucleo-synthesis – Bethe, Gamow

1952 Hydrogen Bomb

1956 Parity Violation in beta decay

technological developments e.g. medical imaging / treatment

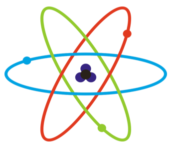
↓

present day

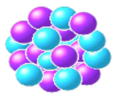
Scales in Nuclear Physics

Sizes	**Typical Energies**
Everyday Matter ~1m	0.01 eV - thermal energies

Molecule 10^{-9} m	1 eV - binding energy of molecule



Atom 10^{-10} m	10 eV – 1keV



Nucleus 10^{-14} m	1 MeV – 10 MeV

Proton 10^{-15} m	1 GeV

Nucleus is 4 orders of magnitude smaller than atom

Binding Energy

Nuclear mass M_N less than sum of nucleon masses

Shows nucleus is a bound (lower energy) state for this configuration of nucleons

Leads to concept of **binding energy** B of a nucleus

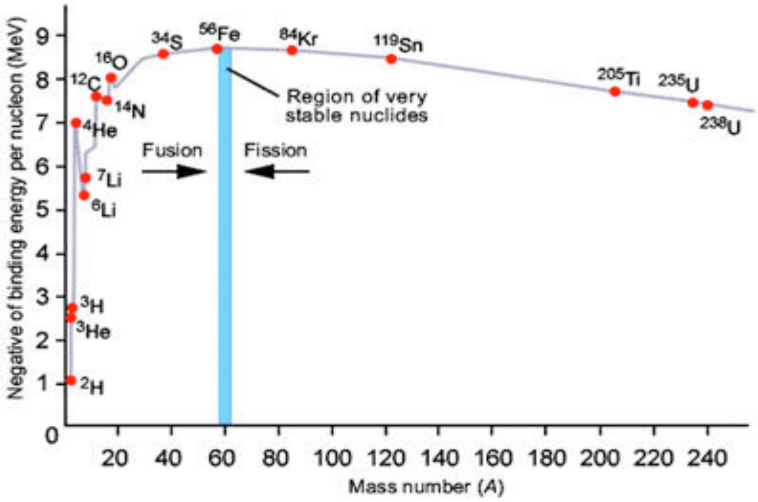
$$M_N(A,Z)c^2 = Zm_pc^2 + (A-Z)m_nc^2 - B$$

m_p = proton mass
m_n = neutron mass

Binding energy: Energy required to separate nucleus into component parts

Binding energy of average nucleon is ~ 8 MeV
significant compared to nucleon mass itself!

Binding Energy Per Nucleon



The nuclear binding energy allows us to explain and investigate many nuclear properties e.g. fission, fusion and models of nuclear forces

We will attempt to understand this curve using the Semi-empirical mass formula (future lecture)