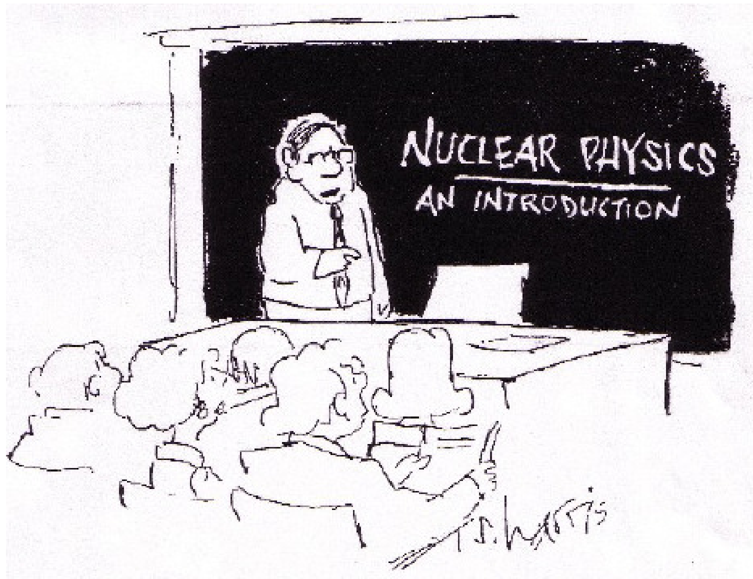
Nuclear Physics



First and foremost, the word is not 'nucular'!

Objectives

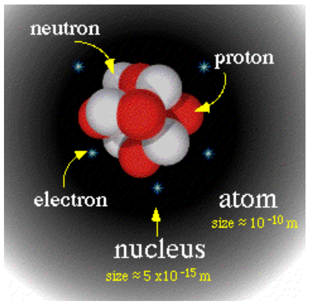
- You should know and understand

a) The number of neutrons, protons in an atom (the Nucleus)

b) Describe and understand the 3 forms of radioactive decay

c) Solve nuclear equations

Nuclear Physics



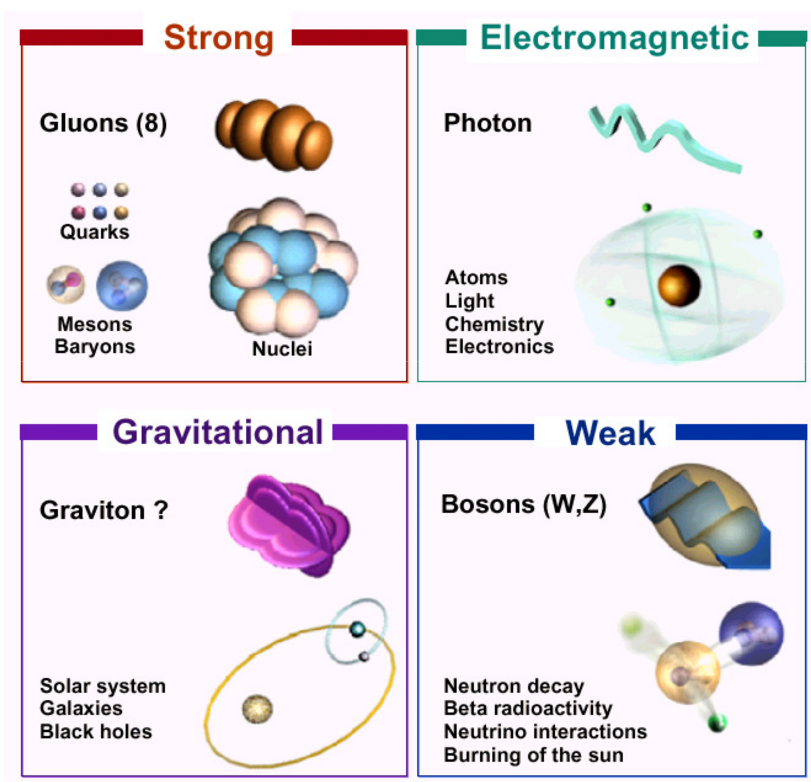
Typically the nucleus is less than one ten-thousandth the size of the atom.

The nucleus contains more than 99.9% of the mass of the atom!

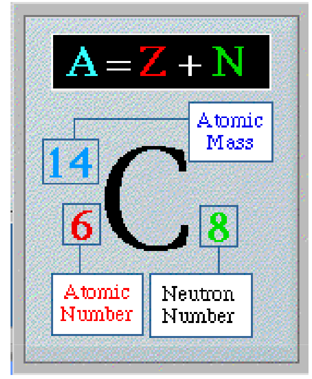
Nuclei consist of positively charged protons and electrically neutral neutrons held together by the so-called strong or nuclear force.

This force is much stronger than the familiar electrostatic force that binds the electrons to the nucleus, but its range is limited to distances on the order of a few x10^{-15} meters.

Four Fundamental Forces



The number of protons in the nucleus, *Z*, is called the atomic number. This determines what chemical element the atom is. The number of neutrons in the nucleus is denoted by *N*. The atomic mass of the nucleus, *A, is* equal to *Z + N*



The Carbon Atom:

Typically has 6 protons (Z) (atomic number)

All carbon atoms have 6 electrons!

Most Carbon Atoms have 6 Neutrons

N = atomic mass – atomic number = 12 – 6

(note atomic mass is a whole number, ie 12 things in the nucleus)

Periodic Table

Chemical elements are labelled by two numbers

atomic number and atomic weight

Atomic number Z tells the number of protons in an atom (and number of electrons)

Always an integer, all integers used.

Atomic weight tells the mass of typical atom in "atomic mass units" (amu's)

1 amu = 1.661 * 10-27 kg

Usually close to an integer, around 2 * *Z.*

A-Z Notation

Atomic Number = Protons

$^{12}_{6}C$

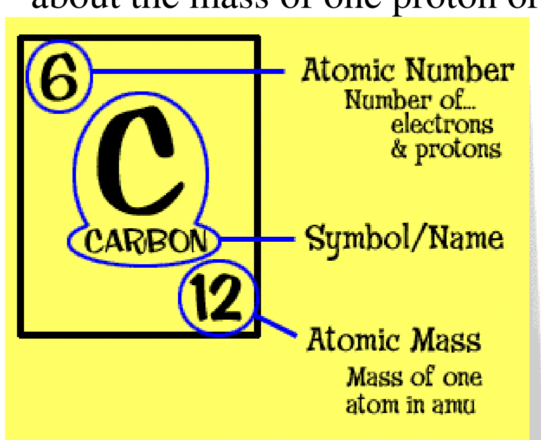
$^{A}_{Z}X$

Atomic Mass = number of particles in the nucleus

Thus atom X is composed of Z protons, (A- Z) neutrons and Z electrons.

Do we now know how much atoms really weigh, in pounds or grams?

Yes, but we don't normally use those units for measuring the mass of an atom. It's much more convenient to use something called the **atomic mass unit**, or **amu**. That's about the mass of one proton or neutron



Isotopes

A given element can have many different isotopes, which differ from one another by the number of neutrons contained in the nuclei.

All of the elements heavier than uranium are man made. Among the elements are approximately 270 stable isotopes, and more than 2000 unstable isotopes.

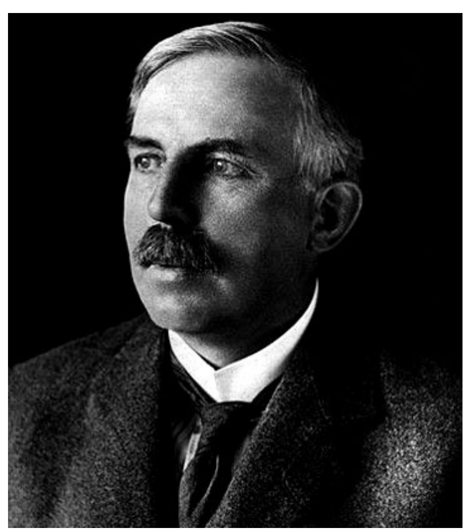
Isotopes of Carbon

- There are a variety of naturally-occurring isotopes of carbon. These isotopes are characterized by differing atomic weights resulting from varying numbers of neutrons in the atomic nuclei. The relative abundances of these isotopes are given below:
  - ^{12}C 98.89%
  -
  - ^{13}C 1.11%
  -
  - ^{14}C 1E-10%
- 12C and 13C are both stable isotopes, meaning that unlike their radioactive cohort, 14C, they do not undergo radioactive decay.

The Becquerel Connection

- Photo plates exposed by radiation from uranium.
- Unstable isotopes undergo what is known as transmutation and this can occur naturally as Becquerel and Curie discovered but it can also be artificially created.

- In 1899, Ernest Rutherford discovered that uranium compounds produce three different kinds of radiation.
- He separated the radiations according to their penetrating abilities and named them α alpha, β beta, and γ gamma radiation, after the first three letters of the Greek alphabet.



α Particles

- The α radiation can be stopped by a sheet of paper.
- Rutherford later showed that an alpha particle is the nucleus of a He atom, 4He (without electrons!)

$$^{4}_{2}He$$

β particles

- Beta (β) particles were later identified as high speed electrons.
- Six millimeters of aluminum are needed to stop most β particles

$$^{0}_{-1}e$$

Charge = -1

Mass = mass of an electron

γ Rays

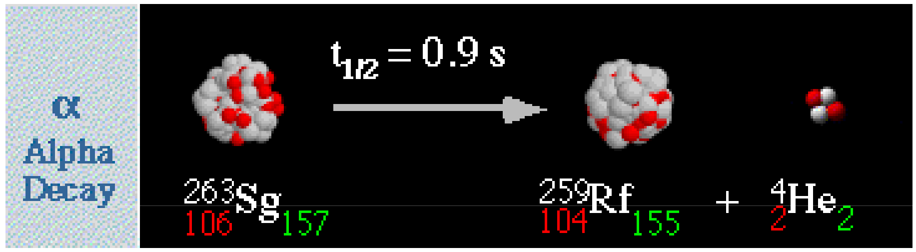
- Several millimeters of lead are needed to stop γ (Gamma) rays , which proved to be high energy photons. A type of light.
- No charge and no mass !
- Very penetrating!

$$^{0}_{0}\gamma$$

α Decay

- The emission of an α particle, or ^{4}He nucleus, is a process called α decay.
- Since a particles contain protons and neutrons, they must come from the nucleus of an atom.
- The nucleus that results from α decay will have a mass and charge different from those of the original nucleus.
- A change in nuclear charge means that the element has been changed into a different element.
- Only through such radioactive decays or nuclear reactions can transmutation, the age-old dream of the alchemists, actually occur

For example, for the decay of an isotope of the element seaborgium, ^{263}Sg



The atomic number of the nucleus changes from 106 to 104, giving rutherfordium, an atomic mass of 263 - 4=**259**

You try… (α decay)

$$^{226}_{88}Ra \rightarrow ^{4}_{2}He +$$

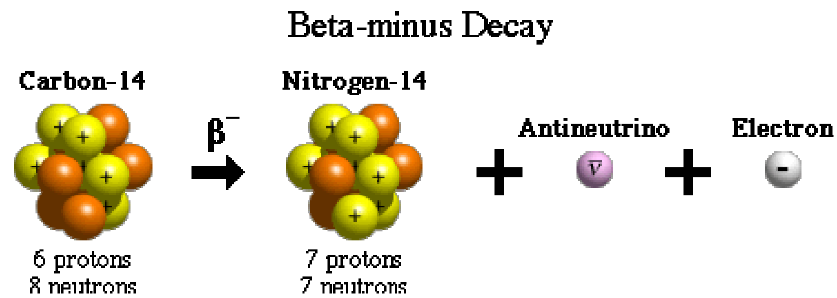
$$^{226}_{88}Ra \rightarrow ^{4}_{2}He + ^{222}_{86}Rn$$

β Decay

- Beta particles are negatively charged electrons emitted by the nucleus. (or positrons)
- Since the mass of an electron is a tiny fraction of an atomic mass unit the mass number is unchanged.
- The nucleus contains no electrons. So where does it come from?
- Rather, β decay occurs when a neutron decays. nucleus.
- An unseen neutrino, accompanies each β decay.
- The number of protons, and thus the atomic number, is increased by one.

β = Beta Decay

- In beta decay, a neutron in the nucleus spontaneously turns into a proton, an electron, and a third particle called an antineutrino. The nucleus ejects the electron and antineutrino, while the proton remains in the nucleus.
- The ejected electron is referred to as a **beta particle,** yes it is simply an electron….



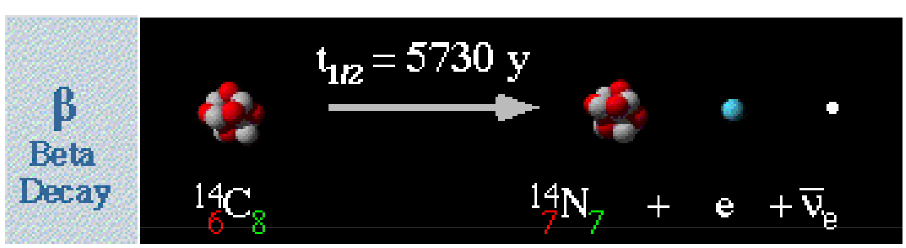
What do you notice?

# of protons increased by 1
# of Neutrons decreased by 1.

Because the atom is defined by the number of Protons it becomes a new element!

Carbon 14 has decayed!

- The isotope ^{14}C is unstable and emits a β particle, becoming the stable isotope ^{14}N:



In a stable nucleus, the neutron does not decay.
A free neutron, or one bound in a nucleus that has an excess of neutrons, can decay by emitting a β particle.
Sharing the energy with the β particle is a neutrino.
The neutrino has little or no mass and is uncharged, but, like the photon, it carries momentum and energy.

Beta β Decay

$$^{14}_{6}C \rightarrow \boxed{?} + ^{0}_{-1}e$$

Solution:

$$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$$

Gamma Radiation

- Gamma rays are a type of electromagnetic radiation that results from a redistribution of electric charge within a nucleus.
- A γ ray is a high energy photon. The only thing which distinguishes a γ ray from the visible photons emitted by a light bulb is its wavelength; the γ ray's wavelength is much shorter.
- For complex nuclei there are many different possible ways in which the neutrons and protons can be arranged within the nucleus. Gamma rays can be emitted when a nucleus undergoes a transition from one such configuration to another.

Gamma Decay

$$\underbrace{{}^{A}_{Z}X}_{\text{Parent Nucleus}} \rightarrow \underbrace{{}^{A}_{Z}X}_{\text{Daughter Nucleus}} + \underbrace{{}^{0}_{0}\gamma}_{\text{Particle}}$$

Gamma Radiation accompanies both Alpha and Beta decay and is not always included in the written part of the equation. See page 754 for samples.

Particle Summary

Proton	${}^{1}_{1}H$
Neutron	${}^{1}_{0}n$
Electron	${}^{0}_{-1}e$
Helium Nucleus	${}^{4}_{2}He$
Gamma Ray	${}^{0}_{0}\gamma$

Your Turn…

- Reference Page 753-6, 772.
- Page 756 #1 a-e
- Page 773 Do practice Questions (a-g)
- Page 782 #1,9,10,18,19
- Next day we will look at Half lives, read ahead and prepare.