NUCLEAR PROPERTIES

- The **atomic number,** Z (sometimes called the *charge number*), which equals the number of protons in the nucleus
- The **neutron number,** N, which equals the number of neutrons in the nucleus.
- The **mass number,** A, which equals the number of nucleons (neutrons plus protons) in the nucleus.

The isotopes of an element have the same Z value but different N and A values.

The natural abundances of isotopes can differ substantially. For example, ${}^{11}_{6}C$, ${}^{12}_{6}C$, ${}^{13}_{6}C$, and ${}^{14}_{6}C$ are four isotopes of carbon. The natural abundance of the ${}^{12}_{6}C$ isotope is about 98.9%, whereas that of the ${}^{13}_{6}C$ isotope is only about 1.1%. Some isotopes do not occur naturally but can be produced in the laboratory through nuclear reactions. Even the simplest element, hydrogen, has isotopes: ${}^{1}_{1}H$, the ordinary hydrogen nucleus; ${}^{2}_{1}H$, deuterium; and ${}^{3}_{1}H$, tritium.

$$ {}^{A=Z+N}_{Z}Atomic\_symbol $$

$$ {}^{A=Z+N}Atomic\_symbol $$

as Z is the ordering principle of the periodic table of the elements, it is often dropped

Table 13.1 Masses of the Proton, Neutron, and Electron in Various Units

	Mass		
Particle	**kg**	**u**	**MeV/c^2**
Proton	$1.672\,623 \times 10^{-27}$	1.007 276	938.272 3
Neutron	$1.674\,929 \times 10^{-27}$	1.008 665	939.565 6
Electron	$9.109\,390 \times 10^{-31}$	$5.48\,579\,9 \times 10^{-4}$	0.510 999 1

$$r = r_0 A^{1/3}$$

Table 13.2 Masses, Spins, and Magnetic Moments of the Proton, Neutron, and Electron

Particle	Mass (MeV/c^2)	Spin	Magnetic Moment
Proton	938.28	$\frac{1}{2}$	$2.7928\mu_n$
Neutron	939.57	$\frac{1}{2}$	$-1.9135\mu_n$
Electron	0.510 99	$\frac{1}{2}$	$-1.0012\mu_B$

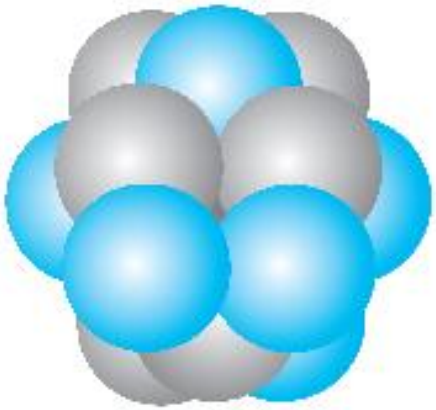


Figure 13.3 A nucleus can be modeled as a cluster of tightly packed spheres, each of which is a nucleon.

The nuclear density is approximately 2.3×10^{14} times as great as the density of water ($\rho_{water} = 1.0 \times 10^3$ kg/m^3)!

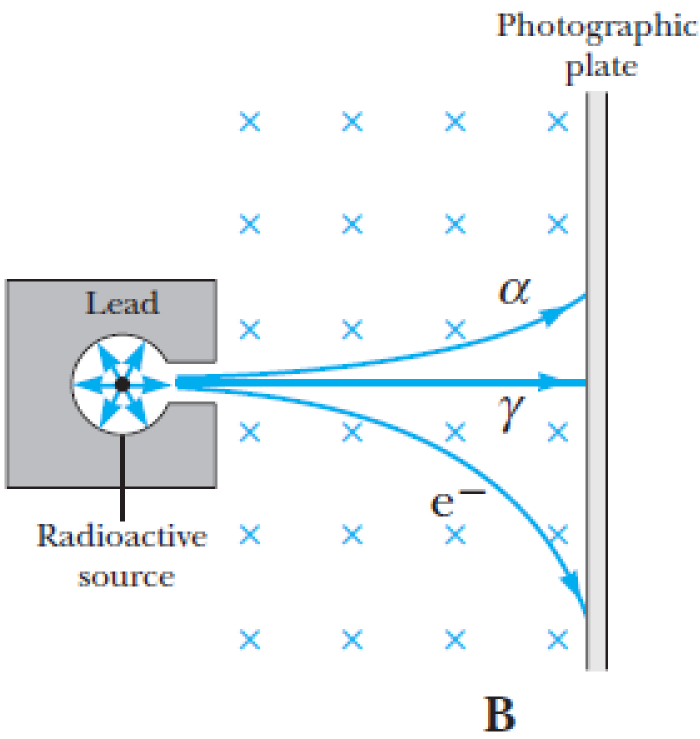


Figure 13.14 The radiation from a radioactive source can be separated into three components through the use of a magnetic field to deflect the charged particles. The photographic plate at the right records the events. The gamma ray is not deflected by the magnetic field.

Positrons have same mass and spin as electron but positive charge

e^- and e^+ are also called beta radiation

DISCOVERY OF THE NEUTRON

- Rutherford proposed the atomic structure with the massive nucleus in 1911.
- which particles compose the nucleus was known only in 1932
- **Three** reasons why electrons cannot exist within the nucleus:

1) **Nuclear size**
The uncertainty principle puts a lower limit on its kinetic energy that is much larger that any kinetic energy observed for an electron emitted from nuclei (its actually the result of β-decay).

2) **Nuclear spin**
If a deuteron nucleus were to consist of protons and electrons, the deuteron must contain 2 protons and 1 electron. A nucleus composed of 3 fermions must result in a half-integral spin. But it has been measured to be 1. So no electrons can possible in the nucleus (but they apparently come out of certain nuclei)

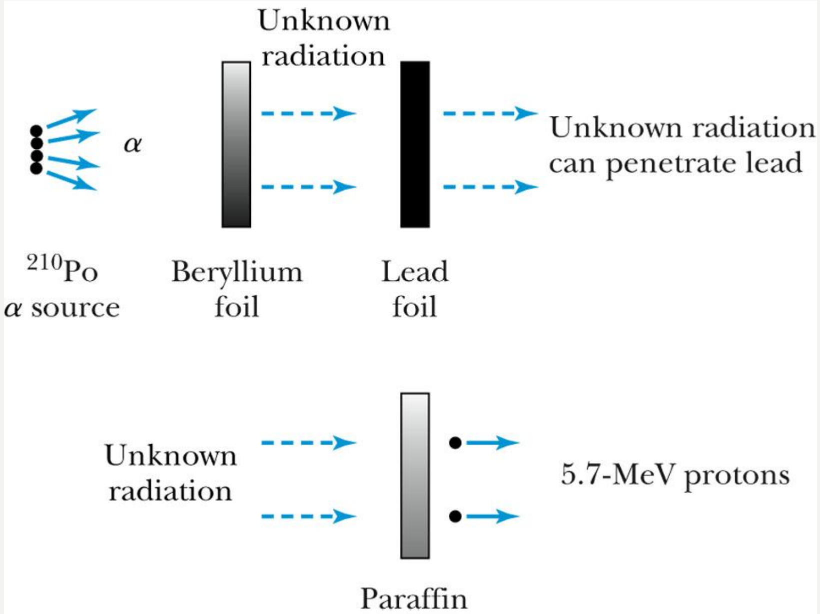
DISCOVERY OF THE NEUTRON

3) **Nuclear magnetic moment:**

The magnetic moment of an electron is over 1000 times larger than that of a proton.

The measured nuclear magnetic moments are on the same order of magnitude as the proton's, so an electron canot be a part of the nucleus.

- In 1930 the German physicists Bothe and Becker used a radioactive polonium source that emitted α particles. When these α particles bombarded beryllium, the radiation penetrated several centimeters of lead but was readily absorbed
- by **paraffine wax**



DISCOVERY OF THE NEUTRON

- In 1932 Chadwick proposed that the new radiation produced by α + Be consisted of neutrons. His experimental data estimated the neutron's mass as somewhere between 1.005 u and 1.008 u, not far from the modern value of 1.0087 u.

- The electromagnetic radiation (photons) are called **gamma rays** which have energies on the order of MeV.

- Curie and Joliot performed several measurements to study penetrating high-energy gamma rays.

- There are also electrons (and positrons) emerging from atoms, beta rays (but they are not constituents of the nucleus themselves)

NUCLEAR PROPERTIES

- The symbol of an atomic nucleus is $^{A}_{Z}X_{N}$

  where Z = atomic number (number of protons)

  N = neutron number (number of neutrons)

  A = mass number ($Z + N$)

  X = chemical element symbol
- Each nuclear species with a given Z and A is called a **nuclide**.
- Z characterizes a chemical element.
- The dependence of the chemical properties on N is negligible, certain physical properties, e.g thermal expansion show measurable differences due to isotope effects.

- Nuclides with the same neutron number are called *isotones* and the same value of A are called *isobars*.

NUCLEAR PROPERTIES

- The nuclear charge is +e times the number (Z) of protons.

  Hydrogen's **isotopes**:

  - **Deuterium**: Heavy hydrogen. Has a neutron as well as a proton in its nucleus.
  - **Tritium**: Has two neutrons and one proton, is radioactive, about 40 tons on earth.

- The nuclei of the deuterium and tritium atoms are called *deuterons* and *tritons*.

  Atoms with the same Z, but different mass number A, are called **isotopes**.

NUCLEAR PROPERTIES

- Atomic masses are denoted by the symbol u.
- **1 u = 1.66054 × 10^{-27} kg = 931.49 MeV/c^2**

Table 12.1 Some Nucleon and Electron Properties

Particle	Symbol	Rest Energy (MeV)	Charge	Mass (u)	Spin	Magnetic Moment
Proton	p	938.272	$+e$	1.0072765	1/2	$2.79\ \mu_N$
Neutron	n	939.566	0	1.0086649	1/2	$-1.91\ \mu_N$
Electron	e	0.51100	$-e$	5.4858×10^{-4}	1/2	$-1.00116\ \mu_B$

- Both neutrons and protons, collectively called **nucleons**, are constructed of other particles called *quarks*.

1 proton plus 1 neutron = 2.0159414 u = mass of the nucleus of deutrium ??? Nope its 2.014102 u, why?

SIZES AND SHAPES OF NUCLEI

- Rutherford concluded that the range of the nuclear force must be less than about 10^{-14} m.

  Assume that nuclei are spheres of radius *R*.
- Particles (electrons, protons, neutrons, and alphas) scatter when projected close to the nucleus.

  The nuclear force is often called the **strong** force.

- There is no simple closed form equation for this force, so we don't have a simple potential energy function that we could put into the Schrödinger Equation, but quantum mechanics reigns supreme in the nuclear realm as well

SIZES AND SHAPES OF NUCLEI

- The nuclear radius may be approximated to be $R = r_0 A^{1/3}$ where $r_0 \approx 1.2 \times 10^{-15}$ m.

- We use the **femtometer** with 1 fm = 10^{-15} m, or the fermi.