Atomic structure and stability

A.C. Norman, Bishop Heber High School

Constituents of the atom

The atom comprises a tiny ($\approx 10^{-14}$ m) nucleus, containing protons and neutrons, around which are electrons in atomic orbitals (of radius $\approx 10^{-10}$ m).

Name	Location	Charge / C	Relative mass	Actual mass / kg
Proton	nucleus	$+1.6 \times 10^{-19}$	1	1.67×10^{-27}
Neutron	nucleus	0	1	1.67×10^{-27}
Electron	orbitals	-1.6×10^{-19}	1/1833	9.11×10^{-31}

Table 1: The particles which make up matter and their properties.

An atom is written as

$$^{A}_{Z}\mathrm{X}$$

where A is the nucleon number (the number of protons and neutrons),
Z is the proton number, and
X is the element symbol.

Proton number, Z

Also called the atomic number. This defines the element, and therefore dictates its properties. In an atom, the number of electrons will equal the proton number; in an ion, there will be fewer or more electrons than Z.

Nucleon number, A

Also called the mass number. This is the total number of nucleons (i.e. protons + neutrons) in the nucleus.

The number of neutrons is therefore $A - Z$. All nuclei, except for one isotope of hydrogen, contain neutrons.[1] The neutrons hold together the protons, which electrostatically repel each other.

[1] In general, for lower Z elements, there are roughly the same numbers of protons and neutrons, but the number of neutrons increases more rapidly as large nuclei are made.

The number of neutrons have no effect on the chemical properties of the element, but may make it more or less stable and therefore determine whether an element is radioactive.

Isotopes

Isotopes are nuclides with the same proton number, but different nucleon numbers (i.e. same number of protons, but different numbers of neutrons).

Many elements exist in several stable isotopes, and they are not given separate names, except for:

- $^{1}_{1}$H is hydrogen.
- $^{2}_{1}$H is deuterium.

- $^3_1$H is tritium.

Nuclear stability

Within a nucleus, which normally has a diameter of about 10^{-14} m, a large attraction force is needed to overcome the coulomb repulsion of the very closely packed protons.[2]

[2] The magnitude of this force is of the order 10^4 N.

Experimental investigations of nuclear material show that it is very dense, and the density is independent of the nucleon number. This implies that the force between nucleons is a short range force, only extending to the adjacent nucleons (if it extended further a density increase with A would be expected, as more and more nucleons pulled tighter and tighter on each other!)

The nuclear force—called the strong force—is very complex and it is not possible to deduce its form precisely. However, we can note that

- it is essential to keep the nucleus stable and bound together (balancing the effect of proton–proton electrostatic repulsion)
- it is about 10^8 times stronger than interatomic forces
- it is charge independent, i.e. at any given separation the strong force between two neutrons is the same as that between two protons or between a proton and neutron
- it is attractive down to about $3\,$fm=3×10^{-15} m
- it has to be repulsive at very short range ($<\ 0.5$ fm) otherwise there would be a tendency for the nucleus to collapse in on itself

Radioactivity

Radioactivity is the spontaneous disintegration of the nucleus of an atom, from which may be emitted some or all of the following

- α alpha particles,
- β beta particles,
- γ gamma rays.

The process allows an unstable nucleus to become more stable, and its rate is not affected by chemical combinations or changes in physical environment. Natural sources of background radiation (which must be taken into account when taking experimental radioactivity measurements) include cosmic rays, rocks (especially granite) and some luminous paints.

α decay

An α particle is identical to a helium nucleus, consisting of 2 protons and 2 neutrons.

When an element disintegrates by the emission of an α particle it turns into an element with chemical properties similar to those of an element two places earlier in the periodic table $(A, Z) \rightarrow (A-4, Z-2)$.

e.g. Radium decays via α emission to form radon (Rn):

$$^{226}_{88}\mathrm{Ra} \longrightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha.$$

β decay

A β particle is an electron. During β decay a neutron changes into a proton. When an element disintegrates by emission of a β particle it turns into an element with chemical properties similar to an element one place later in the periodic table $(A, Z) \rightarrow (A, Z+1)$.

e.g. Sodium-24 (also known as radiosodium) decays via β emission to magnesium-24:

$$^{24}_{11}\mathrm{Na} \longrightarrow {}^{24}_{12}\mathrm{Mg} + {}^{0}_{-1}\beta.$$

γ radiation

Frequently, spare energy released during a radioactive disintegration is emitted as very penetrating and harmful γ radiation (very short wavelength electromagnetic radiation). Though the nucleus loses energy by γ emission, the structure of the nucleus (A, Z) does not change.

Except where otherwise noted, this work is licensed under
http://creativecommons.org/licenses/by-nc-sa/3.0/