Properties of Nuclei

Static Properties : Electric charge, radius, mass, binding energy, angular momentum, parity, magnetic dipole moment, electric quadrupole moment, energies of excited states.

Dynamic Properties : Decay & reaction probabilities, scattering cross sections.

We shall start with static properties.

Nucleons : neutrons and protons

The force that binds nucleons together is by far stronger (within the nucleus) than the EM force. So, we can non-destructively probe the nuclear properties with EM interaction (i.e., we do not seriously distort the object - nucleus we are trying to measure.) According to many scattering experiments, we can model a nucleus as a sphere with radius R that depends on the total # nucleons = A ← nucleon number.

$$R = \underbrace{R_0}_{1.2\,\text{fm}} A^{1/3}$$

1.2 fm ... an experimentally det'd const.

A is also called the mass number because it is the nearest integer number to the mass of the nucleus measured in unified atomic mass units (u).

$$1\,u = 1.660538782(83) \times 10^{-27}\,\text{kg}$$

NB: All masses in this course refer to rest masses.

Nuclear Density : The volume (V) of a nucleus is proportional to A. Dividing A (the approximate mass in u) by V, $\rho = \frac{M}{V}$ cancels out A. Thus **all nuclei have approximately the same density**. This is of crucial importance in nuclear structure.

NB: $\rho_{nucleon} = \frac{A}{V} = 2.84 \cdot 10^{17}\ kg/m^3$ compare with $\rho_{water} = 10^3\ kg/m^3$ ← Normal matter is full of empty space!

Example: Comparing H with U

Uranium has mass number 238 and hydrogen has 1, accordingly their nuclear diameters reflect this $\sqrt[3]{A_U/A_H} \approx 6.2$ ratio.

Actual values are
$$\left.\begin{array}{l} D(\text{H nucleus}) = 1.75\ fm \\ D(\text{U nucleus}) = 15\ fm \end{array}\right\} \text{ratio} : 8.57$$

Compare this with their atomic diameters.

$$\left.\begin{array}{l} D(\text{H atom}) \simeq 2.54\ \text{Å} \\ D(\text{U atom}) \simeq 3.45\ \text{Å} \end{array}\right\} \text{ratio} : 1.36$$

So, note that even though nuclear diameters are quite different, the two atoms' diameters are very close! This is because of the contrast bet. the behavior of nuclear vs. EM forces. The latter is long range and does not saturate; the 92 protons of U exert a huge Coulomb force on the $\bar{e}$'s, reducing the diameter close to that of H.