Summary

The discovery of the neutron in 1932 solved several outstanding problems, including the understanding of the nuclear constituents and the origin of very penetrating radiation.

A nuclide ${}^{A}_{Z}X$ has mass M and is composed of Z protons and N neutrons. Its mass number is $A = Z + N$. Masses are measured in terms of atomic mass units u. The radius of a nucleus is $R = r_0 A^{1/3}$, where $r_0 \approx 1.2 \times 10^{-15}$ m = 1.2 fm. Electron scattering is useful to measure the size and shapes of nuclei. The properties of the nucleons are as follows:

Property	Neutron	Proton
Mass (u)	1.008665	1.007276
Charge (e)	0	+1
Spin ($\hbar$)	1/2	1/2
Magnetic moment ($e\hbar/2m_p$)	−1.91	+2.79

The study of the deuteron and nucleon-nucleon scattering indicates that the nuclear force is attractive and much stronger than the Coulomb force. However, it is effective only over a short range (up to about 3 fm). The nuclear force is charge independent and has a hard core.

A nuclide is stable if its mass is smaller than any other possible combination of the A nucleons. Stable nuclides tend to have $N \approx Z$ for small A and $N > Z$ for medium and large A. The total binding energy for a nuclide is

$$B({}^{A}_{Z}X) = [Nm_n + ZM({}^{1}\text{H}) - M({}^{A}_{Z}X)]c^2 \qquad (12.10)$$

The von Weizsäcker semi-empirical mass formula is useful in predicting the nuclear binding energy. There are no stable nuclei with $Z > 83$ or $A > 209$. Nuclei tend to be more stable with an even number of protons and/or neutrons. Nuclei near ^{56}Fe have the highest binding energies per nucleon, and the average binding energy per nucleon for most nuclei is about 8 MeV.

The radioactive decay law is $N = N_0 e^{-\lambda t}$, where λ is the decay constant and the half-life $t_{1/2} = 0.693/\lambda$. The activity $R = \lambda N$. A becquerel (Bq) is 1 decay/s. Radioactive decay occurs when the disintegration energy $Q > 0$. The four kinds of alpha and beta decay are

Alpha decay

$$ {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}D + \alpha \qquad (12.30)$$

$$ Q = [M({}^{A}_{Z}X) - M({}^{A-4}_{Z-2}D) - M({}^{4}\text{He})]c^2 \qquad (12.31)$$

β^- decay

$$ {}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}D + \beta^- + \bar{\nu} \qquad (12.37)$$

$$ Q = [M({}^{A}_{Z}X) - M({}_{Z+1}^{A}D)]c^2 \qquad (12.38)$$

β^+ decay

$$ {}^{A}_{Z}X \rightarrow {}_{Z-1}^{A}D + \beta^+ + \nu \qquad (12.40)$$

$$ Q = [M({}^{A}_{Z}X) - M({}_{Z-1}^{A}D) - 2m_e]c^2 \qquad (12.41)$$

Electron capture

$$ {}^{A}_{Z}X + e^- \rightarrow {}_{Z-1}^{A}D + \nu \qquad (12.43)$$

$$ Q = [M({}^{A}_{Z}X) - M({}_{Z-1}^{A}D)]c^2 \qquad (12.44)$$

There are only four radioactive series. For example, two of them begin with uranium isotopes, ^{235}U and ^{238}U. Radioisotopes are useful to date objects like the age of Earth and ancient objects. Radiocarbon ^{14}C is one of the most useful.