

Radioactivity

1 – The Structure of the Nucleus

- The nucleus consists of protons (positively charged particles) and neutrons (electrically neutral). The neutron is slightly heavier than the proton. The total number of protons and neutrons inside a nucleus is given by the **atomic mass number** A , with $A = Z + N$, where Z denotes the number of protons and N the number of neutrons.
- The protons and neutrons are strongly bound inside the nucleus in a tiny, approximately spherical region of radius $r \approx 10^{-15}m$.
- What keeps the nucleus of flying apart due to the electrostatic repulsive force between the protons ? A much stronger nuclear force, the **strong force**.
- To break a nucleus apart one needs to overcome the **binding energy**. The difference in the mass of the nucleus and the sum of the masses of its constituents is called the **mass defect**, Δm . The binding energy corresponds to the rest energy of the mass defect, $E_0 = \Delta mc^2$.

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2 – Radioactivity

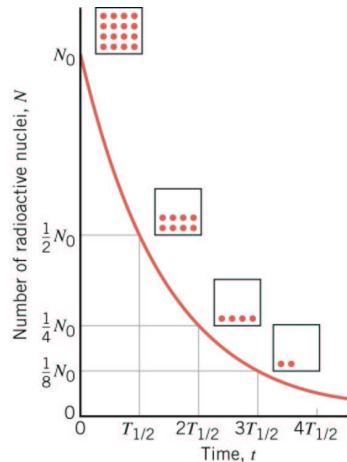
- The more protons and neutrons are inside a nucleus, the harder it is for the strong force to hold them together, and the nucleus may eventually spontaneously disintegrate. For example, ${}_{83}^{209}\text{Bi}$ ($A = 209, Z = 83$) is unstable, hence **radioactive**.
- When an unstable nucleus “disintegrates”, energy in form of α (helium nuclei), β (electrons or positrons) or γ (photons) rays is set free.
- To describe how many of unstable nuclei in a sample are left over after a certain time, the **half time** of a radioactive nucleus is introduced: $T_{1/2}$ is the time in which half of the original present nuclei have disintegrated.

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- The number of radioactive nuclei present after a certain time t is

$$N = N_0 e^{-\lambda t} \quad \text{with} \quad \lambda = \frac{\ln 2}{T_{1/2}} \quad (1)$$

where N_0 denotes the initially, i.e. at $t = 0s$, available number of nuclei. λ is the decay constant.



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3 – Radioactive Dating

- Radioactive nuclei can be used to determine the age of archeological or geological samples.
- For instance, the radiocarbon technique uses the ${}^6_{14}\text{C}$ isotope of carbon ($T_{1/2} = 5730$ years).
- We know that living organisms contain about one atom of ${}^6_{14}\text{C}$ per $8.3 \cdot 10^{11}$ normal carbon. When the organism dies, the intake of ${}^6_{14}\text{C}$ stops. The number of these isotopes measured in the organism determines how much time has passed since it died.
- Example:** *Oetzi's* age, a mummy found in the alps in 1991, has been measured to be about 5300 years. What percentage of the original amount of ${}^6_{14}\text{C}$ isotopes is left in *Oetzi* ?

$$\frac{N}{N_0} = e^{-\ln 2 \frac{t}{T_{1/2}}} = e^{-0.693 \frac{5300}{5730}} = 0.5267 ,$$

i.e. only 52.67 % is left over.