PH202-1G
Spring 2014

Worksheet April 16

Nuclear physics

What is the atomic number Z and the atomic mass number A?

Z = number of protons A = number of nucleons = number of protons + number of neutrons

Give a mathematical expression for the radius of a nucleus.

$$r = (1.2 \times 10^{-15}) A^{1/3}$$

What is a unified atomic mass unit?

$$u = 1.6605 \times 10^{-27} \text{ kg}$$

What is the strong nuclear force?

Force that overcomes the repulsion of protons to keep the nucleus together.

What is binding energy? Give a mathematical expression for it.

Binding energy is the energy required to break a nucleus apart. It is $(\Delta m) c^2$ where Δm is the mass defect, the difference between the mass of the individual nucleons and the mass of the nucleus.

Radioactivity

What is radioactivity? What quantity is always conserved in radioactive decay processes?

Radioactivity is the decay of unstable nuclei. The number of nucleons is always conserved.

Describe α decay.

$${}^{A}_{Z}P \longrightarrow {}^{A-4}_{Z-2}D + {}^{4}_{2}He$$

Describe β^- decay.

$${}^{A}_{Z}P \longrightarrow {}^{A}_{Z+1}D + {}^{0}_{-1}e + \bar{\nu}$$ ← antineutrino that balances energy

Describe B^+ decay.

$${}^{A}_{Z}P \longrightarrow {}^{A}_{Z-1}D + {}^{0}_{1}e + \nu$$ ← neutrino that balances energy

Describe γ decay.

excited state →
$${}^{A}_{Z}P^* \longrightarrow {}^{A}_{Z}P + \gamma$$

How are α, β^-, and γ particles affected by magnetic fields?

Alpha particles are positive and are deflected.

Beta particles are negative and are deflected in the opposite direction.

Gamma particles are not deflected.

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Radioactive decay

What is activity? What two units are commonly used for activity?

Activity is the number of decays per second. Measured in becquerel $(1\ Bq = 1\ s^{-1})$ and in curie $(1\ Ci = 3.70 \times 10^{10}\ Bq)$

Give a mathematical expression for activity.

$$\left|\frac{\Delta N}{\Delta t}\right| = \lambda N \quad \text{Using } N = N_0 e^{-\lambda t}, \quad \left|\frac{\Delta N}{\Delta t}\right| = \lambda N_0 e^{-\lambda t}$$

What is half-life? Give a mathematical expression for it.

Half-life is the amount of time required for half of the nuclei in a sample to decay.

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

Describe how radioactive dating can determine the age of an object.

Activity of radioactive carbon in the atmosphere is constant, but at death organisms stop taking in carbon and existing carbon decays. Comparing current carbon activity to atmospheric carbon activity gives the age of the organism.

Problems

1. What is the binding energy of the isotope silver-109 (atomic mass108.904 757 u)? $^{109}_{47}Ag$

Silver-109 has 47 protons, 47 electrons, and 109 − 47 = 62 neutrons. The binding energy is

$$(47\ M_{Hydrogen} + 62\ M_{Neutron} - M_{silver})\ c^2$$

$$[47(1.007825) + 62(1.008665) - 108.904757](1.6605 \times 10^{-27}\ kg)(2.9979 \times 10^8\ m \cdot s^{-1})^2 = 1.49 \times 10^{-10}\ J$$

2. Write the radioactive decay equations for the α decay of americium-243 and the β⁺ decay of sodium-22.

$$^{243}_{95}Am \longrightarrow {}^{239}_{93}Np + {}^{4}_{2}He$$

$$^{22}_{11}Na \longrightarrow {}^{22}_{10}Ne + {}^{0}_{1}e + \nu$$

3. A sample of krypton-89 initially contains 4 billion radioactive nuclei at time $t = 0$. After 9.48 minutes, 500 million radioactive nuclei remain in the sample. a) What is the half-life of krypton? b) What is the activity of krypton after 11.00 minutes?

a) $\frac{4\text{ billion}}{500\text{ million}} = 8 = 2^3$, so 3 half-lives have passed. $T_{1/2} = \frac{9.48\text{ min}}{3} = 3.16\text{ min} = 189.6\text{ s}$

b) $$\frac{\Delta N}{\Delta t} = \lambda N = \frac{\ln 2}{T_{1/2}} N_0 e^{-\frac{\ln 2}{T_{1/2}} t}$$

$$\frac{\Delta N}{\Delta t} = \frac{\ln 2}{189.6\text{ s}} (4 \times 10^9)\, e^{-\frac{\ln 2}{189.6\text{ s}}(660\text{ s})} = 1310000\ s^{-1}$$

$$= 1.31\text{ million } s^{-1}$$