Gamma Radiation preparation report

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1 General subjects in nuclear physics

1.1 Typical sizes

The typical radius of a nucleus is:

$$R = 1 * 10^{-15} m = 1 fermi = 1 fm$$

The typical radius of a atom is:

$$R = 1 * 10^{-10} m = 1 \mathring{A}$$

1.2 Nuclear structure

Rutherford has found in his experiments that the atom has a dense core in the middle (the nucleus), surrounded by a cloud of electrons. The size of the nucleus for an aluminum atom is:

$$r_{nucleus} = 3 * 10^{-15} m$$

(found by Rutherford). Since Rutherford experiments showed that the radius of the nucleus is:

$$R = r_0 A^{-\frac{1}{3}}$$

where A is the atomic mass number (number of protons times number of neutrons) and:

$$r_0 = 1.2 * 10^{-15} m = 1.2 fm$$

1.3 Components of the nuclues and their property's

The nucleus is made out of protons and neutrons. These particles are called hadrons and they are composed from Quarks. The protons are made of 2 up quarks and one down quark and the neutron is made out of two down quarks and one up quark.The property's of these particles are detailed in table 1.

1.4 Forces in the nucleus

There are two main forces inside the atomic nucleus:

1) The electromagnetic force, that acts between two charged particles according to:

$$F_{12} = \frac{k q_1 q_2}{|\vec{r}|^2} \hat{r}$$

This force is a repellent force in the nucleus because all the protons are positively charged, and therefore works in order to disassemble the nucleus.

2) The strong force, which is a force pulling all the parts of the nucleus together. This force is short distance which leads to a finite nucleus. It is much stronger then the coulomb force in short distances (for two protons with a distance of 2 fm the coulomb force is 60 N and the strong force is $2 * 10^3 N$), but if the distance is really short the strong force is repulsive. This force is independent of charge, and dependent on spin. For equations and explanation see Ohanian Modern Physics page 351 (might be added later).

1.5 The Liquid-Drop model

This model is based on the similarity of intermolecular forces and the strong force, suggesting the nucleus acts like a liquid (can't be a solid because of zero point energy). In that view the nucleus is an almost incompressible fluid with constant density. This model leads to an approximated formula for the binding energy of the nuclei that depends on A and Z (atomic mass and number of protons). The binding energy term is:

$$a_1 A - a_2 A^{2/3}$$

where a_1 and a_2 is a positive constant. The electrostatic potential can be written as:

$$-a_3 \frac{Z^2}{A^{1/3}}$$

Nucleon	Mass	Spin	Magnetic Moment	Radius	Charge
Proton	$1.00727647u$	$\frac{1}{2}\hbar$	$2.7928474 * \frac{e\hbar}{2m_p}$	$10^{-15}m$	$1e$
Neutron	$1.00866490u$	$\frac{1}{2}\hbar$	$-1.913043 * \frac{e\hbar}{2m_p}$	$10^{-15}m$	0

Table 1: This table explains the property's of protons and neutrons

where a_3 is an adjustable constant. The quantum mechanical correction gives:

$$-a_4\frac{(A-2Z)^2}{A}$$

which is called the asymmetry energy. In total the binding energy B is:

$$B = a_1A - a_2A^{2/3} - a_3\frac{Z^2}{A^{1/3}} - a_4\frac{(A-2Z)^2}{A}$$

From experiments we find:

$$a_1 = 15.753Mev$$

$$a_2 = 17.804Mev$$

$$a_3 = 0.7103Mev$$

$$a_4 = 94.77Mev$$

This is called Weizsäcker's semiempirical formula for binding energy. The formula for the mass is:

$$M = Zm_H + (A-Z)m_n - \frac{B}{c^2}$$

where m_H is equal to $Z(m_p + m_e)$ (you can plug in values and get eq 44 in page 357). This approximation is good for large nuclei and is not expected to work for small A's. (Note- the larger B is the atom is more stable and when negitive the atom will burst apart). The nucleus is most stable when $\frac{\partial M}{\partial Z} = 0$. Solving for Z we get:

$$Z = \frac{A}{2 + 0.01499A^{2/3}}$$

1.6 Basic idea of shell model

The Liquid-Drop model isn't quantum and therefore misses important aspects of the nucleus,like the quantization of the angular momentum. Every nucleus has a spin which is a multiple of $\frac{1}{2}\hbar$. It also misses the energy levels of the nucleus, which is a potential sorce of γ radiation.
The shell model attempts to calculate the the energy levels of the protons and neutrons in a nucleus under the assumption that the net force on every nucleon is approximated by an average central force. The idea is that nucleons can only be scattered near the nuclear surface (from the exclusion principal. more detailed in page 360). This means there is no force in the nucleus and very strong forces on the surface.

2 Radioactivity

2.1 Statistics of radiation

The statistics that describe radiation is the half-life formula. This says that if half the particles decay by a time of τ, the rate of decay is:

$$N(t) = N_0(\frac{1}{2})^{t/\tau}$$

where $N(t)$ is the number of particles at time t and N_0 is the initial number of particles.

2.2 Background radiation

Background radiation is the ionizing radiation present in the environment. Background radiation originates from a variety of sources, both natural and artificial. Sources include cosmic radiation, and environmental radioactivity from such as naturally occurring radioactive materials including radon and radium, and fallout from nuclear weapons testing and nuclear accidents. Here are a few examples:

2.2.1 Cosmic radiation

These are mainly positively charged ions from protons to iron and heavier elements. These particles interact with the atmosphere to create secondary radiation like X-rays, muons, protons...

2.2.2 Naturally occurring

The main reason for this kind of radiation is radon, a radioactive gas that emanates from the ground. The radiation this gas emits is γ radiation (will be explaind shortly).

3 α, β and γ radiation

3.1 Short explenations of kinds of radiation

α radiation: a nucleus of a helium 4 atom, which is comprised of 2 protons and two neutrons.
β radiation: a high energy electron or positron. these are denoted as β^- for an electron and β^+ for a positron.
γ radiation: electromagnetic radiation with a frequency of above $10^{19}Hz$.

3.2 Emission processes of radiation

3.2.1 α decay

α decay happens when a unstable (most of the time also massive) particle (like Uranium 238) "breaks" apart and releases the alpha particle. It is imposible to predict when a particle will decay but for large quantity's you can expect a decay that fellows the half-life formula.

Part of the reason alpha particles are emittid and not single protons or neutrons is conservation of wave function symmetry, which prevents a particle from spontaneously changing from exhibiting Bose-Einstien statistics to Fermi-Dirac statistics or vise versa. The other reason is that α particles have a high binding energy. That means that a massive atom will have all the energy needed to create a α particle, while other kinds of emitions would require additional energy.

The mechanism that creates the α particles is quantum tunneling.

3.3 β decay