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:

$$F_{12} = \frac{kq_1 q_2}{|\vec{r}|^2}\hat{r}$$

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:

$$B = a_1 A - a_2 A^{2/3} - a_3 \frac{Z^2}{A^{1/3}} - a_4 \frac{(A - 2Z)^2}{A}$$

From experiments we find:

$$a_1 = 15.753 Mev$$

$$a_2 = 17.804 Mev$$

$$a_3 = 0.7103 Mev$$

$$a_4 = 94.77 Mev$$

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

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

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:

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

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 given by the half-life formula:

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

where $N(t)$ is the number of particles at time t, N_0 is the initial number of particles and τ is the half-life time.

2.2 Background radiation

This kind of radiation is ionizing, and is 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.

3 α β and γ radiation

3.1 The type of radiation and its emission process

3.1.1 α decay

α particles are a nucleus of a helium 4 atom and is comprised of 2 protons and 2 neutrons. These particles are emitted when a massive and/or unstable particle break apart. There are 2 reasons why these particles are emitted (instead of protons, neutrons...):

1) Emission of α particles conserves the wavefunction symmetry, which prevents a particle from spontaneously changing from exhibiting BoseEinstein statistics (if it had an even number of nucleons) to FermiDirac statistics (if it had an odd number of nucleons) or vice versa.

2) α particles have really high binding energy. This means it will not tend to break apart. the result is that heavy elements have enough energy in them to create this particle while other models of decay require additional energy.

The mechanism that explains α decay is quantum tunneling. In this process the α particle teleports out of the large nucleus to a point where the strong force is not strong enough to pull the α particle back, and then the electromagnetic force violently pushes the α particle away.

3.1.2 β decay

β particles are high energy electrons (β^-) or positrons (β^+). The emission process for a β^- happens when an unstable atomic nucleus with an excess of neutrons converts a neutron into a proton while emitting an electron and a electron anti-neutrino $n \rightarrow p + e^- + \bar{\nu}_e$. This process is mediated by the weak interaction. The neutron turns into a proton through the emission of a virtual W^- boson. At the quark level, W^- emission turns a down quark into an up quark, turning a neutron into a proton. The virtual W^- boson then decays into an electron and an antineutrino. This process happens in fission byproducats.

The emission process for a β^+ is explained by $p \rightarrow n + e^+ \nu_e$. This decay can only happen inside nuclei when the absolute value of the binding energy of the daughter nucleus is greater than that of the parent nucleus, i.e., the daughter nucleus is a lower-energy state.

3.1.3 γ decay

γ radiation is an electromagnetic wave with a frequency of more then $10^{19} Hz$. One source for γ rays is γ decay. When a heavy and/or unstable atom goes through α or β decay, the resulting nucleus usually is in a high energy state. The nucleus then decays to a lower energy state while emitting a γ ray photon. The emission takes $10^{-12} sec$.