Inorganic Chemistry

Atomic nucleus. Nuclear reactions. Radioactivity.

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1 Why don't nuclei break apart?

Although the electron-proton-neutron model of atoms answered many questions, two new questions emerged, which this model failed to explain. Those questions are:

1. Why doesn't a nucleus break apart?

2. Why don't electrons fall onto an atomic nuclei?

By no means these two questions were idle, because they could not be answered in terms of XIX century physics. Let's forget for a while about the second question, and focus on the question number 1. Indeed, as we all know, the interaction between two charged particles obeys Coulomb law. In other words, its strength is inversely proportional to the square of the distance between two charges. Now imagine two protons separated by a distance which is 100,000 (one hundred thousand) times smaller than the size of an atom. Do you realize, how strong the repulsion between those protons will be? (please, calculate this repulsion force at home).

Obviously, such a tremendous repulsion force needs to be compensated for by some other, equally powerful force. However, only two forces exist in our world (i.e. in our big, *macroscopic* world), gravity and Coulomb forces, and none of them is capable of holding protons in the nucleus. That is why physicists hypothesized some new force exists in nature that holds protons and neutrons in atomic nuclei. They called it a "strong force". It is really strong, but it acts only at very short distance, the distance comparable with the size of atomic nuclei. That is why we cannot feel it, and cannot detect it using our conventional instruments. This force acts only upon protons and neutrons[1]. Electrons are not affected by this force at all. In nuclei, strong forces act both on protons and on neutrons, and Coulomb repulsion occurs only between protons. As a result, strong forces are capable of compensating repulsion between protons.

[1]...and other particles called hadrons. Several hadrons exist in nature, but only neutrons and protons are stabe. Other hadrons have a very short life time, they form in high energy collisions of accelerated particles. We do not discuss them.

2 Decay of a neutron

Although neutrons, like protons and electrons, can be considered fundamental building blocks all matter is composed of, they are not stable in free from. A freely flying neutron undergoes a fast decay onto a proton, an electron and a *neutrono*, a massless and neutral particle, which is very hard to detect.

$$\mathrm{n} \longrightarrow \mathrm{p}^{+} + \mathrm{e}^{-} + \nu \tag{1}$$

From this equation, one may conclude neutron is composed of a proton, electron and neutrino. However, protons also may undergo a decay when they are inside some nuclei. The equation of this decay is astonishing:

$$\mathrm{p}^{+} \longrightarrow \mathrm{n} + \mathrm{e}^{+} + \nu \tag{2}$$

In other wards, when proton falls apart, it generate a neutron, a neutrino, and a new particle called *positron*, a particle totally identical to electron, except its charge is positive. We cannot devote much time to this apparent paradox, however these two equations demonstrate the elementary particles world differs from our “big” world.

3 Three types of radioactive rays

When scientists discovered the radioactivity phenomenon, they observed radioactive rays can be separated onto three different fractions. Two of them were deflected by magnetic field in opposite directions, which meant those rays actually were some accelerated particles with opposite charges. The positive particles were heavy[2], its charge was equal to the charge of two protons, and its mass was equal to the mass of four protons. In other words, those particles (alpha-particles) were the nuclei of helium atoms.

The second type particles (bets-particles) were negatively charged, their charge and mass were equal to the charge of electron (and physicists concluded they are electrons).

The third type rays were not affected by magnetic field. They were true rays of light, although it was a very high energy light.

4 Nuclear reactions

Which processes lead to generation of radioactive rays? Obviously, the easiest question was the question about the origin of beta-particles. If you look at the equation 1, you will see, that electrons (beta-particles) are generated as a result of neutron decay. That means one neutron in some nucleus became a proton, so the atomic number of that atom increased by one, but its mass remained the same. Indeed, physicists established that the radioactive decay that generates beta-particles leads to conversion of a radioactive element into an element in the next cell of the Periodic table. For example, radioactive decay of ^{3}H leads to formation of a helium isotope with atomic mass of 3.

[2]Scientists realized that because their deflection angle was comparatively small

$$^{3}\mathrm{H} \longrightarrow {}^{3}\mathrm{He} + \mathrm{e}^{-} + \nu \tag{3}$$

In contrast, when an alpha-particle is generated during the decay, the atomic number of the atom decreases by 2, and its atomic mass decreases by 4. For example, alpha-decay of uranium (atomic number 92) leads to formation of thorium (atomic number 90):

$$^{238}\mathrm{U} \longrightarrow {}^{234}\mathrm{Th} + \alpha \tag{4}$$

Homework

1. Calculate the repulsion force (in newtons) between two individual protons in a helium nucleus. The values of Coulomb constant, proton charge and nucleus diameter can be found on Internet.

2. Three different isotopes of oxygen and three different isotopes of hydrogen exist in nature (although some of them are much less abundant). How many different water molecules can be found in a glass of water?

3. Natural copper exists as a mixture of two isotopes, ^{63}Cu and ^{65}Cu. Based on the atomic mass of the natural copper, calculate a relative abundance of its isotopes.

4. Radon, the heaviest know noble gas, was named after radium (Ra), a metal that produces a radon gas as a result of radioactive decay. Which type of nuclear reactions this process belongs to?

5. Tritium (^{3}H) is a radioactive isotope of hydrogen. During its undergoes radioactive decay beta-particle is being emitted. Which element is a product of that reaction?

My e-mail is mark.lukin@gmail.com