Discovering the internal world of nuclei

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Hi, traveler! Our mission today is to discover the internal world of nuclei. Here raises the initial question: what are nuclei? Take an hydrogen (H) atom as an example. If we make a step further into an it, a very dense and positively charged region can be found in the center surrounded by negative electrons, which is called the nucleus (single form of nuclei). When we continue our journey, it can be seen inside the nucleus that two kinds of particles are bound together, where the positive ones are called protons and the neutral ones are called neutrons. For the ${}^{2}_{1}\mathrm{H}$ nucleus, there are only one proton and one neutron. It is a little bit hard for us now to wander around inside the nucleus, but luckily we get here finally. Figure 1 shows the inner structure of an atom.

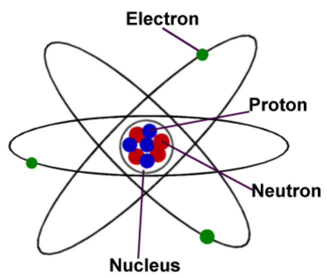

Figure 1: Structure of an atom

Here comes another question. How are the nucleons, which include both protons and neutrons, arranged in a nucleus? For this, we take into consideration a very famous and useful model in nuclear physics, called the "shell model". Imagine yourself as a neutron for example, and now you are in the queue of the "neutron shells". You cannot jump into the queue of the "protons shells", which means the shells for protons and for neutrons are independent of each other. Each row of the queue can only allow one identical nucleon, which represents a state. What should be noted is that when you get into the queue, you are intended to fill the row which is not already occupied, which means the added nucleons are tending to go into the lowest energy level. In some cases, when the number of the protons or neutrons reaches the "magic numbers" as 2, 8, 20, 28, 50, 82, 126 and so on, the nucleus will become extremely stable. Then, when you get into the queue, you will find the rows before you are so difficult to break up and you may consider staying away from them. On this occasion, the added nucleons are in valence shells and they do not have to fit into the lowest energy levels. Let's take ${}^{20}\mathrm{Ne}$ as an example. It has 10 protons and 10 neutrons. As we have known, ${}^{16}\mathrm{O}$ with 8 protons and 8 neutrons is extremely stable, so there should be 2 protons and 2 neutrons in the valence shells for ${}^{20}\mathrm{Ne}$. Figure 2 shows the mechanism of the nuclear shell model. Considering the notation $1p_{3/2}$, p and 3/2 are quantum numbers l and j, and 1 represents the number of times the "p" appears. The number of the "rows" we have mentioned equals to $2j+1$, which is shown beside the quantum numbers in Figure 2. The red numbers in the figure are magic numbers.

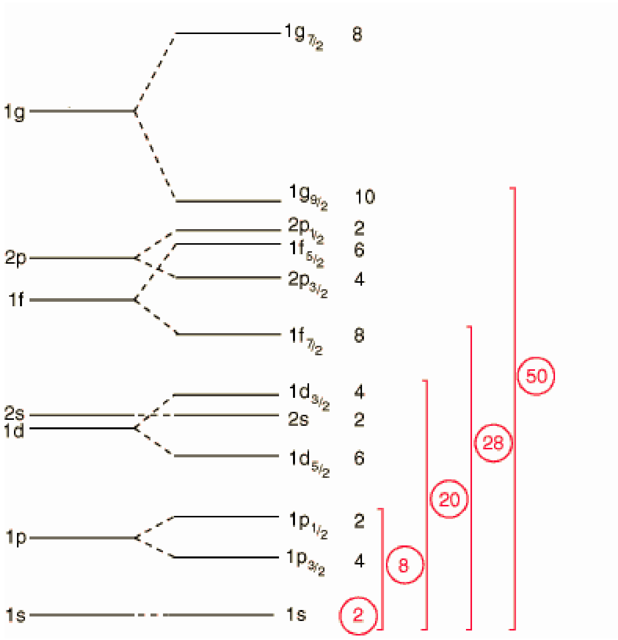

Figure 2: The nuclear shell model

The nuclear shell model successfully predicts the properties of nuclei which are one nucleon removed or added to the one of the magic number. The nuclei with nucleon numbers that are between the magic numbers may have very complex configurations in the shell model. Thus, we need to rely on the power of the computer programmes to calculate the model and reach the energy levels of the nuclei. The method I am focusing on is called the Configuration Interaction (CI) method. The approximation of the shells and the interaction between the nucleons should be included in the programming. With the knowledge of the properties of the nucleus, you can make progress in the nuclear structuring. Congratulations! You have made a great exploration and had a deep look into the world of the tiny neutrons and protons, but there could be far more ways to understand the nuclear shell model and far more fields of the nuclear studying. So with the understanding of the shell model, we just start our journey of discovering the internal world of nuclei.