Nuclei, Protons and Neutrons

At the core of the atom lies the atomic nucleus: a sometimes stable, sometimes radioactive complex structure of protons and neutrons... It is not always easy to properly describe this assembly, nor to grasp why some nuclei are more stable than others!

Mendeleev, Rutherford, Chadwick

Dmitri Mendeleev (1834-1907)

Esther Rutherford (1871-1937)

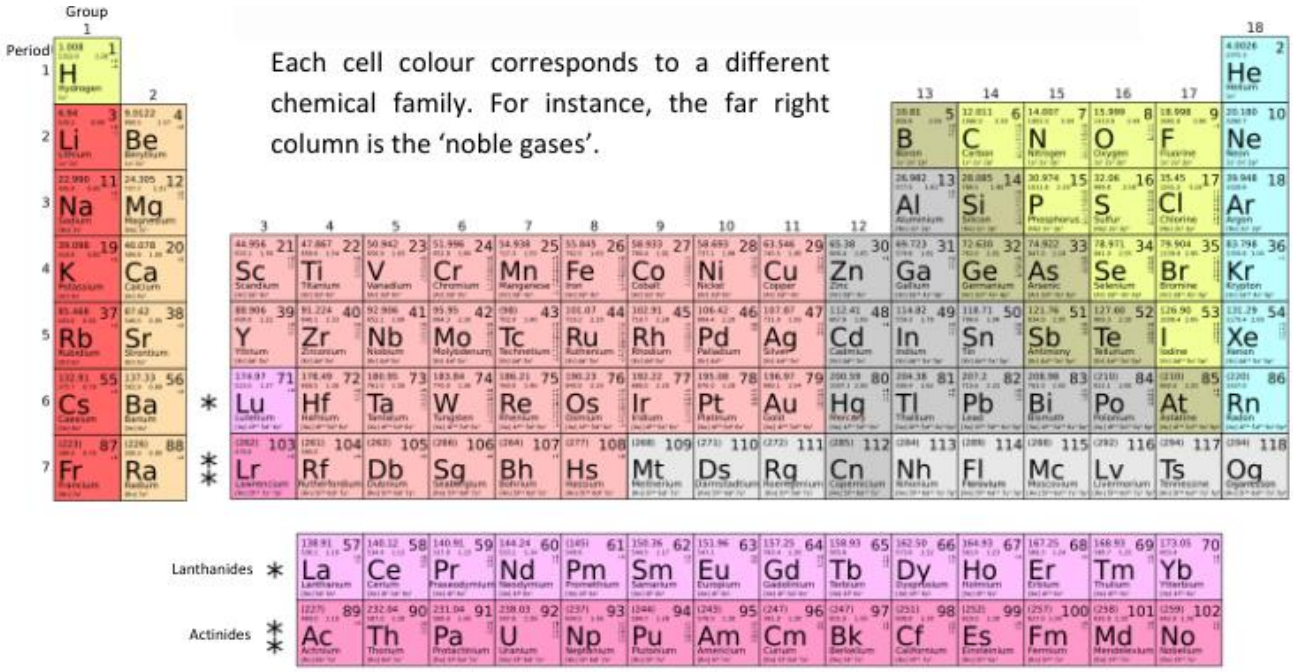
James Chadwick (1891-1974)

Following experimental observations made in the 18th and 19th centuries, the Russian chemist Dmitri Mendeleev suggested in 1869 a system for classifying atoms: the 'periodic table' of elements. In this table, chemical elements are ordered by ascending mass. The adjective 'periodic' refers to its organisation illustrating the periodic recurrence of certain physical and chemical properties in this ordered list of atoms. Elements in a same column form a family; we now know that they have the same number of electrons in the furthest shell from the nucleus, which explains the similarity of these elements from a chemical point of view. A line in the table corresponds to a period: we go from one element to the next by adding an electron in the outermost shell.

Mendeleev proposed this classification from mere experimental observations, long before their explanation in terms of electrons was discovered. It was only in 1911 that Ernest Rutherford experimentally showed that the nucleus is a tiny charged particle at the core of the atom.

A tiny, yet essential particle: the nucleus is ten thousand times smaller than the atom and its electronic cloud, yet it accounts for more than 99.9% of the total mass. When James Chadwick discovered the neutron 20 years later, two types of nucleus constituents (nucleons) were distinguished: protons, with a positive charge, and neutrons... which are electrically neutral.

The lightest nucleus is that of hydrogen, which contains a single proton. The heaviest nucleus to be found naturally on Earth is that of Uranium-238 (92 protons, 146 neutrons). Nuclei with the same number of protons but different numbers of neutrons have similar



chemical properties, they are called isotopes. This is the case, for example, of carbon (6 protons), which occurs in nature in the form of two stable isotopes (Carbon-12 and Carbon-13, containing 6 and 7 neutrons, respectively) and a radioactive isotope (Carbon-14, containing 8 neutrons).

The vast majority of known nuclei are unstable and decay through various radioactive processes. As protons with the same electric charge repel each other, the nucleus is made more or less cohesive by another force, the strong interaction. The latter is also responsible for the attraction between protons and neutrons. It is very powerful, but only acts at a short range.

The nucleus is a highly complex system: it involves a great number of particles that are subject to the laws of quantum mechanics; a change affecting only one of them is enough to drastically alter the behaviour of the whole. We are still a long way from understanding all the details of the interaction binding nucleons together: new, difficult to explain phenomena appear when we observe nuclei that are extremely rich or deficient in neutrons.

Credit: Wikipedia

The periodic table of elements

This table lists all the known chemical elements in ascending order of atomic number (the number of protons in the nucleus). Elements in the same column have very similar chemical properties which stem from the organisation of their outermost electronic shell. In addition to the element's symbol, each cell indicates the molar mass, i.e. the mass of 6.02 × 10^{23} atoms (a number called the Avogadro constant). More than 20 elements in the table are artificial radioelements: they do not exist in nature – their isotopes are all radioactive and therefore unstable.

Translated from 'Les noyaux, protons et neutrons',* Passeport pour les deux infinis, *IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG