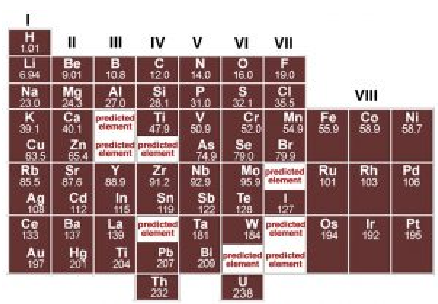
2.5: Organizing Elements: Introduction to the Periodic Table

Up to this point we have made a number of unjustified assumptions. We have talked about elements but we have not explicitly specified how they are different, so let us do that now. If we start with hydrogen we characterized it by the presence of one proton in the nucleus and one electron surrounding it. Atoms are always neutral, which means that the number of positively-charged particles is equal to the number of negatively-charged particles, and charges come in discrete, equal, and opposite units. The presence of one proton and one electron defines a hydrogen atom but the world is a little more complex than that. A hydrogen atom may also contain one or two neutrons in its nucleus. A neutron can be considered, with the forgiveness of physicists, a proton, an electron, and an uncharged neutrino, and so it is electrically neutral. Neutrons are involved in the strong nuclear force and become increasingly important as the element increases in atomic number. In hydrogen, the neutrons (if they are present) have rather little to do, but in heavier elements the strong nuclear force is critical in holding the nucleus together, because at short distances this force is ~ 100 times stronger than the electrostatic repulsion between positively charged protons, which is why nuclei do not simply disintegrate. At the same time, the strong force acts over a very limited range, so when particles are separated by more than about $2 \times 10^{-15}\ \mathrm{m}$ (2 femtometers or fm), we can ignore it.

As we add one proton after another to an atom, which we can do in our minds, and which occurs within stars and supernova, in a rather more complex manner, we generate the various elements. The number of protons determines the elemental identity of an atom, whereas the number of neutrons can vary. Atoms of the same element with different numbers of neutrons are known as isotopes of that element. Each element is characterized by a distinct, whole number (1, 2, 3, …) of protons and the same whole number of electrons. An interesting question emerges here: is the number of possible elements infinite? And if not, why not? Theoretically, it might seem possible to keep adding protons (and neutrons and electrons) to produce a huge number of different types of atoms. However, as Rutherford established, the nucleus is quite small compared to the atom as a whole, typically between one and ten femtometers in diameter. As we add more and more protons (and neutrons) the size of the nucleus exceeds the effective range of the strong nuclear force ($< 2\ \mathrm{fm}$), and the nucleus becomes unstable. As you might expect, unstable nuclei break apart (nuclear fission), producing different elements with smaller numbers of protons, a process that also releases tremendous amounts of energy. Some isotopes are more stable than others, which is why the rate of their decay, together with a knowledge of the elements that they decay into can be used to calculate the age of rocks and other types of artifacts.[14]



Each element is defined by the number of protons in the nucleus, and as such is different from every other element. In fact, careful analysis of different elements reveals that there are periodicities (repeating patterns) in the properties of elements. Although John Dalton produced a table of elements with their atomic weights in 1805, it was only when Dimitri Mendeleev (1834–1907) tried to organize the elements in terms of their chemical and physical properties that some semblance of order began to emerge. Mendeleev, a Russian chemistry professor, was frustrated by the lack of organization of chemical information, so he decided to write his own textbook (not unlike your current authors). At the time, scientists had identified about 60 elements and established their masses relative to hydrogen. Scientists had already noticed that the elements display repeating patterns of behavior: and that some elements have very similar properties. It was Mendeleev's insight that these patterns could be used as a guide for arranging the elements in a systematic way. In his periodic table, published in 1869, he placed elements in order of increasing atomic weight in repeating rows from left to right; elements with similar chemical properties were placed in vertical columns (known as groups).

Although several other scientists were working on schemes to show patterns in elemental behavior, it was Mendeleev's arrangement that emerged as the basis for the modern periodic table, not only because of the way he arranged the elements but also for what he left out and what he changed. For example he was so sure about the underlying logic of his table that where certain elements seemed out of place, based, for example, on their reported atomic weights, such as tellurium and iodine, he reversed them and he turned out to be correct. Where Mendeleev predicted elements should be, he left gaps in his table to accommodate them. Subsequently, scientists discovered these missing elements (for example germanium, gallium, and scandium). In fact, we now know that it is not atomic weight (that is the number of protons and neutrons) but rather atomic number, Z, (the number of protons and electrons) that increases periodically. This explains why tellurium ($\text{atomic mass } 127.6, Z = 52$) must come before iodine ($\text{atomic mass } 126.9, Z = 53$). The important point to note is that although the modern periodic table is arranged in order of increasing number of protons and electrons, the repetition and patterns that emerge are the property of the electrons, their arrangements, and energies. This is our next subject.

Questions

Question to Answer

- Science fiction authors like weird elements. Provide a short answer for why no new elements with atomic numbers below 92 are possible.
- Isotopes of the same element are very similar chemically. What does that imply about what determines chemical behavior?

Questions to Ponder

- Why do you think there were no noble gases in Mendeleev's periodic table?
- Why aren't the atomic weights in Mendeleev's periodic table whole numbers?
- Why would you expect different isotopes of the same element to differ in stability?
- You discover a new element. How would you know where would it should go in the periodic table?