ACTIVITY 9– WHAT DETERMINES AND LIMITS AN ATOM'S MASS?

Background Information

Dalton believed that the elements differed from one another due to their different masses. Today we know that what determines an element's identity is not its mass but the number of protons in its nucleus. The number of protons for an element is specified by its **atomic number** (Z). Since protons are located in the nucleus and have a relative charge of 1+, the number of protons also represents the nuclear charge.

Atomic Mass

There is no instrument that is sensitive enough to determine the mass of one atom. Therefore, a scale of relative atomic masses has been devised. The current atomic mass unit is based on the mass of 1/12th of a carbon-12 atom's mass. If we say that one mole of carbon has a mass of 12 g then 1 atom of carbon would have a mass of 1.99×10^{-23} g and 1 atomic mass unit (abbreviated amu) would be 1/12th of this mass or 1.66×10^{-24} g. These numbers become awkward to work with so we have a tendency to say that the **atomic mass** (**A**) of carbon is 12 or the mass of oxygen is 16.

So one ^{12}C atom = 12 u, where u is the symbol used in the SI system and means the atomic mass unit (amu). We may also encounter the use of the mass unit **dalton**, where 1 u = 1 dalton.

When we examine the periodic table we see a mass of 12.011 u for carbon, not 12.000. This is due to the fact that the mass recorded on the periodic table is a **weighted average** of the naturally occurring isotopes of carbon (^{12}C and ^{13}C; there is only a trace of ^{14}C and this does not affect the weighted mass). There is a 98.892 percent natural abundance of carbon-12 (12.00000 u), and a 1.108 percent abundance of carbon-13 (13.00335 u). The masses of other elements are treated similarly.

The number of its neutrons and protons determines the atomic mass of an element. The mass of the electrons is insignificant and is not included in the determination of the atomic mass of an element. We should not use the term atomic weight when referring to the mass of an element. Weight is a measurement of gravitational force and would vary from place to place. As scientists we know this and just overlook it. However, it is important that students understand the difference between mass and weight.

What Limits the Number of Elements?

Any element above bismuth-83 does not have a stable isotope because it is radioactive. Iron-56 is considered to be the most stable isotope because it has the greatest binding energy per **nucleon**. Recall that a nucleon is another term for either a proton or neutron. It is also interesting to note that of the 264 stable isotopes, only five have odd numbers of both protons and neutrons. There are 157 isotopes that have both even numbers of protons and neutrons. The remaining have either an odd number of protons or neutrons with an even number protons or neutrons.

An explanation for this observation is related to the spin of the nucleons. If they were all even numbers, then they would have paired spins and this would reduce the nucleus energy. An odd number of nucleons would not be able to achieve this stability.

There is a magic number of nucleons that are also associated with the stability of isotopes. The magic numbers are 2, 8, 20, 28, 50 or 82. Both nucleons do not have to have one of the magic numbers in order to be stable however. For example, lead-206 is a stable isotope and lead contains 82 protons. Calcium-40 is certainly an ideal isotope because it not only has 20 protons but it also has 20 neutrons. The noble gases are also very stable and we note that all of their atomic numbers are even.

Another factor that can be used to determine isotope stability is the neutron-to-proton ratio. We note that the number of neutrons is greater than the number of protons as the atomic number increases. Iron-56 has a ratio of about 1.2:1 and as you work your way out to lead-206 the ratio is about 1.5:1.

We can see that there is not one simple rule that we can use to determine the stability of an isotope but a variety of different conditions. Observations and experimentation will support our understanding of how to determine isotope stability. It probably amazes most people that with protons so tightly packed together and with like charges that the nucleus even stays together but the key is the **binding energy** of the nucleus that holds it together.