MODULE 1

Nuclear Power – The Core

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EDTECH 512 (Summer 2014)

Module 1: Atoms – The Things That Stuff Is Made Of.

Upon Completion of this Module, you will be able to:

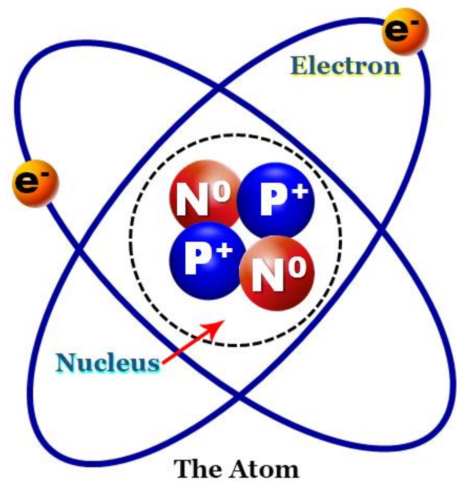
- DETERMINE the number of protons, neutrons and electrons of a given atom, given a Periodic Table of Elements.
- LIST the properties of protons, neutrons and electrons including charge, location within the atom and relative mass.
- DETERMINE the number of protons, neutrons and electrons of a given atom given an atom's standard notation.
- DEFINE the following terms: Atomic Mass Unit, Nucleon, and Isotope.

What is an atom?

Atoms are everywhere. Atoms are everything. They're in the air you breathe, the food you eat. Everything in the universe is made up of atoms. They're pretty important.

The concept of the atom was first conceived in ancient Greece. Greek philosophers Leucippus and Democritus first developed the concept of the atom. They theorized that there were certain small particles which could not be divided any further. They named these particles atoms, from the Greek word *atomos* meaning indivisible.

Of course we know now that atoms can indeed be split, but it's interesting to note that the classical definition of an atom has stood the test of time. Simply put, an atom is defined as the smallest component of an element that retains the chemical properties of that element.



As previously, we now know that atoms are made up of even smaller, common sub-components, and that these sub-components are interchangeable. Each atom essentially has two separate regions. There is the nucleus, which will be our primary focus for this course and the electrons which are orbiting the nucleus. In many ways, an atom is similar to our solar system where the nucleus is the sun and the electrons are the individual planets.

There are many real and theoretical components of an atom's nucleus, but for the purposes of this course, we are only going to concern ourselves with the two major components, namely protons and neutrons. It is important to remember that any sub-atomic particle found in the nucleus be it proton, neutron or anti-neutrino are referred to as nucleons.

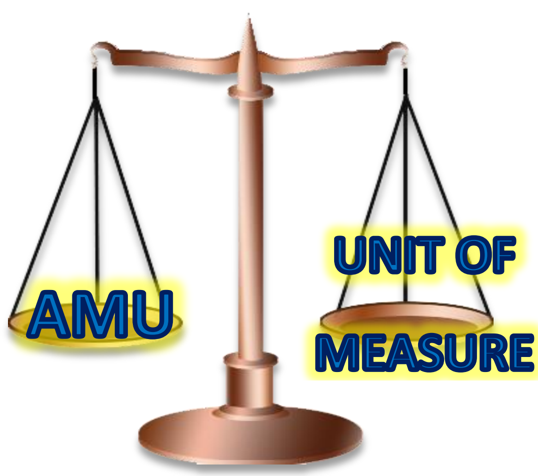
Property Values

Atoms matter. In fact, atoms are matter. More to the point, atoms are matter made up of matter. For the purposes of this course, in general, we will be considering three of the building blocks that make up an atom: the proton, the neutron and the electron.

Matter is, for lack of a better term, stuff. That's it. There's no mystery. It's just stuff. So let's take a look at stuff, and more importantly, what stuff has in common.

All stuff has mass. It's there. It exists. It's impossible to put stuff in the same space that other stuff occupies. Quite a few people confuse mass with weight. Mass is not weight. This is important, repeat after me. Mass is not weight. Let's look at an example. Suppose we have a 300 pound rock here on Earth. On Earth, that rock weighs 300 pounds. Any one of us would be hard pressed to move that rock from our back yard. We would probably just plant flowers around it and call it landscaping. However, if we were to fly that rock to the moon, that rock would weigh only 50 pounds. Most of us could manage 50 pounds. We would probably move the rock out of our moon back yard and not think twice, but wait a minute, that rock is still the same rock. It hasn't changed. It still has the same number of atoms as it had on earth, but it weighs less. That's because weight is a function of gravity. The gravity on the moon is one sixth the gravity on earth so it weighs less, but its mass is constant. Mass is a constant property of matter, and in this course, mass is what we will be considering.

The other property that all matter has in common is electrostatic charge, positive, negative or neutral. When you go to pick up a bag of potato chips and don't get a shock, it's because the net electrostatic charge of all the matter that makes up that bag of chips is electrically neutral. However, when you scuff your feet on shag carpet and reach for a door handle, you may receive a static shock. This is because while walking across the carpet, your body picked up some extra electrons, lots of extra electrons in fact so when you touch the door handle, those extra electrons go rushing for the door and give you that shock.



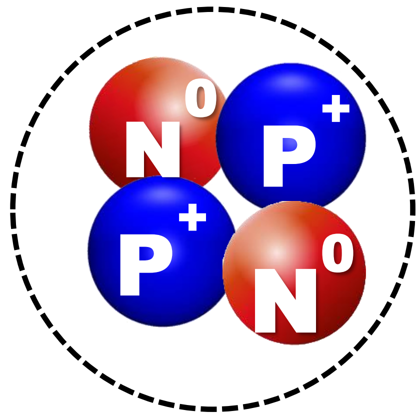
Now that we understand the two most important properties of matter, we have to have a way of measuring them. After all, that's what scientists do, they measure. Let's start with mass. It's safe to say that we can all agree that atoms are very, very small. Well sub-atomic particles are even smaller. Thus they have an even smaller amount of mass. Therefore we need a common measuring stick with which to measure atomic mass. That measuring stick is the Atomic Mass Unit.

We use Atomic Mass Units in the same way we use any unit of measure. Just like there are 5 pounds of potatoes, there are 5 Atomic Mass Units. By adopting our own unit of measure, we keep the math simple. As we progress, we will have to compute different amounts of energy based on mass. Using numbers like 4.076 is far easier than using expressions like $1.66x10^{-24}$. (the mass of an Atomic Mass Unit in grams) Believe me when I tell you, as we move farther along in the course. You'll be thankful that we're minimizing our use of exponents.

What's Inside an Atom?

The atomic model we're going to be using for this course was developed by the renowned Danish physicist, Niels Bohr. His model consists of a central nucleus surrounded by a series of electrons. The electrons orbit the nucleus much like the Earth orbits the Sun. So in a way, atoms are like a smaller version of our solar system. We'll begin by looking at the nucleus.

There is a nucleus at the center of each atom. Since this course is about nuclear fission, I'm sure you've already figured out that, for this course, this is the part of the atom about which we will be the most concerned. It turns out that the nucleus of an atom consists of even smaller bits of matter. The bits of matter are called, conveniently enough, nucleons. For the purposes of this course, we're really only going to concern ourselves with the two most important players in the nucleus, the proton and the neutron.



The Nucleus

We'll begin by discussing the proton. As we'll learn later, protons are really the most important part of the nucleus. They give each element their character. As we said previously, all matter has two properties in common, mass and electrostatic charge. The proton has a mass of 1.00727 Atomic Mass Units and an electrostatic charge of +1.

The other resident of the nucleus which is important to us is the neutron. Neutrons are a bit bigger than protons and have a mass of 1.00866 Atomic Mass Units. Ironically, neutrons have no electrostatic charge. They're neutral, like Switzerland, but without the tasty chocolate. As we'll find out later, even though they lack an electrostatic charge, neutrons are incredibly important to the fission process. Without neutrons, there would be no fission process and I wouldn't be writing this text.

Lastly, there's the lonely electron. It orbits the nucleus and therefore is not considered a nucleon. While electrons are incredibly important when studying chemistry, they're fairly insignificant in the study of nuclear fission. The only thing electrons bring to the nuclear fission party is their electrostatic charge which is -1. In terms of mass, electrons are practically negligible, having a mass of 0.00055 Atomic Mass Units. Generally, we don't consider an electrons mass when discussing nuclear reactions. The table on the next page sums up the properties of the sub-atomic particles which we have discussed.

Table 1 - Sub Atomic Particles

Particle Name	Particle Location	Mass	Charge
Proton	Nucleus	1.00727 AMU	+1
Neutron	Nucleus	1.00866 AMU	0
Electron	Orbits the Nucleus	0.00055 AMU	-1

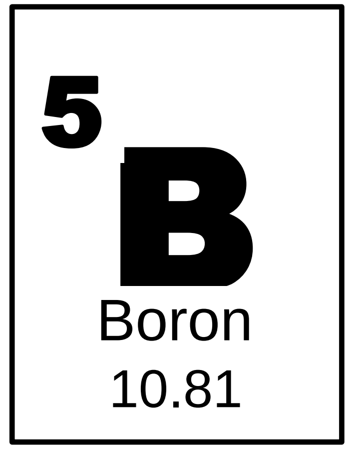
Before we go on, I want to take a minute to discuss the scale of atoms. Because they are so small, it's nearly impossible to visualize the particles we will be studying in this course. So let's put the atom into perspective. If the nucleus of the atom were the size of marble and we put that marble on the goal line of a football field, the outer edges of the electron orbits would be the other goal line. Now quantum physicists will argue about this analogy, but what do you expect from people who spend all day thinking and arguing about things they can't see directly. This information really isn't germane to the course, but it's something cool to think about.

The Periodic Table of Elements

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 **	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
**Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

Behold everything in the Universe. That's right. I said everything. Everything in the universe is made up of atoms whose information is contained in this graphic. Impressive, don't you think? Actually, the Periodic Table of Elements gives us quite a bit of information required for this course. There are various permutations of this table available on line for viewing, but for our purposes, simple is best. Simple you say? It looks pretty complicated to me. Let’s look at the information for a single element in order to see all the things that the Periodic Table has to offer.



Let’s look at the Periodic Table information for the element Boron. The first thing that stands out is the big ‘B’ in the middle. That ‘B’ is Boron’s chemical symbol. Each element in the periodic table has its own unique symbol. Some of them, such as Boron, have a symbol that makes sense. Others, such as Lead, whose chemical symbol is Pb, make less sense, but whether they make sense or not, each element has its own symbol.

The next thing to notice is that the table not only gives us the symbol, but it gives us the name of each element. This is quite helpful just in case we didn’t know that Hg was the symbol for Mercury.

The next two pieces of information are the most pertinent to our discussions. The first is the atomic number of the element, that is to say the number 5 in the upper left hand corner. Each element has, not only a unique symbol, but a unique atomic number. The atomic number for each element is based on the number of protons within the nucleus. Putting it a different way, if a Boron atom were to have 6 protons, it would no longer be Boron, but instead would be carbon. A Boron atom will always have 5 protons just as an atom of Uranium will always have 92 protons.

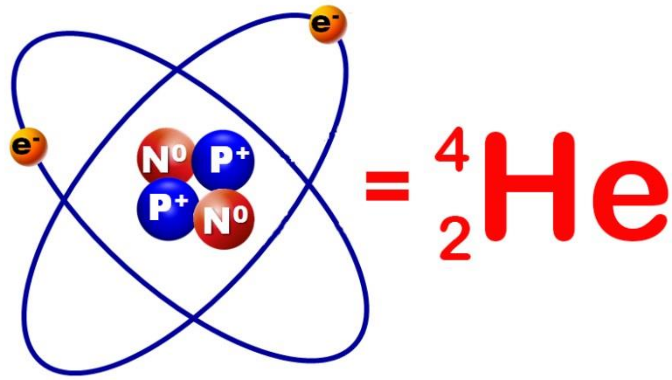
So Boron has 5 protons, but we said that the nucleus contains both protons and neutrons. How come the geniuses who created this table didn’t put the number of neutrons in that little square? Well it turns out they did it for a reason, as geniuses often do and we’ll discuss that reason later in this module, but it turns out that we don’t need to list the number of neutrons in an element. We can calculate the number using the remaining information on the periodic table.

The number which we haven’t discussed yet is the atomic mass of the element. In this case, Boron has an atomic mass of 10.81 Atomic Mass Units. Since we know that protons and neutrons each have an approximate atomic mass of 1Atomic Mass Unit and we know the number of protons in a Boron atom from its atomic number, we can calculate the number of neutrons in an atom by subtracting the number of protons from the rounded atomic mass of the element. Put another way, since we declared electrons as non-contributors to the mass of the atom, the number of nucleons in an atom is approximately equal to the atomic mass off the atom.

Setting the Standard

Scientists are, in general, a lazy bunch, especially when it comes to writing. They’ll spend all day pouring over equations, but when it comes to words, the shorter the better. As you can imagine, this presents a serious problem when they’re writing about atoms. Scientists would have staged a revolt if they had to write, "A Helium atom with 2 protons and 2 neutrons and a Lithium atom with 3 protons and 4 neutrons results from the decay of a Boron atom with 5 protons and 6 neutrons." Come to think of it, their readers would have staged a revolt as well.

Because of this, and because we're going to be discussing many other atoms during this course, a shorthand has been developed. That shorthand is called, "Standard Notation." Take a look at the figure on the right. On one side of the equation we have an actual Helium atom, and on the other side of the equation, we have the standard notation representation of a Helium atom. The first thing we notice when we look at the standard notation is that the chemical symbol of the atom the chemical symbol is always written on the right. The two numbers on the left, though, are the items that we are going to be concerned about. The number on the lower left, in this case the number 2, represents the atomic number of the element, that is to say, the number of protons. The number on the upper left represents the total number of nucleons contained within the atom. As we said previously, the total number of nucleons is equal to the number of protons added to the number of neutrons. Since a Helium atom has 2 protons and 2 neutrons, the upper left hand number is 4.



Now that we understand standard notation, we can now rewrite the long winded statement in the first paragraph as $^{10}_{5}B + ^{1}_{0}n \rightarrow (^{11}_{5}B)^* \rightarrow \ ^{7}_{3}Li + ^{4}_{2}He$. This is much simpler and much quicker which is why scientists use it. I did want to point on one term from the previous equation, and that is the $^{1}_{0}n$ term. This is what we use to represent a neutron, and as we examine it, it only makes sense. A neutron is a single nucleon, but it is not a proton hence the lower left hand number is a zero.

Isotopes, the Atomic Fraternal Twin

As was stated in the video, not all atoms are created equal. Believe it or not, there are many different types of the same atom. If you recall earlier discussions, we stated that each element is dictated by its number of protons. There are, however, instances where an atom can have the same number of protons but a different number of neutrons. Such atoms are called isotopes. For purposes of discussion, let's look at a Uranium atom. Some occurrences of Uranium have 143 neutrons. These when combined with the 92 protons it takes for Uranium to be Uranium gives us a Uranium-235 atom or $^{235}_{92}U$. However, there are naturally occurring incidents where a Uranium atom will have 146 neutrons. In this case, this particular atom would be referred to as U-238 or $^{238}_{92}U$. In both cases the atoms are Uranium atoms because they have the same number of protons, 92, but each of the atoms are physically different with differing nuclear properties based on the number of neutrons in the nucleus. As such there are a number of Uranium isotopes.

Looking Ahead

In the next module, we will examine something truly amazing. It is, without a doubt, one of the most amazing phenomena known to man. We'll touch on the forces present within the nucleus of an atom and how one of those forces, quite literally, makes things disappear.