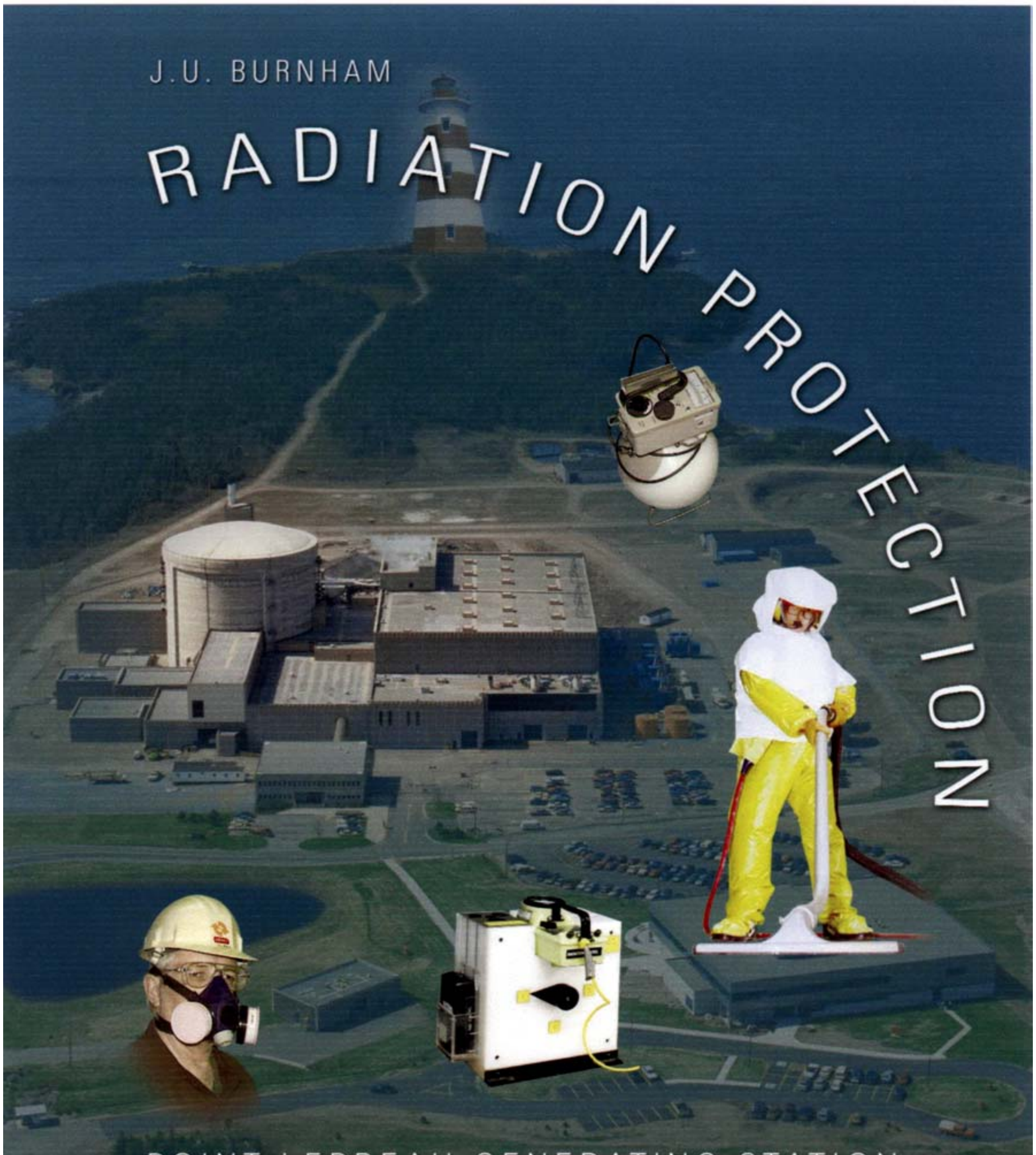


J.U. BURNHAM

RADIATION PROTECTION

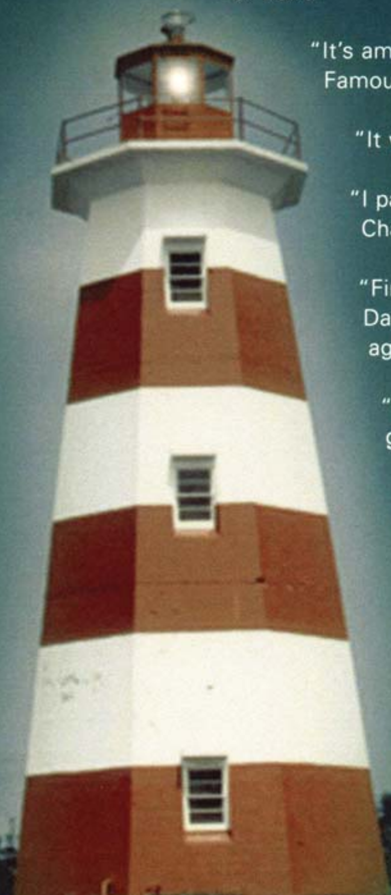
POINT LEPREAU GENERATING STATION

NEW BRUNSWICK POWER CORPORATION

Readers' Comments

"When he asked me for a couple of months off to finish his book, I wondered what he was reading." – *L. Titus*

"I always thought Bremsstrahlung was a respiratory disease until I read this book." – *C. Baird*



"It's amazing what one can accomplish with a case of the Famous Grouse." – *J. O'Donnell*

"It was a pain to profread this book." – *C. Nason*

"I particularly enjoyed the shower scene in Chapter 9." – *H. Clark*

"Finally we have a succinct explanation of the Dawson lead, a little-known defensive manoeuvre against 3 NT." – *D. Dawson*

"Useful portable gamma shielding, but needs grommets." — *S. Frost*

"I learned one thing from this book: which waste can to put it in." – *C. Philip*

"Grabs the reader on the first page, and – barring a psychological lapse of consciousness – continues to inflict pain for another 410 more." – *H. Melanson*

"This is one of those books that you can't pick up once you've put it down." – *J. Sommerville*

In the unlikely event that you want a copy of this book and don't work for NB Power, contact J. Burnham at 33 Chandler Road, St. Andrews. NB, Canada E5B 2H4, or jburnham@nbnet.nb.ca, or 1-506-529-8945

FOREWORD

The objectives of our Radiation Protection Program are:

1. To prevent radiation fatalities.
2. To prevent radiation injuries.
3. To remain within legal dose limits.
4. To keep radiation doses as low as reasonably achievable.

This book forms part of our Radiation Protection Training Program. It is designed to give you an appreciation and understanding of the principles of radiation protection that we want you to follow, so that we can meet our objectives listed above.

Knowledge and training are only a small part of the safety culture required to prevent injuries and keep exposures as low as reasonably achievable. To be truly successful in safety requires a questioning attitude by all employees and supervisors. A good safety program relies on open, frank, appreciative and constructive feedback. This feedback is the means of continuously improving the safety of employees. It is through learning from our successes and mistakes that we achieve world class performance.

Laurie J. P. Comeau
Manager, Health Physics

Rev. 4, June 2001

Jan Burnham spent most of his career with the New Brunswick Power Corporation. Among other things, he was responsible for designing and implementing the radiation protection program for Point Lepreau Generating Station in New Brunswick, Canada.

Since he retired from NB Power in 1997, he has worked as a consultant to the nuclear industry in Canada, primarily in the areas of technical and management review of health physics activities.

Jan is an avid sailor, and enjoys bridge, photography, and making and drinking wine.

CONTENTS

CHAPTER 1

ATOMIC STRUCTURE

INTRODUCTION

In the operation of a nuclear power station you will deal with "atomic radiation" every day. To understand what radiation is, you must first learn a bit about the atom.

Why does each substance possess its own characteristic properties? Why are salt and iron solids under ordinary conditions? Why are oxygen and hydrogen gases? Why does sulphur melt at a much lower temperature than salt? Why do metals conduct electricity whereas non-metals generally do not?

These and countless other questions remained unanswerable until theories were developed about the structure of matter.

BUILDING BLOCKS OF MATTER

Greek philosophers used to speculate as to whether matter was continuous or discontinuous. (I guess they had their slack days like everyone else.) By continuous they meant that, if it were possible, a piece of iron could be divided into two, the two parts divided into two again and this process carried on forever, the two divided parts always being iron. By discontinuous they meant that somewhere in this dividing process you would reach a point when the two halves were not iron.

Thanks to the efforts of many scientists who followed the Greeks, we now know that matter is discontinuous. In the case of iron, there comes a time when on dividing what is undoubtedly a piece of iron, the parts are no longer iron. This last piece of matter with iron characteristics is known as an **atom** of iron. The same applies to any other primary material; the last tiny piece of it is called an atom of that material.

Certain facts have been discovered about these atoms. Here are three of them:

1. Atoms are composed of three basic particles. These particles are called **subatomic** and are

   a) **protons**
   b) **neutrons**
   c) **electrons**

   These subatomic particles are the same in all atoms.

2. All atoms of one kind of material are similar.

3. Atoms of different materials differ only in the number and arrangement of their subatomic particles.

THE NUCLEUS AND ORBITAL ELECTRONS

The simplest kind of atom is the hydrogen atom. It is so simple that it has only two of the three subatomic particles. The hydrogen atom consists of a proton in the centre and one electron circling around it as shown in Fig. 1.1. The second simplest atom is that of helium. It has two protons and two neutrons in the centre of each atom with two electrons circling around it (Fig. 1.2).

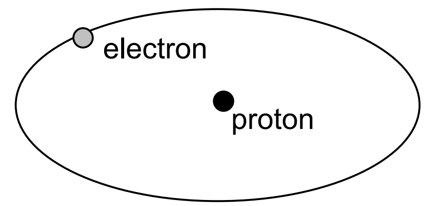


Fig. 1.1. Hydrogen Atom

The neutrons and protons in an atom are so closely packed together that they form a single cluster called the **nucleus** of the atom. The helium nucleus contains two protons and two neutrons. When the two electrons are included, the whole thing is the helium atom.

In fact, we may say that an atom consists of a nucleus and the associated electrons that are called **orbital electrons**. The reason for this name is that the electrons can be pictured as little particles whirling around the nucleus much as the planets orbit about the sun.

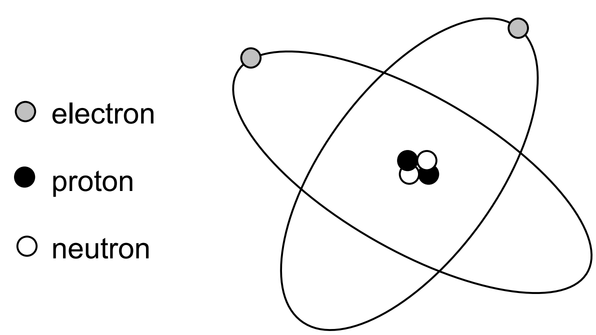


Fig. 1.2. Helium Atom

Why do the electrons stay in their orbits rather than fly off into space? The answer to this is electrical attraction. First, we'll review briefly the nature of electrical force

ELECTRICAL BALANCE IN THE ATOM

There are two kinds of electric charge, positive (+) and negative (-). When two objects are both charged with a positive charge, they repel one another. Similarly, two negatively charged bodies repel one another. But when one object is positively charged and another is negatively charged, the two objects will attract one another. All this can be said very briefly in the statement: **"like charges repel, unlike charges attract"**.

The proton is a positively charged particle.

The electron is a negatively charged particle. Its charge is equal and opposite to the charge on the proton.

The neutron has no electrical charge.

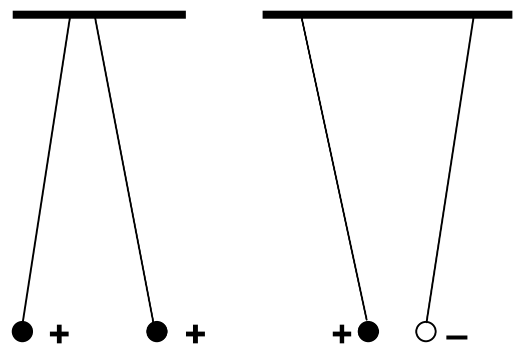


Fig. 1.3. Like Charges Repel, Opposite Charges Attract

Returning to our question of why orbital electrons remain in orbit, an orbital electron can be compared to a weight being whirled about at the end of a string. If you let go of the string, the weight moves off in a straight line in whatever direction it happened to be going at the time. As you pull on the string, holding it tight, the weight cannot move away from you. In the same way, the electrical force of attraction between the positive nucleus and the negative electron keeps the electron in its orbit. Fig. 1.4 gives you the idea.

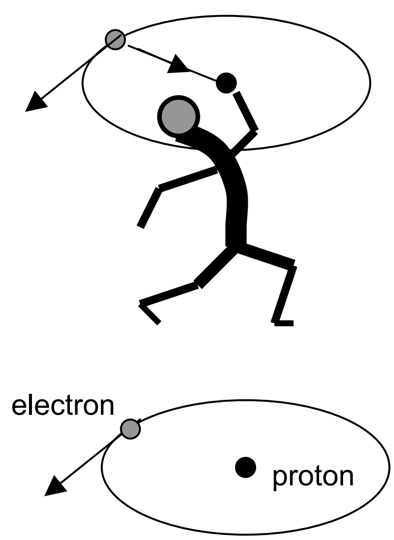


Fig. 1.4. Electron Orbit

For each proton in the nucleus, the atom has one orbital electron. In other words, the number of orbital electrons in an atom is equal to the number of protons in its nucleus. Hydrogen with one proton in its nucleus has one orbital electron. Helium with two protons has two orbital electrons.

Since the charge of a proton is equal but opposite to that of the electron, the total positive charge of the nucleus therefore equals the total negative charge of all the orbital electrons.

In this way the net charge of the **whole** atom is exactly zero. If an atom were short of an electron for any reason, it would have a positive charge. It would then pick up any loose electron that happened to be drifting around and so cancel out the extra positive charge.

ATOMIC NUMBER

Since the number of orbital electrons in an electrically neutral atom is equal to the number of protons in its nucleus, it's quite clear that this **number of protons** determines the overall structure of the atom. If you examine a list of atoms, you realise that the atoms are different not only in structure, but also in their characteristics or in the way they behave.

The number of protons in the nucleus, which makes atoms different from one another in their structure and character, is such an important number that it is given a special name, the **atomic number**.

> **The ATOMIC NUMBER of any atom is the number of protons in its nucleus. The letter Z represents this number.**

Therefore, we say that the atomic number of hydrogen is one (Z = 1), the atomic number of helium is two (Z = 2), and the atomic number of uranium is 92 (Z = 92). So the atomic number tells us how many positive charges there are in the nucleus, and of course, it also tells us how many orbital electrons the atom should have. Neutrons are uncharged particles; they don't affect the electrical state of the atom. But they do add mass to the nucleus and we'll discuss them later.

THE ELEMENTS

If a large number of atoms, all with the same number of protons, are assembled together in one place, we call the substance formed by these atoms an **element**.

> **An ELEMENT is a form of matter whose atoms all have the same atomic number.**

We've already met the elements hydrogen and helium. Hydrogen has the simplest structure with only one proton in the nucleus. Then comes helium with two, lithium with three, and so on.

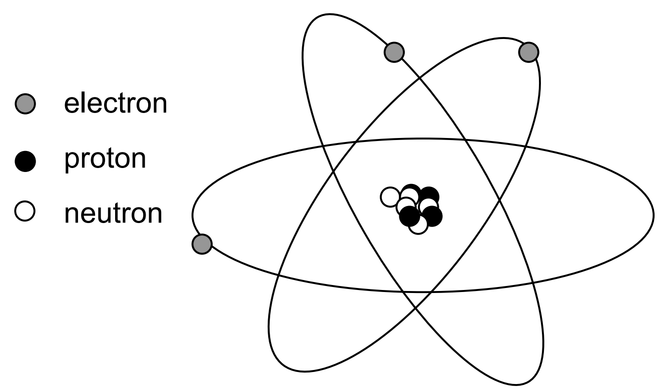


Fig. 1.5. Lithium Atom

Over 100 different elements have been identified. Ninety of these occur naturally, and the remaining elements are man-made in nuclear reactors or particle accelerators.

The table on the next page lists all of the elements. Apart from technetium (Z = 43) and promethium (Z = 61), all the elements from hydrogen to uranium (Z = 92) occur in nature. You'll recognise many of the names of the elements, but others are quite uncommon. Fortunately, we don't have to know many of these names – those with which you will become familiar during this course are shown in *italics* in Table 1.1.

TABLE 1.1. LIST OF THE ELEMENTS

Z	*SYMBOL*	*NAME*	*Z*	*SYMBOL*	*NAME*	*Z*	*SYMBOL*	*NAME*
1	H	*hydrogen*	36	Kr	*krypton*	71	Lu	lutetium
2	He	*helium*	37	Rb	*rubidium*	72	Hf	hafnium
3	Li	*lithium*	38	Sr	*strontium*	73	Ta	tantalum
4	Be	*beryllium*	39	Y	yttrium	74	W	tungsten
5	B	*boron*	40	Zr	*zirconium*	75	Re	rhenium
6	C	*carbon*	41	Nb	*niobium*	76	Os	osmium
7	N	*nitrogen*	42	Mo	molybdenum	77	Ir	iridium
8	O	*oxygen*	43	Tc	technetium	78	Pt	platinum
9	F	fluorine	44	Ru	ruthenium	79	Au	gold
10	Ne	neon	45	Rh	rhodium	80	Hg	mercury
11	Na	sodium	46	Pd	palladium	81	Tl	thallium
12	Mg	magnesium	47	Ag	silver	82	Pb	lead
13	Al	*aluminium*	48	Cd	cadmium	83	Bi	bismuth
14	Si	silicon	49	In	indium	84	Po	polonium
15	P	phosphorus	50	Sn	tin	85	At	astatine
16	S	sulphur	51	Sb	antimony	86	Rn	*radon*
17	Cl	chlorine	52	Te	tellurium	87	Fr	francium
18	Ar	*argon*	53	I	*iodine*	88	Ra	*radium*
19	K	*potassium*	54	Xe	*xenon*	89	Ac	actinium
20	Ca	calcium	55	Cs	*cesium*	90	Th	*thorium*
21	Sc	scandium	56	Ba	barium	91	Pa	protactinium
22	Ti	titanium	57	La	lanthanum	92	U	uranium
23	V	vanadium	58	Ce	cerium	93	Np	*neptunium*
24	Cr	*chromium*	59	Pr	praseodymium	94	Pu	*plutonium*
25	Mn	*manganese*	60	Nd	neodymium	95	Am	americium
26	Fe	*iron*	61	Pm	promethium	96	Cm	curium
27	Co	*cobalt*	62	Sm	samarium	97	Bk	berkelium
28	Ni	*nickel*	63	Eu	europium	98	Cf	californium
29	Cu	*copper*	64	Gd	*gadolinium*	99	Es	einsteinium
30	Zn	*zinc*	65	Tb	terbium	100	Fm	fermium
31	Ga	gallium	66	Dy	dysprosium	101	Md	mendelevium
32	Ge	germanium	67	Ho	holmium	102	No	nobelium
33	As	arsenic	68	Er	erbium	103	Lr	lawrencium
34	Se	selenium	69	Tm	thulium	104	Rf	rutherfordium
35	Br	bromine	70	Yb	ytterbium	105	Ha	hahnium

ATOMIC MASS

We have already learned that atoms are composed of three particles: protons, neutrons and electrons. The central nucleus of the atom contains the neutrons and positively charged protons. The nucleus is surrounded by as many orbital electrons (each with a charge of –1) as there are protons (each with a charge of +1) in the nucleus.

The three sub-atomic particles differ from each other in two important ways. The first of these, electrical charge, we have already discussed. The other main difference between these particles is in their mass.

When scientists discuss the weight of objects, they prefer to use the term "mass"*). We'll go along with them, but this doesn't make you a scientist yet.

Well then, what is the mass of a proton? A single drop of water contains about 20 thousand billion billion protons. You could express the mass of a proton in pounds or kilograms, but you can imagine that it would be a small and difficult fraction to deal with. Instead scientists have created the **atomic mass unit** (abbreviated **amu**). The masses of the proton and neutron are nearly equal and we shall take them both as being 1 amu. The electron is a much lighter particle and has a mass equal to 1/1840 of the mass of the proton. That is, 1840 electrons have the same total mass as one proton or one neutron. Table 1.2 summarises what we know about the three particles.

TABLE 1.2. SUBATOMIC PARTICLES

Particle	*Symbol*	*Mass (amu)*	*Electrical Charge*
Proton	p	1	+ 1
Neutron	n	1	0
Electron	e	1/1840	– 1

Considering the whole atom once again, one thing immediately becomes clear about its mass. The electron has so little mass compared to the proton and neutron that nearly all of the mass of the atom is concentrated in the nucleus. In fact the electron masses may be ignored when calculating the mass of an atom.

The hydrogen atom with its single proton has a mass of one. Similarly, helium with two protons and two neutrons in the nucleus has a mass of four, and this number is referred to as the **mass number** of helium.

The MASS NUMBER of an atom is the number of protons plus the number of neutrons in its nucleus. It is designated by the letter A, i.e., A = Z + N.

*) weight = mass x acceleration due to gravity.

If you are given the mass number (A) and the atomic number (Z) of an atom, you don't have to be a Rhodes Scholar to work out the number of neutrons. If you prefer to work with a formula, you let the number of neutrons equal N, and then

$A = Z + N$, and $N = A - Z$

For example, the mass number of an oxygen atom is 16 and the atomic number is 8. How many neutrons are there in the nucleus of this oxygen atom?

$N = A - Z = 16 - 8 = 8$

What is the mass number A of a uranium atom with 92 protons and 146 neutrons? Your turn.

We have considered the structure of the first three atoms in some detail. The nuclei of the other atoms are built up of protons and neutrons in exactly the same manner.

The relationship between the mass number, the atomic number and the number of neutrons in some individual atoms is shown in Table 1.3. It gives the first 13 atoms and a few others.

TABLE 1.3. SOME ATOMS

Name	*Z*	*N*	*A*
Hydrogen	1	0	1
Helium	2	2	4
Lithium	3	4	7
Beryllium	4	5	9
Boron	5	6	11
Carbon	6	6	12
Nitrogen	7	7	14
Oxygen	8	8	16
Fluorine	9	10	19
Neon	10	10	20
Sodium	11	12	23
Magnesium	12	12	24
Aluminum	13	14	27
Iron	26	30	56
Iodine	53	74	127
Uranium	92	146	238

THE SIZE OF THE ATOM

We haven't said much yet about the size of atoms or about the sizes of the nucleus and its electrons, and the distance between them. Actually, our illustrations of the atom couldn't possibly be accurate, for if you magnified the size of an atom so that the nucleus were a barely visible dot, the electrons would be so far away that you couldn't get them on the page. To illustrate the great amount of empty space in an atom, if you consider a golf ball to represent the size of the nucleus (its diameter is really only about 10^{-15} m), the electrons would then be orbiting it at a distance of several km.

You'll appreciate that subatomic particles of about the same size as the neutron can pass through an atom with little chance of colliding with the nucleus or with an electron.

The actual distance between a nucleus and an orbital electron is of course very small. Ten million hydrogen atoms side by side would form a line one millimetre long. But small as the hydrogen atom is, its diameter is still 50,000 times greater than the diameter of its nucleus. Ten million is often written as 10^7. It can also be written as E7. Similarly 10^{-7} would be written as E-7. Five million or 5×10^6 would be 5E6. We are going to use the exponential E notation for the rest of this book, because it is easier to read. And besides, most calculators use the same notation.

ISOTOPES

Careful studies of the atoms of an element show that they don't all have the same mass. How come? Let's use lithium as an example. Most of its atoms have a mass of 7, but some of them have a mass of only 6. Atoms of the same element with different masses are called **isotopes**. To understand this clearly, let’s repeat the definitions for "Atomic Number" and "Mass Number".

The ATOMIC NUMBER Z of an atom is the number of protons in the nucleus.

The MASS NUMBER A of an atom is the number of protons plus the number of neutrons in its nucleus.

Obviously both isotopes of lithium must have the same atomic number, which for lithium is Z = 3, or one or the other would not be lithium.

For the two lithium isotopes to have different masses, they must have a different number of neutrons in their nuclei: the nucleus of the lighter isotope has three neutrons to give it a total mass of six — the other has four neutrons and a total mass of seven.

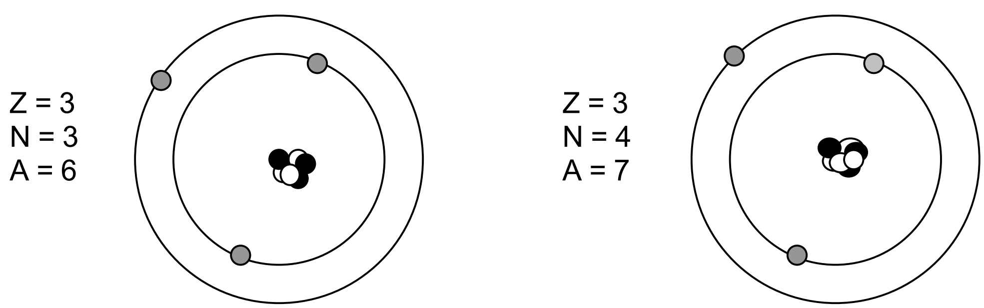


Fig 1.6. Two Lithium Isotopes

The drawing of the lithium isotopes shows that the number of orbital electrons and their arrangement in the outer structure of the two isotopes are exactly the same. The only difference is in the mass of the nucleus (different number of neutrons).

The **chemical properties** of an element describe how an element will react with any other element. It is the number of orbital electrons in the atom that determines the **chemical properties** of an element, and this number is equal to the atomic number. So, **isotopes of the same element have the same chemical properties.**

The difference in the number of neutrons has no effect on chemical properties, i.e., how lithium combines chemically with other elements. It does, however, result in different **physical properties** such as boiling point and freezing point. In other words, **isotopes of the same element have different physical properties**. As you might guess, their nuclear properties (more of this later) are usually very different from one another.

> **ISOTOPES of an element are atoms that have the same atomic number (Z) as the other atoms of the element, but a different mass number (A).**

Naturally occurring lithium has only the two isotopes mentioned above. In addition, another four man-made isotopes of lithium have been produced. Isotopes are not at all uncommon. Hydrogen has the least with 3, but there are several elements with 30 or more isotopes.

SYMBOLS FOR ISOTOPES

In writing the symbols for atoms, we need a system to identify the different isotopes of the same element. For example, we can identify the uranium isotope that has 92 protons and 146 neutrons in any of the following three versions:

$$^{238}_{92}U \qquad {}_{92}U^{238} \qquad U\text{-}238$$

The first two versions show both Z = 92 and A = 238. We don't need to show Z because since it is a uranium isotope, Z has to be 92. But we need to show the mass number A to specify which isotope we mean. In this book we'll use both ${}_{92}U^{238}$ and U-238. If I don't need to remind you of the atomic number, I'll just use U-238.

SEPARATION OF ISOTOPES

Chemists have been quite happy to accept elements as they come in nature since the chemical properties of all the isotopes of one element are the same anyway. However, in the nuclear industry the difference in isotopes of the same element is usually very important. As mentioned above, isotopes are different in their physical properties such as mass, boiling point, and freezing point, and in their nuclear properties. We won't be discussing nuclear properties until later, but they are very important.

Some isotopes have especially desirable nuclear properties and for some applications they must be separated from the other isotopes of the element. This is not easy. Generally, it is not difficult to separate two different elements that have different chemical properties. For example, if you wish to separate nitrogen from oxygen, you pass the gas mixture through a tube containing some metal with which oxygen will unite. The nitrogen freed from oxygen comes out at the other end.

To separate the chemically identical isotopes of an element, one must use procedures that depend upon small differences in physical properties. These methods are complicated and expensive.

THE ISOTOPES OF HYDROGEN

Normal hydrogen has a mass of one amu but about one out of every 7,000 hydrogen atoms has a mass of two amu, and one in about 1E17 hydrogen atoms has a mass of three amu. The light isotope has only one particle in its nucleus, a proton. The heavier isotopes also have one proton in the nucleus plus one or two neutrons to give it a mass of two, or three amu. Fig. 1.7 gives you the general idea. As a rule, the difference in mass between two isotopes is small compared to the total mass of the atom, as in Fe-56 and Fe-57, for example. But this is not the case for hydrogen. Hydrogen-2 has twice the mass of hydrogen-1.

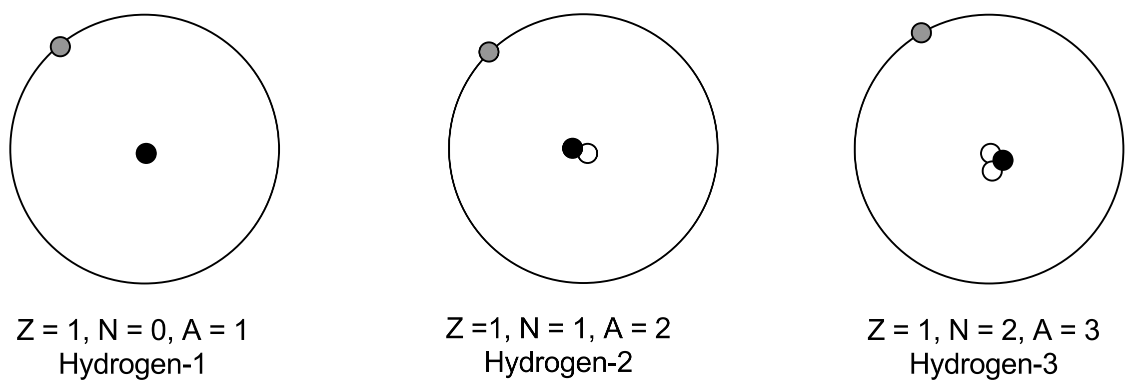


Fig. 1.7. The Hydrogen Isotopes

For this and other reasons, hydrogen-2 was given the name "deuterium", with the symbol D, and hydrogen-3 was called "tritium", with the symbol T. These are exceptions. For all other elements, the isotopes have the same symbol. They are distinguished from each other by the mass number at the upper right of the symbol. You can use the symbols H^2, H-2 and D to represent the same thing, which is one atom of the isotope hydrogen-2.

Since the CANDU reactor uses heavy water, let us compare the properties of light and heavy water.

First of all, water is not an element, but a **compound**. A compound is a chemical combination of two or more elements combined in a fixed proportion. The smallest part of a compound, which still has the properties of that compound, is called a **molecule**. So a molecule is to a compound what an atom is to an element.

The symbol for the compound called water is H_2O. This means that its molecule consists of two hydrogen atoms and one oxygen atom. In light water, the two hydrogen atoms are hydrogen-1 isotopes, and in heavy water they are hydrogen-2 isotopes. Hydrogen-2 is produced from normal hydrogen by separating the hydrogen-2 atoms (1 in 7,000) from the hydrogen-1 atoms.

The properties of light and heavy water are summarized on the next page in Table 1.4. What's missing from the table is the cost! Heavy water costs about 15 times as much as kitchen scotch.

TABLE 1.4. LIGHT AND HEAVY WATER

Properties	*Light Water*	*Heavy Water*
Common Names	Water	Heavy Water or Deuterium Oxide
Formula	H_2O	D_2O
Taste	Same	
Appearance	Same	
Chemical Properties	Same	
Density (kg/L)	1.0	1.106
Freezing Point	0 ^oC	3.8 ^oC
Boiling Point	100 ^oC	101.4 ^oC

THE NATURAL ISOTOPES OF URANIUM

Naturally occurring uranium ore contains the three uranium isotopes U-234, U-235, and U-238. Since the refining of uranium metal from uranium ore is a chemical process, these same isotopes are present in the same concentrations in the pure metal and in the ore. Table 1.5 shows that almost all of the uranium is made up of U-238 (99.28%).

TABLE 1.5. ISOTOPES OF NATURAL URANIUM

Isotope	*Z*	*N*	*A*	*% Abundance*
U-234	92	142	234	0.006
U-235	92	143	235	0.720
U-238	92	146	238	99.275

U-235, which accounts for only 0.72% of natural uranium, has the best nuclear properties for nuclear power generation. Most types of power reactors need fuel with a higher concentration of U-235 than normal. In that case, you have to put the natural uranium through an isotope separation plant. This is super expensive, and you'll be pleased to hear that for CANDU fuel we don't need to do this. Uranium that has a higher than normal percentage of U-235 is said to be **enriched**. The concentration of U-235 in enriched fuel can vary all the way from just greater than 0.72% to 100%.

NUCLIDES

With all elements having three or more isotopes, there are over 300 naturally occurring atoms that differ from one another in the structure of their nuclei. All of the different types of atoms are referred to collectively as the **nuclides.**

Each of the 300 types of atoms mentioned above is a separate nuclide, because each has a distinctive nucleus that differs from all others in its number of protons, or in its number of neutrons, or both. The term isotope is more restrictive, an isotope being one of a group of nuclides which all have the same atomic number Z.

A NUCLIDE is a specific atom defined by the number of neutrons and protons it contains.

Therefore, a list of the nuclides would include all the isotopes of all the elements. This list has over 300 naturally occurring nuclides and over 700 radioactive nuclides. The latter are called **radionuclides**; they are produced in nuclear reactors and accelerators.

A RADIONUCLIDE is a nuclide that is radioactive.

Here's an analogy that might help in understanding the term "nuclide". Think of all the different types of fruit. There are apples, pears, bananas, grapes, and so on. These you can look at as different elements. The various varieties of apples (like Cox, McIntosh, Golden Delicious, Granny Smith, Yellow Transparent, Cortland, Spy, and I don't know what else) would all be isotopes of the element apple. Any particular type of known fruit you can then think of as a nuclide. (Any that are radioactive would be radionuclides.) Maybe it doesn't help after all.

SUMMARY

Matter consists of atoms made up of protons, neutrons and electrons.

The neutron has no charge, the proton a positive charge, and the electron an equal but negative charge.

The masses of the neutron and proton are very nearly equal: 1 amu each. The mass of the electron is 1/1840 of this.

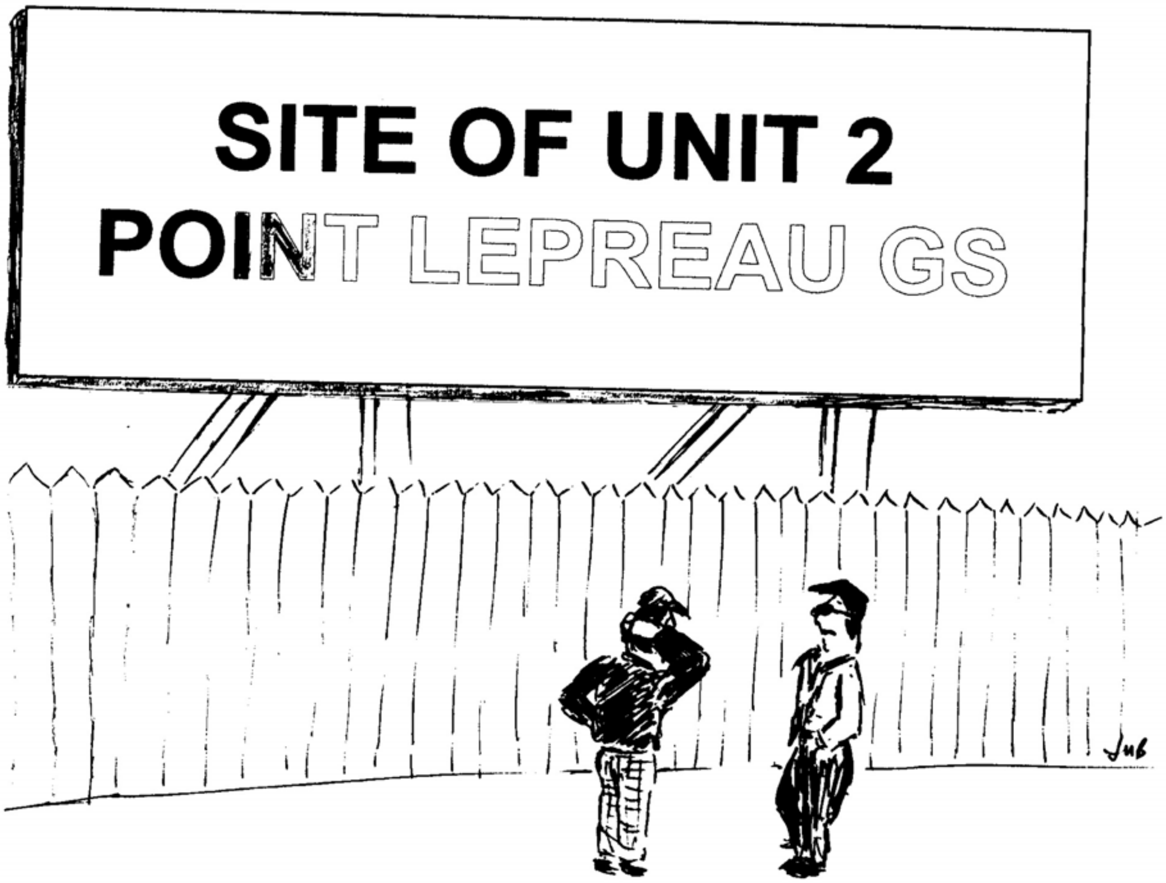
The neutrons and protons form the nucleus of an atom. The number of protons in the nucleus, called the Atomic Number, is equal to the number of electrons orbiting around the nucleus.

The atom is mainly empty space because its diameter is many thousand times greater than the diameter of the nucleus.

An isotope of an element is an atom which has the same atomic number, Z, as other atoms of the element, but a different mass number, A.

Isotopes of an element have the same chemical but different physical properties.

All the different types of atoms are referred to as nuclides; that is, a list of the nuclides would include all the isotopes of all the elements.



"I heard that they ran out of money at an early stage of the Project"

PROBLEMS

1. What number identifies an element? What number determines the mass of an atom of that element?

2. Make a sketch of the atoms of lithium, boron, and carbon.

3. How many neutrons does U-238 contain?

4. Complete the following table.

Symbol	Z	A	N
S	16		16
Cs	55	133	
Pb		208	126

5. (a) State the number of electrons each of the neutral atoms in #4 would contain.
   (b) If the cesium atom had a net charge of +1, how many electrons would it contain?

6. What is an isotope?

7. (a) What determines the chemical properties of an element?
   (b) Name one possible chemical property of an element.
   (c) Name one possible physical property of an element.

8. (a) How many protons are there in one molecule of H_2O? How many neutrons are there?
   (b) How many protons and how many neutrons are there in one molecule of D_2O?

9. A Point Lepreau fuel bundle contains about 19 kilograms of natural uranium. How many kilograms of U-235 does it contain?

10. A 1-kg carboy contains 50 L of heavy water. What is the total weight? Should you lift it?

11. Problems shown in a different font like this one are harder, and reserved for the keen ones amongst you.

    Almost all the mass of an atom is concentrated in the nucleus, because most of the atom is empty space. Can you calculate the density of the nucleus in tonnes per mm^3? (1 tonne = 1 Mg = 1000 kg). The radius of a nucleus of mass number A is 1.2E-15 x $A^{1/3}$ m, and 1 amu = 1.7E-21 kg. Do you know where such amazing densities might be found, if at all?