Module #16: Nuclear Physics

Introduction

It is time now to discuss what I consider the most fascinating field of physics: nuclear physics, which is the study of the atom's nucleus. How do nuclear physicists study the nucleus of an atom? After all, an atom is small enough, but a nucleus is even smaller. For example, the average radius of the hydrogen atom is 0.529 angstroms (5.29×10^{-11} m). The radius of the nucleus of that atom (the proton), however, is a mere 1.3×10^{-15} m. That's pretty small. Think about it this way: if a hydrogen atom were expanded until its average radius were as big as the walls of a major league baseball stadium, the nucleus of the atom could be represented by a tiny marble located at the very center of the stadium!

There are three basic ways that nuclear physicists study the properties of the nucleus. First, they study how the mass number of an atom affects its properties. Since the mass number of an atom depends only on its nucleus, the way that the mass number affects the properties of an atom should tell you something about the properties of the nucleus itself. Second, nuclear physicists study radioactivity. This is a process governed almost exclusively by the nucleus, so by studying radioactivity in detail, nuclear physicists can come to a better understanding of the inner workings of the nucleus. Finally, physicists study what happens when two nuclei collide. If atoms are forced together with enough energy, sometimes the atoms' nuclei will collide and the results can tell us a lot about how the nucleus behaves when it is stressed. In this module, I will discuss each of these means by which nuclear physicists learn about the nucleus.

In the preceding discussion, I used a term that you might have forgotten from your physical science or chemistry course: **mass number**. The mass number of a nucleus is the sum total of the number of protons and number of neutrons in the nucleus. This mass number is usually written as a superscript in front of the symbol for an atom. For example, ^{12}C represents a carbon atom whose mass number is 12. Since all carbon atoms have 6 protons (we know that from the Periodic Table of the Elements), a ^{12}C atom must have 6 protons and 6 neutrons, because its mass number is 12. In the same way, a ^{13}C atom must have 6 protons and 7 neutrons, while a ^{14}C atom must have 6 protons and 8 neutrons. You will be expected to remember all of this and use the periodic table to help you determine the number of neutrons in an atom given its mass number. Thus, if this sounds unfamiliar to you, please review your chemistry or physical science course. Also, please understand that you are free to use the Periodic Table of the Elements as much as you want. It was given to you in the previous module.

Binding Energy

When we disregard the electrons in an atom, only the nucleus is left. Since the nucleus contains both protons and neutrons, these particles are generically called **nucleons**.

Nucleon - A term used to refer to both protons and neutrons

Now remember, the nucleus is rather small. Nevertheless, all of the nucleons in an atom are packed tightly together in this small space. Now that should bother you. After all, protons are positively charged and neutrons have no charge. Thus, the nucleus is composed of several positively charged particles and several neutral particles crammed together in a tight space. What should those positive charges do to one another? They should repel each other. In fact, the nucleus is so small that the repulsive forces between these positive charges should be enormous. Since there are no negative charges in the nucleus to counteract this repulsive force, you should expect that a nucleus would simply be blown apart because of the repulsion between its protons.

Why doesn't the nucleus explode due to the repulsion between protons? This was one of the great mysteries of science in the early twentieth century. Since nuclei obviously do not explode, nuclear scientists postulated that there was something called the "nuclear force" that was strong enough to hold the nucleus together despite the repulsion between protons. Of course, they had no idea *what* the nuclear force was and *how* it worked. They simply assumed that it must exist, otherwise atoms would not exist.

Scientists began to get a clue as to what holds the nucleus together when nuclear chemists and physicists discovered that the mass of a nucleus is actually *less* than the sum total of the masses of the protons and neutrons which make it up. For example, a ^{4}He atom is composed of 2 protons and 2 neutrons. The mass of an individual neutron is 1.0087 amu, and the mass of an individual proton is 1.0073 amu. Thus, the sum total of the masses of all 4 nucleons that make up a helium-4 nucleus is 4.0331 amu (2x1.0087 + 2x1.0073). Nevertheless, a ^{4}He nucleus (composed of those exact particles) has a mass of only 4.0024 amu. There seems, then, to be a **mass deficit** in this nucleus. The nucleus is 0.0307 amu lighter than the sum of the masses of its individual nucleons. What causes this mass deficit?

The answer to that question can be found in the famous equation which you have already studied:

$$E = m \cdot c^2 \tag{8.7}$$

As you should recall from Module #8, this equation basically states that matter and energy are interchangeable. Thus, mass can be converted to energy, and energy can be converted to mass. As you learned in Module #8, both of those processes have been seen in the laboratory.

How does all of this relate to the nucleus? Well, if the mass of a nucleus is less than the sum total of the mass of its individual nucleons, then the nucleons must "lose" some of their mass when they form a nucleus. This mass is converted to energy via Equation (8.7), which nuclear scientists call the **binding energy** of the nucleus.

<u>Binding energy</u> - The energy formed from the mass deficit of a nucleus

As long as you know the exact mass of a nucleus, calculating its binding energy is rather easy.

EXAMPLE 16.1

The mass of a ^{7}Li nucleus is 7.0160 amu. What is the binding energy of the nucleus? (The mass of a proton is 1.0073 amu, and the mass of a neutron is 1.0087 amu. The speed of light is 3.00×10^{8} m/sec and 1 amu = 1.6605×10^{-27} kg.)

Since lithium's atomic number is 3, all lithium atoms have 3 protons. The mass number, which is the sum of the protons and neutrons in a nucleus, therefore indicates that a ^{7}Li nucleus has 4 neutrons. The sum of the masses of 3 protons and 4 neutrons is:

$$3 \times (1.0073 \text{ amu}) + 4 \times (1.0087 \text{ amu}) = 7.0567 \text{ amu}$$

Since the mass of a ^{7}Li nucleus is only 7.0160 amu, there is a mass deficit of 7.0567 amu - 7.0160 amu = 0.0407 amu. This mass deficit is converted to energy according to Equation (8.7). To use this equation, however, we must have consistent units. Since we have the speed of light in m/sec, then the energy will come out in Joules as long as the mass is in kilograms (remember, a Joule is a $(\text{kg}\cdot\text{m}^2)/\text{sec}^2$). Thus, we must first convert the mass deficit to kg:

$$\frac{0.0407 \cancel{\text{amu}}}{1} \times \frac{1.6605 \times 10^{-27} \text{ kg}}{1 \cancel{\text{amu}}} = 6.76 \times 10^{-29} \text{ kg}$$

Now we can use Equation (8.7):

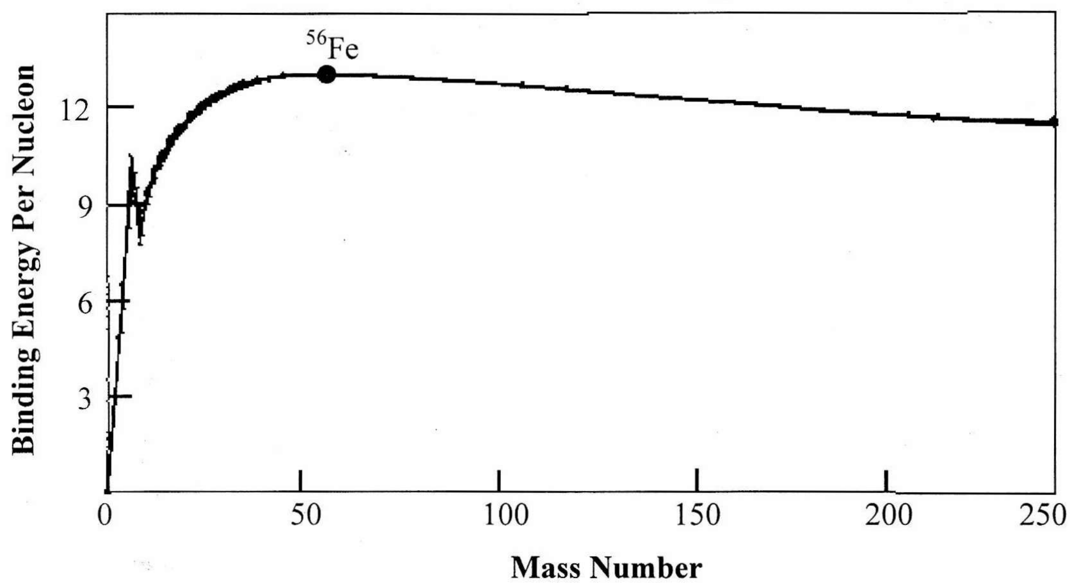
$$E = m \cdot c^2 = (6.76 \times 10^{-29} \text{ kg}) \cdot (2.998 \times 10^{8} \frac{\text{m}}{\text{sec}})^2 = 6.08 \times 10^{-12} \frac{\text{kg} \cdot \text{m}^2}{\text{sec}^2} = \underline{6.08 \times 10^{-12} \text{ J}}$$

Although this doesn't sound like a lot of energy, remember that this is for a *single* atom. In a single gram of ^{7}Li atoms, the total binding energy is 5.21×10^{11} J, which is quite a bit of energy!

As its name implies, binding energy tells us how tightly bound the nucleons are in the nucleus. The larger the binding energy, the stronger the nucleus holds its nucleons together. If you take the binding energy of a nucleus and divide it by the total number of nucleons in the nucleus, you get the **binding energy per nucleon** for that nucleus. This quantity gives you an idea of how strongly each nucleon is bound within the nucleus. If you think about it, the binding energy per nucleon tells you how stable a nucleus is. After all, if the binding energy per nucleon is high in a nucleus, the nucleus holds tightly to each of its nucleons. If the binding energy per nucleon is low, the nucleus' hold on its nucleons is weak.

If you calculate the binding energy per nucleon for several nuclei, you will find that this important quantity changes from nucleus to nucleus. In other words, some nuclei are more stable than others. Figure 16.1 illustrates a plot of binding energy per nucleon as a function of the mass number of a nucleus.

FIGURE 16.1
The Binding Energy Per Nucleon



As you can see from the figure, the binding energy per nucleon rises with increasing mass number until the mass number reaches 56, where the maximum binding energy per nucleon exists. For mass numbers higher than 56, the binding energy per nucleon decreases. This tells us that the most stable nuclei are those with mass numbers around 56. In fact, the most stable nucleus in Creation is ^{56}Fe, because it has the maximum binding energy per nucleon.

ON YOUR OWN

16.1 Calculate the binding energy per nucleon for ^{56}Fe. (Use the data given in the example as well as the fact that an ^{56}Fe nucleus has a mass of 55.9349).

16.2 The binding energy of ^{7}Be is 5.739×10^{-12} J. What is the mass of ^{7}Be in amu?

<u>The Strong Nuclear Force</u>

So now we know what holds the nucleus together, right? The binding energy of a nucleus binds the nucleons together in the nucleus. That's all well and good, but there is still one important question we must answer: *how does the binding energy do it*? That question was a matter of speculation for quite some time. Some scientists thought that the binding energy formed some sort of "force field" around the nucleus, keeping the nucleons inside. Others thought that the energy somehow acted like glue, "sticking" the nucleons together.

In 1937, a nuclear physicist by the name of Heidiki Yukawa postulated that nucleons stayed together because, at short distances, they exchanged tiny particles called **pions** (pie' ons). Yukawa thought that the binding energy was used to give these pions kinetic energy, allowing them to travel from one nucleon to another. In other words, Yukawa believed that nucleons actually gave up a portion of their mass to form a small particle called a pion. Some of the mass that the nucleons gave up would go towards making the pion, and the rest would be converted to kinetic energy, allowing the pion to travel. Based on the properties of nuclei that were already known, Yukawa actually predicited what the mass of a pion should be.

Yukawa further believed that these pions can only exist for a very short time. As a result, he classified them as **short-lived particles**. Thus, Yukawa believed that a nucleon would form a pion, and the pion would begin to travel away from the nucleon. The pion, however, would not be able to live for very long. Thus, it would quickly encounter another nucleon and be absorbed by that nucleon. Since Yukawa believed that it is beneficial for nucleons to make, exchange, and absorb pions, he believed that nucleons crammed together into the nucleus in order to be able to do those things. Of course, all of this was just an hypothesis until 1947, when nuclear physicists discovered pions and found that they had almost exactly the mass that Yukawa predicted.

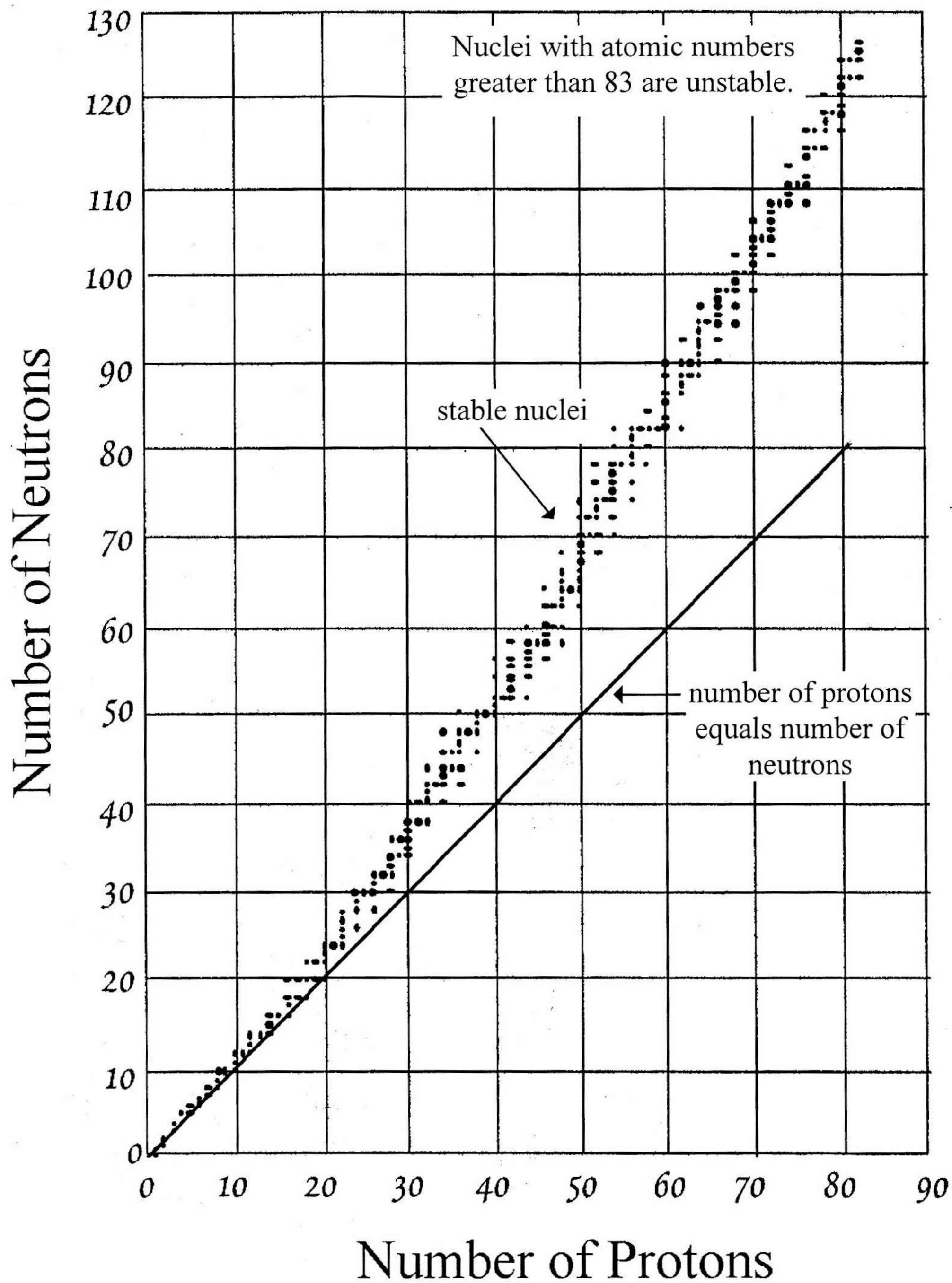
As a result of Yukawa's theorizing and the discovery of the pion, nuclear scientists now view the nucleus as a place full of busy activity. Nucleons in the nucleus are continually making, exchanging, absorbing, and re-making pions. The desire for nucleons to do this is so overwhelming that it overcomes the electromagnetic repulsion between protons, allowing protons to stay very close to one another. Because pions are short lived, nucleons can only exchange these particles when the nucleons are quite close. Thus, pion exchange exists only in the nucleus.

The binding energy of a nucleus, then, is mostly used to facilitate the exchange of pions. The attraction that nucleons feel as a result of this exchange is called the **strong nuclear force**. The strong nuclear force exists only between nucleons (because only they can exchange pions). It is also a very short-range force, because the pions that are exchanged can only exist for a brief period of time. Thus, a pion must travel from one nucleon to another before its lifetime is up. Finally, for very short distances, the nuclear force is incredibly strong, because the desire for nucleons to exchange pions is strong. As a result, for distances on the order of 10^{-15} m, the strong nuclear force is significantly stronger than the electromagnetic force.

The Stability of a Nucleus

Despite the fact that the strong nuclear force is able to hold nucleons together, it is not able to hold just any combination of nucleons together. As a result, a nucleus cannot be made from just any combination of neutrons and protons. Instead, there are certain combinations of neutrons and protons that are stable, and certain combinations that are not.

FIGURE 16.2
A Plot of Neutron Number Versus Proton Number



As noted in the figure, the dots represent the known, stable nuclei. Thus, if the number of protons and neutrons in a nucleus places it at one of the dots in the graph, then the nucleus is stable. If not, the nucleus is not stable. The reason that some nuclei are stable and some are not is beyond the scope of this course. In part, this is because nuclear scientists really don't fully understand the intricacies of what makes a nucleus stable and what makes it unstable.

If you look at the figure, you will see that for small nuclei (those that have only a few nucleons), the dots lie right along a line that corresponds to the number of protons equal to the number of neutrons. This means that for small nuclei, an equal number of neutrons and protons leads to a stable nucleus. Indeed, nuclei like ^{4}He, ^{16}O, and ^{40}Ca are all stable. Notice, however, that as the number of nucleons in the nucleus increases, the dots begin to rise farther and farther above the line that indicates an equal number of protons and neutrons. This tells us that as a nucleus gets larger, it can only be stable if it has more neutrons than protons.

Does this mean that the only nuclei in Creation are the ones represented by the dots? No, of course not. It means that the only *stable* nuclei in Creation are the ones represented by the dots. There are plenty of *unstable* nuclei in Creation as well. This might surprise you a bit. After all, if a nucleus is unstable, how can it exist? The answer is quite simple: it can exist, but only for a certain amount of time. When a nucleus is unstable, we call it **radioactive**. A radioactive nucleus, also called a **radioactive isotope**, will eventually change into another nucleus. As you will soon see, however, that can often take a *significant* amount of time.

ON YOUR OWN

16.3 Using Figure 16.2, determine whether or not each of the following nuclei is stable.

a. ^{237}U b. ^{57}Fe c. ^{100}La d. ^{12}C

Radioactivity

The thick curve formed by the dots in Figure 16.2 is often called the **valley of stable nuclei**. If a nucleus is not in the valley of stable nuclei, then in order to become stable, it must get there. How can it do that? A nucleus can move to the valley of stable nuclei by changing its number of protons and/or neutrons. It accomplishes this through a process called **radioactive decay**.

Consider, for example, the nucleus ^{241}Am. According to its symbol, this nucleus has 95 protons and 146 neutrons. As stated in Figure 16.2, all elements with atomic number greater than 83 are unstable. To try and reach stability, then, the ^{241}Am nucleus emits a ^{4}He nucleus. Remember, a ^{4}He nucleus has 2 protons and 2 neutrons. Thus, the ^{241}Am nucleus actually loses 2 protons and 2 neutrons, which it ends up "spitting out" in the form of a ^{4}He nucleus. So, ^{241}Am has 95 protons and 146 neutrons. If it loses 2 protons and 2 neutrons, the result is a nucleus with 93 protons and 144 neutrons. This nucleus, ^{237}Np, is still unstable, so *it* will emit an alpha particle, continuing the decay. This will happen over and over again until the resulting nucleus is stable.

This process can be represented in the form of a reaction. Please understand that this is not a *chemical* reaction, it is a *nuclear* reaction:

$$\underset{\text{Radioactive isotope}}{{}^{241}_{95}\text{Am}} \rightarrow \underset{\text{Daughter product}}{{}^{237}_{93}\text{Np}} + \underset{\text{Alpha particle}}{{}^{4}_{2}\text{He}} \qquad (16.1)$$

There are three important things I need to tell you about this equation. First notice that there are subscripts before the atomic symbols as well as superscripts. As always, those superscripts represent the mass number of the nucleus. The subscripts, on the other hand, represent the atomic number of the nucleus. Thus, the "95" subscript tells you that the atomic number of Am is 95. Now, of course, those subscripts are NOT necessary. After all, the symbol of the nucleus tells you the atomic number. All Am nuclei have 95 protons, so they all have an atomic number of 95. Even though the subscripts are not necessary, they will make things convenient a little later on, so I will keep using them throughout the module.

The next thing I want you to notice about the equation is that the subscripts on one side of the equation add up to the sum of the subscripts on the other side of the equation. This should make sense to you. After all, the subscripts represent the number of protons in each nucleus. On the left side of the equation, then, there are 95 protons. Since protons are not destroyed in this process, there should be 95 protons on the right side of the equation as well. In the same way, the mass numbers (the superscripts) represent the total nucleons in each nucleus. Since nucleons are not being destroyed in the process, the sum of all nucleons on the left side of the equation must be equal to the sum of the nucleons on the right side of the equation. When these two conditions are met, the nuclear equation is said to be **balanced**.

Finally, notice how I have labeled the participants in the equation. The only reactant is called the **radioactive isotope**. Some nuclear chemists also call it the **parent isotope**. The nucleus that results from the process is called the **daughter product**. Finally, the ${}^{4}\text{He}$ that is emitted in the reaction is called an **alpha particle**. Why is it called an alpha particle rather than a helium nucleus? The reason is historical. Scientists had determined that radioactivity existed long before they understood it. All they knew was that there were three distinctly different radioactive processes which resulted in three distinctly different particles being emitted. Since scientists at that time did not know what those particles were, they simply called them "alpha particles," "beta particles," and "gamma particles" (alpha, beta, and gamma are the first three letters in the Greek alphabet). Despite the fact that we now know what all of these particles are, we still cling to the old terminology. Thus, the radioactive process which produces alpha particles is typically called **alpha decay**.

Now that you know what alpha decay is, I will continue by discussing **beta decay**. When a nucleus undergoes beta decay, an amazing thing happens: *a neutron turns into a proton*! How does this happen? Well, look at the mass of a neutron (1.0087 amu) as compared to a proton (1.0073 amu). Also, consider the fact that a neutron is neutral, whereas a proton is positive. Suppose a neutron were able to emit an electron. What would happen? Its mass would decrease, and it would turn positive. After all, if a neutral particle releases a negative charge, the particle left over must be positive. Thus, *a neutron turns into a proton by emitting an electron.* This process can be written as the following reaction:

$$^{1}_{0}\text{n} \rightarrow \, ^{1}_{1}\text{H} + \, ^{0}_{-1}\text{e} \qquad (16.2)$$

Now what in the world do those symbols mean? Well, the symbol on the reactant side represents a neutron. After all, how many protons are in a neutron? None, of course! Thus, the subscript for a neutron in a nuclear equation must be zero. What is the mass number of a neutron? It is the sum of all neutrons and protons. Thus, for a single neutron, the mass number is 1. That's why we use the symbol $^{1}_{0}\text{n}$ to represent a neutron. In the same way, what is a proton? A proton is simply a hydrogen nucleus with a mass number of 1. Thus, the symbol $^{1}_{1}\text{H}$ is used in a nuclear reaction to represent a proton. Finally, the symbol $^{0}_{-1}\text{e}$ is used to symbolize an electron in a nuclear equation. After all, an electron has no protons and no neutrons in it, so its mass number is zero. Since it has the opposite charge of a proton, you can think of the atomic number of an electron as -1.

Notice that using these symbols, Equation (16.2) balances just like Equation (16.1). The total number of protons on the left side of the equation is 0. The sum total of subscripts on the right side of the equation is also zero. The total number of nucleons on the left side of the equation is 1, and the sum of all superscripts on the right side of the reaction is also 1. Because these kinds of symbols for protons, neutrons, and electrons allow us to balance nuclear equations, I will continue to use them throughout this module.

It is important for you to know that Equation (16.2) represents a spontaneous reaction that will occur with *all* neutrons that are not a part of the nucleus. The rate of this reaction is a bit slow (in a group of neutrons, roughly half of them will undergo the process within 10 minutes); nevertheless, it will eventually happen to any free neutron. Interestingly enough, this reaction is usually not spontaneous for a neutron that exists in a stable nucleus. It is theorized that the pion exchange which goes on in a nucleus stabilizes the neutrons so that they do not decay into protons and electrons. Without that pion exchange, the neutron is not stable, and it will eventually decay into a proton and an electron.

Even if a neutron is in a nucleus, it can still decay if the nucleus itself is not stable. For example, the nucleus ^{90}Sr lies just to the left of the valley of stable nuclei in Figure 16.2. In order to move to the valley of stable nuclei, one if its neutrons will release an electron to make a proton.

$$\underset{\text{Radioactive isotope}}{^{90}_{38}\text{Sr}} \rightarrow \underset{\text{Daughter product}}{^{90}_{39}\text{Y}} + \underset{\text{Beta particle}}{^{0}_{-1}\text{e}} \qquad (16.3)$$

Notice that this equation is balanced, because the superscripts on one side add up to the superscripts on the other, and the subscripts on one side add up to the subscripts on the other.

Also, even though the electron produced in this process is just an electron, we still call it a **beta particle**. As a result, this process is called beta decay.

The last type of radioactive decay that I want to discuss is **gamma decay**. It turns out that a gamma particle (also called a **gamma ray**) is really just a photon. Remember, photons are light "particles," so a gamma particle is really just a "piece" of light. The light has a very large energy (thus a short wavelength), but it is still just light. Since light has no protons and no neutrons in it, a gamma particle is symbolized as ${}^{0}_{0}\gamma$, where the symbol γ is the lower-case Greek letter gamma. Since a gamma particle has no neutrons or protons, the emission of a gamma particle does not affect the identity of the nucleus. However, it does remove energy from the nucleus. Thus, if a nucleus is stable but has too much energy, it will rid itself of the extra energy by emitting a gamma particle. For example, if a ${}^{90}Y$ nucleus has too much energy, it will emit a gamma particle.

$${}^{90}_{39}Y \rightarrow {}^{90}_{39}Y + {}^{0}_{0}\gamma \qquad (16.4)$$

This process, not surprisingly called **gamma decay**, simply rids the ${}^{90}Y$ nucleus of its excess energy. For historical reasons, gamma rays are also called **X-rays**. When you get an X-ray in order for a doctor to diagnose a condition, gamma rays are being shot at you.

Now that you have been introduced to the three forms of natural radioactivity, study the examples and solve the "on your own" problems that follow to be sure you understand how to deal with nuclear equations.

EXAMPLE 16.2

${}^{14}C$ is a radioactive isotope that goes through beta decay. What is the daughter product of this decay? Write a balanced equation for the decay process.

According to the periodic chart, carbon has an atomic number of 6. This tells us that a ${}^{14}C$ atom has 6 protons and 8 neutrons in its nucleus. When a radioactive isotope undergoes beta decay, one of its neutrons turns into a proton. Thus, it will end up with one more proton and one less neutron. The daughter product (the nucleus that results from the beta decay), then, will have 7 protons and 7 neutrons. According to the chart, all atoms with 7 protons are symbolized with an "N." The mass number of this nitrogen atom will be 7+7=14. Thus, the daughter product is ${}^{14}N$.

Now that we know the daughter product, the balanced equation is rather simple. Using the notation for a beta particle that was discussed above, the equation is:

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

Note that this equation is balanced, because the subscripts on one side add up to the subscripts on the other, as do the superscripts.

^{232}Th is a radioactive isotope that goes through alpha decay. What is the resulting daughter product and balanced equation?

According to the chart, thorium (Th) atoms have 90 protons. Thus, this particular atom has 90 protons and 142 neutrons in it. When it goes through alpha decay, it actually spits out 2 protons and 2 neutrons in the form of a ^{4}He nucleus. The result will be only 88 protons and 140 neutrons in the daughter product. The chart tells us that Ra is the symbol for all atoms with 88 protons. The mass number of the resulting nucleus will be 88+140 = 228. Thus, the daughter product is ^{228}Ra.

Now that we know the daughter product, the balanced equation is rather simple. Using the notation for an alpha particle that was discussed above, the equation is:

$$^{232}_{90}\text{Th} \rightarrow \, ^{228}_{88}\text{Ra} + \, ^{4}_{2}\text{He}$$

Note that this equation is balanced, because the subscripts on one side add up to the subscripts on the other, as do the superscripts.

Write a balanced reaction for the gamma decay of ^{22}Na.

Gamma decay simply takes energy away from the nucleus in the form of light. It does not change the identity of the nucleus. Thus, the daughter product is still ^{22}Na. The equation, then, is particularly easy to produce:

$$^{22}_{11}\text{Na} \rightarrow \, ^{22}_{11}\text{Na} + \, ^{0}_{0}\gamma$$

A radioactive decay process starts with a ^{234}Th nucleus and produces a ^{234}Pa nucleus. What kind of radioactive decay is this?

In this case, we are asked to figure out the radioactive decay by examining the radioactive isotope (^{234}Th) and the daughter product (^{234}Pa). In ^{224}Th, there are 90 protons and 144 neutrons. In ^{234}Pa, there are 91 protons and 143 neutrons. Thus, this must be beta decay, because the daughter product has one more proton than the radioactive isotope and one less neutron. This can only happen if a neutron turns into a proton.

ON YOUR OWN

16.4 Write a balanced nuclear equation for the beta decay of ^{87}Rb.

16.5 The daughter product of an alpha decay process is ^{220}Rn. What was the radioactive isotope that went through alpha decay?

16.6 A nucleus goes through radioactive decay but does not change its number of neutrons or protons. What kind of decay process did the nucleus undergo?

Before I leave this section, I want to point out something. Radioactive decay reactions as discussed in this section of the module produce an enormous amount of energy. If you add up the masses of the products produced in radioactive decay, you will find that the sum is less than the mass of the radioactive isotope. The "missing mass" is converted into energy according to Equation (8.7). Most of that energy is released as heat. In fact, radioactive decay processes are so hot that geophysicists speculate they are partially responsible for keeping the earth's interior hot!

Artificial Radioactivity

The three kinds of radioactivity that I discussed so far make up the phenomenon known as "natural radioactivity." The reason for this term is simple. These three types of radioactive decay are the only ones that occur naturally here on earth. As technology has improved, however, scientists have become able to synthesize their own nuclei in a nuclear chemistry/nuclear physics lab. As a result, scientists have artificially produced nuclei that decay via other mechanisms. The two "artificial" forms of radioactive decay are **electron capture** and **positron emission**.

In electron capture, a proton in a nucleus captures an electron (typically from the electrons that surround the nucleus). What will be produced when a proton captures an electron? Well, when a neutron releases an electron, the result is a proton. Electron capture is the reverse of this process. Thus, when a proton captures an electron, the result is a neutron. The following is an example of an electron capture reaction:

$$^{14}_{8}\text{O} + {}^{0}_{-1}\text{e} \rightarrow {}^{14}_{7}\text{N}$$

In this reaction, ^{14}O has too many protons and not enough neutrons. To fix this problem, one of the protons captures an electron from the electron orbitals and the result is a stable ^{14}N nucleus.

In positron emission, a proton emits a positron to become a neutron. What is a positron? Well, it is a form of **antimatter**. A positron is, in fact, an anti-electron. Although this sounds a bit like Star Trek, it is reality. A positron has positive charge and behaves just the opposite of an electron. Not surprisingly, then, a positron is symbolized in with a ${}^{0}_{+1}\text{e}$ in nuclear physics. Interestingly enough, when a positron and an electron encounter one another, they destroy each other, leaving nothing behind but a gamma ray (high energy light).

$${}^{0}_{+1}\text{e} + {}^{0}_{-1}\text{e} \rightarrow {}^{0}_{0}\gamma$$