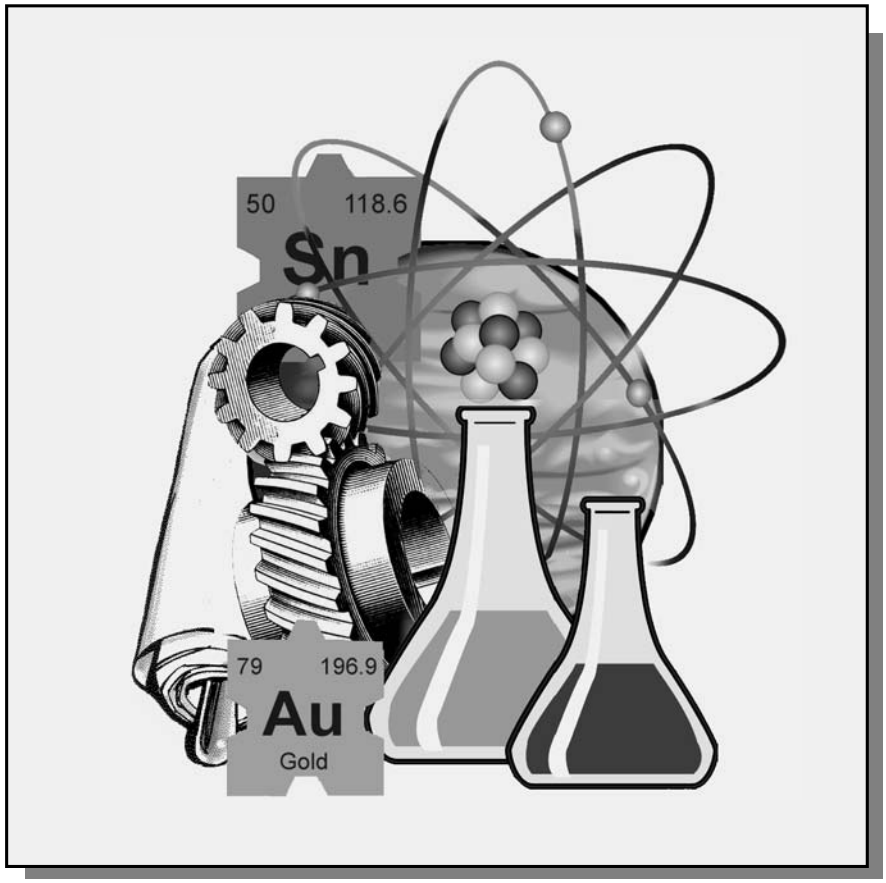
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This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 10

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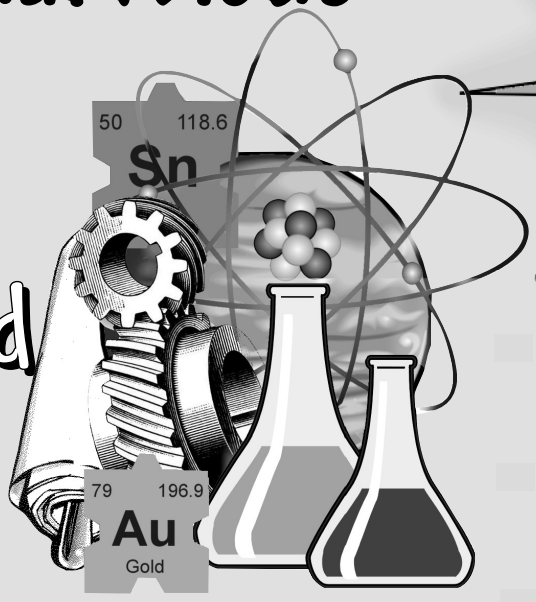
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"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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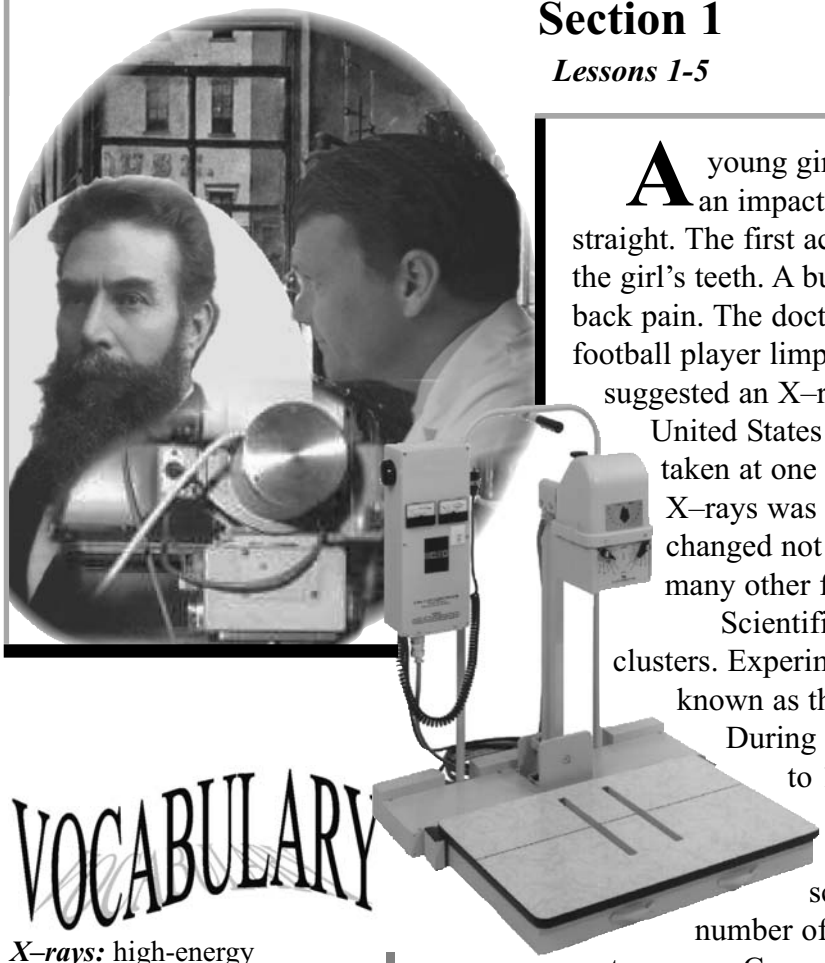
Lesson 1
Energy

Chapter 10

X-RAYS

Section 1

Lessons 1-5



A young girl went to the dentist because of an impacted tooth that was not growing straight. The first action by the dentist was to X–ray the girl's teeth. A businessman complained of lower back pain. The doctor scheduled an ***X–ray***. A football player limped off the field. The paramedics suggested an X–ray. Practically everyone in the United States has had an X–ray photograph taken at one time or another. Discovery of X–rays was an unexpected event that changed not only science but medicine and many other fields.

Scientific advances seem to come in clusters. Experimental science began in the period known as the ***First Scientific Revolution***. During the two hundred years from 1450 to 1650, roughly from the birth of Copernicus (1473) until the death of Galileo (1642), scientists made a remarkable number of scientific advances. The Polish astronomer, Copernicus, proposed the sun-centered planetary system. The Belgium anatomist, Andreas Vesalius, accurately described the structure of the human body. The Italian physicist, Galileo, studied motion of objects on Earth and turned his telescope to study the heavens. The German astronomer, Johannes Kepler, developed Three Basic Laws of Planetary Motion. The English physician, William Harvey, showed that blood circulates through the body and proved that the heart is a blood pump. The English chemist, Robert Boyle, developed the important concept of a chemical element and demonstrated that gases follow laws the same as do solid objects in the atmosphere.

By the end of the 1800s, many physicists believed laboratory experiments would merely improve on what was

VOCABULARY

X–rays: high-energy electromagnetic waves that have more energy, shorter wavelength and higher frequency than visible light and ultraviolet light

First Scientific Revolution: the period when European science awakened from the superstition and stagnation of the Middle Ages and modern experimental science was established, the two hundred years from about 1450 to about 1650

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already known: the speed of light would be measured more accurately; experiments to find information about the elements such as their density, melting temperature and boiling temperatures would be carried out with greater precision. Scientists did not think anything new would be discovered. They were wrong.

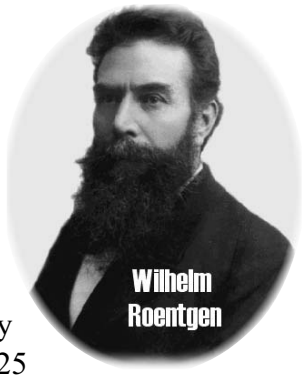


The ***Second Scientific Revolution*** began in 1895. In the space of only 10 years, German physicist, Wilhelm Roentgen, discovered X–rays. French physicist, Henri Becquerel, discovered radioactivity. His two friends, Pierre and Marie Curie, discovered several radioactive elements. English physicist, J. J. Thomson, proved that the electron is smaller than an atom, and his student, Ernest Rutherford, probed inside the atom and discovered the nucleus. American astronomer, Henrietta Leavitt, found a way to measure distances to galaxies outside our own Milky Way system. Gregor Mendel discovered laws of heredity that changed biology. Albert Einstein proposed the Theory of Relativity and developed one of the most famous equations in science, $E = mc^2$. Science again proved to be exciting, interesting and ever changing. Revolutionary ideas of pioneer scientists continue to make differences in the world today.

VOCABULARY

Second Scientific Revolution: the ten year period from 1895 to 1905 when science was jolted with a series of unexpected discoveries including X–rays, radioactivity, Quantum Theory and the Theory of Relativity
Boarding school: a school where pupils are provided with meals and a place to stay while they attend the school

The Second Scientific Revolution began with discovery of X–rays by Wilhelm Roentgen. Although German, he attended a ***boarding school*** in the Netherlands and received his professional training in Switzerland. He earned a Ph.D. at the University of Zurich. For the next 25 years, he taught at a variety of schools. By the time he was 50 years old, Roentgen had done solid but unspectacular work. He had studied elasticity, capillary action, specific heats of gases, conduction of heat in crystals and the effect of electricity on crystals. He knew that most scientists received no public notice. He continued his work not to win fame but because he enjoyed what he did. Wilhelm Roentgen enjoyed teaching and took pleasure from the few hours of experiments he did each day. He earned enough money to support himself, his wife, Anna, and their adopted daughter, Josephine. Wilhelm Roentgen spent his vacation from teaching duties by indulging in his hobby of mountain climbing in the Bavarian Alps. He always had time for his friends and helped them when they had problems.



While serving as a professor of physics at Würzburg in Bavaria, Roentgen experimented with a cathode-ray tube. An English scientist, William Crookes, had invented the device a few years earlier—a glass tube with most of the air pumped out and electrodes connected to a source of electricity at each end. When the electricity was turned on, a stream of rays, called cathode rays, traveled from the negative end

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of the tube to the positive end. Scientists learned later that the cathode rays were streams of electrons.

Substances placed inside the tube glowed when struck by the electrons. On the evening of November 8, 1895, Roentgen noticed in the dark room a glow coming from a sheet of paper coated with a barium compound. The cathode rays could not escape from the tube because they could not penetrate the glass. Roentgen enclosed the cathode ray tube in cardboard to make sure the rays remained in containment. In the dark room, the sheet continued to glow. Roentgen walked into the next room and closed the door. A faint glow persisted. He reasoned that the cathode rays (electrons) struck the metal terminal at the other end of the tube and produced a second and more powerful radiation.

Roentgen wanted to be the first scientist to announce the important discovery, but he needed to know more about the puzzling rays. Their mysterious nature caused Roentgen to use the mathematical symbol, *X*, for the unknown, and called them *X–rays*. The invisible rays passed through glass, cardboard, wood and thin layers of light metals such as aluminum. Heavier metals such as lead stopped the X-rays. Neither magnetic nor electric fields had an affect on the X-rays. In addition to making the barium compound glow, the rays exposed photographic film. Roentgen had a sheet of unexposed film in his desk drawer below the cathode ray tube. Upon developing the film, Roentgen noticed the image of a key that had been on top of the desk. The X–rays had passed through the wood of the desk but had been stopped by the metal of the key.

One day Wilhelm Roentgen placed a sheet of the barium compound in front of the rays, and he noticed the outline of his thumb on the screen. Inside the outline was a darker shadow of his bones. The X–rays would pass through the flesh of his hand, but his bones stopped them. He called his wife, Anna, into the room. She held her hand still under the rays as he exposed a sheet of photographic film. After development, the X–ray photograph clearly revealed the bones of her hand and the darker shadow of her gold wedding band.

After seven weeks of experimentation, Roentgen was ready to let the world know of his discovery. On December 22, 1895, he sent a report to the Würzburg Physical Medicine Society and asked to speak at their next meeting. At their January 23, 1896, meeting Roentgen delivered a lecture on the new kind of ray. He stated that the rays could penetrate the human body and leave a record of the bones beneath the flesh. Most of the doctors listened in silence because they did not believe such a thing to be possible. Roentgen asked for a volunteer from the audience. Albrecht von Kölliker, elderly and well respected, came forward. The developed film showed the bones and joints of the man's hand. The lecture ended with enthusiastic applause. Some of the scientists came forward to ask questions. Most laboratories already had cathode ray tubes, so many of the men hurried away, eager to conduct tests for possible uses of X–rays.

The first use of X–rays was in medicine. Doctors could examine the nature of broken bones and locate foreign objects inside the body.

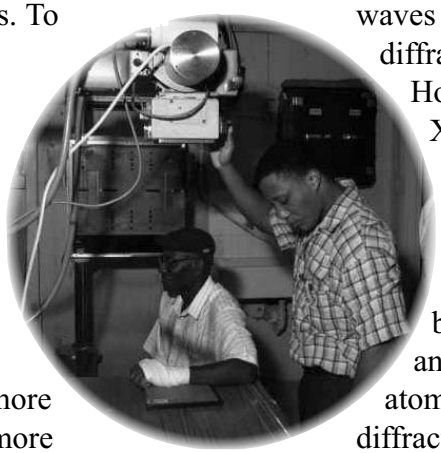


Roentgen could have made a fortune by patenting the discovery. However, because of its important medical use, he chose to release it

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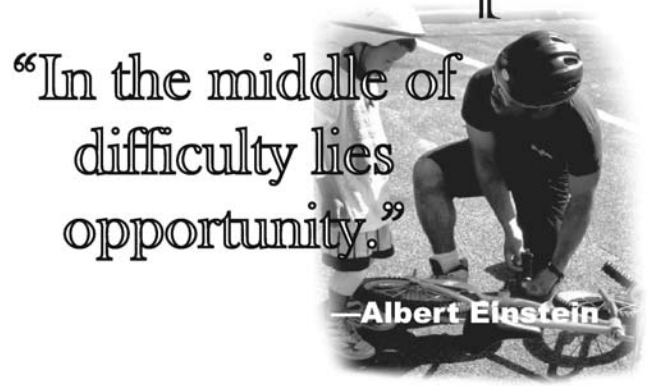
for the whole world to use. In 1901, Roentgen received the first Nobel Prize for his discovery. The cash award that accompanied the prize was the only money Roentgen received for his discovery.

X–rays are highly penetrating electromagnetic waves released by high-speed electrons when they strike metal targets. Electrons that are beamed from the negative terminal of a cathode ray tube have energy due to their motion. The metal target stops the rays suddenly, and their kinetic energy is converted into high-energy electromagnetic waves. To make more powerful X–rays, the electrons must be given greater speed. Improving the vacuum in the cathode ray tube reduces the air molecules that slow down the rays. The electrons then travel more quickly and produce more powerful X–rays. Increasing the voltage also moves the electrons along at a higher rate. An X–ray machine in a hospital produces about two million volts. Electric and magnetic fields can focus the electrons so more of them strike the metal target which produces a greater number of X–rays and controls their direction.



X–rays are part of the electromagnetic spectrum above visible and ultraviolet light. X–rays have a higher frequency, shorter wavelength, more energy and greater penetrating power than ultraviolet light or visible light. Roentgen was not aware that X–rays accumulated in the body and were (are) harmful to human and animal tissue, partly because he did not realize they were waves which would refract (bend), reflect or diffract (interfere with one another). However, other scientists showed that the X–ray did have these properties and that they were waves. One of the most useful of their properties is the interference pattern that they produce when they enter a crystal and bounce back. The waves interfere with one another to reveal the placement of the atoms in the crystal. In the 1950s, X–ray diffraction photographs of deoxyribonucleic acid (DNA) revealed its structure. DNA controls the functioning of cells and passes hereditary information to the next generation.

Life Principle



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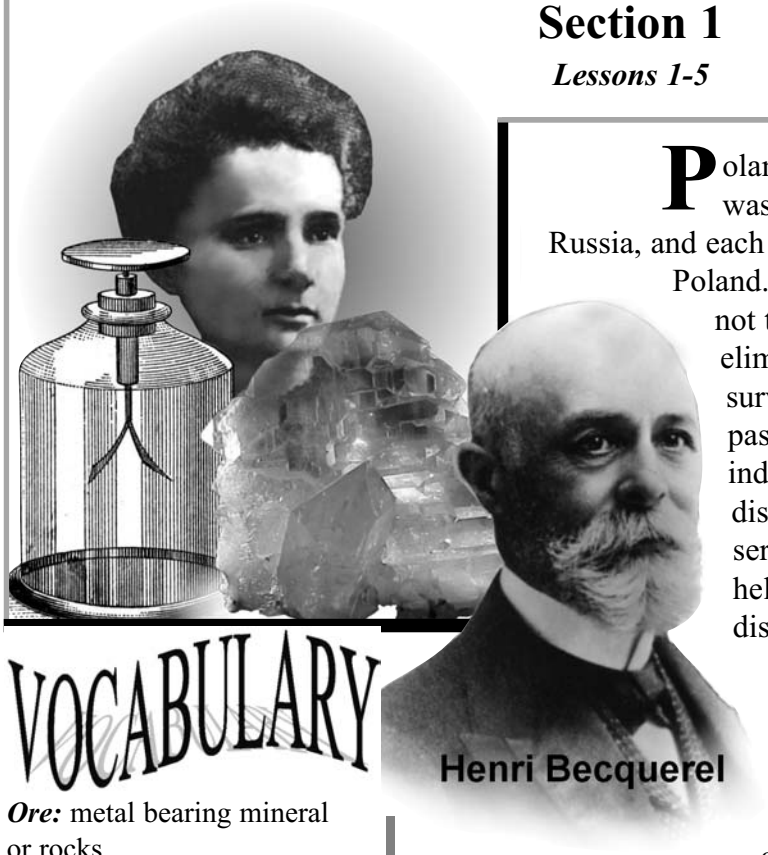
Lesson 2
Energy

Chapter 10

RADIOACTIVITY

Section 1

Lessons 1-5



Poland disappeared in 1863. The country was divided between Germany and Russia, and each government decided to eliminate Poland. Students in its schools were ordered not to speak Polish. The country was eliminated from maps. Yet, Poland did survive. Although more than 100 years passed, Poland finally became an independent country. Ironically, the discovery of radioactivity, through a series of events begun in Paris, France, helped keep the name of Poland from disappearing entirely.

Henri Becquerel of Paris, France, was the first person to detect the radioactivity of uranium ore. He came from a family of scholars and scientists. Antoine, Henri's grandfather, had been a member of the Royal Society and invented a way to use electricity to extract metals from their ***ores***. Alexander, Henri's father, had done research on energy from the Sun and *phosphorescence* of crystals. Phosphorescence is the emission of light when the substance absorbs energy. When some crystals are exposed to light and then put in a dark room, they glow for a time after being removed from the source of energy. Other crystals produce visible phosphorescence when exposed to invisible ultraviolet rays.

Henri Becquerel decided to become an engineer. He studied construction at the Bridges and Highways School. Becquerel was able to do a variety of jobs. In addition to his duties as an engineer, he began teaching science at École Polytechnique, a well-known school in Paris. He kept both jobs and did research at the Paris Museum. Despite its name, the

VOCABULARY

Ore: metal bearing mineral or rocks
Pitchblende: black, pitch-like rock containing uranium and radium
Radioactivity: a property of certain elements which spontaneously emit radiation
Electroscope: a simple device that reveals the presence of electric charge by the attraction or repulsion of metal foils, Marie Curie used the electroscope to measure the intensity of radioactivity by how quickly the electroscope lost its charge due to ionization caused by radioactive rays

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Paris Museum was an important research institution in the science of physics. Becquerel read about Roentgen's experiments with X–rays. In the year after that discovery, more than a thousand research papers had been written about the rays. Becquerel had a large collection of crystals that he had been given by his father. Rather than repeating the work of other scientists, Becquerel decided to investigate whether crystals exposed to ultraviolet sunlight gave off X–rays.

Becquerel selected a compound of potassium sulfate and uranium, which was known to glow when, exposed to light. He wrapped a piece of photographic film in heavy, dark paper to keep out the light. Then he placed the crystal on top of the wrapped film and put both of them outside in bright sunlight for several hours. Any X–rays produced by the action of the sunlight on the crystal would penetrate the paper and fog the film. Upon development, the photographic plate revealed a silhouette of the mineral sample. Becquerel modified the experiment by putting a coin between the crystal and the wrapped film. The image of the coin was clearly visible on the wrapped film.

Becquerel assumed ultraviolet light from the Sun entered the crystal and caused it to give off the penetrating rays that fogged the film. However, he found this incorrect during March 1896 when a long period of cloudy weather cut short his experiments. He put the film in his desk, still wrapped in paper to keep out the light. The clouds persisted. He decided to develop the film although it had been exposed to sunlight for only a few minutes. To his surprise, the film had been completely exposed. Becquerel realized that some mineral in his desk had given off rays that fogged the film.

The crystal alone gave off the new rays and did not have to be exposed to sunlight. Becquerel had several different samples of crystals and ores in his desk. By a process of elimination, he discovered that ***pitchblende***, a type of uranium ore, was the strong source of rays that fogged the film. While sitting in the dark, the ore gave off rays hour after hour, day after day. Like X–rays, these rays could pass through paper and even thin sheets of metal. However, the rays were not the same as X–rays. The rays from uranium were even more penetrating. They could be deflected by electric and magnetic fields, which left X–rays untouched. Additional testing showed that all uranium ores gave off the rays. They came from atoms of uranium. In 1896, only a year after the discovery of X–rays, Becquerel announced another discovery just as unexpected, the discovery of the invisible radiation emitted by uranium.


Pitchblende

During 1896, Becquerel published seven papers on ***radioactivity***, a term invented by his friend Marie Curie. In 1900, Becquerel measured the mass and electric charge of some of the particles and showed that the rays contained high-speed electrons. He intentionally carried a sample of a radioactive element in his vest pocket for

VOCABULARY

Thorium: an element discovered in 1828 by Jakob Berzelius that was found by Marie Curie to be radioactive, symbol is *Th*
Polonium: a naturally occurring, dense radioactive element, it has 84 protons and its most stable isotope has 126 neutrons for a total atomic weight of 210, symbol is *Po*
Ionize: a process by which air becomes a conductor of electricity

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several days. It produced a burn that was slow to heal. Although some people described his detection of radioactivity as a chance event, he had worked hard to prepare himself to make the breakthrough. Becquerel was an expert in phosphorescent materials. He could identify the various chemicals and crystals. He was skilled in the laboratory and the use of scientific tools, including photography. Becquerel shared the 1903 Nobel Prize in physics with Pierre and Marie Curie.

The next advance in the understanding of radioactivity came from Pierre and Marie Curie. Pierre Curie's parents had worried about their child. He did not seem to learn as quickly as other children. His parents were afraid the schools would label him as retarded. Pierre's father was a medical doctor who decided to teach Pierre at home. Years later, Pierre became a chemistry professor and made several important discoveries. One was the discovery that quartz crystals gave off electricity when squeezed. This property, which he named *piezoelectricity*, is used in crystal microphones and in very accurate quartz crystal watches. Pierre discovered that iron compounds lose their magnetic properties if heated above a certain temperature. This temperature is different for every magnetic material and is now called the *Curie temperature.*


Quartz

In 1894, Marie Sklodowska enrolled in one of Pierre Curie's classes. She had been born in Warsaw, Poland. Because of political changes in Europe, Poland no longer existed; Germany claimed it. Students in Polish schools were forbidden to speak that language, and maps no longer showed Poland as a country. German politicians wanted to eliminate Poland completely. Marie Sklodowska, however, made a discovery that kept the name of Poland alive.

Pierre Curie and Marie Sklodowska married in 1895. They had been married for a little over a year when their friend Becquerel discovered the radioactivity of uranium. Marie Curie needed a research project as part of her studies, and she decided to look for other radioactive elements. One way to test for radioactivity was to see if the minerals fogged film. Marie found a faster way by using an ***electroscope***, a simple device that had two metal foil strips that repelled one another when given a static electric charge. When the electroscope lost its electric charge, the metal foil strips fell back together. By bringing the radioactive elements near the charged electroscope, she could measure the amount of radioactivity by how quickly the foil leaves fell together. Testing radioactivity with the electroscope was much faster than developing a photograph.



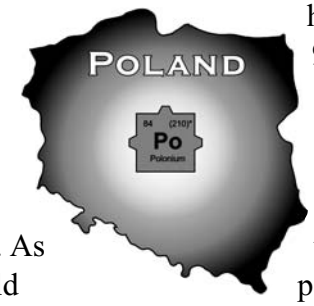
In 1896, Marie Curie tested all of the elements known at that time and found uranium and ***thorium*** (Th) to be the only radioactive elements. She tested a variety of compounds that contained uranium and thorium. The amount of radioactivity did not depend upon the compound but did depend on the amount of uranium or thorium in the compound. Marie concluded that radioactivity was not a chemical property but instead issued from the atom itself. Because chemical reactions affected the outer part of the atom, radioactivity had to be coming from deep within the atom.

Pierre began helping Marie with her radioactive studies. Together, they refined uranium from pitchblende. With all the uranium removed, the ore still showed

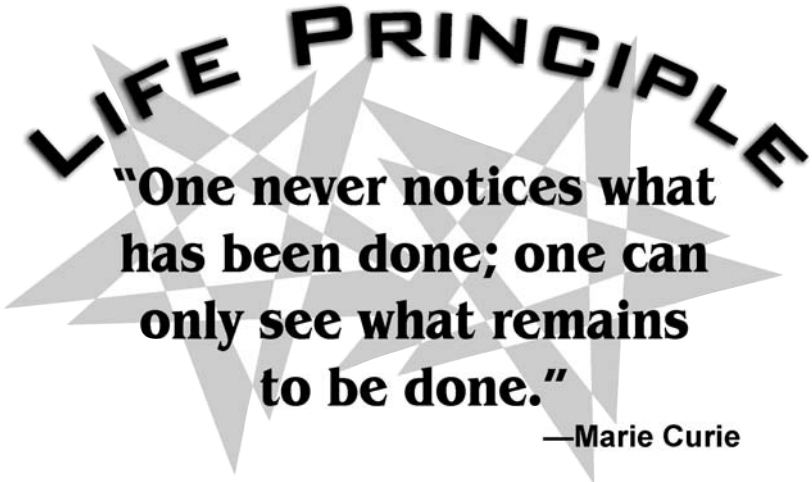
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radioactive properties. In fact, it was even more radioactive than uranium itself. Chemists had analyzed pitchblende and thought that all of its elements had been found. Pierre and Marie realized an undiscovered element was hidden in the dark ore. It could have escaped detection only by being present in very small amounts. For such a small amount to cause the radiation that her electroscope showed, Marie realized the substance must be intensely radioactive.

In 1898, Pierre and Marie Curie isolated a new element from *pitchblende*. As the discoverer of the element, Marie could name it. She decided to call it ***polonium*** after her native country, Poland. By international agreement, the new element was given that name and added to the Periodic Table of the Elements. On the periodic chart, *polonium* is located at the bottom of the family that contains oxygen. The politicians in Germany and Russia may have eliminated Poland from the map, but they could not eliminate polonium from the Periodic Table of the Elements. Polish chemistry students could see that at least on the chart their country still existed.

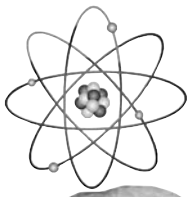


Polonium (Po) is a naturally radioactive metallic element. It is a heavy metal with a density, 9.32 g/ml, near that of lead, 11.35 g/ml. Polonium-plated metal is used to carry off static electricity. The radiation from the polonium ***ionizes*** the air and gives an escape path to conduct away accumulations of static electric charges. Photographers pass a polonium brush across a photographic negative to keep it from attracting dust particles and spoiling an enlargement made from it. Some high-speed printers attached to computers use polonium brushes to prevent the paper from jamming because of static build up.



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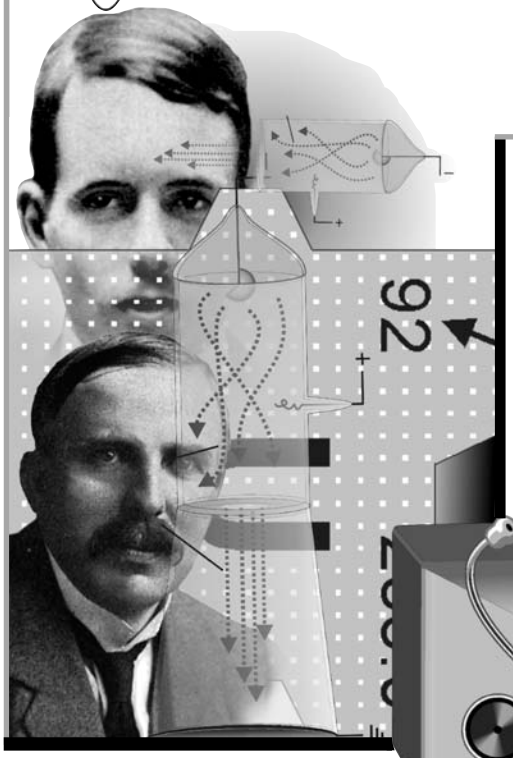
Lesson 3
Energy

Chapter 10

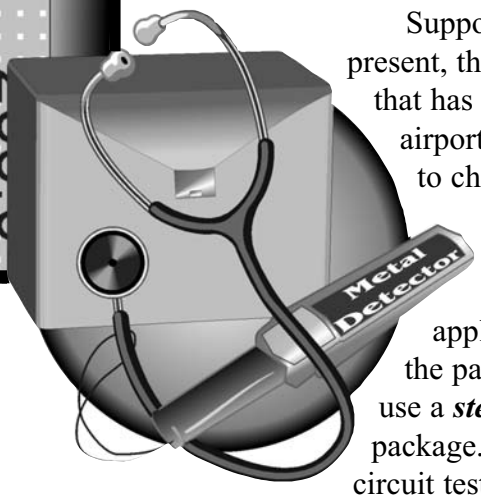
THE ELECTRON AND PROTON

Section 1

Lessons 1-5



A person who receives a wrapped present may shake the package. Some people hold it to their ears and move it around to listen for a rattle. Others heft it in their hands to gauge its weight. From the weight, they can tell it is too heavy to be socks. From the lack of a rattle, they know it is not a game with loose pieces. Finally, they open the present to see what is inside.



Suppose that instead of a wrapped present, the box is a mysterious package that has been left unattended at the airport. Airport security is called in to check the package. It could contain explosives. The airport security guards conduct several tests. They apply metal detectors to learn if the package contains metals. They use a ***stethoscope*** to listen to the package. The guards pass a sensitive circuit tester nearby to determine whether electricity is flowing through an electric circuit. Specially trained dogs are brought in to smell for drugs or explosives. Guards may want to X-ray the package to determine of it is merely a box that someone accidentally left behind, or if it is dangerous and must be transported away to be exploded in an open field.

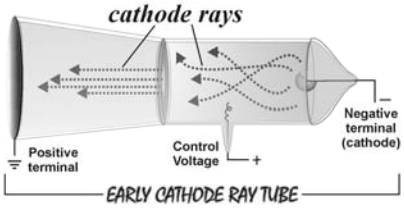
For scientists, the atom was like a wrapped package with contents that could not directly be seen. Through most of the 1800s, scientists did not ask themselves what was inside the atom because they believed the atom to be the smallest piece of matter known. Even if scientists had wanted to see into the atom and learn its composition, they could not shake, smell or weigh it. However, late in the 1800s, scientists realized that

VOCABULARY

Stethoscope: a device used by doctors to listen to sounds within the body
Cathode rays: streams of electrons emitted from the negative (cathode) electrode of a cathode ray tube
Electron: a subatomic particle that orbits outside the nucleus of an atom
Alpha particle: a high-speed radioactive particle with the mass of a helium atom and an electric charge of +2

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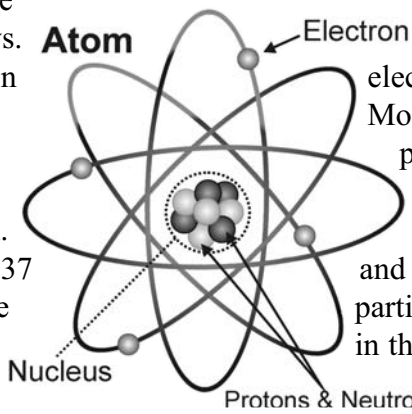
they could make some tests to learn more about the composition of the atom. The first clue came from electrical studies. Scientists built a glass tube and pumped out most of the air. Then they ran a high current of electricity through the tube. They attached the negative terminal to one end of the tube and the positive terminal to the other end. Some sort of ray traveled from the negative terminal to the positive terminal inside the vacuum tube. The rays came from the negative terminal, which was also known as the cathode, so the stream of rays became known as ***cathode rays***.



In 1897, English scientist, Joseph John Thomson, tested the cathode rays in various ways. By placing electrically charged plates on either side of the cathode rays, Thomson showed that the rays carried a negative charge. He also placed the tube in a magnetic field and measured how much the magnetic force changed the path of the rays. From the amount the path curved, Thomson could calculate the mass of the rays. He found that the cathode rays were actually particles far smaller than an atom. Hydrogen is the smallest and lightest atom. Yet, his calculations showed that about 1,837 cathode particles equaled the weight of one hydrogen atom. The hydrogen atom is 1,837 times heavier than the electron. Thomson called the particles ***electrons*** because an electric current produced them. Thomson had discovered the first subatomic particle, the electron.

In 1899, Thomson learned more about electrons. He found that when he directed powerful ultraviolet light on the surface of a metal, the metal would release electrons. This experiment demonstrated that electricity was not necessary to produce electrons. Electrons were part of matter. Atoms, the smallest known building blocks of nature, contained still smaller building blocks. Electrons carried a negative electric charge, but atoms are electrically neutral. To balance the negative electric charge of the electron, the atom must also carry a positive charge.

Early in the 1900s, Ernest Rutherford tested the atom by shooting high-speed radioactive particles into a piece of gold foil. The particles, known as ***alpha particles***, had about the same mass as four hydrogen atoms, but they traveled at about $^{1}/_{10}$ the speed of light. The alpha particles were so powerful they could easily brush aside the electrons in the atom. Most of the alpha particles passed right through the gold foil. However, now and then an alpha particle struck something in the atom that was so massive it bounced back. Rutherford's calculations showed that the atom was mostly empty space, but at its very center was a very massive core that he called the ***nucleus***. The nucleus contained the positive charge that balanced the negative charge carried by the electron.



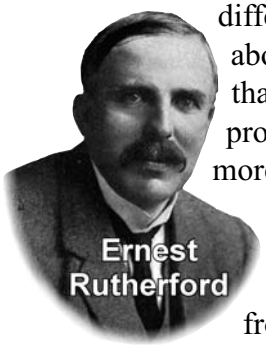
During certain chemical reactions, an electron can be removed from the hydrogen

VOCABULARY

Nucleus: the dense central core of an atom composed of protons and neutrons
Proton: one of the three fundamental particles that make up an atom

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atom. Without an electron, the hydrogen atom has a positive charge. The hydrogen atom without its electron is a single positively charged particle. A hydrogen atom without its electron is a ***proton*** with a positive electric charge that is the same size but opposite that of an electron. Although the electric charges of the electron and proton are equal and opposite, the mass varies greatly. The proton is far more massive than the electron. Imagine a 115-pound boy who is holding a sponge ball that weighs one ounce. That is how much the proton and electron differ. The boy weighs about 1,837 times more than the sponge ball. The proton weighs 1,837 times more than the electron. The word *proton* was invented by Ernest Rutherford and comes from a Greek word meaning *first*. Rutherford is credited with the discovery of the proton.



The paths of charged particles are bent when they pass through a strong magnetic field. The direction particles bend depends upon whether they have a positive charge or a negative charge, and the degree to which they are bent depends on their mass. An electron is not very massive; therefore, an electron which enters a magnetic field is bent in a tight arc. When protons are sent through the same strong magnetic field, they are bent in the opposite direction but not as strongly. When two particles have the same charge (or equal but opposite charges) and enter a magnetic or electric field, the path of the one with the greater mass is bent less. The shallow arc of the proton's path shows that it is many times more massive than the electron and that they have opposite charges. Information about other charged particles can be found by how they act in a magnetic field.

In 1906, Rutherford tested alpha particles which were known to have a double positive charge and about the same mass as a helium atom. A helium atom is the second lightest atom known. It is four times as heavy as a hydrogen atom. When Rutherford allowed an alpha particle to gain two electrons, the particle changed into a helium atom and became electrically neutral. By 1906, the structure of the atom was becoming clearer to scientists. They learned that a proton is a bare hydrogen atom that has lost its one electron. An alpha particle is a bare helium atom that has lost both of its electrons.

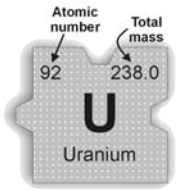
In other words, a hydrogen atom is made of one proton and one electron. If you remove an electron, the hydrogen has a single positive charge, +1. If you remove the electrons from a helium atom, then it has a double positive charge, +2. In 1914, English scientist Henry Moseley developed a test to show how many protons are in an atom. For the first time, scientists could see why atoms are arranged as they are on the periodic table. Atoms of the same element always have the same number of protons. Atoms of different elements always have a different number of protons. Each atom is different from another atom by the number of protons contained in the nucleus. Hydrogen has one proton, helium has two protons, lithium has three protons, beryllium has four protons, boron has five, carbon has six, nitrogen has seven, oxygen has eight and so on all the way up to uranium, which has 92 protons.



The *atomic number* is the number of protons in the nucleus of an atom. Rather than mentioning atoms by name, some scientists refer to them by number. Scientists

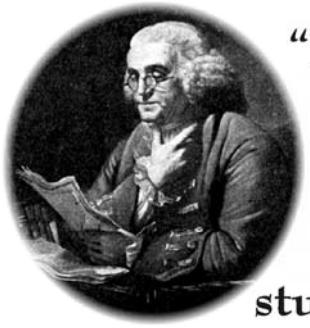
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may say they are working with element 92, meaning uranium. On the Periodic Table of the Elements, the atomic number is given at the top of the cell (in this course shaped like a puzzle piece) that tells about the element. The atomic number is always a whole number because it is the number of protons in the nucleus; elements cannot have parts of protons. For example, an element may have one proton or two protons but not 1.5 protons.



A helium atom is made of two protons and two electrons. However, scientists realized the helium atom had to contain additional particles because it weighed four times as much as a proton. The two protons in the helium nucleus account for only half of the mass. Electrons do not weigh enough to be significant, so the nucleus must contain another subatomic particle that contains a lot of mass. Other atoms weigh more than can be accounted for by their protons alone. For instance, element number eight is oxygen. It contains eight protons. However, its total mass is 16, with eight being from the protons and the other eight being from some other particles. The difference is even more dramatic for uranium. With an atomic number of 92, uranium has a total mass of 238. The uranium atom has 92 protons but must contain other particles to account for the additional mass. Scientists were not certain about what particle gave the atom its additional mass. The next lesson will help you know more about atoms than was known by most scientists of 100 years ago.

Life Principle



"Do you love life? Then do not squander time, for that is the stuff life is made of."

—Benjamin Franklin

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Integrated Physics & Chemistry

Lesson 4
Energy

Chapter 10

THE NEUTRON

Section 1

Lessons 1-5



When pilots approach a small landing strip, they prefer to touch down facing the wind which makes controlling the plane easier. From the airplane, the pilot cannot see the wind and cannot tell which way it is blowing. The pilot looks for the windsock on the ground that makes the wind visible. A windsock is an open-ended tube of lightweight fabric, a foot in diameter and ten to 12 feet long. It is wide at one end and tapers down to a narrower opening at the other. Even the slightest breeze fills the tube of lightweight material. Although the pilot cannot see the wind, the windsock indicates the direction the wind is blowing. When landing on the Moon July 4,1997, the Mars explorer, *Pathfinder*, carried a small windsock. Scientists photographed the windsock to determine the direction of the thin Martian winds.



Like the wind, some subatomic particles can be detected only by the affect they have on something else. For a physicist, detecting a particle that carries no charge is difficult. A charged particle is easier to detect because it affects those particles near which it passes. A charged particle that passes through a sheet of photographic film causes the film to fog. If a charged particle passes through a special chamber known as a ***cloud chamber***, the particle causes tiny droplets of fog to form along its path. Both electrons and protons leave a record of their trail when they pass through film or a cloud chamber. A neutral object, however, passes unseen through either film or cloud chamber.

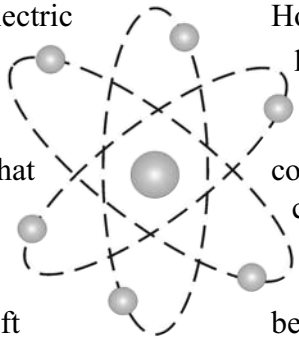


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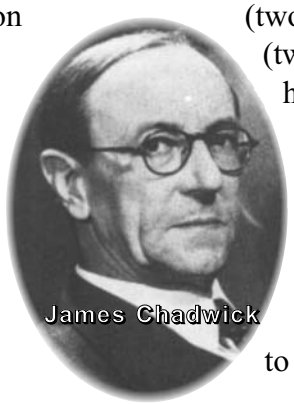
Cloud chamber: a radiation detector made of a container with air that is heavily saturated with moisture, charged particles that pass through the air cause droplets of moisture to form along their tracks
Neutron: a subatomic particle in the nucleus of an atom that has about the same mass as a proton but no electric charge
Chemical reaction: a reaction that produces changes in the energy, number or arrangement of electrons about an atom
Nuclear reaction: a reaction that produces changes in the energy, number or arrangement of protons or neutrons in the nucleus

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Scientists felt confident that the atom was made of three subatomic particles. One was the electron with a –1 electric charge and a mass of $^1/_{1,837}$ that of a proton. The other was a proton with a +1 charge and a mass equal to that of a hydrogen atom. Both carried an electric charge, and both were easy to detect in a variety of ways. They left visible tracks in a cloud chamber. The atoms of elements other than hydrogen were more massive than could be accounted for by electrons and protons. A third particle had to exist to give the atoms additional mass. Although scientists suspected that the particle existed, several years passed before its existence was verified.



Scientists wondered what kind of particle made the additional mass of an atom. Physicists knew the particle could not carry an electric charge. A helium atom has two protons that carry a charge of +2 and two electrons that carry a charge of –2. Overall, the helium atom was neutral, so the particle that carried the extra mass had to be neutral, too. Scientists did not know the mass of the particle that gave the atom its additional mass. In the helium nucleus, protons accounted for half of the mass, so the neutral particle or particles would account for the other half. Later, scientists would identify the second particle in the nucleus as the neutron. It has the same mass as a proton but is electrically neutral. The third subatomic particle had zero electric charge and a mass equal to that of a proton.


James Chadwick

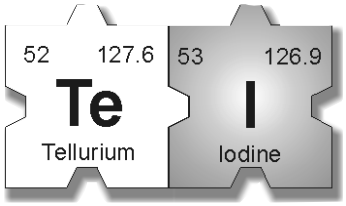
In 1932, an English scientist, James Chadwick, provided the proof. He sent alpha particles into a block of the metal beryllium. The alpha particles appeared to have no effect on the beryllium. However, Chadwick placed nearby a block of paraffin which contained molecules of hydrogen and carbon. Suddenly protons were given off from the paraffin. Chadwick could see the protons by their tracks in a cloud chamber as they escaped from the paraffin. He could see the alpha particles by their tracks as they entered the beryllium, but he could not see any particle going from the beryllium to the paraffin. Yet, he knew the particle had to be there. Something had to be leaving the beryllium, going to the paraffin, striking protons and knocking them loose. It had to be a massive particle without a charge. Chadwick did additional tests and showed that the particle was about the same size as the proton, but without a charge—it was electrically neutral. Chadwick called the invisible particle a ***neutron***.

The neutron explained why an atom has an atomic number and atomic mass that are different. *Atomic number* is the number of protons, and *atomic mass* is the total number of protons and neutrons. The atomic mass is measured in *atomic mass units*. An atomic mass unit is equal to $^1/_{12}$ the mass of a carbon atom. A proton or neutron has a mass of about one atomic mass unit. For most purposes, the total number of protons and neutrons gives the atomic mass of an atom. A helium nucleus has an atomic number of two (two protons) and an atomic mass of four (two protons and two neutrons). Uranium has an atomic number of 92 (92 protons) and an atomic mass of 238 (92 protons and 146 neutrons). Hydrogen is the only exception; it has one proton and no neutrons, so its atomic number is one, as is the atomic mass.

The atomic number is always a guide to where an element should be placed in the

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periodic table. For instance, iodine has 53 protons, and should be placed between tellurium (atomic number 52) and xenon (atomic number 54) in the periodic table. If you look at iodine's atomic weight (126.90), you can tell it is lighter than tellurium (atomic weight of 127.60). Iodine would come before tellurium based on atomic weight. Atomic number (number of protons) and not atomic weight (number of protons plus number of neutrons) tells where an element is located in the Periodic Table of the Elements.



The electron, proton and neutron are the three subatomic particles that make an atom. Electrons are primarily involved in chemical reactions. A neutrally charged atom has the same number of electrons as protons. A neutral oxygen atom (atomic number 8) has eight protons and eight electrons; therefore, the atom has a neutral charge. However, during ***chemical reactions***, the oxygen atom often gains two electrons. The atom has 10 electrons but still only eight protons, so the oxygen atom has a –2 charge. Some atoms lose electrons during chemical reactions. The neutral sodium atom (atomic number 11) has 11 protons and 11 electrons. Overall, this atom has no electric charge. However, during chemical reactions the sodium atom often gives up one electron. The atom then has 10 electrons but 11 protons, so the sodium atom has a +1 charge.

The number of electrons in an atom is equal to the number of protons, provided the atom is electrically neutral. An atom does not change into a different element when it gains or loses an electron. A sodium atom is still a sodium atom whether it has a positive charge or whether it is neutral. Losing one of the electrons that orbits around the atom does not change it from sodium into something else. An oxygen atom is still an oxygen atom whether it is neutral or has gained two electrons. Getting two more electrons to fill in the orbits around the nucleus does not change oxygen into something else.

Chemical reactions can change only the number of electrons that orbit an atom. Chemical reactions do not change the nucleus of the atom. During chemical reactions, the number of protons and neutrons remain constant. Only the number of electrons changes, and only they are involved in chemical reactions. During a chemical reaction an element may gain electrons, lose electrons or share electrons. Although the number of electrons changes, the atomic number and atomic weight of an atom are not affected by a chemical reaction.

Atoms of the same element always have the same number of protons. For an element to be hydrogen (atomic number 1), it must have one proton. Although chemical reactions cannot change the number of protons in an atom, ***nuclear reactions*** can change the number of protons. Suppose a nuclear reaction caused hydrogen to gain a proton. It would have two protons and no longer be hydrogen. Instead, it would be helium (atomic number 2). Suppose a nuclear reaction caused carbon (atomic number 6) to gain a proton. Its new atomic number would be 7 (seven protons), and it would become nitrogen. Suppose lead (atomic number 82) lost three protons. It would become element number 79, gold. Chemists have been unsuccessful in attempts to change lead into gold.

Atoms of the same element do not have the same number of neutrons. An element can have atoms that differ in the number of neutrons in their nuclei yet still have the same number of protons. For

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instance, the most common variety of uranium has 92 protons and 146 neutrons, for an atomic mass of 238. However, another version of uranium has 92 protons but only 143 neutrons for an atomic number of 235. To show the difference, physicists called the more common one uranium-238 and the less common one uranium-235.

Scientists question the effect of having fewer neutrons in an atom. Experiments proved that the number of neutrons does not change the atomic number, but it does change the atomic weight (mass). Uranium-238 and uranium-235 each have 92 protons, but uranium-235 has three fewer neutrons, so it is a lighter element. Also, the right number of neutrons helps in making the atom stable. If the atom has too many or too few neutrons, the atom may be radioactive. The nucleus is unstable and undergoes radioactive decay. Uranium-235 is far less stable than uranium-238. Uranium-235 is used in nuclear reactors and nuclear bombs.

With discovery of the neutron, understanding of the composition of the atom was complete. Scientists were able to make a model that showed electrons orbiting at a distance from the nucleus; the electrons were light in weight and carried a negative charge; the nucleus was at the center of the atom. The model showed that an atom is made of protons and neutrons. Later, Danish physicist Niels Bohr modified the model and showed that the electrons were confined to orbits with specific energy levels. The nucleus was about $^{1}/_{10,000}$ the diameter of the atom. If you enlarged an atom so that the nucleus was the size of a baseball (2.86 inches), then the outer electrons would be orbiting at a distance of more than 1,100 feet.

LIFE PRINCIPLE

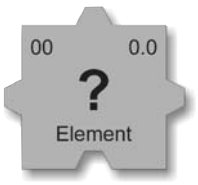
"The best way to get something done is to begin."

— Anonymous



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Integrated Physics & Chemistry



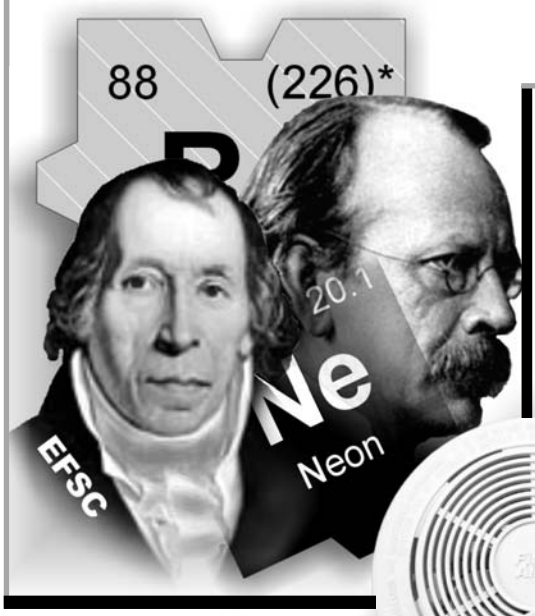
Lesson 5
Elements

Chapter 10

ISOTOPES

Section 1

Lessons 1-5



All new motels built in the United States are required to have a smoke detector in each room. Most homeowners also install the devices to sound warnings at the presence of smoke. Usually, smoke is produced in the early stages of a fire, and if a warning is sounded, people can safely escape from the building. Although smoke can be detected in a variety of ways, the most common method is to measure the flow of charged particles that travel through a small gap of air between two electrodes. The charged particles, ions, travel between two metal plates that act as electrodes. If no smoke particles are in the air, then the electric signal between the plates remains constant. Smoke particles attract charged particles. If smoke is present, it reduces the strength of the current passing through the electrodes. When the current drops, a signal goes to the control unit to sound the alarm.



Smoke Detector

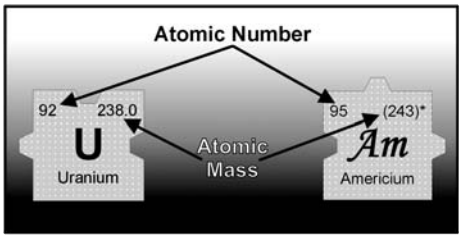
Most home smoke detectors use the radioactive element ***americium***-241 to ionize the air. Such smoke detectors release particles that cause air molecules to become charged. Americium-241 has 95 protons and 146 neutrons. Physicists often show the number of protons and the atomic mass with superscripts and subscripts. Americium is represented as ${}_{95}Am^{241}$. Ninety-five (95) is the atomic number (number of protons), 241 is the atomic mass (total number of protons and neutrons), and *Am* is the symbol for americium. Uranium-238 is ${}_{92}U^{238}$ with 92 the atomic number, 238 the atomic mass and *U* the symbol for uranium. Scientists designed a symbol for uranium-235: ${}_{92}U^{235}$ with 92 the atomic number, 235 the atomic mass and *U* the symbol for uranium.

VOCABULARY

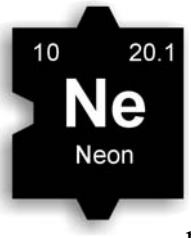
Americium: an artificially produced radioactive element used in smoke detectors
Isotopes: atoms of the same element with the same atomic numbers but different atomic masses
Tailings: the rock that is left over after ore has been processed
Stable: an atom that is not subject to disintegration due to radioactive change
Radium: highly radioactive element, discovered by Pierre and Marie Curie

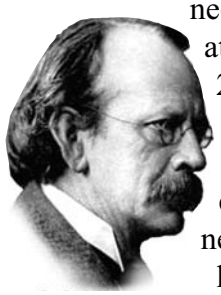
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Uranium-235 and uranium-238 have the same number of protons but a different number of neutrons. Atoms whose nuclei have the same number of protons but different number of neutrons (and therefore different weights or mass) are called ***isotopes***. The word *isotope* comes from *iso* meaning *same* and *tope* meaning *step* or *place*. Two isotopes are found in the same place in the Periodic Table of the Elements although they differ in atomic weight. Most elements have isotopes although some are more common than others. For instance, uranium-238 is far more common than uranium-235. Out of 1,000 uranium atoms, about 993 are uranium-238 and only 7 are the uranium-235. The isotopes of an element are not always equally abundant.



J. J. Thomson, who discovered the electron, also investigated isotopes. He found that neon with an atomic number of 10 is made primarily of two isotopes. One is neon-20 (with an atomic weight of 20); the other is neon-22 (with an atomic weight of 22). Supposing each atom to be electrically neutral, you can understand how Thomson determined the quantity of electrons, protons and neutrons each isotope has. Solution: the atomic number is the number of protons, so the neon atom has 10 protons. The atom is electrically neutral, so each positive proton must be counterbalanced with a negative electron. The neon atom has 10 electrons. The atomic weight is the sum of the number of protons and neutrons. Neon-20 has 10 protons and 10 neutrons (10 + 10 = 20), and neon-22 has 10 protons and 12 neutrons (10 + 12 = 22).




J. J. Thomson

Most elements have atoms with two or more isotopes. J. J. Thomson found that neon has two isotopes, neon-20 and neon-22. Later, scientists discovered the even rarer isotope neon-21. It has 10 protons, 10 electrons and 11 neutrons. The three isotopes are not equally common. In a sample of 10,000 neon atoms, about 9,000 were neon-20, 973 were neon-22, and only 27 were neon-21. In the Periodic Table of the Elements, the atomic weight for neon shown at the bottom of the symbol is an average of all three isotopes. In the case of neon, the atomic weight is 20.183, which is closer to 20 than 21 or 22 because the number of neon-20 atoms with an atomic weight of 20 is far greater than the other two isotopes.

In general, the atomic weights of the elements do not come out to be whole numbers. One reason is because of isotopes. Although most atoms have an atomic weight that is a whole number, different isotopes exist in the sample, causing the average atomic weight to be a fraction. This often happens when scientists take an average. Look below the elements in the periodic table; most elements will have atomic weights that are fractions. For instance, the atomic weight of mercury (Hg, element number 80) is 200.59. Mercury has seven isotopes, ranging in atomic weight from 196

VOCABULARY

Calorie: a measure of heat energy equal to the heat required to raise the temperature of one gram of water one degree Celsius

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to 204. The most common is mercury-200, and the average atomic weight is 200.59. You can determine the quantity of electrons, protons and neutrons resident in an electrically neutral atom of mercury-200. Mercury is element number 80. Its atomic number is 80, and it has 80 protons and 80 electrons. The number of neutrons is 120 (80 + 120 = 200).

Notice that some elements have their atomic weight in brackets, and the number is a whole number. Those elements are radioactive, and the bracket contains the atomic weight of their most stable isotope. For americium, the atomic weight is given as [243] because that is the most stable isotope of americium.

The radioactive elements were discovered in the late 1800s. In 1895, the French physicist, Henri Becquerel, found that photographic film left in his desk became fogged. He traced the cause to a sample of uranium ore. His friends, Marie and Pierre Curie, investigated other radioactive substances. They discovered polonium in 1898 in pitchblende, a uranium ore. More than a hundred years earlier, a German chemist, Martin Klaproth, had investigated a dark, heavy mineral found in the ***tailings*** of a mine in Bohemia. The mineral was called *pitchblende* because it had the shiny dark color of tar (pitch). By chemical analysis, Klaproth extracted from pitchblende a yellow powder, which tests indicated to be an oxide of a new metal. He named it uranium after the planet Uranus. In 1898, Marie and Pierre Curie refined from uranium ore a new radioactive element, polonium, that Marie named after her native country of Poland.



Martin Klaproth

Normally, chemists could use the spectroscope to detect a new element. Once heated to *incandescence*, the point at which light is emitted, each element has a distinctive pattern of bright lines that reveals a specific element's presence. The distinctive light patterns are like fingerprints on humans. Each element has a specific design that is unique, absolute and constant since the Earth was formed. In the case of polonium, present in pitchblende in extremely small amounts, its lines are obscured by those of more abundant elements in the compound. Polonium was found not by its spectrum but by its radioactivity.

Most of the lighter elements have at least one ***stable*** isotope. A stable isotope is one that is not radioactive. Polonium has several isotopes, and all of them are radioactive. The most common is polonium-210 with a half-life of 138 days. In the Periodic Table of the Elements, the isotope with the longest half-life is the one that is shown in the brackets. Polonium (Po) atomic number 84 has its atomic weight shown in brackets as [210]. The brackets show that polonium is radioactive, and the 210 is the atomic mass of its most stable isotope.

Even the presence of uranium and polonium could not account for all of the radioactivity that the Curies detected in pitchblende. For four years, Marie Curie and her husband worked in a primitive unheated shed to separate the new element from tons of ore. By 1902, they had one tenth of a gram, a sample about the size of a pinhead. It was enough to weigh and analyze, and they named it ***radium***. Because it was so radioactive, the tiny sample sent out a blue glow. Marie Curie kept the vial of radium by her bed for the ghostly glow it gave at night.

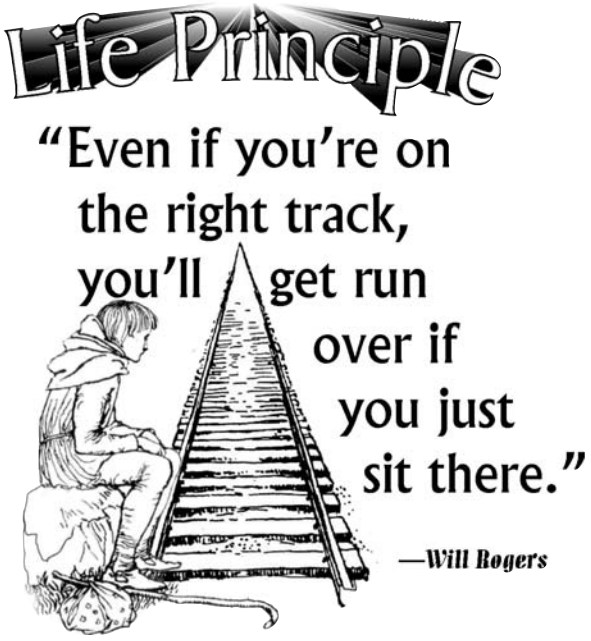


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That habit may have led to an early death, as you will learn later.

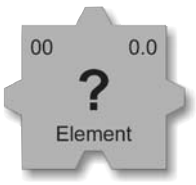
Radium (Ra, atomic number 88, atomic mass 226) is formed by the radioactive disintegration of uranium. Radium is found in all uranium ores but in very minute concentrations. There is one radium atom for every three million uranium atoms. Most radium is recovered during the refining of uranium. The element is used and transported as radium salt, either radium chloride or radium bromide. Radium has a valence of +2 while chlorine has a valence of –1. To form the compound $RaCl_2$, two chlorine atoms are required for each radium atom. Because bromine (Br) is from the same family as chlorine, the formula for radium bromide is similar, $RaBr_2$.

Marie Curie invented the term *radioactivity* for the rays emitted by uranium, polonium and radium. Pierre Curie calculated the energy given off by radium. He stated the energy in ***calories***. A calorie is the amount of heat required to raise one gram of water by one degree Celsius. One gram of radium gave off 100 calories of heat energy every hour. Normally, a fuel is burned to produce heat. To raise the temperature of a glass of water at room temperature to its boiling point requires about 1.5 grams of gasoline to be burned. Burning the gasoline is a chemical change, and after it is burned no more energy can be gotten from it. In 181 hours, an ounce of radium has released enough energy to heat a glass of water from room temperature to its boiling point. Radium continues to release heat energy hour after hour, day after day, for many years. The decline in the energy it releases is very slow. A total of 1,620 years must pass before radium loses half of its radioactive energy. Scientists wanted to know what was the source of the energy in radioactive elements. The next lesson explains the source.



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Integrated Physics & Chemistry



Lesson 6
Elements

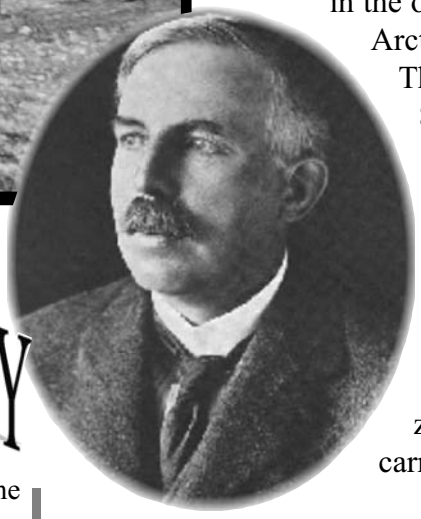
Chapter 10

SUBATOMIC PARTICLES

Section 2

Lessons 6-10





The words "We didn't know it couldn't be done" are displayed on a monument honoring the men and women who constructed the trans-Alaska pipeline. Built during the 1970s, it was one of the great scientific and engineering feats of all time. The pipeline originates in the oil fields at Prudhoe Bay on the Arctic Ocean on Alaska's northern coast. The pipeline carries crude petroleum 800 miles to the ice free port of Valdez, Alaska, on Prince William Sound on Alaska's southern coast. For about half of that distance, the pipeline is built above ground to prevent heat from the pipe melting the permanently frozen ground. The pipeline, 48 inches in diameter, zigzags up hills and across valleys and carries two million barrels of oil a day.

One concern was that the pipeline might cause damage to the delicate ecosystem of Alaska. The steel pipe was welded together in sections, and each weld had to be tested to make certain it was perfect. X–rays can be used to test some materials. Wood, plastic and some light metals can be examined by X–rays. However, the steel pipe of the Alaska pipeline required stronger rays than common X-rays. The solution was to use ***gamma rays***, one of the rays given off by radioactive elements such as radium. A strip of film in a lightweight aluminum foil was placed against the weld to be tested. A source of gamma rays from a radioactive element in a lead container was positioned on the other side of the pipe. The gamma rays shot through the pipe and exposed the film to leave an image of the weld. Several photographs were taken all around the pipe to cover the weld

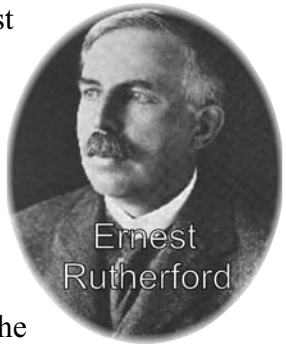
VOCABULARY

Gamma rays: have a speed the same as that of light, emitted from the nucleus of an atom during radioactive decay; is a high frequency, short wavelength, high energy, very penetrating electromagnetic wave

Alpha particle: a particle with a mass of a helium nucleus, a charge of +2 and a speed of about 20,000 miles per second that is emitted from the nucleus of an atom during radioactive decay; technically a helium nucleus

completely. After development, the film showed whether defects existed where the pipes joined together.

Use of gamma rays on the Alaskan pipeline was possible because of the scientific work of Ernest Rutherford. Gamma rays are one of the three types of radiation given off by radioactive material.

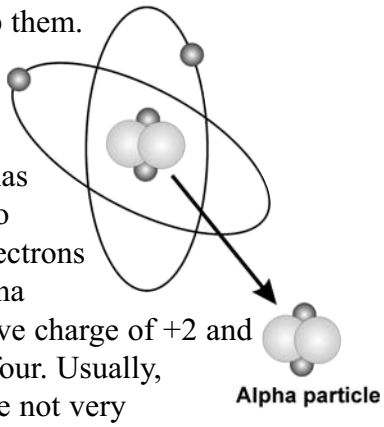


The British physicist, Ernest Rutherford, examined the properties of radioactive rays. Although a large, clumsy looking person, Ernest Rutherford had exceptional skill at constructing delicate experimental apparatus in the laboratory and was a great experimental physicist. In 1898, shortly after the discovery of radioactivity, Rutherford decided to investigate radiation to learn its nature.

Particles that carry an electric charge will bend when sent through a magnetic field. Rutherford tested the radiation given off by a sample of radium that had been given to him by Marie Curie. He put the radium in a lead container with a small hole. The radioactive particles from radium escaped through the hole and then traveled in a straight line to strike a screen coated with zinc sulfide. The radiation produced a single glowing dot on the screen. Next, Rutherford sent the rays to the screen through a strong magnetic field. This time, the radiation no longer struck the screen as a single dot. Instead, the radiation separated into three streams that struck the screen in three different places. One stream was strongly curved, and one stream was slightly curved but in the opposite direction. The third stream went straight on through the magnetic field without being affected in any way. An electric field also split the radiation into three different streams, and from the direction the particles turned, he could figure out whether they carried a positive or negative charge.

In 1898, Rutherford showed that radioactive elements gave off three types of discharges, which he named alpha, beta and gamma. He proved that alpha particles had the same mass as helium atoms, a charge of +2, and a speed in the neighborhood of 20,000 miles per second. Beta particles were identical to electrons traveling at nearly the speed of light. Gamma radiation was made of electromagnetic rays even more energetic and penetrating than X-rays. Rutherford tested the penetrating power of the gamma rays by putting various targets in the paths of the rays. A thin sheet of aluminum stopped alpha particles. Almost a full centimeter of aluminum was needed to stop beta particles. Gamma rays were the most penetrating of all. They easily passed through aluminum, and several centimeters of lead were needed to stop them.

An ***alpha particle*** can be thought of as a helium nucleus. It has two protons and two neutrons, but the electrons are missing. An alpha particle has a positive charge of +2 and an atomic mass of four. Usually, charged particles are not very



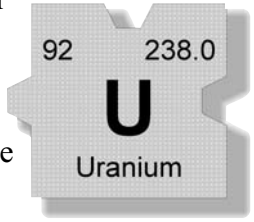
VOCABULARY

Beta particle: an electron with a speed near the speed of light, emitted from the nucleus of an atom during radioactive decay

Half-life: the time required for half of the atoms in a radioactive substance to undergo radioactive decay, after one half-life a substance will have one-half of its original radioactivity

penetrating. The charge causes them to be attracted to other particles, and the interaction saps some of their energy. A few centimeters of air, a thin piece of aluminum foil or a sheet of paper stops alpha particles.

Rutherford wanted to know the source of the alpha particles. He learned that they come from within the nuclei of unstable, radioactive atoms. During radioactive decay, the nucleus of an atom is disrupted, and it shoots out radioactive particles. By emitting alpha particles, an unstable nucleus is transmuted into a different element. Because the alpha particle carries away two protons and two neutrons, both the atomic number and atomic weight of the radioactive atom are changed. For instance, uranium has an atomic number of 92 (the number of its protons) and an atomic weight of 238 (the number of its protons and neutrons). When a uranium atom emits an alpha particle, the atomic number goes down by two because the alpha particle carries away two protons. The atomic mass goes down by four because the alpha particle carries away that amount of mass.

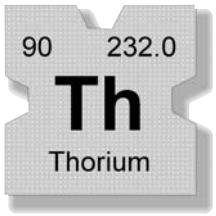


After the loss of the alpha particle, the atom is no longer uranium. Instead, it is thorium (element 90) with a mass of 234 or in symbols: $_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$. Notice that the number of protons is the same on both side of the reaction: 92 = 90 + 2 and the total mass is the same: 238 = 234 + 4.

When physicists first isolated uranium, they found that it became contaminated with other elements such as radium. At first, they had no explanation because the uranium was kept in a closed container. Above the sample, the air became filled with helium. Rutherford's experiments explained what was happening. The uranium emitted an alpha particle and changed into radium. Each alpha particle captured two electrons and became helium gas.

Beta particles are high-speed electrons. The speed of beta particles is near the speed of light. Beta particles have half of the charge of an alpha particle and travel nearly nine times as fast. For that reason, they are about 100 times more penetrating than alpha particles. A thin sheet of aluminum will stop alpha particles, but a plate of aluminum one centimeter thick is needed to stop beta particles.

Beta particles come from the nucleus of the atom, not from the cloud of electrons that surround the nucleus. During some forms of radioactive decay, a neutron emits an electron as a beta particle. In doing so, the neutron changes to a proton. The nucleus in which this occurs is transformed into one with essentially the same mass because the mass of an electron is very slight. However, by changing a neutron to a proton, the atomic number increases by one. For example, thorium produced by the decay of uranium is unstable. Thorium releases a beta particle, and the atomic number is increased by one. Thorium (element number 90) changes into protactinium (Pa, element number 91).



Rutherford found that the path of gamma rays was not changed by electric or magnetic fields. He concluded that they carried no charge. Protons, electrons, beta and alpha particles all carry a charge and all have their paths curved when they enter electric or magnetic fields. Gamma rays stayed on their straight-line path. Further tests showed that gamma rays are not particles. Instead, they are electromagnetic waves similar to light and X-rays but with much higher energy, shorter wavelengths and more penetrating power. Gamma waves can

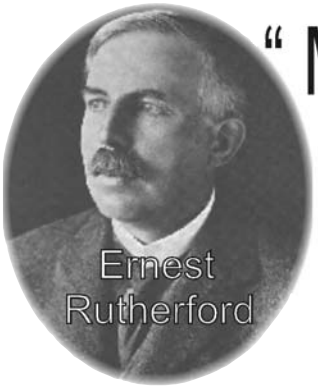
pass through several feet of concrete and right through the human body.

Like alpha and beta particles, gamma waves are emitted from the nucleus of an atom. A gamma wave is not a particle, so it has no charge and no mass. When an atom emits a gamma wave, the atomic number and atomic weight are unchanged. Gamma rays do carry away energy. Generally, when gamma waves are released, they carry away excess energy that results in the nucleus becoming more stable.

Although chemists believed atoms were indestructible and unchangeable, Rutherford showed that radioactive elements tore themselves apart and changed into atoms of an entirely different element. Radioactivity is caused by atoms whose nuclei come apart. They give off alpha, beta and gamma rays. Radioactivity can change one element into another. When an atom comes apart, it is said to *disintegrate*.

Although no one could predict when a uranium atom would break down, a large sample disintegrated at a very predictable rate. Rutherford invented the term ***half-life***, the time for one half of the sample to be gone, to measure the rate of radioactive decay. For example, the rate at which radium produces energy becomes less with time, but the decrease is very slow. For radium, 1,620 years must pass before the energy a sample of radium releases is reduced by half. Thus, the half-life of radium is 1,620 years.

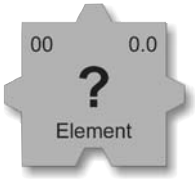
Life Principle



"Most people talk themselves into success or failure."

—Ronald Johnson

Integrated Physics & Chemistry



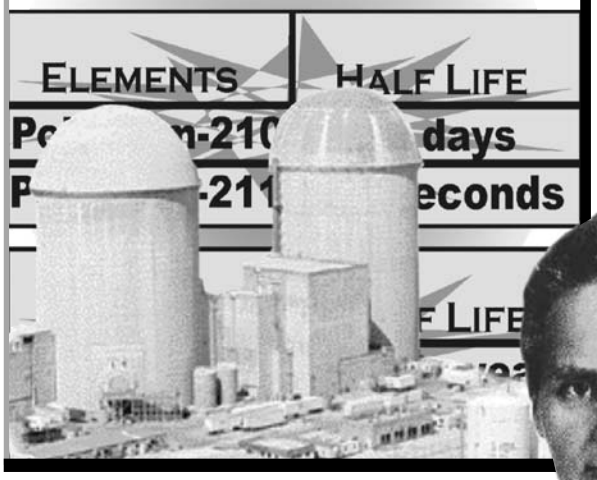
Lesson 7
Elements

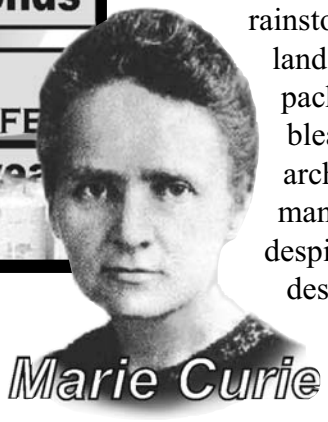
Chapter 10

HALF-LIFE AND RADIATION SICKNESS

Section 2

Lessons 6-10





The scene is the Sonoran Desert in southwestern Arizona. A female ***archaeologist*** stands on a bluff overlooking a broad desert valley. The abrasion of wind blown sand and the erosion of brief but violent rainstorms has shaped the stark landscape. The soil is red and hard packed. Where other people see a bleak and desolate place, the archaeologist sees the life that has managed to survive and even thrive despite the harsh conditions. Hardy desert plants grow in the rocky soil. Saguaro and prickly pear cacti are equipped with thorns to ward off animals that might seek moisture stored in the plants' stems and trunks. The hardy creosote bushes grow in isolation. Their roots produce a chemical that prevents other plants from growing nearby. Through her binoculars, the archaeologist sees a faint trail left by a rabbit that had foraged for food under a mesquite bush at night.

She also sees evidence of human activity. Her practiced eye can trace out evidence of an ancient dry streambed. At one time, the climate was slightly wetter than it is now. Water from rain gathered in natural tanks below the cliff. Game came to the pool for a drink. Predators, including humans, came in search of a meal. This valley had periodic human visitors. She can see where they had set up camp. Hundreds of years ago, a small group of hunters had camped in the valley. The hunters probably stayed no more than three or four days and moved on. Yet, the faint dark smudge of the charcoal from their campfire is still visible. It had survived wind, rain and the heaving of heat and cold for many decades.

VOCABULARY

Archaeologist: a scientist who studies past human life and cultures by the evidence that they leave behind such as tools and pottery

Carbon-14 dating: the determination of the approximate age of ancient organic material such as bone or charcoal by the amount of radioactive carbon-14 it contains

Cosmic ray: a high speed charged particle from outer space; most cosmic rays are made of protons

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Modern science enables archaeologists to estimate how long ago the campfire was used to cook food, and how long ago a small group of people stood around the fire to warm themselves at night. The archaeologist can estimate the age of the charcoal by ***carbon-14 dating***. In 1947, Frank Libby, an American chemist working at the University of Chicago, developed the method of calculating the age of organic material by carbon-14. Natural radiation from outer space such as ***cosmic rays*** strikes Earth's atmosphere and collides with nitrogen. The nuclear reaction caused by that collision changes nitrogen into carbon-14, a radioactive isotope with a half-life of 5,760 years. Regular carbon is carbon-12. The chemical action of photosynthesis cannot tell the difference between carbon-14 and carbon-12, so as a tree grows, the carbon-14 becomes part of the tree.

To check age, all that is needed is organic material such as a piece of wood, cloth or bone. After a tree dies, no more carbon-14 is added to the wood, and the radioactive carbon-14 in the wood's cells fades away as the atoms breakdown. By taking a bit of charcoal from the ancient campfire, the archaeologist can submit it for carbon-14 testing to learn about how long ago the tree died. The carbon is extracted from the sample and its radioactivity tested. In an older sample, the carbon-14 is less abundant because some of it has undergone radioactive decay. The radioactivity is less than in a more recent sample. Because it can have errors, radioactive carbon-14 dating is usually teamed with other methods of dating. For a campfire that is 1,000 years old, the carbon-14 method may miss the exact date by as much as 30 years. Should the specimen be contaminated with ground water or radiation fallout from nuclear weapon tests, the errors are even greater.

Carbon-14 has a *half-life* of 5,760 years. The half-life of a radioactive element is the time required for half of the atoms in any given sample to disintegrate. In 5,760 years, half of carbon-14 atoms in a sample will decay. Radioactive decay is a ***statistical*** process. A physicist cannot predict when a particular atom will breakdown or how long it will remain intact, but he can make predictions concerning a large number of atoms. A radioactive sample contains billions of atoms. From the half-life, a physicist can predict how many atoms will breakdown during a particular period. As an atom disintegrates, its nucleus may emit particles smaller than itself such as alpha or beta particles. Or, the nucleus may split into two pieces of more or less equal size or split apart emitting alpha and beta particles, changing the atom's atomic weight and atomic number.

The half-life for one radioactive element may be a fraction of a second while for another it may be hundreds of years. Not only does half-life vary by element; it also varies by each isotope of the element. For instance, the half-life of polonium-210 is 138

VOCABULARY

Statistical: applying mathematical and numerical methods to a large sample in order to derive laws that apply to the group as a whole but not to individual items in the sample

Curie: a measure of radioactivity equal to $3.7 * 10^{10}$ disintegration per second

Microcurie: a measure of radioactivity equal to $3.7 * 10^{4}$ disintegrations per second, or one-millionth of a curie

Anemic: suffering from anemia—a condition in which the blood cannot carry sufficient oxygen, usually caused by damaged or too few red blood cells—resulting in paleness and physical weakness

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Elements	Half-Life
Polonium-210	138 days
Polonium-211	0.5 seconds

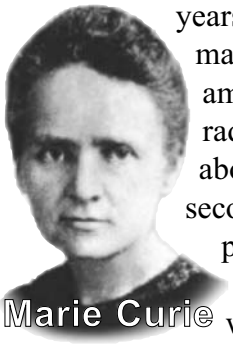
Elements	Half-Life
Uranium-238	Million years
Uranium-227	One minute

days while the half-life of polonium-211 is 0.5 seconds. Uranium-238 has a half-life in the millions of years while uranium-227 has a half-life of about one minute. The shorter the half-life, the more radioactive the element. Polonium-211 with a half-life of 0.5 seconds is far more radioactive than polonium-210 with a half-life of 138 days.

Radium-226 has a half-life of about 1,620 years. A one-gram sample of radium today would contain ½ of a gram of radium in 1,620 years. In another 1,620 years, half of the remaining sample will undergo radioactive decay. Only ¼ gram of the original amount will remain after 3,240 years. Half-life is independent of the size of the sample. Whether one starts with 1.0 gram or 1.0 kilogram, at the end of the half-life only ½ of the original sample remains. After 1,620 years, a 1.0 gram sample of radium-226 becomes a 0.5 gram sample, and a 1.0 kilogram sample becomes a 0.5 kilogram sample.

Scientists tried in vain to slow or speed up the rate of radioactive decay. They found that the half-life of an isotope was independent of physical factors and chemical changes. Uranium kept its radioactivity whether it was a solid, liquid or gas. A sample of uranium had the same half-life regardless of its physical state. Physical treatment such as pressure or hammering the element did not disrupt the radioactive decay. Combining it with other elements such as oxygen or sulfur caused no change. Chemists concluded that the radioactivity of uranium was not affected by physical or chemical changes. What was true of uranium was true of other radioactive elements, too.

The radioactivity of an element is measured in ***curies***, named in honor of Marie Curie. A radioactive sample that has $3.7 * 10^{10}$ atoms that disintegrate every second has a radioactivity of one curie. The americium in smoke detectors has a half-life of 462 years. When the smoke detector is manufactured, a sample of americium is installed with a radiation level of one ***microcurie***, about $3.7 * 10^{4}$ disintegrations per second, or 37,000 disintegrations per second. In 462 years about half of the americium atoms will disintegrate. This reduces the radioactivity of americium to one half of its previous level, or 18,500 disintegrations per second, that is ½ of a microcurie.


Marie Curie

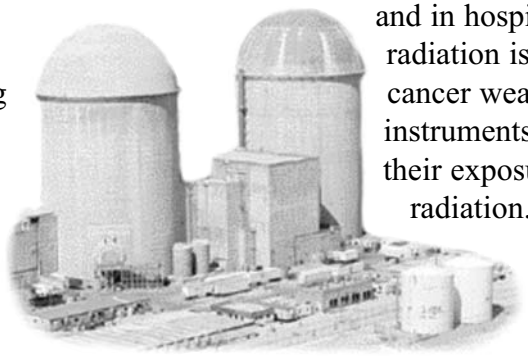
Radioactive substances are dangerous. Alpha and beta particles cannot travel far in living tissue. Their effect is to produce a burn on the skin that is slow to heal. Gamma rays are much more penetrating. Gamma rays damage living cells deep in the body by producing charged ionic particles within human flesh. These ions attach themselves to nearby molecules and cause chemical change. The newly created substances are foreign to the cell and cause *radiation poisoning*.

At low dosage of radioactivity, the cells may be only temporarily damaged and succeed in repairing themselves. If a person survives radioactivity exposure, long term effects such as cancer or hereditary effects may appear in the next generation. If the dosage is high, damage may be irreparable and severe enough to interfere with the function of body cells. The cells may die either immediately or after several divisions. High dosages can damage the body so

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severely as to cause death within a few hours. Radiation is also cumulative, which means it can build up over time in the body until disease or organ malfunction results.

Symptoms of radiation poisoning include nausea, vomiting, internal bleeding and lack of muscle control. Hair falls out and the person becomes ***anemic***. The body's immune system is less capable of fighting off infection. Long term effects include cancer such as leukemia and heredity changes that appear in the next generation. Patients exposed to radiation are often kept in isolation rooms to avoid being exposed to diseases against which the weak patient has little defense. During the weeks following exposure of large doses of radiation, patients are given blood transfusions, antibiotics and bone marrow transplants. The purpose of the bone marrow transplants is to generate new white blood cells that fight infection. Some nutritional experts recommend that people exposed to X-rays take kelp, which has been determined to reduce cell damage caused by radiation, as demonstrated in Japanese hospitals with World War II atom bomb victims.



People who work at nuclear power plants, research laboratories and in hospitals where radiation is used to treat cancer wear *dosimeters*, instruments that measure their exposure to radiation. Photographic film is sensitive to radiation. Film badges were one of the first devices used to measure radiation. The film dosimeter contained a small piece of photographic film. Radiation exposed the film as if it had been exposed to light. Upon development, the amount of darkening revealed the amount of radiation to which the worker has been exposed. Today, more sensitive devices are used. For instance, one dosimeter is about the size of a writing pen with a tube containing a gas that has been put under pressure to change it into a liquid. Radiation passing through the liquid causes bubbles to form. The number of bubbles shows the amount of radiation exposure.

Life Principle



"Too many people spend money they haven't earned to buy things they don't want to impress people they don't like."

—Will Rogers

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Integrated Physics & Chemistry

Lesson 8
Energy

Chapter 10

ARTIFICIAL RADIOACTIVITY

Section 2

Lessons 6-10





Henri Becquerel

The first people to experiment with radiation were not completely aware of its dangers. Both Henri Becquerel and Pierre Curie carried radioactive materials with them and received radiation burns because of their lack of knowledge and caution. In 1903, Henri Becquerel and the Curies shared the Nobel Prize in physics for their studies of radioactivity. Neither Pierre nor Marie could attend the ceremony in Stockholm because they suffered from ***undiagnosed*** radiation poisoning. The Curies' notebooks are still radioactive and cannot be handled without precautions.

The radiation gave Pierre muscle spasms. Although he did not know the reason, the radiation poisoning affected his nerves. Sometimes his hands shook, and he was unsteady when he walked. In 1906, Pierre crossed a street during a rainstorm. He fell under a horse drawn carriage and died of his injuries. Marie raised their two daughters, Irène born in 1897 and Éve born in 1902, and oversaw their education.

School officials offered Pierre's teaching position at the Sorbonne to Marie. This old and famous school had not had a woman teacher in its 650-year history. Marie became the first woman professor there. She used her husband's lecture notes and simply continued from where he had been lecturing at the time of his death.

Marie became the first person to win two Nobel Prizes. In 1911, she received the Nobel Prize in chemistry for her discovery of polonium and radium. She stayed in France during World War I to build portable X-ray machines for field hospitals and ambulances. She drove the ambulances to the battlefields. A laboratory, the Radium Institute, had been built for her in 1914, but she did not occupy it until after the war.



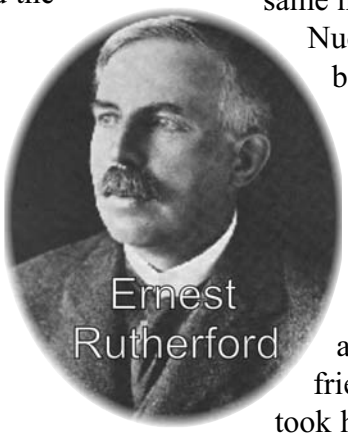
VOCABULARY

Undiagnosed: a medical condition that is not noticed or its nature not identified
Leukemia: cancer of the bone marrow where the body's blood supply is produced, commonly known as cancer of the blood
Radioactive tracers: radioactive substances that are introduced into the body and their motion traced by their radioactivity to reveal the condition and functioning of organs in the body
Assumed name: a false name adopted to protect a person from being recognized

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Marie Curie died in 1934 of ***leukemia*** caused by exposure to radiation. Shortly before she died, her younger daughter Ève wrote a best selling biography of her mother. Éve married a former United States Ambassador, who became the head of the United Nations' Children's Fund. She traveled with him to more than 100 underdeveloped countries. The organization that Ève and her husband guided received the 1965 Nobel Peace Prize.

Following Marie and Pierre's discovery of the radioactive elements of polonium and radium, the next major advance came in England at the University of Manchester in the laboratory of Ernest Rutherford. He had visited Marie Curie and received from her samples of radium that he took back to England. He used the radium as a source of alpha particles for his experiments. Rutherford had received the 1908 Nobel Prize in chemistry for his studies of alpha, beta and gamma rays given off by radioactive elements. The British government honored him by knighting him in 1914. He became *Sir* Ernest Rutherford.

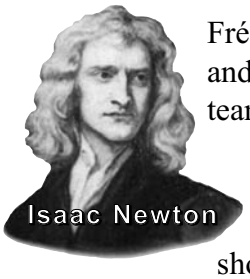


Uranium, radium, polonium and the other radioactive elements were naturally radioactive. Rutherford wondered if he could cause a nuclear reaction in elements that were not normally radioactive. For his test, he used alpha particles to bombard nitrogen atoms. Alpha particles are high-speed helium nuclei. Each one has two protons for an atomic number of two, which with the two neutrons give an atomic mass of four. The contents of an alpha particle can be shown by the symbol ${}_2He^4$. Nitrogen has seven protons, its atomic number, and seven neutrons for an atomic mass of 14, and can be shown as ${}_7N^{14}$. The alpha particles struck the nitrogen atoms and caused a nuclear reaction. The alpha particle embedded itself in the nitrogen nucleus and knocked free a proton. The symbol for a proton is ${}_1p^1$. It has one proton and no neutrons, so its atomic number and atomic mass are both one.

The reaction of a nitrogen nucleus with an alpha particle produced an isotope of oxygen (${}_8O^{17}$). The symbol, ${}_8O^{17}$, shows that oxygen has an atomic number of 8 (8 protons) and an atomic mass of 17 (8 protons and 9 neutrons). The equation for the reaction is ${}_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17} + {}_1p^1$. On the left of the equation are 9 protons (2 + 7) and the same number of protons is on the right (8 + 1). On the left of the equation the total of protons plus neutrons is 18 (4 + 14 = 18) and the same number is on the right (17 + 1 = 18). Nuclear physicists check their work by balancing each equation. If the numbers do not balance the scientists know that they failed to detect some other particle which had been created.

Rutherford was the first person to change one element into another artificially. Rutherford was a friendly, outgoing person. Although he took his work seriously, he did not think more highly of himself than he ought. While newspapers described him as the first person to "smash atoms," Ernest Rutherford described his efforts as "playing with marbles." In 1919, Rutherford became head of the Cavendish Laboratory at Cambridge where he remained the rest of his life. From 1925 to 1930 he served as the president of the Royal Society. During the 1930s, when Germany was taken over by the Nazi party under Hitler, Rutherford helped scientists escape from that country. After his death in 1937, Ernest Rutherford was buried in Westminster Abby in London, England, not far from the

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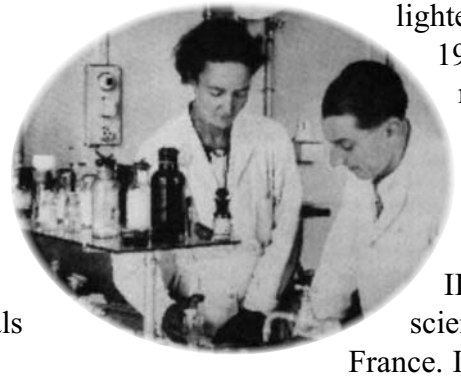
burial site of the great Isaac Newton. Like Newton, Ernest Rutherford is often ranked as one of the ten greatest scientists of all time. In 1997, the International Union of Pure and Applied Chemistry announced that the chemical element with the atomic number 104 would officially be given the name rutherfordium (Rf) in Rutherford's honor.

The naturally occurring radioactive elements such as polonium, thorium, radium and uranium are heavy elements. The lightest one is polonium with an atomic number of 84 and atomic mass of 210. Physicists realized that for medical and biological research, lighter weight radioactive elements would be helpful. Most of the elements found in the human body and in the bodies of plants and animals are lightweight elements such as carbon, hydrogen, oxygen, nitrogen and phosphorus. The heaviest of those elements is phosphorus with an atomic number of 15 and an atomic mass of 31. If radioactive versions of the atoms found in living organisms could be made, then they could be used as ***radioactive tracers*** to show what was taking place in the body. A tracer is an element whose motion through an organism can be followed because of its radioactivity. This reveals information about whether or not an organ is functioning properly. For instance, the accumulation of radioactive iodine reveals the condition of the thyroid gland.

Marie Curie's daughter, Irène, and her husband, Frédéric, were the first to create artificial radioactivity in lighter elements. Irène had attended the Sorbonne where her mother taught. During World War I, Irène served as nurse and operated X–ray equipment. After the war, she continued her education and worked with her mother at the Radium Institute in Paris. There she met Frédéric Joliot, and they were married. Irène and Frédéric worked together as a scientific team.

In 1934, the Joliots bombarded aluminum with alpha particles. Radioactive particles were given off, showing that the alpha particles had changed the aluminum in some way. They found that the aluminum had been changed into phosphorus. Naturally occurring phosphorus has 15 protons and 16 neutrons, known as phosphorus-31. When the husband and wife team tested the product of their nuclear reaction they were surprised to find that they had changed aluminum into a phosphorus atom with 15 protons and 15 neutrons, or phosphorus-30, a new isotope of phosphorus never before seen in nature. When the source of alpha particles was removed, the radiation continued. Not only was phosphorus-30 a new isotope, it was a radioactive isotope—the first one produced from a stable element.

Irène and Frédéric received the Nobel Prize for chemistry in 1935 for generating radioactive isotopes from lighter elements. By 1937, Irène gave up much of her work to take care of her family, daughter, Hélène, and son, Pierre. World War II (1939-45) ended scientific research in France. Irène and her husband managed to smuggle out the largest amount of heavy water then available. Heavy water contained hydrogen atoms with extra neutrons that were important for atomic research. Irène took her children to Switzerland in 1944, although Frédéric lived in Paris under an ***assumed name***. Like her mother, Irène died of leukemia caused by exposure to radiation.



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Scientists succeeded in making radioactive isotopes from most of the lighter elements. The bullet used to crash into the nuclei of each element was the alpha particle. The alpha particle, approaching the nucleus of an atom, was repelled by the strong positive charge. The alpha particle had a positive +2 charge and the nucleus of phosphorus had a +15 charge. Because of its speed, the alpha particle could force its way into the phosphorus nucleus. Usually, the nucleus absorbs the alpha particles and emits a proton. However, as the charge on the nucleus increases (for a heavier atom), its repulsion of the alpha particle grows stronger. Elements above phosphorus on the periodic table exert repulsion so great that the alpha particle never hits the nucleus. The particle is deflected to one side or bounced back. The source of the alpha particle was a radioactive element that required a faster and more penetrating bullet. You will learn more details in a later lesson.

Life Principle



" Human felicity [happiness] is produced not so much by great pieces of good fortune that seldom happen, as by little advantages that occur every day."

—Benjamin Franklin

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Integrated Physics & Chemistry

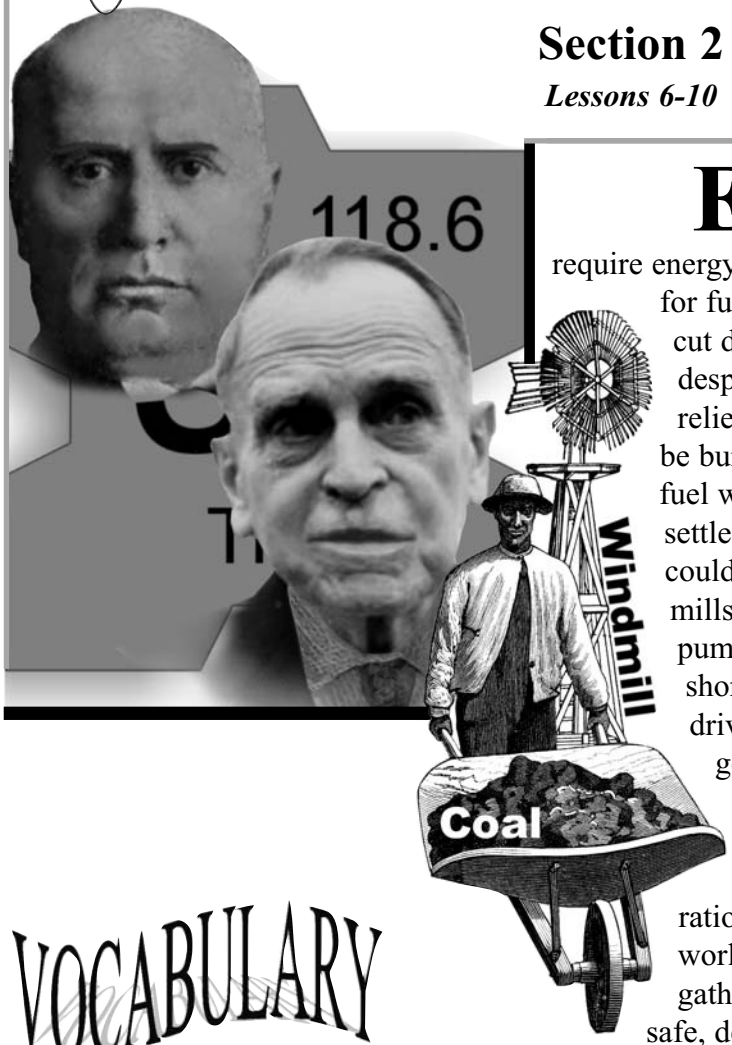
Lesson 9
Energy

Chapter 10

FISSION

Section 2

Lessons 6-10



Energy is a necessity for an industrial civilization. Even rural economies require energy. During the 1200s in England, the need for fuel had resulted in most of the trees being cut down for firewood. People became desperate for fuel. Their dire situation was relieved with the discovery that coal could be burned as fuel. People built towns where fuel was available. As the United States was settled, towns grew up along streams that could be dammed to supply waterpower to mills. In the west, windmills were used to pump water. During the 1970s, gasoline shortages caused problems for automobile drivers. Fuel prices increased, and the government lowered the interstate speed limit to 55 miles per hour (mph) so cars would be more fuel-efficient. Some cities implemented fuel rationing. Today, in some poorer parts of the world, children spend several hours each day gathering firewood for preparing food. A safe, dependable and nonpolluting source of energy would produce major changes in the world today. Energy is as important as the other necessities of life.

During the 1900s, an entirely new source of energy was discovered—***nuclear energy***. By the mid-1930s, scientists had learned many facts about the composition of atomic nuclei and about nuclear energy. They learned that the Sun is fueled by a nuclear reaction that changes hydrogen into helium. On Earth, however, the energy of the nuclear reactions had not been harnessed. No one knew how to get useful energy from an atom. When an alpha particle or a proton struck a nucleus, it often came apart and released energy. However, the amount of energy was less than the energy that scientists used in the

VOCABULARY

Nuclear energy: energy from the nucleus of an atom
Fascist: one who believes in a system of government controlled by a dictator who suppresses opposition, and advocates extreme nationalism and intolerance for ethnic groups; Italy was under a Fascist government (fascism) with Benito Mussolini as dictator from 1922 -1943

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electric and magnetic fields that guided the protons and alpha particles to their targets—much like a motor that required more energy to start than was produced once the motor began running.

Nuclear scientists looked for other particles to cause nuclear reactions. Both alpha particles and protons have positive electric charges. Atomic nuclei have positive electric charges. Because the alpha particle has a positive charge, it is repelled by the nucleus. The same is true of a proton. As atomic bullets, alpha particles and protons require great speed to blast their way into the nucleus of an atom. However, alpha particles are emitted by radioactive substances at certain speeds that are too slow to strike into the nucleus of heavier atoms. Particles beyond phosphorus, element number 15, on the element chart were ineffective as "bullets" fired at the nucleus of an atom.

Scientists wanted to discover an effective bullet. They considered the neutron. It was discovered to have about the same mass as a proton but with no charge, so it could shoot deep into the atom without experiencing a force of electrical repulsion pushing it away.

VOCABULARY

Nazi: one who believes in a system of government of extreme nationalism, intolerance for ethnic groups, national expansion and strict government control of the economy; Germany was under Nazism while dictator Adolf Hitler was in power from 1933 to 1945

Ethnic: a minority people who share a common language, religion, national origin or cultural heritage within a larger society

Fission: splitting the nucleus of an atom, which releases large amounts of energy



Enrico Fermi

Enrico Fermi was a brilliant student who graduated from the University of Pisa in Italy with a Ph.D. in physics at the age of 21. In 1934, he shot the neutrons from radioactive beryllium into various elements. Because the neutron had no charge, it penetrated deep into the atom. Most researchers assumed that faster neutrons would have a greater effect than slow ones. Fermi found the reverse true. By sending the neutrons through paraffin, Fermi slowed down the neutrons to the speed of molecules at room temperature. Such slow neutrons are called *thermal neutrons*. Their heat causes them to have the same speed as the motion of molecules. *Thermal* means *related to heat*. Fermi showed that bombardment with thermal neutrons caused changes in almost every element. The next quest was to learn why slow neutrons were better than fast ones. Because of their neutral charge, the fast ones passed by the nucleus so quickly they were unlikely to be captured. However, slower neutrons are more likely to be attracted by nuclear forces and combined with the nucleus.

Neutrons could cause changes in atoms that were heavier than phosphorus. Indium (In, atomic number 49, atomic weight 115) is about halfway in weight between hydrogen (atomic weight 1) and uranium (atomic weight 238). A slow neutron that struck the indium nucleus changed it into an isotope of tin (Sn) with an atomic number of 50. This was surprising. By gaining a neutron, the indium's proton count went up by one, and became tin. A beta particle (electron) was emitted which changed the neutron into a proton. Fermi found that other elements increased their proton counts by one



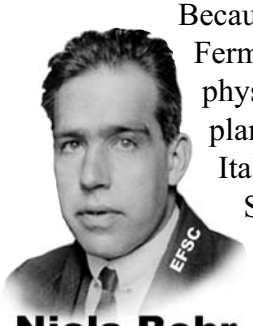
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when struck by a neutron. The neutron became a part of the nucleus, the nucleus released a beta particle (with a –1 electric charge), and one of the neutrons in the nucleus became a proton (with a +1 electric charge).

The naturally occurring element with the highest atomic number was uranium with 92 protons. No elements with a mass greater than uranium were known. Because such an element (if it existed) would be beyond uranium in the periodic chart, such an element would be a transuranium element. Fermi wondered what would happen if he sent neutrons into uranium nuclei. He speculated that the proton count would increase by one and produce an entirely new element, element 93, beyond uranium in the periodic table. He tested the idea. Something happened, but the results were puzzling. Fermi's friends believed that he had made a new element beyond uranium. Although the uranium atom had become unstable and changed in some way, Fermi was not certain about what had happened. He believed that slow neutrons could cause only slight changes to the nucleus.

Fermi's work was interrupted by political changes in Italy. The ***Fascist*** government had come into power in Italy in 1922. During the 1930s, Benito Mussolini implemented many repressive practices similar to those of the ***Nazi*** government of Hitler in Germany. For instance, only people of certain ***ethnic*** backgrounds could own property. Jews were restricted in the places they could work. Fermi was opposed to fascism, and his wife was Jewish. In 1938, Fermi won the Nobel Prize in physics for his discovery of nuclear reactions caused by slow neutrons. He was given permission by the Fascist government to travel to Sweden to receive the award.


Benito Mussolini



Niels Bohr

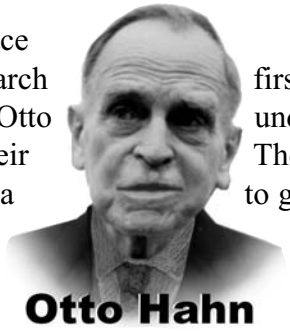
Because of advance notice given to Fermi about the award by Danish physicist Niels Bohr, Fermi planned secretly to escape from Italy. Fermi took his family to Stockholm to accept the prize. After the ceremony, he did not return to Italy but instead traveled to New York. He joined the staff of Columbia University in New York City.

During this time, Lise Meitner and Otto Hahn investigated the element produced by Fermi's slow neutron action on uranium. Lise Meitner came from a Jewish background in Vienna, Austria. Marie Curie and Florence Nightingale were her heroes. She became one of the first women to receive a Ph.D. in physics at the University of Vienna. She traveled to Berlin and became an assistant of chemist Otto Hahn. Meitner noticed that mercury fumes caused headaches. When she received a promotion as physics professor at the Kaiser Wilhelm Institute, she took steps to ventilate the laboratory, and she insisted that students handle poisonous and radioactive chemicals properly.

In 1934, Lise Meitner and Hahn followed up on the experiments that had been begun by Fermi. Hahn believed that a neutron caused the uranium atom to release a couple of alpha particles. Losing the mass and protons of two alpha particles would change uranium into the radioactive element radium. Although tests showed that a lighter radioactive element was formed, it was not radium. Although living in Berlin, Meitner felt relatively safe because she was an Austrian citizen. However, in 1938, the German army overran Austria. Because of her Jewish background, Meitner was dismissed from her post. At age 59, she escaped from Nazi Germany. Danish

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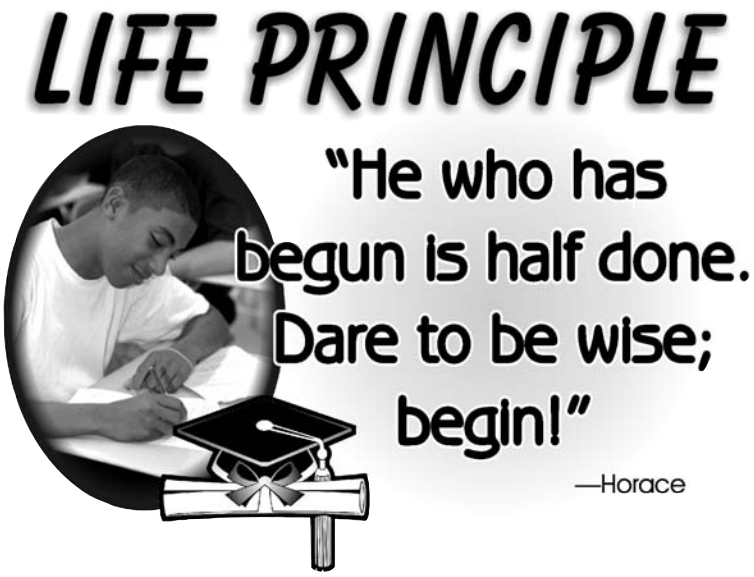
physicist Niels Bohr found a place for Meitner to continue her research in Sweden. Early the next year, Otto Hahn published the results of their work but did not list Meitner as a co-author. Her name had been banned from German publications.


Otto Hahn

Rather than radium, the product from the unstable uranium was the much lighter barium. Barium (Ba, atomic number 56) had an atomic weight of 137, only about half that of uranium. Hahn could not explain how this happened because to make barium, the uranium nucleus would have to emit more than a dozen alpha particles. As Meitner thought about the problem, she realized the uranium nucleus had split into two roughly equal pieces. One part was barium. She calculated that the other part would be krypton (Kr, atomic number 36, and atomic weight 84). Her nephew, Otto Frisch, who worked at Bohr's laboratory in Copenhagen, Denmark, agreed to test her theory. Meitner and Frisch kept in daily communication by telephone and ran up an enormous telephone bill. After a month, however, Frisch showed that his aunt's theory was entirely correct.

In 1939, Lise Meitner became the first physicist to state that uranium could undergo ***fission***. Fission means to split. The unstable uranium atom would fission to give barium, krypton and a great amount of energy. In addition, the uranium atom released two or three additional neutrons. These secondary neutrons could then cause additional atoms to split, which in turn would cause still more to split. A *chain reaction* is one in which the cause of a reaction is also one of the products. Lise Meitner predicted that a fission reaction could become a self-sustaining chain reaction by the neutrons that the reaction released.

Meitner's co-worker, Otto Hahn, was awarded the Nobel Prize for Chemistry in 1944. Meitner, however, was never so honored. Meitner was ahead of her time in implementing rigid laboratory rules for working with radioactive elements and heavy metals such as mercury. She spent the last six years of her life in Cambridge and died just short of her 90th birthday. In 1992, one of the elements beyond uranium was named meitnerium in her honor.



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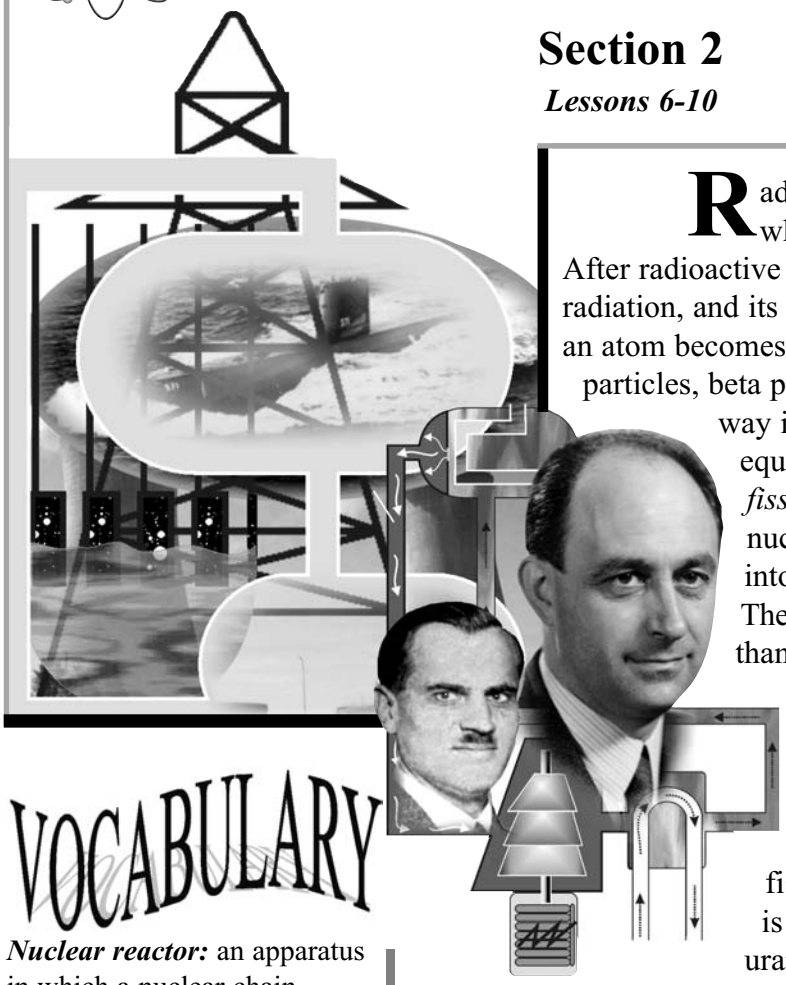
Chapter 10

Lesson 10
Energy

NUCLEAR REACTOR

Section 2

Lessons 6-10



Radioactive decay is a process by which nuclei become more stable. After radioactive decay, an atom is less likely to emit radiation, and its half-life becomes longer. One way an atom becomes more stable is by emitting alpha particles, beta particles or gamma rays. Another way is to split into two pieces of roughly equal size. Dividing in half is called *fission*. During fission, a heavier nucleus, such as uranium, separates into two atoms of about half the weight. The products of fission are more stable than the original uranium atom.

Suppose the total atomic mass of the uranium atom before it splits is compared to the total atomic mass of all the particles produced by the reaction. After fission, the total mass of all the pieces is less than that of the original uranium nucleus. The missing mass is slight, only about $^1/_{10}$ of one percent, or $^1/_5$ of the mass of a proton. The matter does not just disappear. It is changed into an equivalent amount of energy as given by Einstein's mass energy equation: $E = mc^2$ with E the energy, m the mass and c^2 the speed of light squared. The energy can take several different forms. It can be heat, light or the kinetic energy carried away by high speed particles. In the original uranium atom, the extra energy that holds the nucleus together is *binding energy*. Binding energy makes its presence known by giving the uranium atom slightly more mass. The fact that energy can show itself as mass is one of the revelations of Einstein's mass energy equation ($E = mc^2$).

Enrico Fermi learned of Meitner's discovery from Niels Bohr who visited the United States in 1939 during a gathering

VOCABULARY

Nuclear reactor: an apparatus in which a nuclear chain reaction is sustained and controlled to generate heat
Sustained: to keep in existence or keep going, a sustained nuclear reaction is one that continues for as long as desired
Cryptic: mysterious, secretive
Moderator: graphite (carbon) or water that is used to slow neutrons
Control rods: rods, usually of the metal cadmium, that absorb neutrons to control the speed of a nuclear reaction

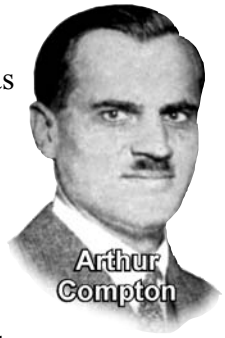
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of nuclear chemists. The slow neutrons caused greater changes than possible with the faster alpha particles. Fermi saw two important facts about uranium fission. First, the amount of energy released was tremendous. Second, the release of secondary neutrons meant that a chain reaction was possible to produce a self-sustaining nuclear reaction. If it could be controlled, then it would release more energy than any other fuel source. In its simplest form, uranium fission could make a bomb of a destructive power never before imagined. Fermi recognized the danger to democracy if Adolf Hitler's German scientists developed a nuclear weapon to use against Europe. Unfortunately, Fermi could not interest the American government in research into nuclear energy.


Enrico Fermi

Fermi and a friend wrote a letter to President Franklin D. Roosevelt. Rather than sending it himself, Fermi asked Albert Einstein to sign the letter. Albert Einstein had very little to do with nuclear fission except for his development of the equation $E = mc^2$. However, he was the best-known scientist in the world, and politicians would listen to him. Albert Einstein agreed to send the letter. It said in part, "Some recent work by E. Fermi . . . leads me to expect that the element uranium may be turned into a new and important source of energy . . . . it is conceivable—though much less certain—that extremely powerful bombs of a new type may thus be constructed." By signing the letter, Einstein convinced the politicians to take the potential of nuclear energy seriously.

The President authorized a secret effort that became known by the code name *Manhattan Project* to build a ***nuclear reactor***. American physicist Arthur Compton was put in charge of the overall effort. Enrico Fermi and a group of scientists at the University of Chicago were given the task of building the first controlled and ***sustained*** nuclear reaction. The work was done beneath an athletic court at the University. The scientific crew stacked blocks of uranium-235 and uranium-235 oxide as fuel, graphite as a moderator and cadmium rods to absorb neutrons. On December 2, 1942, only one year after being given the assignment, the cadmium rods were slowly withdrawn, and the chain reaction became self-sustaining. The success was


Arthur Compton

VOCABULARY

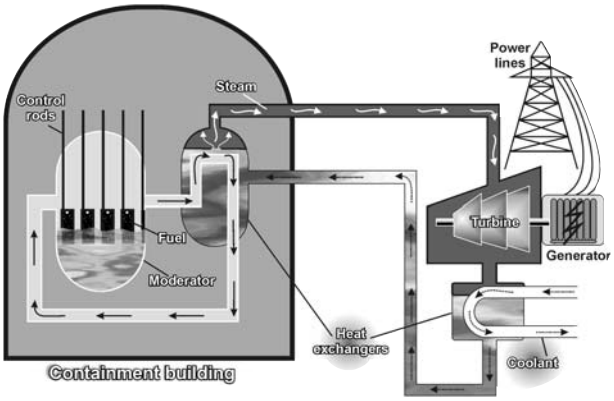
Coolant: a liquid such as water or molten sodium that carries heat away from a nuclear reactor
Heat exchanger: a series of coils that transfer heat in a closed circuit from one coolant to another, the coolant of a nuclear reactor is transferred to water which changes into steam and runs a steam turbine
Heat pollution: heat released in an area where it is not wanted, heat pollution can cause environmental changes in rivers and bays where it is released
Cooling tower: a large structure to cool the hot water that comes from the steam turbines of a nuclear power plant
Containment building: a structure of concrete and steel that encloses a nuclear reactor with the purpose of preventing leakage of radioactive material
Commercial: an enterprise that is intended to make a profit, generally commercial businesses are owned by private companies or individuals and not by the government
Conventional: a term applied to non-nuclear weapons or power plants

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telegraphed with the ***cryptic*** message, "The Italian navigator has entered the New World" to physicist Author Compton who was in Washington.

Shortly before World War II ended, Fermi became a United States citizen (1944), and a professor at the University of Chicago. Element 100 was named fermium in his honor.

Today, the basic parts of a nuclear reactor include the fuel, moderator, control rods, coolant, heat exchanger and containment building.



Uranium-235 is the fuel used in nuclear reactors, but it makes up only about 0.7 percent of naturally occurring uranium. Refining pure uranium-235 is difficult. It and uranium-238 are found together, and they differ in physical properties only slightly and in chemical properties not at all. The first method used to separate uranium-235 was to react the uranium with fluoride and produce uranium hexafluoride, a gas. Then the gas molecules were allowed to diffuse through long pipes. Because molecules containing uranium-235 were slightly lighter, they passed through the pipes more quickly.

Another method used to separate uranium is with a *mass spectrograph,* which separates isotopes of an element according to their mass. Electrons are removed from the atoms to give them a charge. Then, they are shot through a magnetic field that causes their paths to curve. The lighter uranium-235 curves more sharply than the heavier uranium-238 and can be captured when their paths diverge.

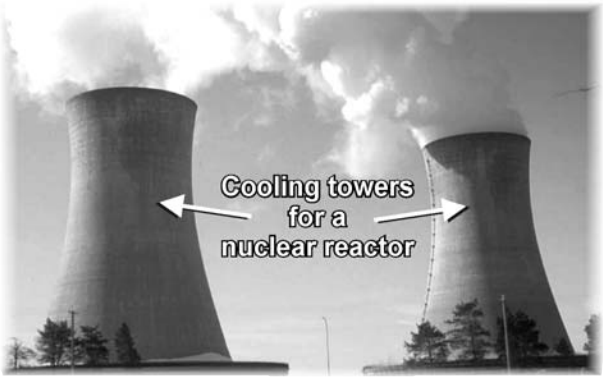
Refining uranium by gas diffusion or by a mass spectrograph is tedious and expensive. However, nuclear chemists learned that pure uranium-235 is not required for atomic explosives. Instead, it is only necessary to increase the proportion of uranium-235 in a regular sample of uranium from 0.7 percent to about 3.0 percent. Uranium fuel that has a higher proportion of uranium-235 found in nature is known as *enriched uranium*.

When bombarded with slow moving neutrons, uranium-235 becomes unstable and undergoes fission. Several different reactions are possible, but the most common one is to produce krypton and barium with the release of two or three neutrons and energy. The release of the extra neutrons makes the reaction self-sustaining. When the neutrons are released, they strike other uranium atoms to continue the chain reaction. If the sample of uranium is too small, then the neutrons escape entirely and no chain reaction occurs. The amount of material needed to maintain the chain reaction is the *critical mass*. For pure uranium-235, the critical mass is 11 pounds.

Fermi used pure graphite as a ***moderator*** to slow down action of neutrons so they will cause uranium-235 atoms to split. Graphite is a form of carbon also used as pencil lead. Blocks of the enriched uranium fuel and graphite moderator were stacked together in the basement of the athletic court at the University of Chicago in 1942. The first reactor had about 52 tons of enriched uranium. A typical reactor today has twice as much. Most reactors in use today use ordinary water as a moderator.

The purpose of ***control rods*** is to adjust the speed of the nuclear reaction by

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removing neutrons. By inserting rods completely into the fuel, neutrons are absorbed, and the chain reaction dies. By removing the control rods from the fuel, the reaction proceeds at a faster rate. The first reactor used cadmium as control rods. They were withdrawn and pushed back in manually by scientists. In a modern nuclear plant, the condition of the reaction and the temperature of the water ***coolant*** are continuously monitored, and the control rods are automatically inserted should a problem develop.

The goal of the Fermi reactor was merely to show that a nuclear reaction was possible and not to generate energy. It had no ***heat exchanger***, turbines or containment structure. The purpose of a modern nuclear reactor is to generate energy, and that energy is usually in the form of heat. A coolant is used to absorb the heat and carry it elsewhere for use. The first reactor was air-cooled. It could be operated only for short periods. Otherwise, it would overheat. In a modern reactor, water is pumped through the reactor core, where it is heated to about 325°C (about 620°F). As a safety measure, the heat the water contains is passed by a closed secondary loop to a secondary source of water. The heat exchanger is used to transfer the heat. The secondary water changes to steam and drives a turbine. The turbine can then generate electricity.

After passing through the turbine, the steam still carries a tremendous amount of heat. To release it into a river or the ocean would produce ***heat pollution*** and might cause environmental changes. Most nuclear power plants cool the steam and condense it back into liquid water for reuse. Most nuclear reactors include large ***cooling towers***.

In the United States and in many other countries, a large concrete and steel ***containment building*** surrounds the nuclear reactor. The purpose of the containment building is to prevent any radioactive elements from escaping in case of a radiation leak.

Following a series of well-publicized problems with nuclear reactors, the growth in the number of nuclear power plants has been reduced. The last ***commercial*** nuclear power plant built in the United States was in 1978. Some plants have closed since then. By the 21st century, 100 nuclear power plants operated in the United States. Those plants produced about 1/5 of all the electrical energy consumed in the United States. France leads the world in the use of nuclear energy. France has made an effort to reduce its dependency on fossil fuels such as coal and oil, so that almost 75 percent of that country's electricity is supplied by nuclear reactors.

Nuclear reactors can be made small enough to be put in ships and submarines. Batteries power ***conventional*** submarines when under water. They must surface to run their diesel engines in order to charge the batteries. The advantage of a nuclear reactor in a submarine is that it does not need oxygen to burn its fuel. The first nuclear powered submarine was the USS Nautilus launched in 1954. Because of restrictions at civilian ports, the only surface ships that have nuclear power plants are military vessels.



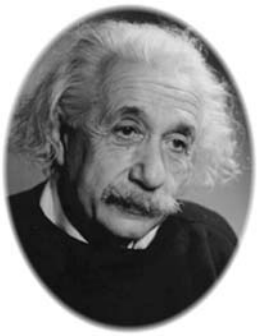
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In 1986 Chernobyl, Russia experienced a devastating nuclear power plant meltdown that injured and killed hundreds of Russians. The Russian government had failed to conduct proper maintenance on the nuclear powered generators. One day the system failed to operate properly and fire broke out. Within a few hours, thousands of people were exposed to deadly radiation.

Life Principle



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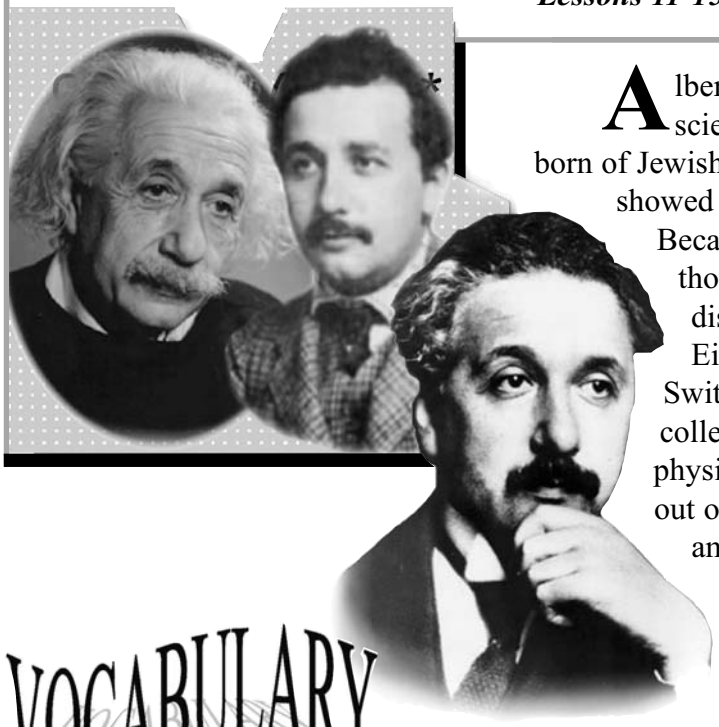
Integrated Physics & Chemistry

Lesson 11
Energy

Chapter 10

Section 3
Lessons 11-15

ALBERT EINSTEIN AND NUCLEAR WEAPONS



Albert Einstein is recognized as the greatest scientist of the 20th century. Einstein was born of Jewish parents in 1879 in Ulm, Germany. He showed no particular promise as a youngster. Because he was slow to speak, his parents thought Albert might have a learning disability. When his family moved to Italy, Einstein was put in high school in Switzerland. After graduation, he attended a college that trained him to be a teacher of physics. A teacher encouraged Einstein to drop out of school. The teacher said, "You'll never amount to anything, Einstein." He received his diploma and became a Swiss citizen in 1901, but he could not find employment as a teacher. He found a low paying job as a technical assistant at the Swiss Patent Office. In his spare time, Einstein studied mathematics and physics and read everything he could about science. He then succeeded in gaining admission to the University of Zurich where he received a Ph.D.

In 1905, Einstein published three important papers. The first one was on Browning motion. Tiny particles in water or some other fluid such as air, have a ceaseless and unpredictable motion. Einstein explained the motion in terms of the ***Kinetic Theory of Heat***. Heat energy puts water molecules in random motion. The water molecules are shoved around the tiny pollen grains. Einstein developed equations that chemists could use to calculate the size of water molecules, as long as the size of the pollen grains was known.

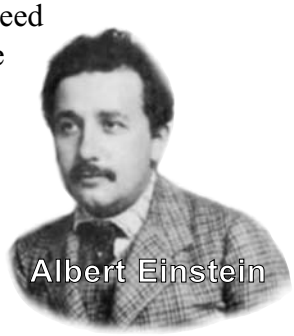
Albert Einstein's second paper dealt with the ***photoelectric effect***. When light strikes some metals, electrons are knocked loose. Physicists had learned that the brightness of the light produced more electrons but had no effect on their

VOCABULARY

Kinetic Theory of Heat: the theory that heat is due to the motion of atoms and molecules

Photoelectric effect: the observation that light causes certain metals to emit electrons from their surface, the brighter the light the greater the number of electrons, the higher the frequency (color), the greater the speed of the electrons, this effect is explained by assuming that light is made of packets of energy – photons—whose energy content varies with the color of the light

speed. To increase the speed of the electrons that were emitted, the color of the light had to be changed. Higher frequency blue light caused the metal to emit electrons at greater speed than lower frequency green light. Below a certain color (on the color chart) such as red, no electrons would come off the metal. An increase in the brightness of the red light made no difference. The color of the light controlled the speed at which electrons were emitted, and the brightness of the light controlled the number of electrons.


Albert Einstein

Scientists asked why blue light produced electrons of higher speed than green light. They also wondered why increasing the brightness produced more electrons than at the original brightness. Scientists questioned why light below a certain color produced no electrons regardless of its brightness.

Einstein explained the photoelectric effect by assuming that light came in small packets of energy (later called photons). When an electron was struck by a photon, it absorbed the photon and gained the photon's energy. Each photon gave an electron a certain amount of energy based on the frequency (color) of the light. Blue photons had more energy. Red photons had less energy. More photons (brightness) released more electrons, while photons with greater energy (blue and violet) gave electrons more energy so they could escape from the metal at higher speed. Breaking free of the metal required a certain amount of energy. A photon of red light did not have enough energy to free an electron. Increasing the brightness of red light increased the number of photons but not their energies. An electron could absorb only one photon at a time, so the electron could never escape from the surface of the metal. Almost all scientists had come to accept the idea that light was made of waves. Yet, Einstein's theory explained the photoelectric effect so thoroughly, scientists could not avoid the idea that light had a particle nature.

Einstein's third paper of 1905 was on the subject of the ***Special Theory of Relativity***. Einstein read about an interesting experiment conducted by two American scientists. Physicist Albert Michelson and chemist Edward Morley proved that the speed of light is a constant even if the source of the light or the person measuring its speed is in motion. Einstein accepted the results of the Michelson and Morley experiment and developed additional conclusions based on the speed of light always being a constant

VOCABULARY

Special Theory of Relativity: the theory developed by Albert Einstein that the Laws of Physics are the same for any observer whether at rest or in uniform motion

General Theory of Relativity: the theory developed by Albert Einstein that forces caused by acceleration are in every way the same as forces caused by gravity, this theory predicted that starlight passing near a large gravitational body such as the Sun would have its path bent

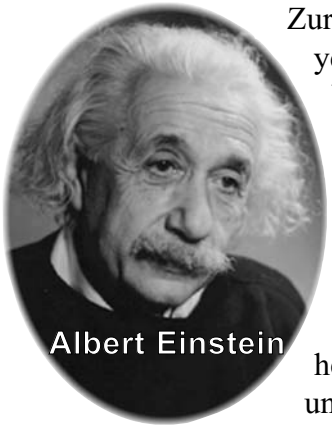
Accelerated motion: motion in which velocity (speed) changes

Breeder reactor: a nuclear reactor that produces more fuel than it consumes, most breeder reactors produce plutonium-239 from uranium-238

Transuranium: beyond uranium, an element with an atomic number greater than 92, the atomic number of uranium

(absolute) in a vacuum. Several conclusions come from this assumption: the Laws of Physics are the same for all observers provided they are in uniform motion; the rate that time passes varies with velocity; information cannot be communicated at a speed greater than that of light. Modern computers with assistance from fiber optics process information at the speed of light. Nothing, however, has ever been communicated in excess of the speed of light.

Einstein also worked out one of the most famous equations in physics, $E = mc^2$. Several experiments proved Einstein's equation to be correct. For instance, as an electron approaches the speed of light, the electron gains energy due to its motion. This energy causes the electron to have a greater mass. The most dramatic confirmation of the relationship between mass and energy comes from the energy released by nuclear reactions. When an electron is traveling at about 87 percent of the speed of light, the electron's mass is double its mass when at rest. The extra mass is due to the kinetic energy of the electron's motion.


Albert Einstein

A *fission* reaction takes larger nuclei and breaks (splits) them into smaller ones. Very heavy nuclei such as those of uranium tend to become more stable by emitting radioactive particles or by splitting. When the mass of fragments from radioactive fission are added together, their total mass is less than that of the original uranium atom. The lost mass has been changed into energy. The amount of energy is given by Einstein's equation, $E = mc^2$. In a fission reaction, about 0.1 percent of the mass disappears and reappears in the form of energy.

A *fusion* reaction takes small nuclei and builds them into larger ones. During fusion, lightweight atoms such as those of hydrogen combine to produce heavier atoms such as helium. The word *fuse* means *to melt*. During fusion, some of the mass of the lighter nuclei seems to disappear. This difference between the actual weight of the nucleus and the total weight of its components is the mass defect. In a fusion reaction, about 0.5 percent of the mass disappears and reappears in the form of energy. A fusion reaction produces about five times as much energy from the same mass as a fission reaction.

Despite the importance of the discoveries that Einstein announced in 1905, four more years passed before he was offered a position at a college. In 1909, he became professor of Physics at the University of Zurich in Switzerland. In another four years, he became a professor at the University of Berlin in Germany. There, in 1915, he stated the ***General Theory of Relativity***. In his Special Theory of Relativity, Einstein assumed the observer was at rest or in uniform motion. In the General Theory of Relativity, he assumed the observer was in uniform ***accelerated motion***. The General Theory of Relativity explains gravitation as due to the curvature of space. Einstein predicted that as starlight passed near a strong gravitational source such as the Sun, its path would be curved. During a total eclipse of the Sun, stars near the line of sight of the Sun are visible. Photographs taken during the eclipse of 1919 showed that the rays of light had been shifted out of position in the manner Einstein predicted.

The Nobel Prize committee was careful to award the prize for achievements that were not likely to be proven wrong. Despite the fame of his Theory of Relativity, it had not been fully tested, so the Nobel

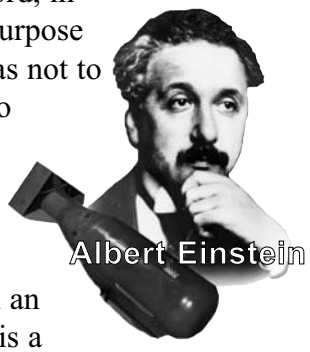
Prize committee awarded the Nobel Prize in physics to Einstein for his paper on the photoelectric effect.

Einstein was in California when Hitler came into power in Germany early in 1933. As the world's best known Jewish scientist at the time, returning to Germany would have made Einstein a prime target of Nazi terrorism. Instead, he moved to Princeton, New Jersey to work at the Institute of Advanced Study. Shortly before becoming a United States citizen in 1940, Einstein sent a letter about nuclear weapon concerns to President Roosevelt at the request of nuclear chemist, Enrico Fermi. Through a chain of events, development of the atomic bomb resulted.

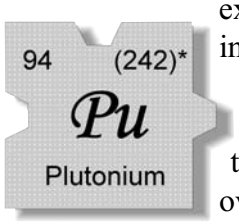
Albert Einstein held a strong belief in a Supreme Creator, variously described by Einstein as "a superior mind" and "a superior reasoning power." "My religion consists of humble admiration of the illimitable (limitless) Supreme Spirit who reveals Himself in the slight details we are able to perceive with our frail and feeble minds," said Einstein. On another occasion he was asked about the source of his ideas. He replied, "Ideas come from God."

In 1952, Einstein turned down an invitation from Israel's first Prime Minister, David Ben-Gurion, to become the president of the newly formed nation of Israel. Albert Einstein died in 1955. Television networks broke into their regular programming to announce his death. By then, he had become the best-known scientist in the world.

Because of Einstein's letter to President Roosevelt, the United States produced the first nuclear chain reaction. Following Enrico Fermi's success at the University of Chicago, the U.S. program for developing an atomic bomb moved to the secret city of Los Alamos, New Mexico. During the next four years, another team of scientists under American physicist J. Robert Oppenheimer built a nuclear fission bomb. Collecting enough uranium-235 for the atomic bomb was a problem. Then, scientists learned that exposing regular uranium-238 to neutrons changed uranium into plutonium-239, which could be used as a nuclear fuel and for constructing bombs. The United States built a ***breeder reactor*** at Hanford, in Washington State. The purpose of the breeder reactor was not to generate electricity but to produce plutonium-239 for use as a nuclear fuel and for nuclear weapons. Plutonium is a radioactive element with an atomic number of 94. It is a ***transuranium*** element and lies beyond uranium in the Periodic Table of the Elements.

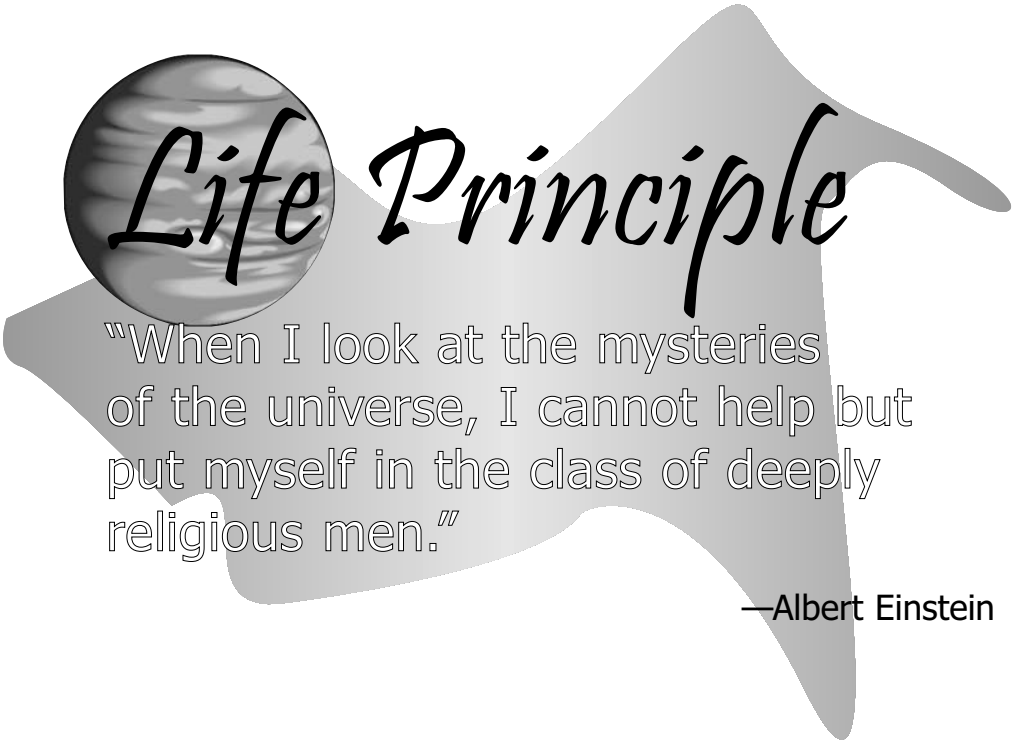


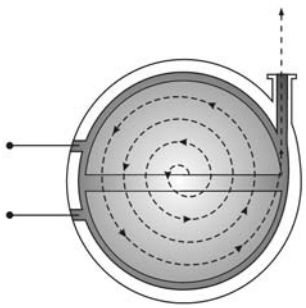
The first nuclear bomb was built in place in a tower at a remote site on the Alamogordo Air Force Base in New Mexico. This test bomb exploded with the force of 20,000 tons of TNT. Two other bombs were built small enough to be carried in an airplane. Although the Germans and Italians had surrendered to allied forces by the spring of 1945, the Japanese refused to surrender. One of the bombs with Uranium-235 was exploded over the Japanese industrial city of Hiroshima on August 6, 1945. The second one, which used plutonium-239 from the Hanford facility, was exploded over Nagasaki two days later. Within two weeks, Japan surrendered, and World War II ended. The work of Fermi, Einstein, Oppenheimer and other scientists helped bring the war to an end.



The weapons were fission bombs that produced their energy by the splitting of

uranium and plutonium atoms. Although the United States, England, France and Soviet Union built thousands of nuclear weapons during the next 50 years, the weapons were almost too terrible to use. By the end of the 1900s, the two atomic bombs that exploded in World War II were the only nuclear devices ever used in combat conditions.



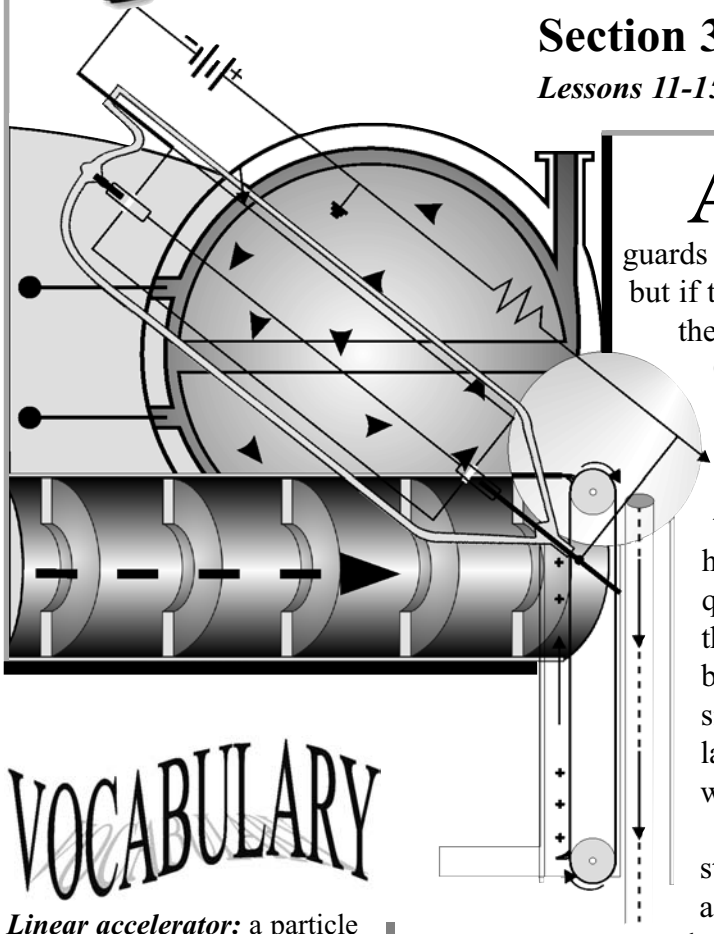


Chapter 10

Lesson 12
Inventions & Discoveries

PARTICLE ACCELERATORS AND DETECTORS

Section 3
Lessons 11-15

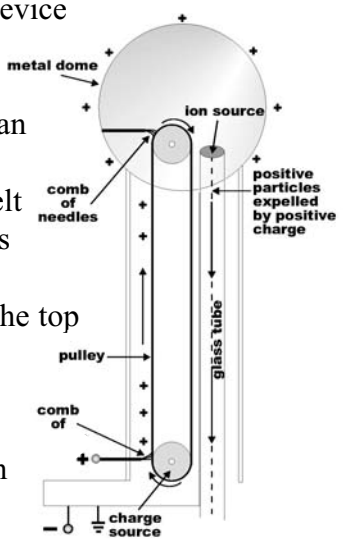


A football coach encourages his defense to hit the line and hit it hard. The guards protecting the quarterback may be large, but if the opposing linebackers hit hard enough, they may break through the protective line. Of course, this works only if the difference in size is not too great. If the player hitting the line is too small, he will be unable to break through and sack the quarterback. If the linebacker is fast, he could outrun the guard and sack the quarterback. Physicists of the 1930s faced the same kinds of problems. The nuclear bullets that came from radioactive elements simply did not travel fast enough to breakup larger nuclei. Scientists began experimenting with artificial ways to accelerate particles.

Suppose a hydrogen atom is stripped of its electron. The atom becomes a proton with a positive charge. By passing the proton through an electric field, the proton gains energy. A *particle accelerator* is a device that accelerates the speed of a charged particle.

One of the first particle accelerators was the Van de Graaff generator, named after American physicist Robert Van de Graaff. In 1931, he built the first high-voltage electrostatic generator. A belt at the bottom of the generator picked up electrons by friction applied against a glass rod. The belt transferred the electrons into a hollow sphere at the top of the device.

The strength of a particle accelerator is given in *electron volts*. An electron volt is the energy that is given to an electron as it crosses an



VOCABULARY

Linear accelerator: a particle accelerator that uses high alternating voltages to push particles through a series of hollow tubes in a straight line
Ionization: to form charged particles
Geiger counter: an instrument that detects and measures the intensity of radiation by the ionization caused by a nuclear particle passing through a gas within a tube connected to an electric circuit
Audible: capable of being heard

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electric potential of one volt. The Van de Graaff generator could produce a potential difference of about 5 million volts (5,000,000 or $5.0 * 10^6$). Scientists could use the generator to accelerate electrons, proton or ions to bombard nuclear targets. However, stronger methods to produce even faster ions were needed to cause some nuclear reactions.

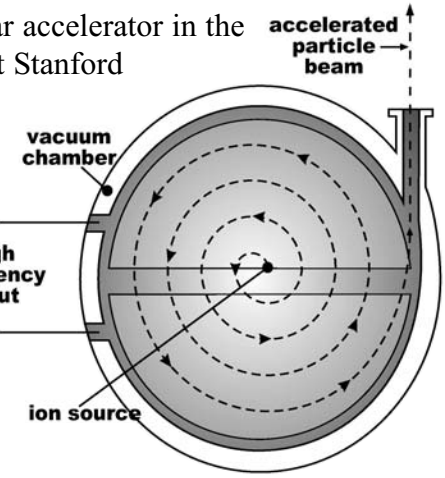
The Van de Graaff generator offered only one opportunity to give an electron or proton a change in speed. That's because it operated like a person on a swing. When a person is on a swing, pumping at the right moment can increase the motion. By timing the swing and adding a little energy each time, the swing goes higher and higher. Some scientists wanted a more efficient accelerator, so they made straight-line particle accelerators based on progressive increases in speed. A ***linear accelerator*** was a series of hollow metal tubes in a straight line. The tubes were given an alternating voltage so timed as to push the charged particle forward each time it passed from one tube to the next. A target put at the end of the tube was hit by the high-speed charged particle and underwent nuclear change.

American scientist Ernest Lawrence made a circular version of the linear accelerator, which he called a *cyclotron*. Suppose a charged particle could be put in circular motion and given a small additional speed each time it went around the track. Eventually it would build up to a tremendous amount of energy. Rather than a long tube, Lawrence used magnets to bend the path of the charged particles into a circle. Each time around the cyclotron, the charged particles received another push of electric potential. This push made the particles move faster, and they tended to spin farther and farther from the center of the circular magnet. By the time they spiraled out of the cyclotron, the particles had accumulated enormous energies.

The high-speed bullets leaving the cyclotron caused nuclear reactions that had never been seen before. For instance, in some nuclear reactions, a particle similar to beta particles was given off, but it curved in the opposite direction. Rather than carrying a negative charge, the particle carried a positive charge. In every other way, the particle was identical to a high-speed electron. The particle was given the name *positron*, meaning positive electron, because it had the same mass as an electron but carried an opposite electric charge.

The first cyclotron was eight inches in diameter. An improved version of the cyclotron, known as a synchrotron, was built in the 1940s. A large *synchrotron* is located at the Fermi National Accelerator Laboratory near Batavia, Illinois. The laboratory is also known as Fermilab and is named after Enrico Fermi. The giant accelerator was so expensive to build and operate that several universities in the United States, Japan and Canada pooled their research funds. The electric bill to operate it is twenty million dollars a year. Fermilab's particle accelerator, known as the Tevatron, is a circle 1.25 miles in diameter and gives particles and energy of about one trillion electron volts (1,000,000,000,000 or $1.0 * 10^{12}$). The Tevatron is the most powerful accelerator in the world.

The largest linear accelerator in the world, located at Stanford University in California, is two miles long and can produce electrons with energies of 20 billion electron volts (20,000,000,000 or $2.0 * 10^{10}$).

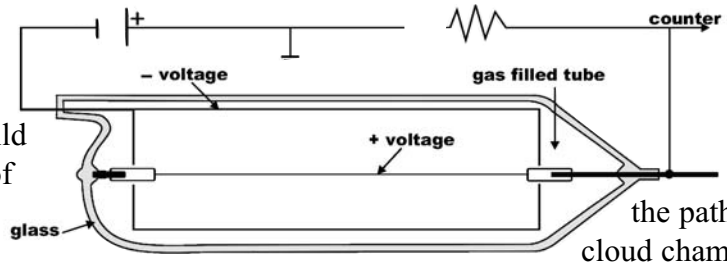


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Particle detectors are devices that identify radioactive particles and reveal their properties. Once a collision occurs and a nucleus is blasted apart, some method must be available to detect the products and measure their charge, mass, speed and half-life. Most particles knock loose electrons, which produce charged particles. Most charged particles become visible because of the ***ionization*** they cause along their paths.

The first particle detector was photographic film. A man named Becquerel discovered that radioactive particles would expose photographic film. If a thick photographic emulsion is put on a thin sheet of glass and the glass plates are then stacked together, the path of a nuclear particle can be traced out as it goes from one sheet into the next.

During Ernest Rutherford's experiment with alpha particles to probe into an atom, he observed where the particles came out by setting up screens coated with zinc sulfide. The alpha particle struck the screen and produced a flash of light. An assistant, Hans Geiger, was given the task of moving the screen to various locations around the gold foil and counting the number of flashes. Sometimes the patient Geiger had to count as many as 10,000 flashes over several hours.



Hans Geiger decided to build a better way of testing for radioactive particles. In 1913, he built a ***Geiger counter***. He sealed a nonconducting gas in a metal tube. Down the center of the tube, he ran a fine wire that was connected to a source of high-voltage electricity. The tube was connected to the other side of the circuit. Normally, no electric current passed between the fine wire and the tube because of the resistance of the gas. The Geiger counter worked on the principle that radioactive particles caused ionization. As particles passed through the tube of gas, they knocked electrons from the atoms. The particles created a charged path that briefly completed the circuit. A short burst of electricity flowed. Geiger attached a speaker to the device so that each particle made an ***audible*** click.

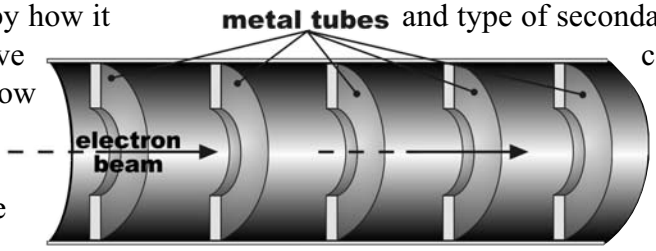
Some radiation is always present on Earth and does not come from human produced sources. If a Geiger counter is turned on, it gives off frequent clicks, even when no radioactive material is in the vicinity. Naturally radioactive substances in the soil cause background radiation, as do high-speed particles that strike the Earth from outer space. The Sun gives off these particles. Another source is cosmic rays that come from far out in space. The natural background radiation serves as a guide to whether a source of radiation is sufficiently shielded. The goal is to shield radiation at a research laboratory or a nuclear reactor so it emits less than the background radiation.

Rather than detecting particles as the Geiger counter does, most physicists wanted to see the track left by a subatomic particle. The curve of the track and its length gave information about the charge on the particle, speed and interaction with other particles. The device that showed the path of a particle was the cloud chamber invented by Charles T. Wilson. He built the first one in 1911. He filled a chamber with clean, dust free air that was saturated with moisture. By lowering the temperature, the air became supersaturated. It contained more moisture than it would normally hold. However, no particles existed for moisture to form around, so the moisture

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remained in a vapor. Whenever a charged nuclear particle passed through the air, it ionized air molecules along its track. The ions served as centers of condensation for tiny water droplets. A condensation trail formed that was visible to the unaided eyes.

When the cloud chamber was placed in a magnetic field, the tracks revealed the charge of the particle by how it curved. Tracks also gave clues to the speed; a slow particle left a thick track, but a speedy one skipped along. The charge of the particle influenced the thickness of the track. An alpha particle with a +2 charge produced a thick, short trail. A beta particle with a –1 charge left a thinner track, although longer. Neutrons, gamma rays and other neutral particles did not leave trails. However, when they struck one of the air molecules, they created secondary particles. From the energy and type of secondary particles, scientists could calculate information about the invisible rays that caused the reaction.



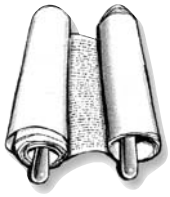
Life Principle

"Handle them carefully, for words have more power than atom bombs."

—Pearl Strachan Hurd

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Integrated Physics & Chemistry



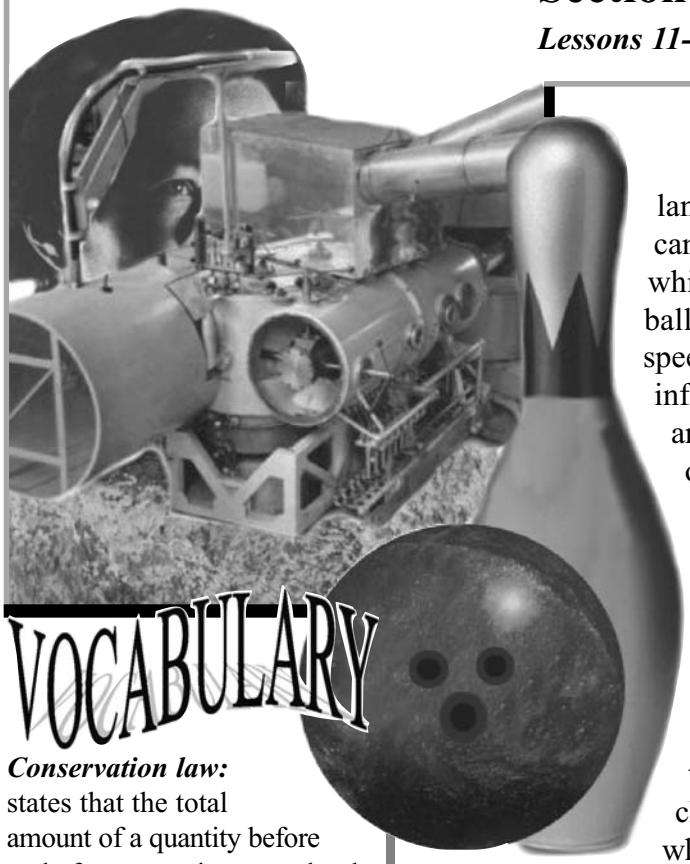
Lesson 13
Scientific Laws

Chapter 10

CONSERVATION LAWS

Section 3

Lessons 11-15



VOCABULARY

Conservation law: states that the total amount of a quantity before and after a reaction must be the same; some quantities in nuclear physics are conserved (electric charge, momentum and spin), while others are not conserved (matter)

Mass defect: the difference in mass of the components of a nuclear reaction compared to the products of the reaction

Bubble chamber: a particle detector that forms bubbles in a liquid along the path of a subatomic particle, the most common bubble chamber contains liquid hydrogen

Imagine a black bowling ball going toward the pins in a darkened bowling lane. A light shines on the pins, but the ball cannot be seen. Suddenly the pins fly every which way from the impact of the bowling ball. From the way the pins scatter and the speed with which they are knocked about, information can be calculated about the speed and direction of the bowling ball at the time of impact.

Nuclear physicists often must work backwards to learn what causes a nuclear reaction. If the particle that causes the reaction has no electric charge, then its presence is not easily revealed until it hits a nucleus. Learning about nuclear reactions is a matter of counting particles that can be seen, measuring their speed, charge and direction and then calculating whether any mass, energy or charge is missing.

Physicists make use of several ***conservation laws*** in calculating nuclear reactions. Charge is conserved. The total charge before a reaction must equal the total charge after the reaction. For instance, when the nucleus of radium with 88 protons emits an alpha particle with two protons, the result is a nucleus with 86 protons (88 = 86 + 2). Each proton carries a +1 electric charge. The total electric charge before the reaction must be the same as the total electric charge after the reaction.

As another example of conservation of charge, when a neutron with no charge emits a particle with a –1 electric charge, the neutron changes into a proton with a +1 charge. In this case, charge is conserved because the positive charge of the proton cancels out the negative charge of the electron to match the zero charge of the neutron: 0 = –1 + (+1).

Scientists had questions about mass and whether it could be conserved. When nuclear physicist, Lise Meitner added the masses of the products of uranium fission, the total was less than a uranium atom. She realized that the lost mass had changed into energy, thus she calculated the amount using Einstein's mass-energy equation, $E = mc^2$. If any mass is lost, then physicists know to look for gamma rays or other particles that carry away the additional energy. When both the mass and the energy are taken together, they are conserved.



Matter is not conserved during nuclear reactions because the components at the start of the reaction process have more mass than the final products. During fusion, the hydrogen atoms that are combined to give helium have more mass than the helium atoms, which are produced. During fission, the uranium atom has more mass than the two smaller atoms that are split from the uranium atom. In either case, the total mass at the end of the reaction is less than the mass before the reaction. The missing mass is changed into energy. In nuclear fusion, about 0.5 percent of the mass is changed into energy. In nuclear fission, about 0.1 percent of the mass of the original atom is changed into energy.

An *atomic mass unit* is defined as $^1/_{12}$ of the mass of a carbon-12 atom. For many purposes, this is equal to the mass of a proton. However, when calculating atomic energy, greater precision is required. Rather than a proton having a mass of exactly 1.0, a proton has a mass of 1.0078 atomic mass units. Although the mass of a neutron is almost the same as the mass of a proton, a slight difference exists. A neutron has a mass of 1.0087 atomic mass units, which is slightly more massive than a proton.

Suppose two protons and two neutrons are put together to make a helium nucleus. The mass of a proton is 1.0078. The mass of a neutron is 1.0087. A helium nucleus has two protons and two neutrons. Individually, the four particles have a total mass of 4.0330 (2 * 1.0078 + 2 * 1.0087 = 2.0156 + 2.0174 = 4.0330). However, the mass of a helium nucleus is actually 4.0026. The difference is 0.0314 (4.0330 – 4.0026 = 0.0314). When two protons and two neutrons are forced together by nuclear fusion, 0.0314 atomic mass units of matter disappear. This mass is called the ***mass defect***. In nuclear fusion, the mass defect is changed into energy. Suppose a gram of mass is converted into heat during a nuclear reaction. According to Einstein's mass energy equation, $E = mc^2$, the mass of one gram converted to heat energy is enough to change a million gallons of water at room temperature into steam.

Although matter and energy alone are not conserved during nuclear reactions, the

VOCABULARY

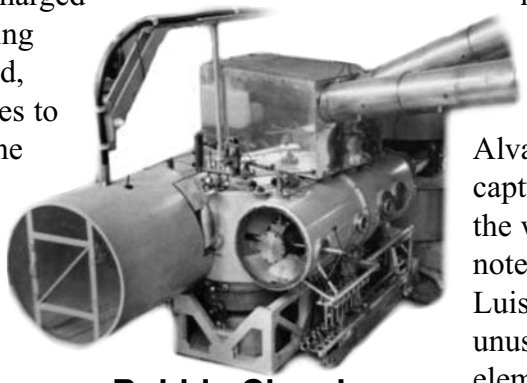
Meteorite: an object that strikes Earth's surface from outer space, meteorites may be made of stone or metal
Stratosphere: the layer of Earth's atmosphere that is usually above most weather phenomenon such as clouds, the stratosphere starts at about 8 miles up
Theoretical: unproven, based on theory, a theoretical discovery may not have any obvious practical benefit
Depression: a time of reduced economic development, falling prices and unemployment, the Great Depression from 1929 through much of the 1930s was the most severe, widespread and longest economic collapse in U.S. history

two together are conserved. Physicists call this condition the Law of Conservation of Mass-Energy. Several other properties of matter are conserved during nuclear reactions such as momentum and spin. Viewing the tracks in a cloud chamber and measuring all of the properties before and after a reaction gives information to physicists about the cause and products of the reaction.

The problem with the cloud chamber was that air contains a variety of gases such as nitrogen, oxygen, argon and other elements. A collision in a cloud chamber was difficult to analyze. A particle striking oxygen might produce one reaction, but if it struck argon, it might cause a different reaction.

Suppose in the bowling ball example, the 10 pins were replaced with a single pin. When hit by the bowling ball, the pin's motion would be much easier to follow and understand than if 10 pins were being scattered around. Collisions between objects are much easier to understand when the number of possible particles that might collide is reduced.

Scientists thought about using hydrogen rather than air to detect subatomic particles. Hydrogen contains one electron and one proton. A hydrogen ***bubble chamber*** detects radiation by the formation of bubbles in liquid hydrogen. Hydrogen is cooled to a liquid and then heated slowly under slight pressure. A charged particle passing through liquid, causes bubbles to form along the particle's path because of extra heat carried with the particle.



Bubble Chamber

Luis Walter Alvarez was one of the best known Hispanic physicists in the United States. He became skillful in the use of the hydrogen bubble chamber to study short-lived subatomic particles. During World War II, while at the secret city of Los Alamos, Luis Alvarez developed the triggering device for plutonium bombs. On July 16, 1945, he witnessed the atomic bomb test at Trinity Site near Alamogordo, New Mexico. He flew as a scientific observer in a B-29 aircraft that accompanied the B-29 bomber *Enola Gay*, which exploded the atomic bomb over Hiroshima.

After World War II, Alvarez returned to Berkeley, California, where he studied short-lived subatomic particles that were created by a linear accelerator that he designed. To detect particles, Alvarez built a large bubble chamber containing pure liquid hydrogen at -270ºC. Particles passing through the liquid created a string of bubbles along a track. One problem was that the trails were very fleeting and soon disappeared. Alvarez set up a camera to photograph the trails for later study. He designed automated equipment to scan the photographs and pass the information to a computer for analysis. His methods revealed a large number of previously unknown subatomic particles, bringing the number of known subatomic particles to several hundred. Luis Alvarez received the 1968 Nobel Prize in physics for his contribution to elementary particle physics and his use of the hydrogen bubble chamber.

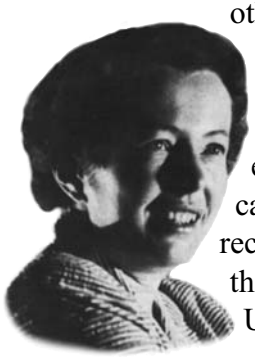
In 1979, Luis and his son, Walter Alvarez, made an announcement that captured the imagination of people all over the world. In Bubbio, Italy, the two men noted a layer of sediment about an inch thick. Luis analyzed the sediment and found an unusually high concentration of iridium, an element that is common in ***meteorites*** but

rare on Earth. Luis and his son developed the Giant Meteorite Impact Theory as the event that killed the dinosaurs. According to the Meteorite Extinction Theory, the meteorite impact allegedly threw a cloud of dust into the ***stratosphere*** that obscured the Sun for three years, plunging the Earth into a long winter that killed vegetation and caused the death of large reptiles.



Alvarez was noted for his ability to turn ***theoretical*** discoveries into useful inventions. In the last years of his life, he worked on devices to detect explosives at airports.

Scientists usually base their theories and discoveries on previous work done by other scientists. Thus, Marie Goeppert-Meyer, a German-American physicist, developed an explanation of why nuclei can release energy. She received her Ph.D. in theoretical physics from the University of Göttingen in Germany, where she married American chemist, Joseph Edward Meyer, who was also a student at Göttingen. After they graduated, Joseph and Marie moved to the United States where Joseph worked at Johns Hopkins University. This was in the 1930s during the economic ***depression*** when Marie could not find professional employment. For much of her life, she held volunteer positions without pay or took part-time jobs.



After World War II, Marie and Joseph moved to the University of Chicago. Marie Goeppert-Meyer met Enrico Fermi who encouraged Marie to take up the study of nuclear structure. Goeppert-Meyer developed the concept that protons and neutrons in the nucleus arranged themselves in layers or shells. Certain shells were more stable and required less energy than others. During a nuclear reaction, protons and neutrons fall into a more stable pattern. That is because they no longer need the extra energy that prior to the reaction held them in the less stable arrangement, thus the unneeded energy is released. In 1963, Marie Goeppert-Meyer received the Nobel Prize in physics for her development of nuclear shell structures.

Life Principle

"Thoughts hidden in the heart eventually find expression in life, revealing who we really are."

—Anonymous

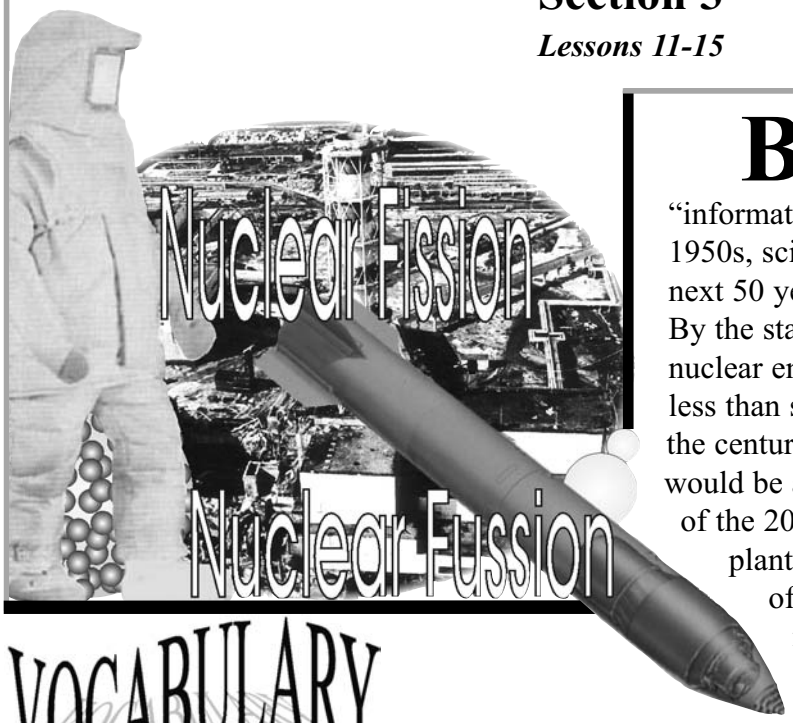
Integrated Physics & Chemistry

Lesson 14
Energy

Chapter 10

THE RISKS AND BENEFITS OF NUCLEAR ENERGY

Section 3
Lessons 11-15



By 2000 A.D., people were thinking about "the computer age" and the "information highway." However, during the 1950s, scientists confidently believed that the next 50 years would be called the atomic age. By the start of the year 2000, the impact of nuclear energy on individual lives was far less than scientists had expected. Earlier in the century, scientists believed atomic fusion would be a major source of energy by the end of the 20th century. Although fission power plants have been built, fusion as a source of peacetime energy has not been realized. Few people think of the period from 1950 to 2000 as the atomic age.

Fusion is a nuclear reaction in which two lightweight nuclei combine to form a more massive nucleus and release energy. Forcing protons and neutrons together to make a larger nucleus requires intense pressure and high temperatures. Fusion occurs at a temperature of millions of degrees and under incredible pressure such as at the core of the Sun. Although physicists of the 1930s figured out the fusion reaction that gave the Sun its energy, scientists doubted whether mankind could duplicate the same reaction on Earth, because at that time there was no way to generate the necessary pressure and temperature.

Success of the fission bomb caused physicists to realize that a fission bomb could supply the necessary conditions to produce fusion. The trigger that sets off a fusion reaction is a fission bomb. First, an ordinary explosive such as TNT causes a critical mass of uranium to come together to produce a fission explosion. Then, the enormous heat and pressure from the fission explosion causes a fusion reaction. The fuel of a fusion bomb is hydrogen. Normally, hydrogen is a gas. Although it can

VOCABULARY

Thermonuclear: based on fusion, thermo means heat and a thermonuclear device creates vast amounts of heat
Useful lifetime: the number of years a factory or plant can continue in operation before it becomes out of date and has to be renovated or replaced, because of the buildup of nuclear radiation, a nuclear power plant has a useful life of 35 to 45 years
Meltdown: a nuclear accident in which the fuel becomes so hot it melts, begins an uncontrolled reaction that burns its way through the bottom of the nuclear plant and contaminates the ground water

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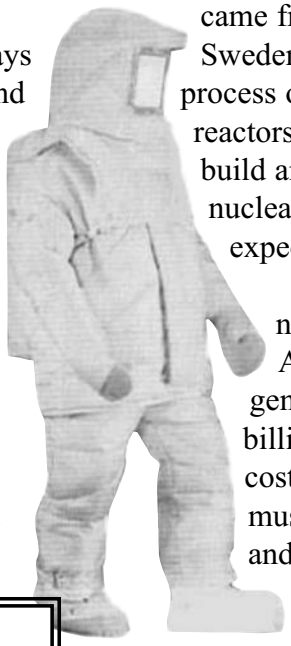
be liquefied, the equipment to do so and keep it as a liquid is too large to be carried in a bomber aircraft or missile. Therefore, the hydrogen is reacted with the metal lithium to make lithium hydride, a solid.

Some newspapers described the fusion bomb as a hydrogen bomb or H-bomb. A better name is ***thermonuclear*** bomb because the bomb is composed of heat (thermo) that causes nuclei to fuse. Fusion bombs are far more powerful than fission bombs. The most powerful ones made had a power equal to 100 megatons of TNT, about 5,000 times the power of the first atomic bomb (A-bomb) that brought Japan to her knees to end World War II.

The thermonuclear explosion resulting from fusion creates great heat, enormous shock waves, high winds and deadly radiation in the form of gamma rays and neutrons that destroy living matter and contaminate soil and water. The destructive power of a nuclear weapon goes beyond the blast. It creates intense radiation energy that can start fires far from the blast site. The blast also releases radiation such as gamma rays, neutrons and charged particles that cause radiation sickness. The charged particles can also cause damage to electronic equipment such as computers. Material in the neighborhood of the blast is made radioactive and thrown into the upper atmosphere by the explosion. Winds can carry radioactive material hundreds of miles from the blast site. Thermonuclear weapons have never been used in wartime.

Because of the great heat and pressure required, no one has yet figured out how to use a fusion reaction to generate electricity. Fission reactors, on the other hand, have been built to generate electricity. The first commercial electric generating fission nuclear reactor was built in 1956 in England. The first United States nuclear reactor to supply electricity began operation in 1957 at Shippingport, Pennsylvania.

Although many scientists predicted that a large proportion of the world's energy needs would come from nuclear power, at the beginning of the 21st century, only 6 percent came from nuclear power. Citizens of Sweden voted in 1980 to start the process of shutting down all nuclear reactors in that country and not to build any new ones. The phase out of nuclear power plants in Sweden is expected to be complete in 2010.



The problems surrounding nuclear power plants are many. A typical atomic power generation plant costs about five billion dollars. In addition to the cost of the building, the uranium must be mined, refined, enriched and transported. During operation, the spent uranium fuel must be removed and disposed of safely. A nuclear power plant has a ***useful lifetime*** of about 35 to 45 years. The plant must earn enough money from the electricity it generates during that time to pay for all the costs and show a profit. After it is shut down, the expenses continue because the radioactive waste has to be dealt with and the plant itself, which has become radioactive, must be dismantled for safe disposal. Disposal of

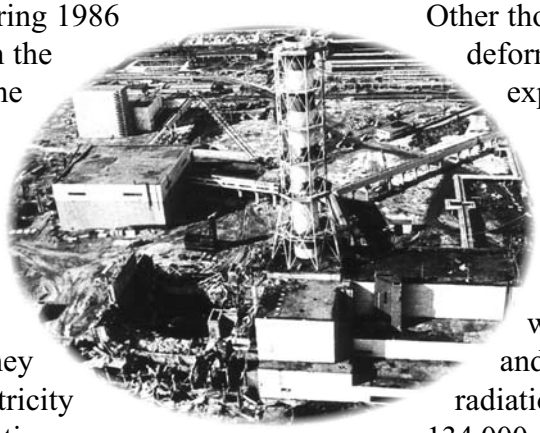
VOCABULARY

Sarcophagus: a stone coffin, the damaged Chernobyl nuclear reactor was encased in a steel and concrete sarcophagus
Scrutiny: a close and careful study
Credibility: the capacity to cause others to believe

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radioactive waste is a difficult problem because wastes can remain radioactive for thousands of years. Most experts believe disposal of radioactive waste is the single most difficult problem facing nuclear power production.

In addition to the radioactive waste, there is also a concern that a nuclear power plant may have an explosion or uncontrolled ***meltdown***. The most destructive nuclear accident was the Chernobyl reactor meltdown that occurred during 1986 in what was then the Soviet Union. The disaster happened during a safety test. Nuclear reactors not only produce electricity, but they also require electricity to operate. Sometimes a power grid suffers a blackout and cannot supply electricity. Normally, a nuclear plant can switch to the internal power that the reactor generates. If it has been shut down, then stand-by diesel powered generators produce the electricity.



In the test, reactor number four of the Chernobyl plant was powered down to test whether its coasting turbines could supply electricity while stand-by generators were started. The shutdown began, but the power level fell too low. An operator removed a number of control rods in an attempt to restore the power level. The reactor surged into production and generated 100 times as much heat as it was designed to handle. The cooling water changed to steam and blew the top out of the reactor. The fuel melted down and generated more heat. Air rushed in and set the graphite moderators afire. Graphite is pure carbon, and it burns furiously.

Chernobyl had no containment building. The explosion blew several tons of radioactive material out of the reactor. Before the Chernobyl meltdown, the most serious nuclear accident at a power station had released 15 curies of radiation. The Chernobyl explosion released about 185 million curies of radiation. The explosion and fire immediately killed two people, and in the next few weeks, another 29 died from radiation. Thousands suffered from radiation poisoning and burns. Other thousands of children were genetically deformed as a result of their parent's exposure to radiation.

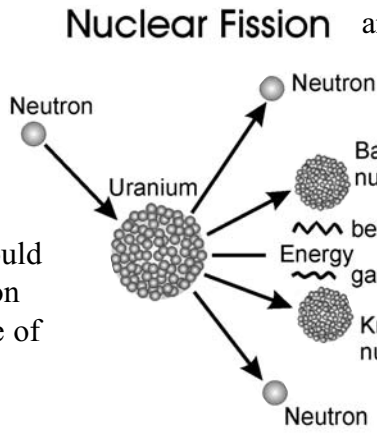
The graphite burned for nine days despite efforts to put it out. Helicopters and airplanes dropped 5,000 tons of sand, clay and rock on the reactor. Reactor number four was enclosed in a protective concrete and steel ***sarcophagus*** to keep the radiation from spreading. Officials ordered 134,000 people living within 20 miles of Chernobyl to move away permanently. About 9 million acres of good farmland in the Ukraine became too radioactive for crops.

Because of the need of electric power during winter, the remaining reactors were put back in operation as soon as possible. Two of the reactors were back in service by November of the same year as the disaster. The third one began operation a year later.

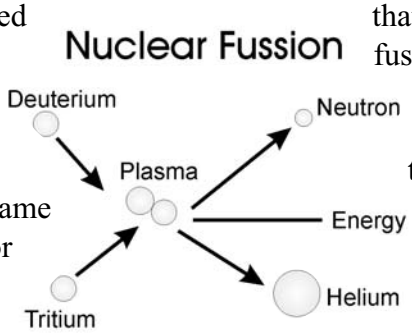
All commercial nuclear power plants use nuclear fission, the splitting of atoms. The United States and other industrialized nations have attempted to generate electricity from nuclear fusion. However, protons from hydrogen atoms must be pressed together so tightly they change into helium nuclei. The United States has spent 15 billion dollars in an effort to produce a successful fusion reaction for commercial power production. Other countries have spent nearly as much, all without success.

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Some scientists think nuclear fusion can be done without resorting to tremendous heat and pressure. Generating power from hydrogen fusion at ordinary temperature is known as *cold fusion*. Because of the reaction, very few radioactive particles would be produced. Cold fusion would be a clean source of energy.



In 1989, two scientists from the University of Utah claimed to have produced cold fusion. Martin Fleischmann was born in Czechoslovakia but settled in Britain and became a well-respected professor of electrochemistry. He was elected to the Royal Society. One of his students was Stanley Pons. Although born in North Carolina, Pons worked toward his Ph.D. in England. After graduation, Pons became a chemistry teacher at the University of Utah. Fleischmann visited with him, and they hiked in the beautiful Utah canyons.



They talked about cold fusion. Under certain circumstances, Fleischmann believed nuclear fusion might occur near room temperature. The two men worked together and built a simple device to test the theory. The test consisted of a glass container of heavy water that has hydrogen atoms with an extra neutron. Into the water were placed two electrodes, one of platinum and the other of palladium, an expensive metal. When electricity flowed, positive hydrogen ions were attracted to the negative palladium electrode. The tests indicated that the hydrogen nuclei became so tightly packed in the palladium that fusion into helium took place.

Fleischmann and Pons announced that they had successfully created cold fusion in 1989. Proving that fusion has occurred is difficult. The simplest way is to measure the temperature of the water. Fusion releases heat that warms the water. However, electricity flowing through the water also causes an increase in temperature. Several scientists tried to repeat the Fleischmann and Pons experiment but failed. Because of the ***scrutiny*** and intense publicity their experiment received, as well as personal attacks on their ***credibility,*** both scientists went into seclusion. By the 21st century, no scientist had succeeded in confirming claims by Fleischmann and Pons or producing cold fusion by any other method. Some scientists now think another 50 years will elapse before the nearly limitless power of cold fusion becomes a reality.

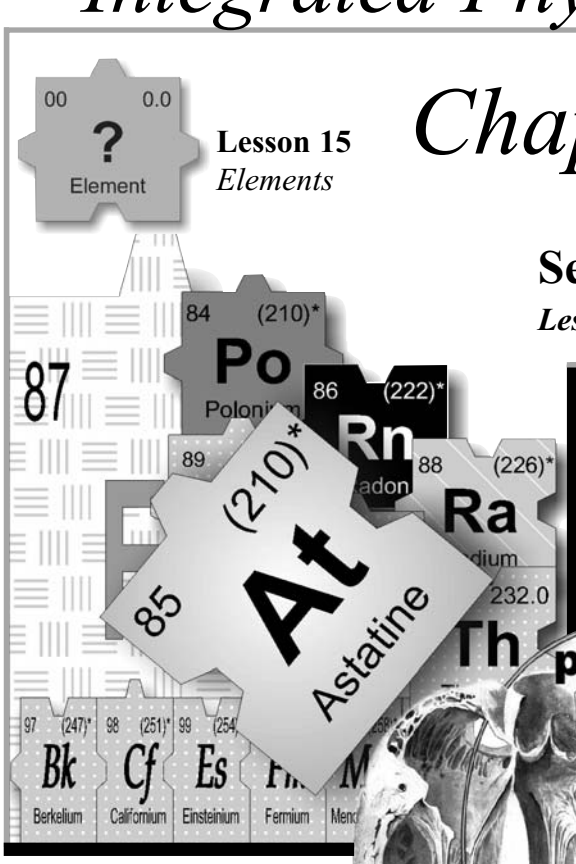
LIFE PRINCIPLE

". . . it is possible to discern enough of the universe's underlying order to tap energy so powerful that it can destroy its discoverers . . ."

—George Johnson

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Integrated Physics & Chemistry



Lesson 15
Elements

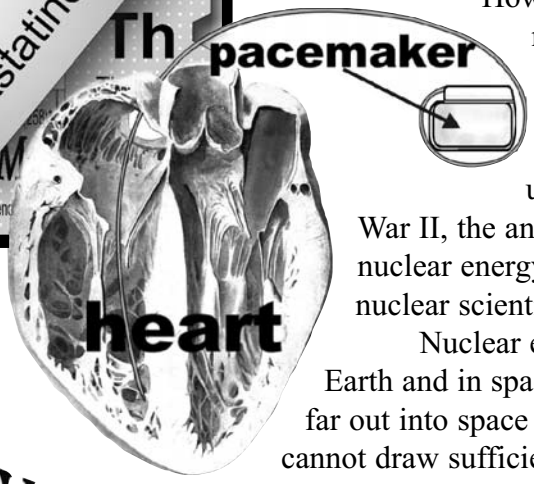
Chapter 10

BENEFITS OF RADIOACTIVITY AND COMPLETION OF THE PERIODIC TABLE

Section 3

Lessons 11-15

Many of the scientists who worked on nuclear weapons became ***disillusioned*** after World War II (1939-1945). Some had done *theoretical* work for which they thought the practical applications would benefit human beings. However, the ***Cold War*** caused many nuclear scientists to question the usefulness of their research. Although no nuclear devices were ever used in fighting after World War II, the anticipated benefits from nuclear energy were far less than most nuclear scientists had hoped.



Nuclear energy has many uses on Earth and in space. Space probes that travel far out into space leave the sun behind and cannot draw sufficient energy from solar power panels. Instead, some spacecraft are powered with small nuclear reactors. An isotope of plutonium is used in heart pacemakers to give them energy for as long as 10 years before they have to be replaced. An isotope of polonium is used in anti-static devices. An isotope of americium is used in smoke detectors. Gamma rays are used to photograph metal parts to detect breaks or poor welds in pipe lines and precision equipment.

One of the most important uses for radiation is as an extremely sensitive test for biological substances in the body. The American physicist, Rosalyn Sussman Yalow, developed the procedure. She became interested in physics while at Hunter College for women in New York City. Yalow read the biography of Marie Curie and heard Enrico Fermi when he spoke at Hunter College. Yalow then attended the University of Illinois where she graduated in 1945 with a Ph.D. in nuclear physics.

VOCABULARY

Disillusioned: to become extremely disappointed because a belief or anticipated event does not occur

Cold War: a period of intense political and military tension that stops short of full scale officially declared war, the Cold War between the United States and the Soviet Union lasted from about 1945 until the fall of the Soviet Union in 1991

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Physicist Yalow returned to Hunter College to teach physics. Because of her interest in medicine, she volunteered to work at the medical laboratory at the Bronx Veterans Administration Hospital. There she met Solomon A. Berson, a medical doctor. In 1950, Dr. Yalow left teaching to become a full time medical researcher. Her goal was to apply radioactive isotopes to measuring the amount of substances in blood and body fluids.

Yalow and Berson combined an antibody with a radioactive sample of insulin. Antibodies are protein substances that destroy invaders by combining with them and changing them chemically. A small sample of blood containing the insulin to be measured was mixed with the radioactive insulin attached to the antibody. Some of the antibodies switched from the radioactive insulin to the blood insulin. The decrease in antibodies attached to radioactive insulin was proportional to the total amount of regular insulin in the blood. The sensitive test could measure the amount of regular insulin in blood from a small sample of the blood.

VOCABULARY

RIA: an abbreviation of the word radioimmunoassay, which is from radioactivity, immunity and assay; RIA is a sensitive test to measure small amounts of biological substances such as enzymes, hormones, steroids and vitamins in blood and other body fluids

Stable element: an element that has at least one stable isotope, if the half-life is greater than 4.5 billion years, the isotope is considered stable

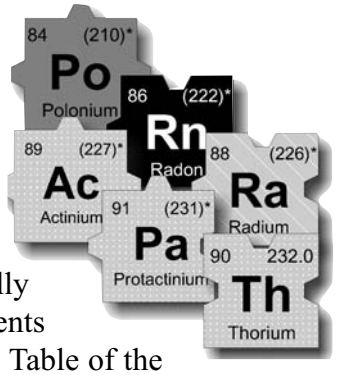
Radioactive element: an element that has no stable isotopes

Synthetic: not of natural origin, produced in a laboratory

Dr. Yalow's method became known as ***RIA*** from the words radioimmunoassay. Antibodies give immunity from disease, and assay means to measure. RIA could measure extremely small amounts of biological substances such as enzymes, hormones, steroids and vitamins in blood and other body fluids. The technique made possible detailed measurements of chemicals that would have escaped detection by any other method. Although incredibly sensitive, the procedure was straightforward and could be carried out in hospitals around the world, even primitive ones in poor countries. Yalow received the Nobel Prize in 1977 for her development of RIA.

The discovery of radioactive elements helped chemists complete the periodic table. From hydrogen with atomic number of 1 to uranium with atomic number 92, the periodic table contains 92 elements. Most of these are ***stable elements***. A stable element is one that has at least one stable isotope. However, 10 ***radioactive elements*** found in the periodic table are below uranium. All of their isotopes are radioactive. They have no stable isotopes.

Of those 10 radioactive elements, six of them are found in Earth's crust. They are naturally occurring radioactive elements. The six naturally occurring radioactive elements are polonium (Po, 84), radon (Rn, 86), radium (Ra, 88), actinium (Ac, 89), thorium (Th, 90) and protactinium (Pa, 91).



After the six naturally occurring radioactive elements were placed in the Periodic Table of the Elements, four gaps remained. The four holes were for elements with atomic numbers of 43, 61, 85 and 87. Chemists searched for them thoroughly in the Earth's crust and could not find any of them.

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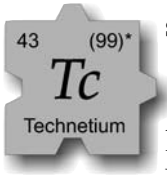
Element number 85 is located between two radioactive elements, polonium and radon. Chemists assumed that element 85 was so radioactive and its half-life so short that even if it had existed in the Earth's crust, it would have long since disappeared. Scientists wondered if element 85 could be made synthetically. Particle accelerators enabled nuclear chemists to take one nucleus and change it into another. Two Italian scientists working in the United States (in exile from Fascist Italy during World War II) bombarded bismuth with alpha particles. Bismuth has 83 protons, and when it gained the two protons from an alpha particle, it changed into the missing element number 85. It proved to be highly radioactive. Its longest-lived isotope has a half-life of 8.3 hours. The Italian scientists called the element astatine, a Greek word meaning unstable. The symbol is *At.*



Element number 87 is located between radon (Rn, 86) and radium (Ra, 88). Because those elements are highly radioactive, scientists reasonably believed that the element number 87 was missing because it was so highly radioactive that all of its atoms had undergone radioactive decay, and none existed in Earth's crust. In 1939, Marguerite Perey worked at the Curie Institute in Paris, France. She had been an assistant of Marie Curie. While investigating the radioactive decay of another element, she found that it broke down and produced the missing element. Marguerite Perey gave element number 87 the name francium (Fr) named after France. It is so radioactive that any sample disappears in a few minutes. At any one moment, the entire crust of the Earth contains only about 25 grams of francium. Its most long lasting isotope has a half-life of only 21 minutes. Any francium in the crust breaks down into other elements by radioactive decay within minutes. Francium would disappear entirely if it were not replaced by the radioactive decay of other elements. It is not found in sufficient amounts in Earth's crust to be considered a naturally occurring element.

Chemists assume the properties of francium are similar to those of cesium, its nearest neighbor in the same chemical family. However, scientists can only speculate because they have never isolated a sample of francium that is large enough to weigh.

The remaining two missing elements, number 43 and number 61, are between stable elements. Chemists assumed they were stable, too, but for some reason had not been detected. However, this proved not to be the case.



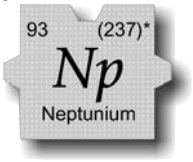


Ernest O. Lawrence used his cyclotron to bombard a sample of molybdenum (Mo, 42) with protons. He provided the sample to another physicist who showed that molybdenum had been changed into element number 43. The new element was named *technetium* from a Greek word meaning *artificial*. Although technetium is not found in Earth's crust, the synthetic version that Lawrence made had a half-life of several thousands of years. It is used as a tracer and, like molybdenum, can be used to reduce the corrosion in steel.

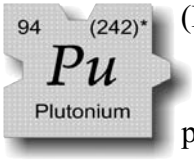
In 1947, some nuclear scientists working at the Oak Ridge National Laboratory in Tennessee examined some of the radioactive material found in the spent fuel of a nuclear reactor. They found element number 61 and called it promethium. In Greek mythology, Prometheus brought fire down from Mount Olympus and gave it to mankind. Promethium is created in the heat of a nuclear reactor.

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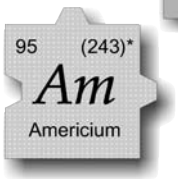
Even before the 92 elements in the periodic table had been found, nuclear chemists were working to produce synthetic elements with an atomic number beyond uranium. These elements have an atomic number greater than 92; that is they have 93 or more protons in their nucleus. They are all ***synthetic*** and are known as transuranium elements. Bombarding one of the isotopes of uranium with neutrons produced the first transuranium element, number 93. Because the planet Neptune is beyond the planet Uranus, the new element was named neptunium because it was beyond uranium. The symbol for neptunium is *Np*.



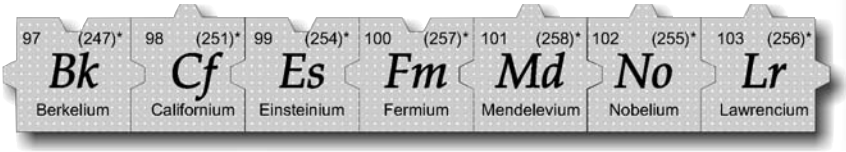
Scientists found that neptunium would emit a heat particle and increase its atomic number by one to 94. Element number 94 was given the name plutonium (Pu) because the planet Pluto is beyond the planet Neptune.



Pluto is the last of the planets in our solar system, so when scientists at the University of California at Berkeley produced the next transuranium element, a name for a planet could not be selected. When the new element, number 95, was placed in the periodic table, it fell below europium (Eu) named after Europe. Because it had been produced in America, they decided to call it americium (Am).

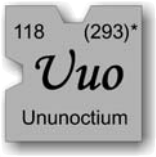


The University of California at Berkeley scientists found still more elements, and they gave them the name curium (after Marie Curie), berkelium (after the city of Berkeley), californium (after California), einsteinium (after Einstein), fermium (after Fermi), mendelevium (after Mendeleev), Nobelium (after Alfred Nobel who started the Nobel Prizes) and lawrencium (after Ernest O. Lawrence who invented the cyclotron).



New transuranium elements continued to be named after people and places up to element number 109, meitnerium, which was named after Lise Meitner, the woman who discovered fission. All transuranium elements are radioactive and most are short lived. In some cases, the amount of the element that has been produced is extremely small. Elements beyond 109 have been detected, but they have been given names and symbols that are based on their atomic number. Element number 110 is ununnilium (un-un-nil-ium, meaning one-one-zero and ium for a metal). The symbol is *Uun*. The elements beyond 110 are the only ones with three letters as their symbols.

The last transuranium element synthesized at the end of the 1900s was element number 118, named ununoctium (un-un-oct-ium, 118 with *-ium* meaning metal), discovered in 1999 at the University of California at Berkeley. Ununoctium has an atomic weight of 293, and the symbol is *Uuo*.





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