ENERGY

Nature's Magic

A MAST Module

Materials Science and Technology

1995

Acknowledgments

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FOREWORD

This module is to be used as a curriculum aide by high school science teachers who would like to introduce their students to concepts in Materials Science and Technology. Teachers are urged to use one, some, or all of the MAST modules. Some teachers may wish to implement this module in its entirety as a subject unit in a course. Others may wish to utilize only part of the module, perhaps a laboratory experiment. **We encourage teachers to use these materials in their classrooms and to contact the workshop with any assessment, comments, or suggestions they may have.**

This is one in a series of MAST modules developed and revised during the Materials Technology Workshop held at the University of Illinois at Urbana-Champaign during 1993-'95.

A combination of university professors, high school science teachers, and university undergraduates worked together to create and revise this module over a three year period.

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Introduction

Module Objective:

To increase energy awareness in students by exploring the physical concepts of energy as well as topics about the different types of energy resources currently available, including fossil fuels, renewables, and nuclear power.

Key Concepts:

At the end of this module the student will be able to:

- Define energy in several different ways.
- Distinguish between different types of energy.
- Use appropriate units to quantify energy.
- Approximate the amount of energy in different materials.
- Discuss the origin and properties of coal, oil, and natural gas.
- Explain why different types of fossil fuels are appropriate for different uses.
- Discuss world and US energy usage--past and projected.
- Discuss the environmental problems associated with the use of each fossil fuel.
- Give a reasonable estimate of how long each fossil fuel will last.
- Discuss unconventional methods of fossil fuel use.
- Discuss different types of renewable energy sources including solar, wind, hydroelectric, biomass, and gasohol.
- Describe the concept of a solar pond.
- Explain the different types of radioactive decay.
- Describe 3 different types of nuclear reactors.

Prerequisites:

The student should have a working knowledge of the following concepts:

- Kinetic and potential energy
- The basic form of chemical equations
- The periodic table, including the definitions of atomic mass, atomic number, protons, neutrons, and electrons.

Placement in Curriculum:

This module can be used in chemistry with organic topics, physics with energy topics, or in interdisciplinary courses such as tech-prep.

The information in the Scientific Principles section may be reproduced in its entirety or in part and distributed to students. Some teachers may prefer to give students only the summary of Scientific Principles, instead of the entire section.

What Is Energy?

Energy provides the driving force of life. What exactly does that mean? Every day as you carry out your normal activities, you depend on energy to help you accomplish your tasks as well as to allow you to maintain your standard of living. An act as simple as flipping on a light switch requires energy use, production, and distribution pathways which we all take for granted. The modernization of society has brought about increased demands on energy sources and production. Societies with limited access to energy resources are significantly hindered from industrialization and economic growth. You can easily see why the study of energy is important. Just about everything you do and consume requires a source of energy.

Think about some of the activities you carry out every day and things you consume that require energy to make possible or produce:

turn off your alarm clock	read books	buy food at the store
jump in the shower	use your computer	get a new CD
use the microwave	watch a movie	mail a letter
listen to the radio	go out to lunch	take a trip in a plane
drive to school	use the telephone	go water skiing
turn on the lights	turn on the A/C	rollerblade

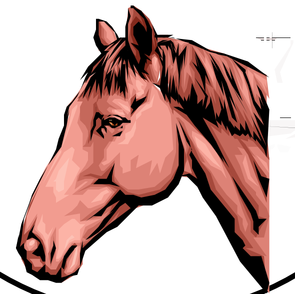
From an economic standpoint, energy is a hot topic! Continual debates occur about which is the "best" energy source, with considerations of availability and cost of the resource, efficiency of production, public safety, health, and marketing. Policy makers must grapple with these decisions as well as the consequences of the energy source they choose. In addition to economic issues, environmental concerns about global warming, acid rain, and radioactive waste influence the energy policies around the world. Understanding energy means understanding resources, their limitations, and the environmental consequences of their use.

ENERGY HISTORICAL TIMELINE

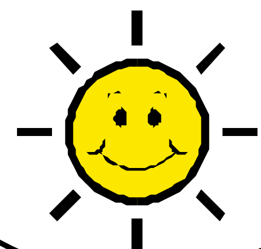
1 MILLION B.C.- PRESENT

c. 1 million BC
Homo erectus learns how to control **fire**.

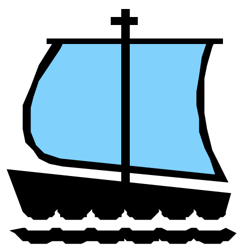
c. 3000 BC
Mules first used for transporting cargo in the Middle East. One of thefirst energy sources was **animal power**.



c. 3,000 BC
Ancient Chinese, Egyptians, Phonecians, Greeks, and Romans used **solar power** to successfully evaporate salt water to produce salt as well as to dry their crops.

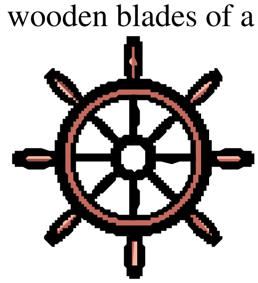


c. 1200 BC
Early sailboats used in Polynesia for transportation over water in order to use **windpower**.



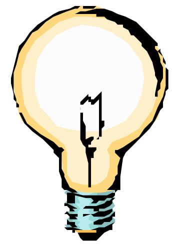
1,000 - 851 BC
Chinese probably used coal as fuel--one of the first uses of **fossil fuels**.

1629
Italian architect Giovanni Branca invents a primitive **turbine** consisting of a boiler with a spout to direct steam against wooden blades of a wheel.

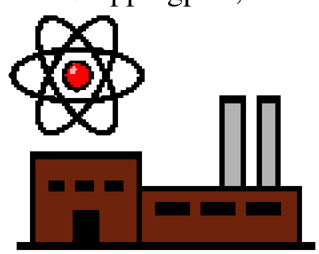


1859
Colonel Edwin Drake first drills for **oil** in the United States in Titusville, Pennsylvania.

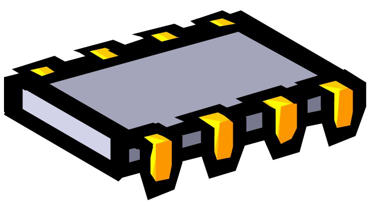
1879
Thomas A. Edison invents the first **electric light bulb**.



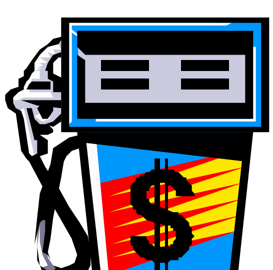
1952
World's first **nuclear reactor** for commercial power in Shippingport, PA.



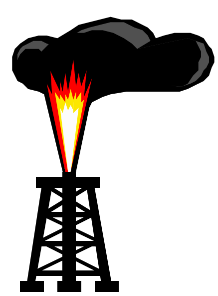
1954
The first successful silicon **solar collectors** were reported by American scientists.



1973
OPEC oil embargo- drives fuel prices up.



1991
Persian Gulf War highlights vulnerability of **oil** supply.



Future Trends

As the world develops and becomes more technologically advanced, energy sources will become increasingly important. No matter how advanced we become, if we don't have the energy sources to support our activities, they won't happen. In the past, we have relied heavily upon fossil fuels like coal, oil, and natural gas to support our energy needs. As fossil fuels run out, we will be looking to employ different energy sources such as renewable sources and nuclear sources, the technology for which is currently being developed.

The United States Department of Energy (DOE) publication ANNUAL ENERGY OUTLOOK 1995 projects that between now and the year 2010, world energy consumption will increase by approximately 19 percent from 1993. One goal will be to provide reliable energy sources for developing countries while protecting the environment. The DOE predicts that oil and coal will provide a smaller portion of the world's energy, while natural gas, solar, hydroelectric, biomass, and geothermal will provide a larger percentage. The major source of renewable energy for electricity generation is hydroelectric power, but because all our potential sites have already been developed, this cannot be expanded much in the United States. Nuclear energy use will grow at a much slower rate than the other energy sources due to concerns such as cost, safety, and radioactive waste. The use of nuclear energy by the United States to generate electricity past the year 2020 is uncertain because no new nuclear power plants have been built in the last ten years. Nuclear fusion is also a possible source of energy in the distant future. It is predicted that commercial production of energy by fusion will not occur for at least 30 years.

Scientific Principles

Basic Energy Principles

Energy is the driving force for the universe. Energy is a quantitative property of a system which may be kinetic, potential, or other in form. There are many different forms of energy. One form of energy can be transferred to another form. The laws of **thermodynamics** govern how and why energy is transferred. Before the different types of energy resources and their uses are discussed, it is important to understand a little about the basic laws of energy.

<u>The Three Laws of Thermodynamics</u>

There are three laws of thermodynamics. The **first law of thermodynamics**, also called conservation of energy, states that the total amount of energy in the universe is constant. This means that all of the energy has to end up somewhere, either in the original form or in a different from. We can use this knowledge to determine the amount of energy in a system, the amount lost as waste heat, and the efficiency of the system.

The **second law of thermodynamics** states that the disorder in the universe always increases. After cleaning your room, it always has a tendency to become messy again. This is a result of the second law. As the disorder in the universe increases, the energy is transformed into less usable forms. Thus, the efficiency of any process will always be less than 100%.

The **third law of thermodynamics** tells us that all molecular movement stops at a temperature we call **absolute zero,** or 0 Kelvin (-273˚C). Since temperature is a measure of molecular movement, there can be no temperature lower than absolute zero. At this temperature, a perfect crystal has no disorder.

When put together, these laws state that a concentrated energy supply must be used to accomplish useful work.

<u>Work</u>

Many of us commonly think of **energy** as the ability of a system to do **work**. Work is a force applied to an object over a certain distance, such as pulling or pushing a wooden block across your desk. Your muscles do work when they facilitate body movement. Units of work and energy are **joules (J)**. One joule equals one Newton meter **(N•m)**.

By definition, work is an energy requiring process. So, how do you describe energy? Energy is not a substance that can be held, seen, or felt as a separate entity. We cannot create new energy that is not already present in the universe. We can only take different types materials in which energy is stored, change their state, and harness the energy that escapes from the system in order to use it to do work for us. If the released energy is not used, it will escape and be "wasted" usually as heat.

<u>Heat</u>

Heat is the quantity of energy stored or transferred by thermal vibrations of molecules. At absolute zero, a system has no heat energy. Heat is additive. If two masses with heat energies of 5 joules and 10 joules are added together, the added masses will have a total heat energy of 15 joules. Heat and temperature should not be confused.

Temperature

The **temperature** of a system is the average vibrational energy of all the molecules within the system. Temperature is not additive. Putting two metal blocks that are 75˚ C together will leave the new system at the same temperature. Putting two masses that are 50˚ C and 100˚ C will make the new system somewhere between 50˚ C and 100˚ C. The temperature of which would be dependent on the masses and heat capacities of each added element.

When a fast-moving molecule collides with other molecules, it loses some of its **kinetic energy** to those surrounding molecules. Those molecules now have more energy than they had before. This extra energy is manifested as vibrations within the molecule. Thus, the temperature of the substance being hit will increase.

Energy Conversion

Consider the explosion of gasoline in your car. The spark ignites the gas, causing combustion. Combustion of gas is the rearrangement of the carbon and hydrogen atoms in gasoline and oxygen in air into more stable forms, carbon dioxide and water vapor. The energy left over from forming CO_2 and H_2O propel these molecules to move faster, causing the gas to expand. The expansion of the gas causes the movement of the pistons in your car engine, which turns the crank shaft, which turns the wheels. The fast-moving gas molecules collide with the wall of the cylinder and transfer their energy to it. This energy makes the metal atoms of the cylinder vibrate faster or in other words heat up. The engine walls must be cooled or the engine will melt. Oil and water from the radiator cool the walls of the cylinder. Air from the fan cools the water in the radiator which is released into the environment as wasted energy. This wasted energy causes the efficiency to be much less than 100%.

Efficiency

Energy efficiency is the amount of useful energy extracted from a system divided by the total energy put into a system. It may also be thought of as the efficiency with which we are capable of utilizing a resource. If we don't use the energy released from the chemical bonds in a resource, the energy goes into **waste heat**, sound, thermal vibrations, or light. The more energy conversion steps there are in a process, the more energy you lose as waste heat. For example, in order to run your car, the **chemical potential energy** in the gas must first be converted into **thermal energy** (or **heat energy**) by igniting the fuel. The thermal energy is converted to **mechanical energy** to make the engine run. This three step process has an overall maximum efficiency of about 30%. That means that 70% of the energy initially stored in the gasoline was lost as waste heat, mostly in the form of thermal vibrations to the surrounding materials. This illustrates the importance of learning about energy and trying to find better ways to responsibly use the resources available to us.

Measuring Energy

To determine the efficiency of a process, a way must be used to measure energy. You cannot pick up energy, turn it around in your hands to describe it, or put it under your pillow to see how long it'll stay there. We do not use mechanical measurements (like how much of a certain resource is needed to make your car go so many miles at such speed) because different pathways and different machines have very different efficiencies. If we tried to quantify it mechanically, we may never know just how much absolute energy is in the resource itself. Therefore, we use the "heating value" of fuels: how using so much of a certain resource (rearranging its bonds into a more stable state) converts to so much heat (motion of molecules).
We all hear every day about counting calories. What is a **calorie**? A calorie (cal) is defined as the amount of heat needed to raise one gram of water 1° C. A food calorie actually consists of one

kilocalorie, or 1,000 calories. Why do we worry about calories in relation to our weight? Energy conservation! If you feed your body more calories than it can use, it will store the energy in a stable state like body fat for you to use and lose later.

Energy is measured in other units as well. A common one is the **British Thermal Unit**, or **BTU**. One BTU is the amount of energy required to raise one pound of water 1° F. One gallon of gasoline contains about 125,000 BTU. A related unit is the **THERM**, or 100,000 BTU. Another familiar unit to physicists is the joule (J), equivalent to 0.239 calories or 9.47×10^{-4} BTU. Most systems of measurement throughout the world use joules to measure energy, even in food. When we speak in terms of energy, we often use the unit of **Quads**, which equals 10^{15} BTU. Another way energy content is often quantified is by converting the amount of energy of different sources to the amount in one barrel (42 gallons) of crude oil. Because the values are usually quite large, the equivalence is usually compared to so many *million* barrels of oil per day (**MBPD**). Burning 500 million tons of coal a year would be approximately 6 MBPD of oil for a year. Currently the United States is using about 18 MBPD, or 6.5 billion barrels per year!

Table 2: The average energy contained in or consumed by some common items. * Note that **10^{15} BTU = 1 QUAD**

Average Energy In Btu Of...

A Match	1
An Apple	400
Making A Cup Of Tea	500
A Stick Of Dynamite	2,000
A Loaf Of Bread	5,100
A Pound Of Wood	6,000
100 Hours Of Television	28,000
A Gallon Of Gasoline	125,000
20 Days Gas Cooking Range	1,000,000
Food For 1 Person For Year	3,500,000
Heat St. Louis House For Year	90,000,000
Apollo 17 To The Moon	5,600,000,000
Hiroshima Atomic Bomb	80,000,000,000
1000 Transatlantic Jet Flights	250,000,000,000
1 Year Oklahoma Energy	1,000,000,000,000,000 *
1 Year Energy 30 African Countries	1,000,000,000,000,000
Energy Used By U.S.1993	83,960,000,000,000,000
Energy Used By World 1993	343,000,000,000,000,000

Forms of Energy

Energy exist in many forms. Table 1 gives different types of energy along with their definitions.

Table 1: Forms of Energy

Energy form	Definition
Chemical Energy	Energy stored in chemical bonds of molecules.
Thermal or Heat Energy	Energy associated with the heat of an object.
Mechanical Energy	
Potential Energy	Energy stored in a system.
Kinetic Energy	Energy that is from motion of matter.
Electrical Energy	Energy associated with the movement of electrons.
Radiant or Solar Energy	Energy that is from the sun.
Nuclear Energy	Energy found in the nuclear structure of atoms

Chemical Energy Basics

When we use a resource, such as coal, to produce energy, we are breaking the chemical bonds within the substance and rearranging them into more stable bonds. This change results in the formation of different products, such as carbon dioxide and water in the case of combustion, and a release of energy.

That may sound complex, but this analogy makes it really simple. Picture an old-fashioned water well. The molecule is at the bottom of the well. It takes energy to bring it to the top of the well (winding up the bucket). Think of the molecule as now being broken up into its atoms--the energy that was expended to do that is its **binding energy**, or the energy holding the atoms together in a molecule. One way to measure binding energy is the **heat of formation**. Now those independent atoms (at the top of the well) combine into other molecules that are even more stable. Combining means that they fall back down into a couple of new wells. These wells are deeper than the original well--there is more binding energy in these new molecules. When the atoms "fall down" into the new wells, becoming new molecules, energy is released. The hand-crank spins wildly as the bucket falls to the bottom. To figure out how much net energy is released, just compare the depths of the new wells to the old one.

A numerical example may help explain this. The combustion of methane to carbon dioxide and water is represented by the following chemical reaction:

$$\mathbf{CH_4 \quad + \quad 2\,O_2 \;+\; spark \quad \longrightarrow \quad CO_2 \quad + \quad 2H_2O \quad + \quad heat}$$

The heat of formation of CH_4 is -17.88 kcal/mol. The heat of formation of O_2 is defined as 0 kcal/mol. The sum of the heats of formation of the reactants (-17.88 kcal/mol + 0 kcal/mol) is the sum of the depths of the original wells in the previous example. Adding a spark to the left side of the reaction is analogous to cranking the bucket to the top of the well and expending energy.

Carbon, hydrogen, and oxygen atoms are now at the top of the well. They then combine into other molecules, namely CO_2 and H_2O. In combining, the molecules fall into new "wells" whose depths correspond to the heats of formation of the new molecules. The well for CO_2 has -94.1 kcal/mol, and the well for H_20 has 2(-57.8 kcal/mol) because there are two moles of water formed for each mole of methane burned. The combined depth of these two new wells for the products is -209.7 kcal/mol, which is deeper than the wells the molecules came from.

With numbers, the equation above looks like:

$$\mathbf{-17.88\ kcal/mol\ +\ 0\ kcal/mol\ =\ -94.1\ +\ 2(-57.8)\ kcal/mol\ +\ heat}$$

Now rearrange:

$$\begin{aligned}\mathbf{heat} &= \mathbf{-17.88\ kcal/mol\ +\ 94.1\ kcal/mol\ +\ 2(57.8)\ kcal/mol} \\ &= \mathbf{+191.82\ kcal/mol\ methane\ burned}\end{aligned}$$

This means that there is 191.28 kcal per mole that is now expressed as heat and the motion of the products, CO_2 and H_2O.

Fossil Fuels

Fossil fuels are **coal**, **oil**, and **natural gas**. We call them **fossil fuels** because all of them in some way originated from the decomposition of organic matter in or on the earth. Each provides a unique source of energy that humans have taken advantage of over thousands of years. Approximately 90% of our energy consumption comes from fossil fuels. Approximately 50% of the fossil fuels humans have consumed throughout history were used in the last 20 years**.** The scary fact is that we cannot make more. In other words, our fossil fuel **reserves** are finite. Humans have used most of our reserves in a 200 year period. We will need to convert our energy usage to the most plentiful fossil or non-fossil fuel sources over the next hundred years in order to meet the world's growing energy needs.

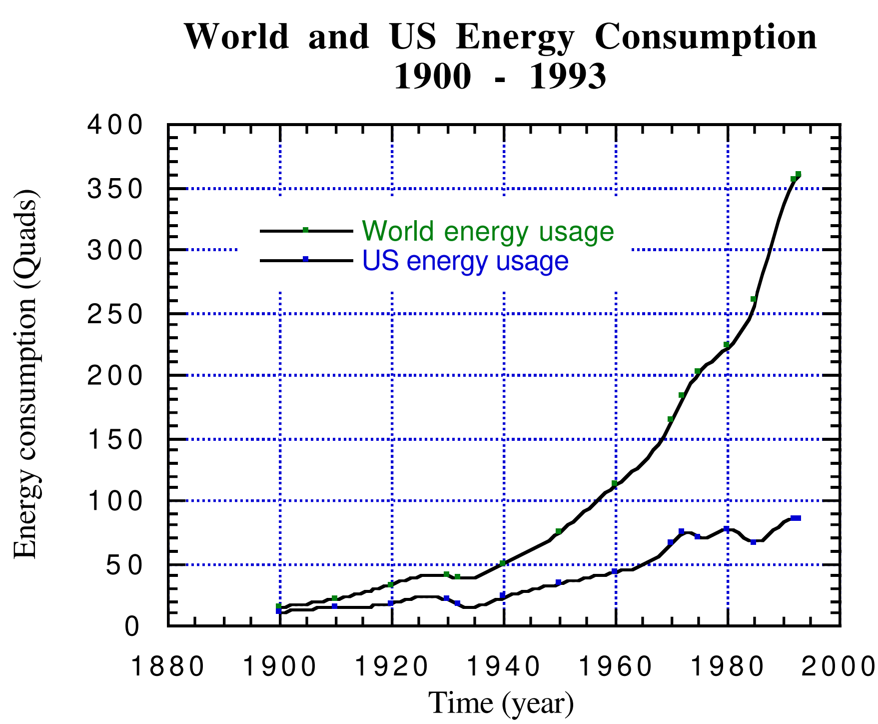


Figure 1: World and US Energy Consumption (1900-1993) represents the approximate amount of energy in Quads used by the world (top line) and the United States (bottom line).

As you can see, the energy consumption of the world has taken a dramatic increase since 1900. The dip in the curve in the 1930's represents a decrease in energy use due to the Great Depression. In 1973 the United States also experienced decreases in usage due to increased oil prices as a result of the Arab Oil Embargo and again in 1983 with increased oil prices. The world energy consumption was not affected as greatly and is increasing at a greater rate because now many third world countries are increasing their energy usage as they industrialize. The United States' consumption is more steady because most of our industrial development has already occurred.

Coal

Coal is composed primarily of carbon. It is formed from dead plant matter which decomposes into peat in swamps over millions of years. The peat is continually buried under other matter, mud, and sand in non-marine environments. This burial causes it to decompose as its bonds recombine and rearrange. With increases in pressure and temperature, coal seams form. Several different types of coal can be found depending on the depth and location of the seam. The four main types of coal, which differ by carbon content are shown in the following table.

Table 3: Types of Coal by Sulfur Content (Hinrichs p458)

Type of Coal	Carbon %	Energy Content (Btu/ lb)
Lignite	30	5000-7500
Subbituminous	40	8000-10,000
Bituminous	50-70	11,000 - 15,000
Anthracite	90	14,000

Lignites are the "youngest" coals, which have high water content and low **heating values**. The heating value of a fuel is used to quantify the useful energy content of different fuels. Lignite often has many impurities and is therefore not a preferable type to use. **Subbituminous coal** is cheaper to mine because it is not as deep as bituminous coal and contains less sulfur than lignites. **Bituminous coal** is the most abundant type of coal. It has a high heating value, but it also has a high sulfur content. **Anthracite coal** is a very hard coal which burns longer, with more heat and with less dust and soot than the other types of coal. These qualities make anthracite a popular home heating fuel.

Not all plant material turns into coal; some eventually becomes graphite, and a tiny amount is compressed into diamonds. Coal is burned in power plants to produce heat which is used to change water into steam. This steam turns a large fan-like structure called a turbine which generates electricity.

Coal Reserves

Coal reserves are located all over the world. Although the United States has approximately 22% of the world's coal reserves, coal only supplies about 24% of the our energy needs. Coal usage worldwide is increasing due to high oil prices and skyrocketing demand for oil in the transportation sector. Electrical utilities consume about 87% of the total coal produced, and about 55% of electrical power generated from fossil fuels comes from coal. Coal resources are projected to last from between 400-450 years. Coal is measured in **short tons**, 2000 lbs each, which are equivalent to approximately 3.5 barrels of oil. One short ton can provide approximately 26×10^6 BTU.

Mining

Coal is commonly recovered from the earth by two methods. **Surface mining**, or strip mining, is preferred due to cost and safety factors. Strip mining usually occurs on flat land. Hilly or steep terrain requires contour mining. **Deep mining** involves digging shafts and tunnels to gain access to the coal seam. The coal can then be excavated from the seam with only some columns of earth left behind for support. Deep mining is unappealing because of safety hazards in the tunnels and health hazards like black lung disease. However, deep mining has become more acceptable due to automation. On the flip side, the negative effects of mining are the intense, irreversible damages inflicted upon the environment.

Coal Gasification

Coal gasification is a process by which coal is converted into a synthetic fuel, natural gas. The process basically adds hydrogen to the carbon in coal. In order to change the carbon to hydrogen atomic ratio from 12 to 1 in coal to 1 to 4 in natural gas, several steps must be carried out. First the coal is brought into contact with high-pressure, high-temperature steam in the gasifier. The heat for the reaction from coal to "synthesis gas" is provided by introducing some oxygen, which causes some of the coal to burn. In the second stage, the C:H ratio is increased by further addition of steam, which increases the heating value of the fuel. The resulting mixture is then purified and converted to methane in the presence of a nickel catalyst. The methanization is an exothermic reaction, in which lots of low temperature heat is lost, therefore making the process inefficient. Synthetic methane is the resulting fuel. See Figure 2 for a schematic of a coal gasifier.

Coal Liquefaction

Coal liquefaction converts coal into synthetic crude oil, or **syncrude**. This process also involves adding hydrogen to heated coal and then separating the gas and liquid product. The hydrogen is added to coal in a slurry at elevated temperatures and pressures. The high temperature breaks the carbon bonds, which produces a liquid phase product due to the high pressure.

Economical considerations hinder the further development of coal gasification and liquefaction systems. It has been neither economical nor efficient to produce synthetic fuels from coal on a large scale basis. The production facilities are more expensive to run and maintain than simply buying the oil or natural gas itself. It is important, however, that the processes are maintained and improved even at a slow rate. As our reserves of crude oil are depleted, the price of oil will probably increase dramatically, making the use of synthetic fuels more economical.

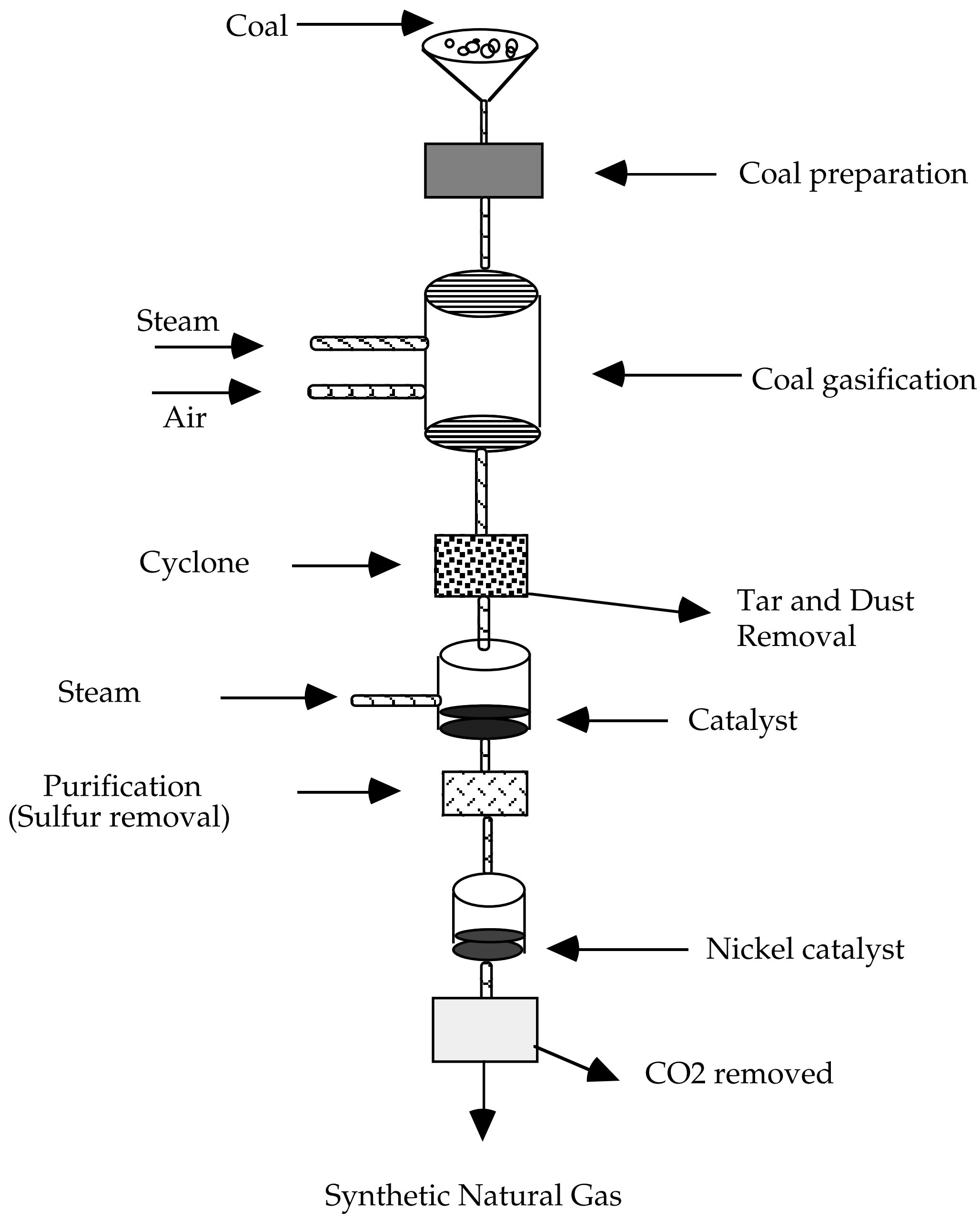


Figure 2: A basic coal gasification scheme.

Oil

Oil is mainly a mixture of hydrocarbons and is formed by the deposition of dead plant, animals, and marine microorganism matter in or near marine sedentary basins. Once the matter is buried at about 450 meters, the temperature and pressure begin to cause the rearrangement of matter. The newly-formed liquid molecules migrate through porous rock formations such as limestone and sandstone until they are trapped by a non-porous rock barrier. **Crude oil** is a mixture of hydrocarbons with some oxygen, nitrogen, and sulfur impurities. Sulfur content of crude varies and is either designated "sweet" (less than 1% sulfur) or "sour" (higher than 1% sulfur). One barrel of oil is equivalent to 42 U.S. gallons and can provide about 6 million BTU, or about 143,000 BTU per gallon.

Reserves

Crude oil reserves are located all over the world, but the Middle East alone has about 63% of the known reserves. Saudi Arabia contains by far the most oil with the equivalent of 1,545 Quads of proven resources available. Even though the United States has only about 161 Quads of proven resources left, we have more wells than any other country in the world. Our use accounts for about 25% of the world's oil consumption, while we only have 3% of the world's oil. We import around 40% of the oil we use. In 1994, 65% of oil used in the United States was used in transportation. Only 3% was used for the generation of electricity, with the other 32% going to industrial, commercial, and residential uses. We rely so heavily upon oil products for transportation purposes because it is an easily transportable liquid, we already have an efficient distribution system set up, and there is an entire fleet of vehicles on the road that use gasoline for operation.

Recovery

Petroleum is usually recovered by drilling wells down through the non-porous rock barrier under which the oil is trapped. There are three types of oil recovery. **Primary oil recovery** occurs as the oil flows out of a well by its own pressure or is pumped out. This removes about 30% of the oil. Another 10% is removed by flooding the well with high pressure water or gas, a method of **secondary** recovery. Some methods of **tertiary** recovery have been developed in which the oil is heated (by burning some underground detergents or the oil itself) to scrub it out. This only removes another 10%, however, and requires energy to do so. Therefore, about half of the oil is left trapped in this rock with no economical means for its recovery.

Unconventional oil recovery entails obtaining oil from **oil shale**. Oil shale is a material with hydrogen content between that of coal and crude oil due to the fact that it was never buried deeply enough or heated enough to form crude oil. The concentration of oil in this material is quite low, and it is chemically bonded to the shale. The maximum amount of recoverable oil is one barrel per 2.4 tons of sand or 1.5 tons of rock. Enormous problems also occur with extraction of oil from oil shale. The advantage is that 20% of the United States contains oil shale. The potential amount of oil contained in oil shale is greater than the known and unproved crude oil resources in the world, which would add approximately 40 years to the projected time before oil will be exhausted. The dilemma is that it takes about half the energy contained in the shale to extract the oil. Prices for barrels of oil from oil shale can range from $40 to $80 per barrel, whereas normal crude oil cost about $18.75 per barrel in June 1995. Recovery of oil from oil shale is therefore not economically feasible at this time.

Refining

Crude petroleum is refined by **fractional distillation**. This means that the distillation process occurs with successive separations carried out at increasingly higher temperatures. The condensed vapors are collected in several portions, or fractions, the first fractions being richest in low boiling point components. These include gasoline, kerosene, furnace oil, naphthas (liquid hydrocarbon mixtures), and lubricating oils. The heavy residues left over are used as asphalt and residual oil. The second step in oil refining is conversion, or cracking, of the molecules in order to squeeze out a higher percentage of lighter, low boiling point products like gasoline from each barrel of oil. The last step, treatment, or enhancement, increases the quality of the product by such means as removing sulfur from kerosene, gasoline, and heating oils. The distribution of products is shown in the following graph, Figure 3.

The crude petroleum that we recover is refined into useful products for the production of electricity as well as for use in machinery and equipment, such as automobiles. Many products we use every day are produced from petroleum such as ink, crayons, bubble gum, dish washing liquids, deodorant, eyeglasses, records, tires, heart valves, and more!

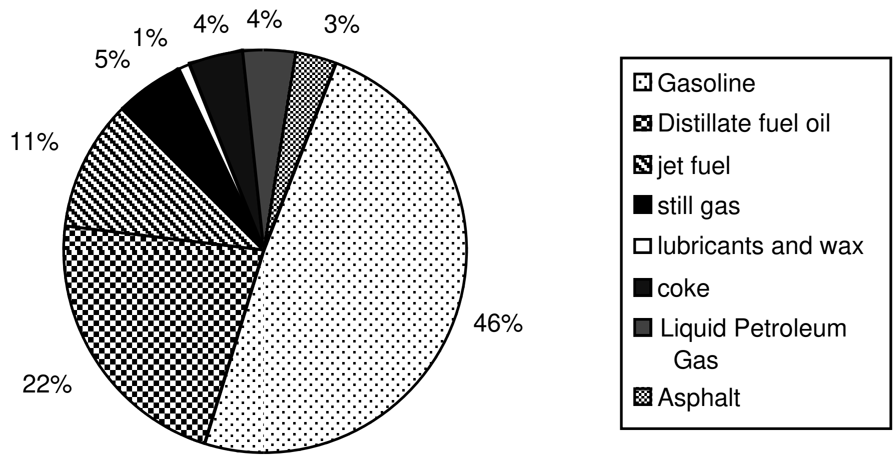


Figure 3: Crude oil products by percentage.

Oil in the Twentieth Century

We rely heavily on oil, and it has fueled most of the global energy consumption since World War II. Past trends have been governed by both economical and political occurrences. The Great Depression marked a decrease in the total amount of fuel used in the United States, and oil consumption decreased accordingly. Nevertheless, the U.S. demand for oil has increased greatly with our energy needs. In 1950, oil accounted for less than one third of the world's energy use, but today it accounts for almost half. The last two decades have been truly pivotal in world oil consumption and prices. In 1960, a cartel called the Organization of Petroleum Exporting Countries, or **OPEC**, was formed by the oil-producing states of Algeria, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, Venezuela, and the United Arab Emirates. OPEC's influence on petroleum prices steadily grew until, in the 1970's, OPEC was able to set their own prices for their exports and take the control of oil away from foreign companies.

Several events marked the dramatic increase of oil prices, which still remain in effect, long after the political situations were resolved. The Arab-Israeli war prompted the Arab Oil Embargo of 1973, during which the Arab OPEC countries cut back on production and refused to export their oil to several Western countries including the United States. This caused the price of oil per barrel to triple from about $8 to $25. Then in 1978 and 1979, the Iranian revolution caused a disruption in production, and prices doubled from $22 to $44 per bbl. These events are reflected in the World and US Energy Consumption chart (Figure 1, p 9). In response, the countries of the world placed a greater emphasis on reduction and conservation of energy use. Thus, the world's dependence on OPEC fell, and the prices began to decline around 1981, continuing until the Iraqi invasion of Kuwait in 1990, which prompted a sudden increase in the price of oil on the world market. Prices then began to fall again as other countries increased production to make up for the drop in production in Kuwait. In June 1995, the cost of oil was approximately $18.75 per barrel.

The low cost of oil and its adaptability to many uses make it a key fuel for expanding economies. The United States, however, depends less today on oil for its fuel mix, and more on coal, natural gas, nuclear, and renewable technologies. Our transportation industry still relies heavily on oil as its chief source of energy. In order to significantly decrease usage, the American public will need to be encouraged to depend less on their cars and more on public transportation. Especially in big cities, car pooling to work and public transportation can reduce the amount of oil consumed.

Natural Gas

Natural gas is 99% methane (CH_4) and 1% other light hydrocarbons such as ethane, (C_2H_6), propane, (C_3H_8), and butane, (C_4H_{10}), as well as some aromatic hydrocarbons. Natural gas is the gaseous component of coal and oil formation. Uses of natural gas range from industrial and commercial heating and power to residential heating, cooling, and making the blue flame in our kitchen burners (gas stoves). Places in the earth where large deposits are found are called **reservoirs**.

Reserves

Natural gas is either found mixed in oil or it is released from coal. It is measured in **cubic feet**, ft^3. The energy content in 6,000 ft^3 of natural gas is the equivalent of one barrel of oil. World reserves are greatest in Russia, followed by Iran, and the United States. The Annual Energy Outlook in 1994 estimates that world gas reserves are over 30 trillion cubic feet, approximately equivalent to 5,000 Quads of energy. Eurasia and the Middle East have about three-fourths of the world's natural gas. The rest is fairly evenly distributed among other regions of the world such as North America, Central and South America, Western Europe, Africa, and Asia/Pacific. Known reserves are projected to enlarge as previously unexplored regions are explored. Projections for the longevity of natural gas range from 80 to 135 years. Remember that every projection of how long any fossil fuel will last is dependent on the actual growth rate of consuming countries and the trends of consumption and economics of the other fuel sources.

Recovery

Wells for natural gas are drilled in underground reservoirs of porous rock. When it is removed from a reservoir, natural gas can either be pumped to the processing station for removal of liquid hydrocarbons, sulfur, carbon dioxide, and other components, or stored in large caverns underground until it is needed. Pipelines are the principal method of natural gas transportation. Because natural gas was not highly valued in the early half of this century, the expansion and development of the pipeline system did not occur until about 1940. In addition, natural gas deposits were often burned off when they were found mixed in oil deposits. Today gas pipelines cover the United States, Canada, Western Europe, and Russia. Transporting it overseas has been made more economically expedient by liquefaction techniques, but it is still quite expensive. The price of oil has been a key factor in determining the development of transportation facilities for natural gas.

Environmental Concerns

Many environmental problems are associated with burning fossil fuels for energy. The combustion reaction of a fossil fuel with oxygen releases water, carbon dioxide, and any impurities contained in the resource into the environment. This section discusses some of the major environmental concerns arising from fossil fuel use.

Coal

Although coal is abundant, its impurities pose potential dangers to the environment, in the form of acid rain, destruction of topsoil fertility and/or global warming. Since the 1960's, increasing importance has been placed on the need for a cleaner use of coal for environmental reasons.

Acid Rain

The high sulfur content in coal is primarily responsible for acid rain. When sulfur-containing coal is burned, the sulfur is usually emitted as sulfur dioxide, SO_2 **(1).**
The SO_2 then reacts with the air, becoming oxidized to sulfur trioxide SO_3 **(2)** and then reacts with water to form droplets of sulfuric acid, H_2SO_4 **(3)**.

$$\mathbf{S + O_2 \longrightarrow SO_2 (1)}$$
$$\mathbf{2SO_2 + O_2 \longrightarrow 2SO_3 (2)}$$
$$\mathbf{SO_3 + H_2O \longrightarrow H_2SO_4 (3)}$$

The sulfuric acid is absorbed by fine particulates in the air along with water vapor. The fine particulates, often formed from the ash of burnt coal, provide an excellent surface for catalytic reactions to occur, producing more H_2SO_4. The acid then falls as acid rain or even as dry deposition, known as acid dust.

Acid rain has negative repercussions on both humans and the environment. Increasing acidity of lakes may cause the death of aquatic plants and animals. Acid rain also damages vegetation in four ways:

- Leeching of nutrients from the soil.
- Causing lesions in photosynthetic leaves.
- Increasing the plants' susceptibility to disease and insects.
- Tainting water supply.

Man's health is also directly affected by acid rain, manifested by afflictions from a minor skin irritation, to severe lung damage, and possibly death. Acid rain also affects our lives in less serious ways. Most people who rollerblade know how annoying it can be to skate on a sidewalk with pits in the surface. Those pits are largely the result of acid rain. The problem of acid rain is not limited to the United States. In Europe many of the marble monuments of the Greek and Roman empires are being destroyed by the effects of acid rain. When fossil fuels with nitrogenous impurities (NO_x) are burned, the nitrogen reacts with water to form nitric acid. This is a particular problem in urban centers where many automobiles that emit oxides of nitrogen are operated daily.

In an attempt to regulate the amount of sulfur and nitrogenous compounds in the air, the government has placed many regulations on power plants in the form of Clean Air Acts. As a result, the amount of acid rain present has decreased as well. What have coal power plants done to reduce the sulfur emissions? Many plants use a combination of methods to decrease emissions of sulfur and nitrogenous compounds:

- Settling chambers or gravitational collectors spin out heavier particles.
- Electrostatic precipitator have high voltage attract particles.
- Fabric filters use bags of fibers that trap particles much like a vacuum bag.
- Scrubbers use water droplets to trap particles and the sulfur is chemically converted to a recoverable solid.
- Coal with lower sulfur content is used.

Global Warming

In addition to acid rain, coal power plants pose yet another problem to the environment known as the **greenhouse effect**. The combustion of coal produces three primary products: ash, H_20, and CO_2. In the atmosphere, these gases trap infrared radiation from the earth which would, under normal circumstances, radiate out to space. The consequence of **greenhouse gas** build-up is global warming, which may adversely affect the earth's climate. The increasing overall temperature could possibly cause warming in the oceans or melting of polar ice caps. Plant and animal life could be greatly affected by these changes. Although estimates vary, experts project a possible 2° C increase in the earth's temperature by the year 2050. This rate of increase is approximately 7 times the normal historical rate of about 0.04° C per decade over the last several hundred years. The question at hand is how much and how fast the temperatures will rise. Destruction of rain forests contributes to this effect because trees are an excellent sink, or utilizer, of $CO_{2,}$ as it is a requirement of **photosynthesis**.

Unfortunately, coal power plant scrubbers cannot take care of CO_2 emissions. Planting more trees would be an obvious way to create users of CO_2. However, because carbon dioxide is a natural product of combustion of a fossil fuel with oxygen, the only real way to reduce the amount of carbon dioxide output is to reduce fossil fuel consumption.

Oil and Natural Gas

As with any fossil fuel, environmental considerations such as pollution and harmful emissions arise with the use of petroleum products. **Smog** is primarily created by hydrocarbons along with carbon monoxide (CO) and other complex toxic molecules from oil processing, all of which are emitted from the exhaust pipes of cars. As the problem with emissions has increased with the growth of automobile use, government regulations of the acceptable amount of emissions have multiplied accordingly. Auto engineers have endeavored to design cars which burn gasoline more cleanly and efficiently and incorporate more advanced filter systems. Car manufacturers have developed automobiles which are capable of reducing hydrocarbon emission by 97 to 99%. They are also making strides to develop "pollution-free" cars, which have modified pollution control devices. Manufacturers are also experimenting with cleaner burning fuels like methanol and natural gas. Other engineers have designed solar and electric cars. However, each fuel source presents a unique set of problems.

Worldwide crude oil distribution and trade occurs mainly by sea. This presents a potential problem in the form of oil spills in the oceans, threatening coastal and marine plants and wildlife in addition to coral reef degradation by anchoring tankers.

In the past decade there has been a movement to expand natural gas usage for several reasons. There are greater domestic reserves of natural gas, and it is the cleanest-burning fossil fuel because it contains the least amount of carbon and virtually no sulfur. Since natural gas is a clean burning fuel, some new cars are designed to use it. Natural gas costs about two-thirds as much as gasoline per BTU, and it is in comparatively plentiful supply. However, in order to convert to natural gas use for transportation, fuel tanks would have to be pressurized, making them heavier and larger.

Cars would also need to be refueled about every 100 miles because natural gas has a lower energy density than gasoline.

Equipment and technology are being developed for natural gas use in the energy -demanding sectors of electricity generation, transportation, and residential and commercial cooling. Electrical generation by natural gas has been enhanced with the development of combined-cycle systems in which a natural gas-fueled combustion turbine combined with a heat recovery steam **generator** and steam turbine work to efficiently produce electricity in two ways. These systems produce less than half the CO_2 per kilowatt hour than do state-of-the-art coal power plants.

Renewable Energy Sources

A **renewable resource** is a fuel source that can provide energy for man forever if man takes care of it. There are many types of renewable resources that man has learned to take advantage of, ranging from solar power to biomass and geothermal to wind power. With these resources, man has utilized the power of the sun, wind, and the earth itself. The efficiency varies with the resource, however.

Passive Solar

One quite common application of renewable energy is **passive solar heating** for the home. A passive solar heating system collects energy from the sun and uses this energy to heat a space directly, such as a sun room, or to heat a fluid. If a fluid is heated, it is considered a source of **thermal mass** for the system, which can be used later to radiate the heat to the surroundings. The five main components of passive solar heating are the collector, absorber, storage mass, distribution system, and control system. In the case of a sunroom, the **collector** is the double layer of glass in thermal window panes that trap the heat in and reduce the amount of heat loss by convection. The **absorber** consists of several parts: surfaces of the walls, floors, and any water-filled containers inside the sunroom. The **storage mass**, or thermal mass, is the building material such as concrete, brick, and any water. Thermal mass usually has a high heat capacity to retain the heat absorbed during the daylight hours, and radiate it at night. One method of increasing the thermal mass of a house is to build the house partially underground. A **distribution system** of fans or vents should be installed to move the heat by natural convection. **Control systems**, or heat regulation devices such as movable **insulation**, roof overhangs, thermostatically controlled fans, and adjustable vents are used to control the temperature of specific rooms. Hot water heating systems may heat a primary fluid that will not freeze in the winter, and pump that fluid to a heat exchanger to heat water for use inside a building. Many innovative passive solar heating systems have been designed to optimize the efficiency of the passive solar home.

Active Solar

Another method of capturing the sun's energy is through the use of **active solar systems**, or **photovoltaic systems**. Photovoltaic systems use solar cells to directly produce electricity from solar radiation. The photovoltaic cell is made by using two semi-conducting materials which have different types of charge carriers, so when they are placed back-to-back a potential difference can be measured. The boundary between the two conductors is called a **depletion region**. If a **photon**, or "bundle" of electromagnetic energy, from the sun strikes an electron near the boundary between these elements, that electron moves to a higher energy level. The potential difference moves this free electron leaving an unoccupied space, or "hole." The entire process causes a charge separation. As the electron and the hole move across the photovoltaic cell and travel through the wire connected to what's being powered (a solar calculator for example), an electrical current in the circuit is produced.

This system is very cost effective in situations where electric power is not readily available and the power requirements are relatively low. It is roughly estimated that about 10,000 square miles of solar cells could produce enough energy for the entire nation! So, why haven't we converted our energy usage to active solar? 10,000 square miles of solar cells is a lot of solar cells! They would have to be built, a maintenance system would be required in order to maximize efficiency, the weather would have to be dependable, and it would be expensive. It has not been economical to develop this source because the cost of the cells is too high. Perhaps as the replacement of fossil fuels becomes essential, this technology may be better developed. Many homes and businesses use solar cells to reduce their electric bill. Solar cars have also been developed as a result of competitive races between major universities.

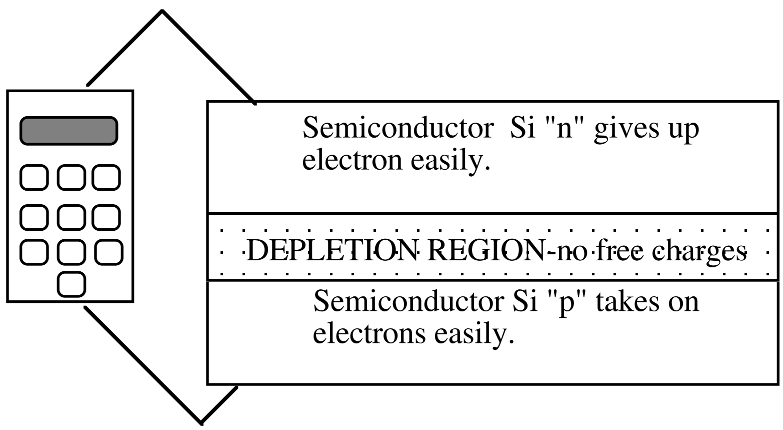


Figure 4: A solar-powered calculator is an example of a complete active solar system. When a photon strikes the cell, an electron is excited and becomes free to move, leaving a "hole." This causes one electron after another to fill the hole. The electron moves one way and the "hole," or lack of electron, moves the other way. This creates a current that is directed through the wire to the calculator. The circuit is now complete, and your calculator turns on.

Solar Ponds

Solar ponds are also utilized to capture the sun's power. A solar pond uses the principles of energy transfer by convection to heat water to steam for heat production. The bottom of the pond is dark colored in order to absorb the sun's rays. The pond is filled with saline water made with NaCl, $MgCl_2$, sodium carbonate, or sodium sulfate. A gradient is maintained at varying densities. The bottom is the most dense and is used as a **storage zone**. It is **convective** and can store a working temperature of up to 80-85° C. Above the bottom layer is a nonconvective zone, or **insulation zone**, with a density gradient which facilitates a temperature gradient as well. This layer functions as insulation. There is no convection in the gradient layer because even though the warm water would normally rise, the high salt concentration at lower levels does not allow the water to be light enough to float up as it warms. This prevents heat in the bottom from reaching the top of the pond. The top layer, or **surface zone**, is convective due to wind-induced mixing and daily heating and cooling. These layers are represented in Figure 5 on the following page. The hot brine, or salt water, on the bottom may be extracted and used for direct heating and low-temperature industrial uses like drying crops and agricultural shelter heating. The problem with solar ponds is that it is essential to have a controlled saline density gradient, which is quite difficult to maintain. Additionally, the pond must be kept free of dirt and other light-absorbing materials. Thus, for large scale operations, the difficulties are too great to rely upon solar ponds for efficient heat production.

Here is one possible system for converting the heat energy from the salt water to electricity. An organic fluid is heated and boiled as it is pumped through tubes in an evaporator. The hot brine is pumped from the bottom of the solar pond through the evaporator (where it transfers heat to the organic fluid), and returned to the pond. The organic fluid, which is now a vapor, has sufficient pressure to spin the turbine and generator. The vapor has transferred some of its kinetic energy to the turbine. The cooler vapor is pumped to the condenser where it is condensed to a liquid as it transfers energy to the cold water being pumped through the tubes of the condenser. The organic liquid is now pumped to the evaporator to continue the process. As the gradient layer diffuses as time passes, new freshwater and salt water can be pumped into the pond to maintain a sufficient gradient layer.

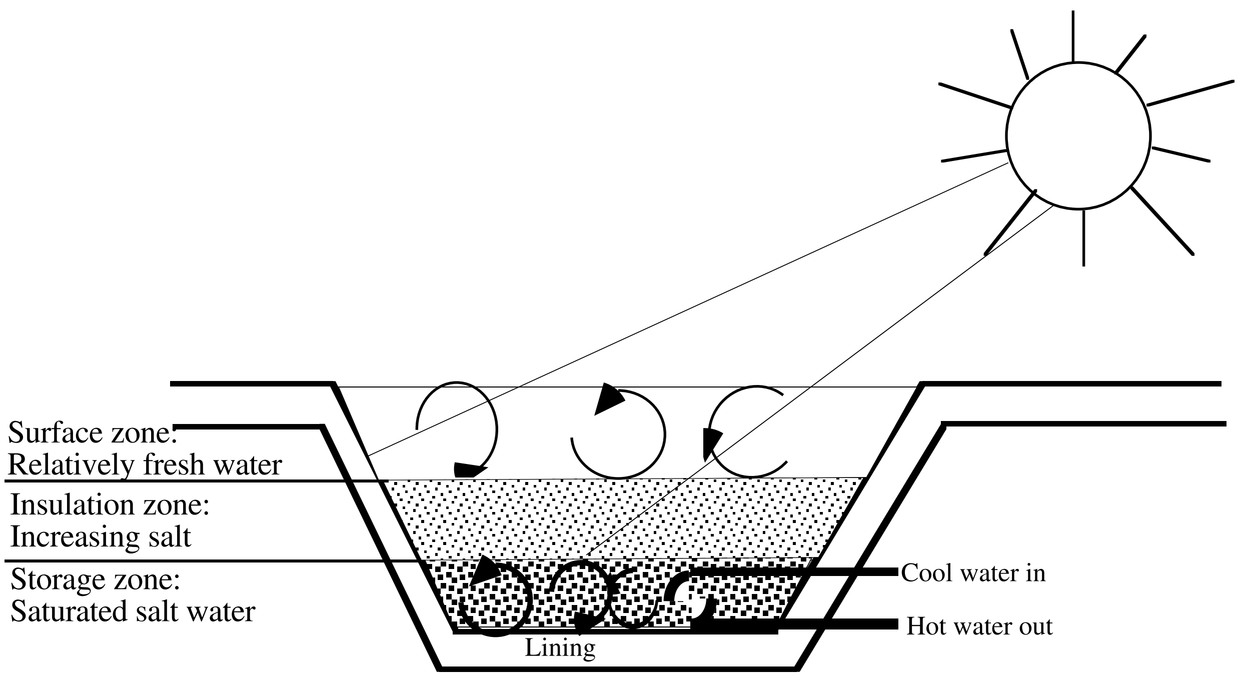


Figure 5: Schematic of a solar pond

Wind Power

Not only does the sun supply the earth with direct **radiant energy**, but it also heats the gases of the atmosphere, which produces wind. **Wind power** uses energy from the moving air to turn large blades on windmills. In the past, the motion of the blades was used to grind flour or pump water, but now the blades turn turbines, which rotate generators in order to produce electricity. Wide open windy spaces are needed in order for this system to be efficient. Wind energy produces no air or water pollution, involves no toxic or hazardous substances, and poses no threat to public safety. The major problem with wind power is the limited ability of sites with steady wind and the lifetime of the wind power generator units.

Hydropower

Flowing water can also be used to generate power. **Hydropower** systems use the energy in flowing water for mechanical purposes or to produce electricity. The head and the flow are two variables that essentially determine the potential efficiency of a site for a hydropower system. The height of the falling water is called the **head**. The greater the head, the higher the velocity of the water falling will be, and hence the greater the pressure with which it hits. The **flow** is the total amount of water moving. The advantages of using water for a power source are that the resource is free, and it can be stored effectively and put to use quickly. Water for hydropower may be stored in a reservoir or above a dam forming a lake. The mechanics of the hydropower system are very similar to the wind power system, the only difference being water turning the blades instead of wind. The turning wheel can also drive a shaft to produce mechanical energy, which may be used to perform simple tasks, especially for agricultural applications such as sawing wood or grinding grain.

Most sites available for large scale hydroelectric plants have already been developed. Therefore, new developments in hydroelectric generation are small scale. Small scale hydropower systems are quite efficient when used to supply local needs. The Hoover Dam is an example of a large scale hydroelectric plant still in use in the United States today. The United States and Canada have the greatest number of hydroelectric plants. Virtually every other country in the world has some development of hydropower plants. **Hydroelectricity** is the power source of choice for many developing countries. However, the development of hydroelectricity is quite expensive as well as site-dependent. There are some concerns over the detrimental environmental effects of hydroelectric power. Environmental problems include siltation and erosion, the breaking up the free passage between oceans and rivers, weed growth, disease spread by small organisms that live in stagnant water, and floods due to dam failures.

<u>Geothermal</u>

Geothermal energy originates from the inner core of the earth. Geothermal energy is evident on the earth's surface in the forms of volcanoes, geysers, and hot springs. Even though the amount of energy within the earth is basically infinite, our ability to use it is limited by site considerations. Favorable sites for geothermal energy extraction are rare and occur where magma, or hot molten rock of the earth's mantle, has been pushed up near the earth's surface through faults and cracks in the crust. The resulting "hot spots" 2 to 3 km from the surface naturally heat water that leaks in. From there, the steam and hot water may be used directly to turn turbines or to heat homes. As the steam and hot water is expelled from the hot spot, cooler water runs back down, and the cycle continues.

<u>Biomass</u>

Biomass materials are the remains of animal or plant life that have not been subjected to the tremendous heat and pressure that formed the fossil fuels. Biomass materials such as wood, dried dung, animal wastes, and even garbage can be used as renewable sources of energy to heat homes, cook food, and even produce electricity. The energy produced when wood is burned was originally stored in the bonds of the glucose formed during photosynthesis in the leaves of the tree. As the wood is burned, energy is required to break the bonds in the cellulose. As the carbon dioxide and water are formed, more energy is released than was initially required to break the bonds. Thus, net energy is released. (Recall the "well" analogy.) Examples of widely-used biomass energy systems are ethanol in gasoline, anaerobic digestion of municipal waste water or swine waste to produce methane gas, and incineration of garbage.

There are several other applications of biomass fuel. **Ethanol** is presently used in **gasohol** (10% ethanol, 90% gasoline), resulting in a cleaner burning fuel, which emits an average of 20% less carbon monoxide than unblended gasoline. Swine farmers collect the manure and add methane-producing bacteria called **methanogens** in a controlled environment. The methane is collected and burned to produce electricity for the hog confinement buildings. Municipal waste water treatment plants use a two stage process to separate the waste into two parts. One converts waste sludge into a variety of organic acids and carbon dioxide; the other reacts the waste with the methanogens to produce methane. The forest industry now burns much of its waste to provide heat and electricity.

Important Considerations

Unfortunately, use of renewable resources can be greater than its rate of renewal. For example, a biomass resource such as corn for ethanol production is dependent on the yield of corn crops. In the case of wind power, the wind must blow at a specific speed and from a specific direction for optimum efficiency. Hydropower is renewable as long as it rains. The efficiency is dependent on the depth of the water behind the dam, which is also site dependent. Further, in a reservoir-based hydropower plant, silting may occur, which would slowly decrease the potential of the power plant.

Even passive or active solar systems are dependent on the weather conditions and the number of daylight hours. For optimum efficiency, photovoltaic systems must be mounted on a movable base to keep the surface of the solar cell perpendicular to the sun's rays. In addition, the electrical energy produced in the daylight must be stored in batteries for use at night. The efficiency of passive solar systems, such as sun spaces and solar water heaters, is greatly affected by climate, season, and building orientation with respect to the sun. Solar heating systems that use fluids and heat exchangers must be designed to withstand the temperature range of the site. For example, in colder climates, antifreeze must be added to water to prevent freezing and subsequent pipe bursting. In the case of sun spaces, the room should be facing south with shade from the roof overhang or exterior structures or trees in order to prevent overheating in the summer.

As long as the sun shines, it will produce wind, rain, and biological growth. The amount of energy reaching the outer atmosphere of the earth from the sun is quite predictable and dependable. The difficulty is that the amount of usable solar energy received on a specific day at a specific site is very unpredictable and undependable. If there are cloudy skies, the solar radiation is said to be **diffuse radiation** which cannot be used efficiently even though it is there. Weather conditions and site conditions including natural disasters such as floods, earthquakes, and hailstorms greatly limit the dependability of solar energy. Thus, solar power plants may not be the magical alternative source to replace fossil fuels for large scale use. However, small scale use of renewable resources to supply energy needs can reduce dependence on fossil fuels.

Nuclear Energy

As the reserves of fossil fuels continue to diminish, alternative energy resources are being developed. Nuclear power is one example of an alternative energy resource. However, public health and safety considerations concerning nuclear power plants are abundant. The purpose of this section is to describe the mechanics of nuclear power as well as to answer some commonly asked questions about nuclear power.

Basic Nuclear Principles

The atom is composed of subatomic particles called **protons**, **neutrons**, and **electrons**.

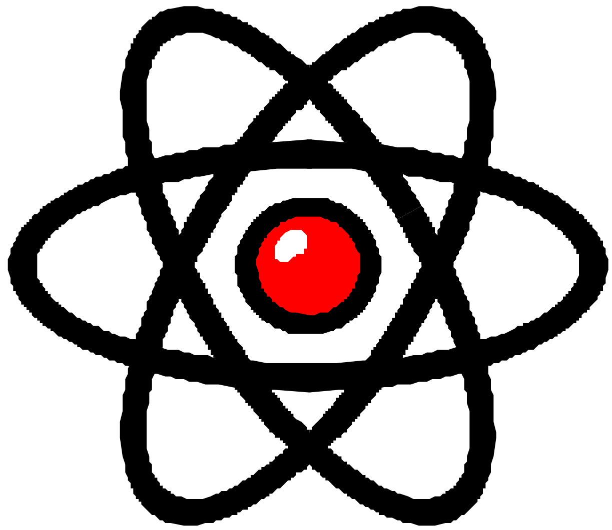


Figure 6: Schematic diagram of an atom. The protons and neutrons are located in the center, and the electrons orbit the nucleus. The electrons are located in an electron cloud surrounding the nucleus, represented by the oval orbits.
NOTE: The atom is not drawn to scale: the atom is approximately 100,000 times the size of the nucleus.

Remember that like charges repel. So how can positively charged protons exist together in a **nucleus**? There is a force called the strong force that holds protons and neutrons together at very small distances. The electrons are "bound" to the nucleus by electric charge because the unlike positive and negative charges of the protons and electrons, respectively, attract.

Two **isotopes** of an element contain the same number of protons and electrons, but a different number of neutrons in the nucleus. An isotope with more neutrons is called "heavy" in comparison with the "lighter" isotope (of the same element) with less neutrons. Take, for example ^{235}U and ^{238}U (read "Uranium 235" and "Uranium 238"). Both consist of 92 protons and electrons, which makes them Uranium. The difference is that ^{235}U has 143 neutrons (235-92) whereas, ^{238}U has 146 neutrons (238-92). Therefore, ^{238}U is heavier than ^{235}U.

Nuclear energy may be defined as the energy found within an atomic nucleus or as the nuclear **binding energy**. If we take the helium nucleus, the mass of its parts (two protons and two neutrons) is less than the mass of the nucleus itself. Using Einstein's equation $E = mc^2$ (where c is the speed of light) we can see that a tiny bit of mass can make an enormous amount of energy.
In a nuclear reaction, an unstable nucleus will become more stable by emitting particles and rearranging the neutrons and protons into more stable nuclei. A stable atomic nucleus does not undergo nuclear reactions unless bombarded with nuclear particles such as protons, neutrons, or **alpha particles,** a process called **nuclear bombardment**.

Radioactivity Basics

Being a science student, you are undoubtedly familiar with the periodic table of the elements. When you read the atomic weight of an element on the chart, such as carbon at 12.01 g/mol, you are not reading the absolute atomic weight of the element. Instead, you are reading the *average* of the naturally occurring isotopes of carbon, some of which include radioactive isotopes. Remember that an isotope of an element has the same number of protons and electrons as the other isotopes, but has a different number of neutrons in the nucleus. This sometimes causes the isotope to be unstable and to radiate energy, or be **radioactive**. The **half-life** of a radioactive substance is the amount of time it takes for the substance to emit one half of its radioactivity.

Radioactivity is all around you, from the food you eat to the bricks in the buildings surrounding you. Radioactive elements that occur naturally are considered part of **background radiation.** Background radiation comes from anything that is part of the natural world that is around *all the time.* Because of this, you can easily conclude that *all* radioactivity is not bad. Rather, your body is bombarded with radioactivity every minute of every day, especially if you get lots of exposure to the sun. Several every day ordinary food objects are slightly radioactive, including table salt substitute and bananas. Check it out the next time you take your Geiger counter to the grocery store! Another common radioactive object sold in stores is the Coleman Lantern mantle, which contains thorium.
The "dangerous" radiation comes in eating or otherwise ingesting radioactive elements which occur in large concentrations, or from external sources which give a high dose.

Measuring Radiation

Radiation is generally measured in units of **rads**, or radiation absorbed dose, which is equivalent to 0.1 J of energy emitted per kg of isotope. Another common unit of measure is the **rem,** or radiation equivalent for mammals, which is equal to a rad in most cases. To give you some qualitative idea, a dental x-ray produces the equivalent of 1 **millirem**. The natural background level of radiation you receive is approximately 200 to 300 millirem per year, depending on where you live. "Natural background" is composed of radiation from cosmic rays, the ground, bricks, stone in buildings, radon gas, medical procedures, and potassium in your body. The government limit of acceptable radiation for the general public is 500 millirem in a year, not counting what a doctor may prescribe for you. The first medical sign of radiation sickness occurs after a single dose (all at once) of **25 rem (25,000 mrem)**, although lower levels may increase the risk of developing cancer at some point in life.

Types of Spontaneous Radioactive Decay

Several types of radioactive decay occur to make an unstable nucleus more stable. **Alpha emission** is the loss of a helium nucleus (2 protons and 2 neutrons) which carries away a mass of four **atomic mass units, or amu.** The charge of the alpha particle is +2.

Name	Symbol	Charge	Atomic #	Nuclear loss	Ability to Penetrate
Alpha	α	+ 2	2	2 p and 2 n	lowest
Beta	β	- 1	0	1 n or 1p	low
Gamma	γ	no charge	0	No change	High

During alpha emission, the **atomic mass** decreases by four and the **atomic number** decreases by two. Alpha decay usually occurs in elements with atomic numbers greater than 82 which do not contain enough binding energy to hold together the massive nucleus. A typical alpha emission is the decay of a heavy isotope such as plutonium-239 to uranium- 235.

$$^{239}_{94}\mathrm{Pu} \longrightarrow \, ^{235}_{92}\mathrm{U} + \, ^{4}_{2}\mathrm{He}$$

Excess binding energy is given off by the kinetic energy of the alpha particle and sometimes by the emission of gamma energy. Gamma energy is emitted as photons and is a type of **electromagnetic radiation**.

Elements below atomic number 40 generally have stable nuclei with an equal number of protons and neutrons (1:1 ratio). As the atomic number increases from 40 to 108, the stable neutron to proton ratio increases toward 1.5 neutrons to 1 proton. **Beta decay** is the loss of an electron from the nucleus. Usually there are no electrons in the nucleus. During beta decay one of the numerous neutrons changes into a proton and an electron. This electron from the nucleus is called a **beta particle** and is ejected from the nucleus. During beta decay, the number of neutrons decreases by one and the number of protons increases by one. The atomic mass remains the same. Also note that the overall charge is conserved.

$$n^{o} = p^{+} + e^{-}$$

The decay of carbon-14 into nitrogen-14 and a beta particle is an example of this type of decay.

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

Another form of radioactive decay is **positron emission**, the loss of a **positron** (positive electron) from a nucleus that has an excess number of protons. Elements that have a higher proton to neutron ratio than normal can decay by positron emission. Here a proton splits into a neutron and a positron (e^{+}). During positron emission the atomic number decreases by one and the number of neutrons increases by one as a proton is converted to a positron and a neutron. The atomic mass remains the same, and the overall charge is again conserved.

$$p^{+} = e^{+} + n^{o}$$

The decay of carbon-10 to boron-10 is an example of this type of reaction.

$$^{10}_{6}C \longrightarrow {}^{10}_{5}B + e^{+1}$$

Gamma emission refers to the discharge of high-energy electromagnetic radiation from an atom. Energy loss in the form of gamma emission occurs when the nucleus is in an excited state and returns to its ground or normal state by releasing a **gamma particle**, or high-energy photon. During gamma emission, neither the atomic mass nor the atomic number change.

An example of this reaction is the emission of gamma radiation from barium -137m. The "m" stands for "meta stable," which means it is stable only for a limited time.

$$^{137m}_{56}Ba \longrightarrow {}^{137}_{56}Ba + \gamma$$

Induced Radioactive Decay

The type of radioactive decay which occurs in nuclear reactors is induced by particle bombardment and is called **transmutation**. We have been able to create hundreds of isotopes and new elements by bombarding existing isotopes with subatomic particles or even the nuclei of light elements. This concept is the basis of **fission**, splitting of the nucleus; and **fusion**, joining of two nuclei.

Neutron bombardment is the process of "hitting" a nucleus with a free **thermal neutron** (one with the correct amount of energy) in order to split it into lighter products. Several products are possible when splitting the nucleus of an atom. A common example is the fission of ^{235}U in a nuclear reactor. Free neutrons are almost always among the products, which propagate the reaction with other nuclei, called a **chain reaction**. When ^{235}U is bombarded with very low energy free neutrons, a fission reaction occurs where the products may be krypton- 92, barium -141, three neutrons, and possibly gamma radiation.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{20}Kr + ^{141}_{56}Ba + 3\,^{1}_{0}n$$

Many different products could have occurred as a result of the breakdown above. The criterion is that the numbers of amu's, protons, and neutrons of the products add up to that of the reactants, much like a chemical reaction. Note that the amu's add up : 235 + 1 = 92 + 141 + 3, as well as the number of protons: 92 + 0 = 36 + 56 + 0 and neutrons: 143 + 1 = 56 + 85 + 3.

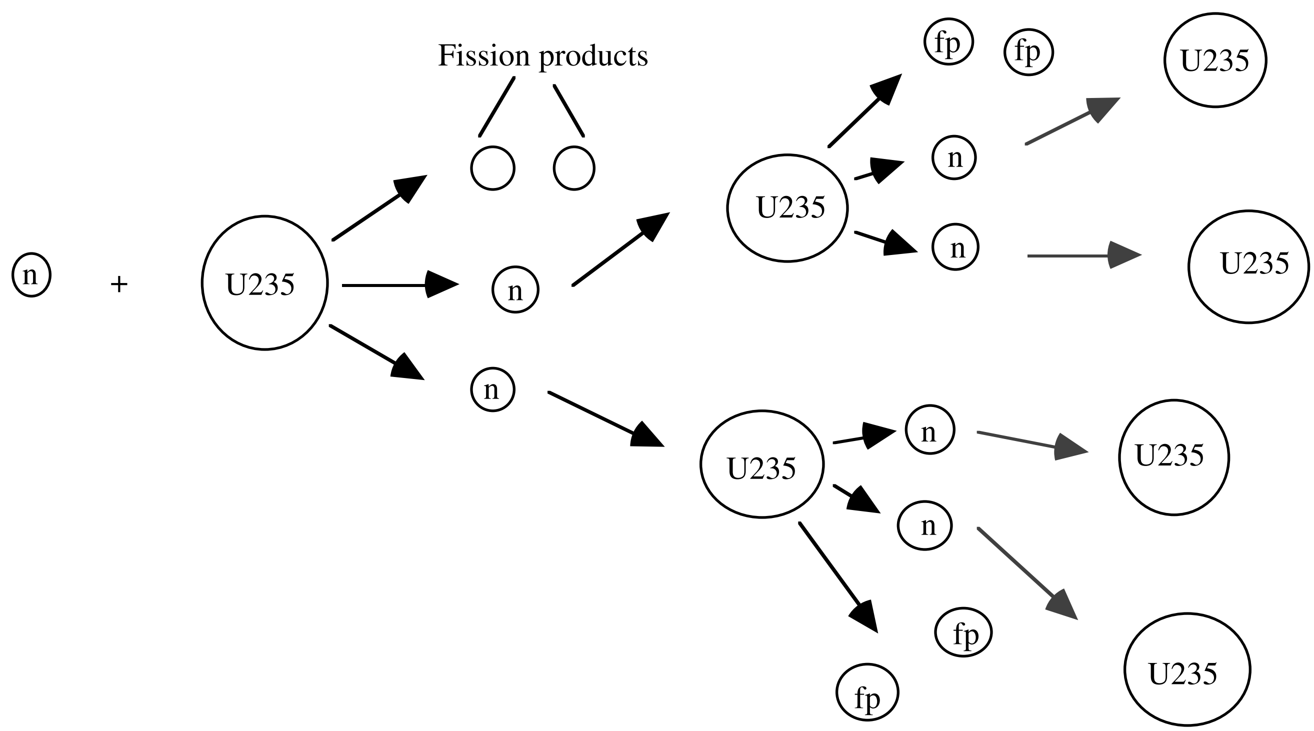


Figure 7: This diagram represents a chain reaction of ^{235}U. A neutron hits the uranium atom which breaks into fission products, and releases 2 neutrons. The new neutrons carry out the chain reaction as shown.

Another way to induce decay is by striking the nucleus with a helium nucleus, or **alpha bombardment**. When an alpha particle reacts with a nitrogen-14 atom, an oxygen-17 atom forms and the energy is released as a hydrogen-1 atom and gamma radiation.

$$^{14}N + {}^{4}_{2}He \longrightarrow {}^{17}O + {}^{1}H$$

Bombarding an aluminum-27 atom with an alpha particle produces phosphorus-30 and a neutron.

$$^{27}_{13}Al + {}^{4}_{2}He \longrightarrow {}^{30}_{15}P + {}^{1}_{0}n$$

Proton bombardment is the bombardment of the nucleus with a proton. When lithium-7 reacts with a proton , two helium-4 atoms are produced.

$$^{7}Li + {}^{1}p^{+} \longrightarrow 2\,{}^{4}_{2}He$$

Nuclear Fusion

Another type of induced nuclear reaction is nuclear fusion. Fusion joins together two small nuclei. Fusion reactions supply the power needed for our sun to shine. The principle behind fusion is that in fusing two small nuclei like deuterium (^{2}H, or one neutron and one proton), a great deal of energy is released. Deuterium (^{2}H) and tritium (^{3}H) are both isotopes of hydrogen which are obtainable in normal water. The reaction of deuterium and tritium follows:

$$^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{1}_{0}n + {}^{4}_{2}He + 17.6\ \text{MeV}$$

Note that 17.6 million electron volts of energy is released per ^{4}He produced. This is due to the difference in the atomic energies of the reactants and products. Conditions needed for fusion are high concentration of fusing elements, high temperature, and high density. It has been estimated that, reacting only 1 gram of deuterium will release an amount of energy equivalent to 2,400 gallons of gasoline.

Nuclear energy (from fission, not fusion) supplies about 7% of the total energy used in the United States, and 22% of the electrical energy used in the United States in a year. Energy from nuclear reactors is considered to be "clean" energy, as carbon and nitrogen oxides as well as smoke and soot are not released into the atmosphere. The disadvantages of nuclear energy include the high cost of building nuclear power plants, finding a politically acceptable ways to dispose of the radioactive wastes including the spent fuel rods, the risk of radioactive release, and the cost of shutting down a nuclear power plant at the end of its useful life.

Types Of Nuclear Reactors

Nuclear reactors use the process of fission, or atom splitting, to release the energy from the nucleus of the fuel. Typically, ^{235}U is used as fuel in most nuclear power plants because it is a **fissile material**, one which will undergo fission upon encountering any neutron, especially a very slow one. The added neutron causes the nucleus to become unstable, and it splits into nuclear fragments.

Nuclear reactors use **enriched** uranium (3% uranium-235 and 97% uranium-238) as the fuel source. Since normal uranium found in the ground is only 0.7% ^{235}U and 99.3% ^{238}U, we put it through an enrichment process in order to increase this percentage to 3%. The fuel is placed in the **core** of the nuclear reactor. A chain reaction is initiated by bombarding the fuel with slow neutrons because slower neutrons with less thermal energy have approximately 1,000 times greater chance of causing a fission reaction to occur than faster neutrons. Neutrons must be slowed down by water or graphite **moderators** to produce a chain reaction. The process repeats itself rapidly or slowly depending on the presence of **control rods**. Control rods are made of cadmium or boron which absorb neutrons to control or stop a chain reaction. Heat from the chain reaction and the resulting speed of the **fission products**, such as Kr and Ba in the last example, is absorbed by water in the reactor. Very fast neutrons, or thermal neutrons, are released too. If there is no moderator to slow them down, the chain reaction will stop by itself. U.S. reactors use the cooling water as the moderator. If the coolant is lost or the reactor gets too hot and it boils away, the moderator is lost as well, and the reaction stops. Unfortunately, the Russian Chernobyl reactor was designed with a graphite moderator. When the coolant was lost the reactor got even hotter and caught on fire. Because water is both the moderator and the coolant in U.S. reactors, an accident like Chernobyl cannot physically occur.

There are several types of nuclear reactors in use today. The first two types of nuclear reactors we will discuss are **light water reactors**, or LWRs. LWRs account for about 80% of the world's nuclear power production. One type is the **boiling water reactor**, or **BWR**. In a BWR, water is pumped through the reactor core where it serves two functions: moderator and coolant. The thermal energy released by the nuclear reactions is absorbed by the water which turns into steam. The steam is shot through turbines that run generators for electricity production.

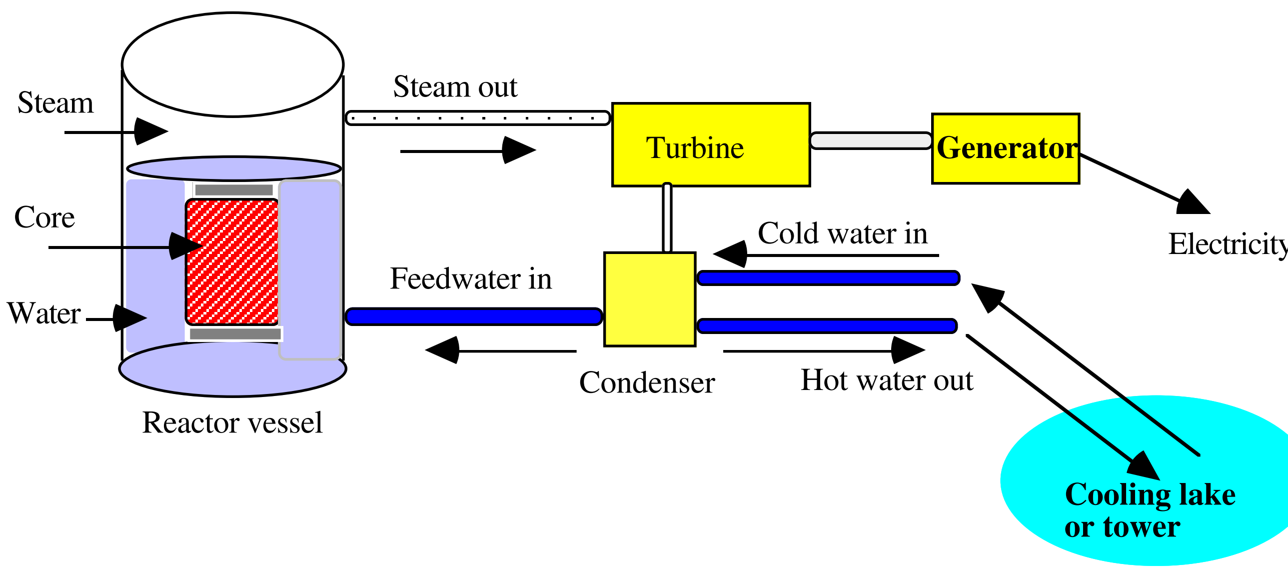


Figure 8: Schematic of a Boiling Water Reactor (BWR). The water in the reactor vessel is heated by the nuclear reaction in the core. The water then turns into steam which is directed to a turbine and then a generator to produce electricity. The hot water then cycles through a condenser which is flooded with cold water from the lake or cooling tower in order to exchange heat. The warm water goes out to the lake and the cool water into the reactor vessel.

The other type of LWR is the **pressurized water reactor**, or **PWR**. In a PWR, the water is pressurized to prevent it from boiling, even at temperatures approaching 315° C. The water in the core passes through a primary loop which passes through a heat exchanger. The heat exchanger removes the thermal energy in the primary loop and transfers it to water in a secondary loop. The water in the secondary coil flashes into steam due to the decreased pressure as it is passed through a series of turbines that drive electrical generators. It is important to note that regardless of the fuel, all power plants use steam to drive turbines to generate electricity.

The third type of nuclear reactor is the **breeder reactor**, so-named because it makes more fissile fuel than it uses. In a breeder reactor, some of the usually nonfissile ^{238}U is converted to ^{239}Pu, which is fissile, by the series of beta decays in the following reaction:

$$^{238}_{92}\mathrm{U} + \mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} \longrightarrow {}^{239}_{93}\mathrm{Np} \longrightarrow {}^{239}_{94}\mathrm{Pu}$$

This reaction is facilitated by the use of fast neutrons because they are more likely to be caught by ^{238}U than by ^{235}U. A general nuclear reaction usually releases fast neutrons, therefore, breeder reactors are inherently efficient. They also produce heat and require a coolant. Liquid sodium is commonly used as the heat exchange medium, or coolant, because it does not slow down high speed neutrons like water does.

The main advantage of a **breeder reactor** is that it generates more nuclear fuel, ^{239}Pu, than it uses. It converts ^{238}U, a plentiful non-fissile, or stable, isotope into a fissile one, making this fuel source virtually inexhaustible. Supplies of ^{238}U will last for more than the next *40,000* years. There are also some disadvantages of breeder reactors. If plutonium escapes into the environment, it carries a high health risk due to its toxicity. Plutonium is also used to make atomic weapons. Though ^{235}U can also be used for weapons, it requires such an enormous amount of effort to purify it that it is not easily used. Breeder reactors also have the ability to melt down if problems occur. This problem has been solved recently by Argone National Laboratory through the development of a Fast Breeder Reactor. The nuclear reaction will stop automatically if the fuel temperature gets to high in this type of reactor. Unfortunately, the U.S. congress has removed funding from this project which held a safe answer to our energy needs.

Currently, the United States does not use breeder reactors to provide nuclear energy. France has used breeder reactors, and Japan is planning to use breeder reactors to generate both electricity and more nuclear fuel.

Nuclear Waste

One obstacle to using nuclear power is that the **nuclear waste** generated cannot just be thrown in a dumpster, it is radioactive! **High-level radioactive waste**, the fission products in the spent fuel rods, will be dangerous for the next hundred or thousand years. Engineers have developed ways of storing this waste in hopes of protecting the environment. Spent fuel rods are first stored in large tanks or swimming pools on the site of the power plant to remove the heat left over from the reaction. Once they are no longer thermally hot, the spent fuel rods, usually in the form of small metal tubes, are encapsulated in ceramic or glass containers which can withstand radioactive decay. These small containers are then placed in stainless steel containers which are stored underground in large caves. Because the waste is all in solid form, nothing can leak from the inside. In order to prevent water from leaking in, materials are placed all around the waste which will absorb any ground water that may seep in. These "caves" are always contained within very stable geologic formations. This type of containment system is called a **multiple barrier containment system.**

Fortunately, very little high level waste is made per reactor per year. Unlike a coal plant which produces about 15 tons of carbon dioxide, 200 pounds of sulfur dioxide, and about 1,000 tons of solid ash per *minute,* the high level waste from one *year* of nuclear power plant operation produces about 1.5 tons and would occupy a volume of about half a cubic yard, which could easily fit under your coffee table!

However, other things become radioactive in the process of operating a nuclear power plant. Objects like water and air filters for trapping radioactive material, rags, gloves, lab equipment, pipes, and mops are considered **low-level radioactive waste**. They have been used near or in the reactor and were exposed to neutrons. About 25% of all low-level waste comes from hospitals, research labs, and industry. Although the radioactivity in low-level waste is about a million times lower than that in high level waste, it occupies about 1,000 times the volume of high-level waste. Because the radioactivity is so low, low-level waste is buried at about 20 feet underground in controlled areas and allowed to decay.

A major problem with radioactive waste is not the amount or even what to do with it. The real problem is the public's perception. Most people seem to agree that we need to do something with this waste, but no one wants it in their neighborhood, no matter how safe the containment structure. Here is another instance where energy becomes perhaps a greater political issue than a scientific one.

Catastrophic Accidents

One major event in the history of American nuclear reactors was the accident at the nuclear power plant, a PWR, at Three Mile Island in 1979. Many term the accident a "near meltdown," while others feel that this is a gross over-exaggeration. The cause of the accident was a failed valve, which allowed water to run out of the pressure vessel. Of course, with no moderator, the chain reaction stopped. However, the core was still hot and needed to be cooled to keep the fuel from melting and ruining the reactor. The engineers thought the valve was closed due to a faulty indicator on their instrument panel, but were able to determine the cause of the problem and close an auxiliary valve to keep the water from escaping. Had the water continued to run out for 30-60 more minutes, the loss of coolant may have caused a **meltdown**. A meltdown occurs when the fuel rods become so hot that they melt, allowing the radioactivity to escape into the reactor vessel. However, what many people don't realize is that the **containment structure** for the reactor is designed to keep all the radioactivity inside and filter it out of the inside atmosphere in the event of an accident. Containment structures are tested for susceptibility to tornadoes, earthquakes, airplanes flying into them (really), and explosives. In the case of Three Mile Island, the containment structure worked and very little radioactive material was released into the environment.

The world's most serious nuclear power plant accident occurred in 1986 when the plant at Chernobyl, Russia exploded. The Chernobyl reactor is an RMBK type reactor, which uses water as the coolant and graphite as the moderator with natural uranium. As a result of a poorly conducted test, the coolant ended up at a low level in the reactor vessel, which prompted the removal of some control rods. When the power increased back to normal levels, there was not enough time to replace them. Thus, the coolant was at a very low level and began to boil. Due to the reactor design, the graphite moderator was still intact, and the chain reaction continued. The high temperature and heat built up and caused two chemical explosions (like dynamite), **not** nuclear ones, which blew off part of the top of the reactor building. Note that there was not a sophisticated containment structure surrounding the reactor vessel like those in the United States. As a result, a large amount of the radioactivity that was once in the reactor core was dispersed to the surrounding areas as radioactive dust. The fires were eventually put out by dropping sand onto the reactor by helicopter.

Common Questions And Misconceptions

Here are a few common statements nuclear power and responses to them.

S. Nuclear power plants emit radioactivity.
R. False. The radioactive material used in nuclear power facilities is contained in the fuel rods in the core of the reactor. In some reactors, the water coolant also becomes slightly radioactive, but has a short half life and is also contained inside.

S. Nuclear power is dangerous because it cannot be controlled.
R. False. Control rods are kept in the core of reactors with elements (cadmium or boron) which absorb the free neutrons that propagate chain reactions. Also, if the water boils away in LWR's (the U.S. and European reactors) the reaction stops because the moderator is missing.

S. Nuclear power plants are environmentally unsound because of the waste heat released into the environment by the water.
R. True. The hot water released from the reactors (which is often stored in ponds near the reactor) does release more heat into the environment, which could cause problems in the immediate environment of the plant. However, fossil fuel power plants release about twice as much heated water for making the same amount of electricity and therefore have the same environmental problems. Cooling towers can alleviate this.

S. Nuclear power avoids several of the environmental problems associated with fossil fuels.
R. True. Because nuclear reactions are not based on combustion, greenhouse gases are not released, and nuclear power plants are therefore not a contributor to the greenhouse effect. Similarly, there is no harmful SO_2 emission that causes acid rain. Nuclear power plants also tend to require less land than fossil fuel plants which decreases the impact on the immediate environment of the plant.

S. A nuclear power plant is unsafe because it can explode like a bomb.
R. False. An atomic bomb is composed of extremely concentrated ^{235}U and ^{239}Pu. Explosives force them together, and the chain reaction proceeds so fast that an extremely large amount of energy is released in a very short time. In a nuclear reactor, the percentage of ^{235}U in *enriched* fuel is only 3%, as opposed to 95% in a bomb. Thus, it is physically impossible for a nuclear power plant to explode like a nuclear bomb.

S. There is so much radioactive waste generated that it is inefficient to utilize nuclear power for a large portion of our energy.
R. False. The amount of high-level radioactive waste generated by a power plant to produce the amount of energy a person will use over a 70 year lifetime is about the size of a soda can. Compare that to the tons of ash produced by a coal power plant! Low level wastes increase the amount slightly, but they generally have short half lives and can be stored economically until they can be safely disposed of.

S. High level waste can not be cleaned up.
R. True. There is no known technologically feasible or biological means to quickly remove the radioactivity from high level waste.

S. Nuclear power is very controversial and right now this controversy can not be resolved.
R. True. The good and bad issues associated with nuclear power make it difficult for anyone to say it should or should not be used. Until better means of disposing or making less waste are found, some people will be against this energy form.

References

Cohen, Bernard, The Nuclear Energy Option, Plenum Press, NY (1990).

Dostrovsky, I., Energy and the Missing Resource, Cambridge University Press, NY (1988).

El-Wakil, M.M., Power plant Technology, McGraw-Hill Book Co, NY (1984).

Hinrichs, Roger, Energy, Saunders College Publishing, PA (1991).

Paulos, John, Innumeracy, Vintage Books, NY (1988).

Rose, David, Learning About Energy, Plenum Press, NY (1986).

Ruedisili, Lon and Morris Firebaugh, Perspectives on Energy, Oxford University Press, NY (1982).

Ruzic, David, lecture notes from the University of Illinois undergraduate course "Introduction to Energy," 1995.

Sears, Francis, Mark Zemansky, and Hugh Young, University Physics, Seventh Edition, Addison- Wesley Publishing Co, MA (1987).

United States Department of Energy, Annual Energy Outlook 1994, Energy Information Administration, DC (1994).

United States Department of Energy, Annual Energy Review 1993, Energy Information Administration, DC (1994).

United States Department of Energy, Energy Information Sheets, Energy Information Administration, DC (1995).

United States Department of Energy, International Energy Outlook 1994, Energy Information Administration, DC (1994).

Zumdahl, Steven, Chemistry, DC Heath & CO, MA (1986).

Resources

General energy information:

U.S. Department of Energy
Energy Information Administration
Forrestal Building, EI-231
Washington, DC 20585

Oak Ridge National Laboratory
PO Box 2008, MS-6266
Oak Ridge, TN 37831-6266
(615) 574-4160

Energy newsgroup on the World Wide Web
news:sci.energy

Illinois Power
1-800-363-7693

Hydropower:

National Hydropower Association (NHA)
122 C Street, NW
Fourth Floor
Washington, DC 20001
(202) 383-2530

Nuclear:

Nuclear Information and Resource Service
1424 16th Street, NW
Washington, DC 20036
(202) 328-0002(202) 586-8800

American Nuclear Society (ANS)
question line: 1-800-NUCLEUS

Wind power:

World Power Technologies
19 Lake Avenue North-WWW
Duluth, MN 55802
(218) 722-1492

Sites on the World Wide Web:

An excellent source of information is the Internet. You can find almost anything you are looking for. An excellent place to begin has been created by students here at the U of I in conjunction with an Advanced Energy Systems course. The WWW address of the starting point with all the links is:

http://starfire.ne.uiuc.edu:80/ne201/students.html

This page contains links to all of the students' pages about energy-related topics. From these pages, then, you can find links to many energy agencies and energy information pages. In a matter of minutes, you can unlock a rich resource! Some pages I found of interest are:

http://www.ecn.nl/eii/man.html

http://www.nrel.gov/documents/energy/energy.html

Master Materials and Equipment Grid for Demos

Material	Demo 1	Demo 2	Demo 3 Cardboard Box	Demo 3 Plexy glass
balance and masses	LE			
matches	LE			
empty soda can	O			
small firecracker	S			
meter stick	LE			
large hot plate		LE		
1 L supersaturated salt soln		LE		
2000 mL beaker		LE		
thermometers, 10˚- 100˚C		LE		
Styrofoam disk		HS/H		
dark construction paper		O		
paper clip		DS		
safety goggles	LE	LE	LE	LE
mouse traps			H/G/DS/HS	H/G/DS/HS
ping-pong balls			DS/O	DS/O
cardboard box (~2'x2'x2')			O	
box cutter			H/HS	
transparencies			DS/O	
tape			H/G/DS/HS	
Plexiglas box				O
string				DS

KEY FOR TABLE:

H = HARDWARE
G = GROCERY
DS = DISCOUNT STORE
HS = HOME IMPROVEMENT STORE
LE = LAB EQUIPMENT / SCIENTIFIC CATALOG
S = SPECIALTY SHOP
O = OTHER

Demonstration 1

Potential to Kinetic Energy

Principles of Energy Transfer

Objective: The objective of this demonstration is to investigate the principles of energy transfer.

Time: 25-30 minutes

Review of Scientific Principles

The law of conservation of energy states that energy can neither be created nor destroyed but can be changed into different forms. **Potential energy** is stored energy, and **kinetic energy** is energy of motion.

We will investigate the transfer of potential energy (PE) to kinetic energy (KE) with the use of a firecracker and soda cans. The firecracker has chemical potential energy that is released when it is ignited. This energy is changed to kinetic energy after the firecracker explodes, causing the cans to move. This process is similar to what happens when your car moves. The gas (PE) explodes in the cylinder (KE) throwing the piston down. This mechanical energy is eventually translated to movement of the wheels.

Calculations:

Gravitational Potential Energy= mass of an object (kg) x gravity ($9.8 m/s^2$) x height (m)

Unit conversions: 1 joule = 1 Nm = 1 kg m^2/s^2

Kinetic Energy = 1/2 x mass of an object (kg) x velocity ^{2} $(m/s)^2$

Hypothesize: If the can were initially placed above the ground, what direction(s) would we see the cans traveling?

Materials and Supplies

balance
matches
2 empty soda cans
a small firecracker
meter stick

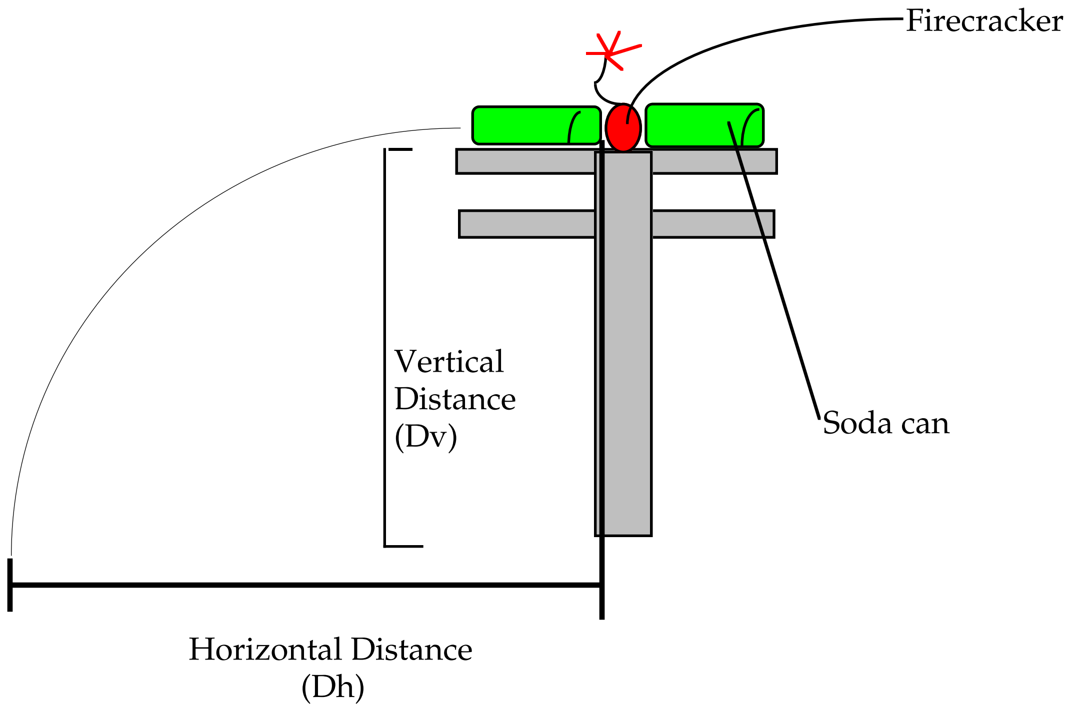
General Safety Guidelines

- When working with matches, be sure that you do not have bulky clothes which could catch on fire.
- Be sure that the area around the demonstration setup is clear, so that when you light the firecracker you have plenty of space to move away from it.
- Stay far enough away from the setup once you have ignited the firecracker (3 m).

Procedure

1. Set up your materials to look like the picture below.
2. The height of the table should be one to two meters above the ground, making sure that it is level. Be sure to have at least 10 m radius clear around your table.
3. Mass the two identical empty soda cans. Mass _____g
4. After placing the cans end to end on the table, measure the distance from the bottom of the can to the floor. ________m
5. Aim the cans such that they will not hit anyone or anything during their flight.
6. Carefully fit an unlit small firecracker between the two cans.
7. Mark the edge of the can towards the firecracker on the table with a pencil.
8. Ignite the firecracker, and STEP BACK FROM SETUP AT LEAST 3 M.
9. Measure the horizontal distance each can traveled from spot on the floor just below the original mark. __________ m ; __________ m
10. Add the two distances and divide by two. The average distance is __________ m .

Set up:



Calculations: (show your work)

1. Falling and flying time of can $D_v = 1/2gt^2$

2. Horizontal velocity of can $D_h = V\,t$

3. Kinetic energy of each can: $KE = 1/2mv^2$

4. Gravitational potential energy of each can: $PE = mgDv$

Questions:

1. Compare the PE and KE, are they equal?

2. Should PE and KE be equal?

3. Support your answer for # 2 with facts from this experiment.

4. List the pathway the energy transformed into, from the firecracker being lit to the cans resting on the floor.

For Further Thought and Discussion:

1. What do you think the sound of the firecracker exploding and the can hitting the floor might have to do with the released energy?

2. What do you think the light or sparks from the fuse might have to do with energy? If there were no sparks, would the net energy released be greater or the same?

3. In terms of molecular motion, where does some of the energy go when you shoot off a firecracker or bottle rocket?

Answers

1. No.

2. No see answer to #3.

3. The kinetic energy of calculation 3 is from the firecracker. The potential energy of calculation 4 is from gravity and the height of the cans which has nothing to do with the firecracker.

4. The match allows the chemical energy of the wick to transfer into light, sound, and heat energy. This heat energy set off the chemical reaction of the explosive which is converted to different forms of energy. This energy goes into light, sound, heat, and kinetic energy. This kinetic energy is absorbed by the cans which have also absorbed some of the heat of the explosion. As the cans move off of the support, their potential energy is converted into kinetic energy in the vertical direction. The cans continue to gain kinetic energy in the vertical direction until the cans hit the ground. At this point, the kinetic energy of the cans is converted into heat and noise of which the ground and air absorb.

For further thought and discussion:

1. Sound is the transfer of energy in waves at audible frequencies. Some of the initial energy in the spark of the firecracker was lost to sound as the can hit the floor.

2. Light is similar to sound in that it travels as both a wave and a particle. It takes energy to produce light waves. Some of the chemical energy went into making the light in the spark.

3. When you shoot off a bottle rocket, the same principles of the experiment apply. The energy derived from the match is used to explode the firecracker. That then heats the molecules and creates an explosion forcing the bottle rocket up in the air. The remaining energy heats the molecules in and around the bottle itself, pushing it backwards.

Demonstration 2

Dipping Into Solar Ponds

Objective: Students will observe the process of forming a solar pond and understand the use of solar heat generated from a solar pond.

Review of Scientific Principles:

A solar pond uses the principles of energy transfer by convection to heat water. The bottom of the pond is lined with a dark material that absorbs the sun's rays. The water above the liner consists of three layers of varying salt concentrations. The bottom is very salty. The middle layer changes from salty to fresh. The top layer is fresh water. Due to the difference in densities of the three zones, the gradient zone acts as an insulator, so it doesn't allow heat to be passed by convection currents from the saturated middle layer to the fresh water layer. To be more explicit, the gradient zone is a non-convective layer. The bottom layer is a supersaturated salt solution that reaches temperatures of 60-80° C and has convection currents. The top layer of cool fresh water is also convective due to daily heating and cooling from the sun and the wind. The convection currents circulate only above and below the concentration gradient. Cool water is pumped through a pipe placed into the hot supersaturated salt zone. There the water is heated as it passes through the surrounding salt water. From there, the water may be pumped through surrounding homes or barns for heat, or it may be converted to steam for electricity production.

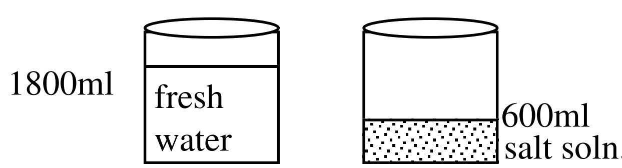
Materials and Supplies:

- 1 large hot plate
- 1 L supersaturated salt solution
  - Pour 500 ml of water into a 1 L beaker. Dump salt in until it precipitates. Repeat procedure until you have 1 L of supersaturated salt solution.
- 2 2000 ml beakers
- 2 thermometers
- 1 Styrofoam disk (size of inside beaker)
- 1 sheet of dark construction paper
- 1 paper clip

Procedure:

1. Fill one beaker with 1800 ml of cold water.

2. Fill other beaker with 600 ml of supersaturated salt solution.

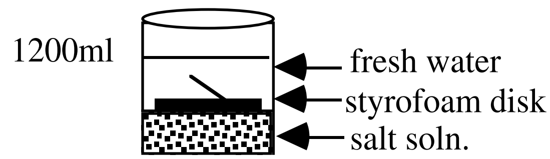


3. Record initial temperature of each.

4. Bend a paper clip as shown and insert into disk to make handle. 

5. Place Styrofoam disk in the top of the beaker with the salt solution very carefully. The disk should float!

6. Slowly pour 600 ml of the fresh water over the Styrofoam disk, DO NOT allow solutions to mix. (This will begin to set up the concentration gradient.)

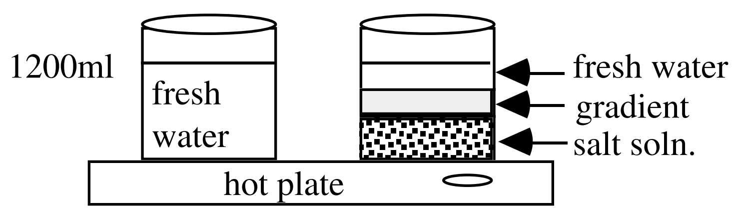


7. Carefully remove Styrofoam disk.

8. Both beakers should have equal volumes.

9. Place a dark sheet of construction paper behind both beakers to show the different concentration levels. The supersaturated salt solution will remain on the bottom with a concentration gradient separating it from the salt solution.

10. Place both beakers on the hot plate for approximately 15-20 minutes.



11. Record the temperature at the top and bottom of each beaker. The temperature should be uniform throughout the fresh water beaker and very warm to the touch. The salt solution will not have a uniform temperature. The top layer will be quite cool to the touch and the bottom with the salt solution will have a much higher temperature.

12. Have students come up, one-by-one, and place their finger into the fresh water beaker and then in the top layer of the salt solution beaker. They will be quite surprised at how cool the top layer of the salt solution beaker is.

NOTE: Caution the students against stirring the solution when they put their hand into the water. Mixing will destroy the gradient you have set up and burn them.

14. To save the salt solution, use gloves to carefully pour off the fresh water into the beaker of fresh water until the solution appears to be cloudy. The remaining solution is the supersaturated salt solution and is very hot.

Suggestion to teachers: Time permitting, this procedure would make a good laboratory experiment. Or, alternatively, having a few students set this up would be instructive.

Demonstration 3

Nuclear Mice

Objective: This demonstration will teach the principles of chain reactions.

Review of Scientific Principles:

A nuclear reactor produces energy by causing a fission reaction of a heavy unstable atom like ^{235}Uranium into smaller elements we call fission products. The reaction is started by hitting the atom with a slow neutron. Then, a chain reaction begins as each atom breaks into fission products and more neutrons. So, if you start with one atom of Uranium and each atom gives off 2 neutrons (for example) when it undergoes fission, then after each fission reaction you have 2 new neutrons which could cause fission events of their own. (See Figure 7 in Scientific Principles for a review.) This type of reaction can be simulated with mouse traps and ping pong balls. By setting up several mouse traps all loaded with ping pong balls and hitting one of them with a free ping pong ball, you can see a chain reaction for yourself!

Safety note: Mouse traps can really hurt your fingers! Be careful both when setting up this demo and when taking it down.

Materials and Supplies:

- 24 mouse traps for each group
- 24 ping-pong balls for each group plus a few extra for ones lost
- 1 foot of string
- 1 containment box
  - <u>Plexiglas containment box</u>
    - a Plexiglas box open at one end around (2' x 2' x 2')
  - <u>Cardboard containment box</u>
    - a cardboard box around (2' x 2' x2')
    - a box cutter
    - tape
    - a transparency

Procedure:

1. Make the containment box. See teacher's notes for instructions.

2. Set a mouse trap and place on smooth surface.

3. Carefully place a ping-pong ball on the trap so that it rest on the metal snapping piece and the holding arm.

4. Repeat steps 1 and 2 starting with the traps away from your body and finishing with the traps toward your body. Laying out the traps in the pattern shown below works particularly well.

5. On the last trap attach a string to the holding arm before setting.

6. Carefully place the containment vessel to cover the traps.

7. Pull swiftly on the string and watch as the traps go off.

Teacher's Notes:

Construction of a Plexiglas containment vessel requires time and patience. Consult your Plexiglas dealer for instructions on how to work with Plexiglas.

<u>Construction of cardboard containment vessel</u>

1. Cut the four, top lids off the box.

2. Cut a 7.5 inch wide by 10 inch high hole in the side of the box. The hole should be 1/2 from the open end and an inch away from the corner.

3. Tape the transparency to the <u>inside</u> of the box so that it covers the hole made in step 2.

Other Notes:

1. Have the students come up with ways of simulating control rods. Any original idea that would remove ping pong balls from the reaction would be appropriate. An example is hanging strips of tape from the top of the containment box.

2. This would be a great contest or science fair project. Encourage students to experiment with different shapes of trap layouts, different densities of traps, or different number of balls on each trap.

3. Tape the mouse traps to the surface so that only ping-pong balls set off traps.

4. Use in conjunction with the accompanying explanations in the nuclear section for best results.

Master Materials and Equipment Grid for Labs

Material	Lab 1	Lab 2	Lab 3	Lab 4
balance and masses	LE			
matches		LE		
empty soda can		O		
meter stick			LE	
thermometers, 10˚- 100˚C	LE	LE		
dark construction paper				O/DS
paper cup	O			
stirring rod	LE	LE		
150 mL beaker	LE			
Styrofoam cup	O			
eye dropper	LE			
graduated cylinder, 100 mL	LE	LE		
safety goggles	LE	LE		
baking soda (sodium bicarbonate)	LE/DS			
washing soda (sodium carbonate)	LE			
Plaster of Paris	LE			
vinegar	LE/DS			
Bromthymol blue indicator	LE			
household ammonium (ammonium hydroxide)	LE/DS			
Epsom salts (magnesium sulfate)	LE/DS			
thick clothesline cord		DS		
paper clips, large		DS		
ring stand with ring		LE		
400 mL beaker		LE		
eye dropper bottles and pipettes		LE		
red licorice or string			G/DS	
80 M&M's or 80 pennies			G/DS	
cardboard box			O	O
graph paper			LE	
tape cellophane			LE	
red pencils			LE	
Plexiglas or glass				H
aluminum foil (large quantity)				G/DS
clear mailing/packaging tape				DS
newspaper				O
string				DS
stick--3/4" long				O
scissors				O

KEY FOR TABLE:
H = HARDWARE
G = GROCERY
DS = DISCOUNT STORE
LE = LAB EQUIPMENT / SCIENTIFIC CATALOG
S = SPECIALTY SHOP
HS = HOME IMPROVEMENT STORE
O = OTHER

Experiment 1

Great Chemistry!

How is energy released in chemical reactions?

Objective: The objective of this experiment is to investigate in what ways energy is released in chemical reactions.

Review of Scientific Principles:

Picture energy as the movement of molecules. Energy is the rearrangement of chemical and nuclear bonds to achieve a more stable state. It is not a substance that can be held, seen, or felt as a separate entity. We cannot create new energy that is not already present in the universe. We can only take different types of materials in which energy is stored, change their state, and harness the energy that escapes from the system in order to use it to do work for us. If the released energy is not used, it will escape and be "wasted" as a change in motion, vibration, or light.

Different energy forms exist because people need a way to relate and measure different states of molecular motion. **Chemical energy** is the energy stored in the chemical bonds of molecules. Energy in the form of heat can be used to break chemical bonds. When the bonds are broken, their chemical energy is converted into more **thermal,** or **heat, energy.** When the heat energy is used to do work for us, we call it **mechanical energy**. Mechanical energy can either be **potential** which is stored energy, or **kinetic** which is the energy of motion. The sum of the potential and kinetic energy of an object is the amount of its total mechanical energy. If we transfer the energy through wires, it is called **electrical energy** which we use to power televisions and compact disc players. Two other types of energy are **radiant**, from the sun, and **nuclear**, from changes in the nuclear structure of atoms. While it is necessary to discuss these different types of energy, it is important to remember that energy is really the motion of molecules, electrons, or photons, and released by rearrangement of chemical or nuclear bonds.

Some additional vocabulary is needed to be able to record the results of this experiment accurately. **Temperature** is defined as the average kinetic energy, which is proportional to the average velocity, of all the molecules in a certain vicinity. **Heat** is the movement of molecules. A reaction is said to be **exothermic** if it produces heat (feels warm); endothermic if it uses more heat than it gives off (feels cool). Bond breaking is an **endothermic** process. Bond making is an exothermic change.

Applications: Eating meals, driving your car, and running a race are all examples of chemical reactions that release energy.

Materials and Supplies:

1 large paper cup
1 stirring rod
2 beakers, 150 ml
2 Styrofoam cup
1 balance and masses
1 eye dropper
1 Graduated cylinder,
1 pair of safety goggles
1 thermometer -10˚ to 110˚ C
Epsom salts (magnesium sulfate)

Washing soda (sodium carbonate)
Plaster of Paris
Vinegar (acetic acid)
Bromthymol blue
Household ammonia (ammonium hydroxide)
100 ml Water
Baking soda (sodium bicarbonate)

General Safety Guidelines:

- Wear safety goggles at all times.
- Perform the experiment in a well-ventilated area.

Procedure:

Part 1

1. Put on your safety goggles.
2. Add Plaster of Paris to a paper cup until it is about half full.
3. Add room temperature water to a beaker until it is about half full.
4. Feel the outside of the cup and the beaker.
5. Add the water to the Plaster of Paris and stir.
6. Be sure to take note of the temperature changes of the outside of the cup as the Plaster of Paris hardens.
7. Describe your observations in the data section for Part 1.

Part 2

1. Avoid putting your face directly over the cup of ammonia -*breathing in ammonia fumes is dangerous.*
2. Pour 50 ml of ammonia into a Styrofoam cup and record the color of the ammonia in the data table.
3. Pour 50 ml of vinegar into a beaker.
4. Add 5 drops of bromthymol blue to the vinegar.
5. Record the color of the vinegar mixed with the bromthymol blue in the data table.
6. Measure and record the temperature of the ammonia.
7. Clean your thermometer.
8. Measure and record the temperature of the vinegar.

9. Add the vinegar solution to the ammonia and stir.

10. Measure and recorded the temperature of the vinegar and ammonia solution.

Part 3

1. Pour 150 ml of water into a Styrofoam cup.
2. Measure and record the temperature of the water in the data table for Part 3.
3. Put a level teaspoon of baking soda into the water, and stir with a stirring rod.
4. Measure and record the temperature of the water & baking soda solution.
5. Add another teaspoon of baking soda to the solution.
6. Measure and record the temperature change of the water & baking soda solution.
7. Add another teaspoon of baking soda to the solution.
8. Measure and record the temperature change of the water & baking soda solution.
9. Add another teaspoon of baking soda to the solution.
10. Measure and record the temperature change of the water & baking soda solution.

Part 4

1. Put 50 ml of water in each of 2 beakers.
2. Add 10 g of washing soda to one beaker and stir.
3. Add 10 g of Epsom salts to the other beaker and stir.
4. Let the beakers stand for <u>5 minutes.</u>
5. Measure and record the temperature of washing soda and water beaker in the data table provided.
6. Clean the thermometer.
7. Measure and record the temperature of the Epsom salts and water solution in the data table provided.
8. Add the Epsom salts to the washing-soda solution and stir.
9. Measure and record the temperature of the Epsom salts, washing-soda, and water solution in the data table provided.

Data:

Part 1: Observations of the cups:

Data table part 2:

Substance	Temperature ,˚C	Color
Ammonia		
Vinegar		
Ammonia & vinegar solution		

Data table part 3:

Substance	Temperature, ˚C	Temperature Change
Distilled water + 1 teaspoon of baking soda		
mixture + 1 teaspoon of baking soda		
mixture + 1 teaspoon of baking soda		
mixture + 1 teaspoon of baking soda		
mixture + 1 teaspoon of baking soda		

Data table part 4:

Substance	Temperature ˚C
Washing - soda solution	
Epsom - salts solution	
Combination of Washing-soda and Epsom salts	

Questions:

1. For each part list the evidence that a chemical change took place:

Part 1:

Part 2:

Part 3:

Part 4:

2. What do the following three chemical reactions have in common?
A) hardening of plaster, B) burning gas in your car; C) eating food.

3. The heat given off when coal burns can be explained as a chemical reaction in which energy is released to the surroundings. How would you explain what happens in a chemical reaction like baking soda dissolving in water?

4. What forms of energy were evident in these experiments?

Experiment 1: Teacher's Notes

Great Chemistry!

Is there an energy change in chemical reactions?

Prep Time: 10 minutes
Time: 45-50 minutes

Sample Data and Calculations:

Part one: Observations of the cups: **It started at 28˚ C and increased in temperature as it hardened. In essence you made a gypsum rock. It took energy to remove the liquid from the gypsum rock, and now that energy is released when water is added to the gypsum powder (Plaster of Paris).**

Data table part 2:

Substance	Temperature, ˚C	Color
Ammonia	26	clear
Vinegar	26	yellow
Ammonia & vinegar solution	30	green

Data table part 3:

Substance	Temperature, ˚C	Temperature Change
Distilled water + 1 teaspoon of baking soda	21	
mixture + 1 teaspoon of baking soda	19	
mixture + 1 teaspoon of baking soda	17.5	
mixture + 1 teaspoon of baking soda	17	
mixture + 1 teaspoon of baking soda	17	

Data table part 4:

Substance	Temperature ˚C
Washing - soda solution	33
Epsom - salts solution	23
Combination of Washing-soda and Epsom salts	23

Answers to Questions:

1. For each part list the evidence that a chemical change took place:

Part 1: The temperature increased. It took energy to remove the water from the gypsum rock to make the Plaster of Paris. That energy is being released when the water is added to the Plaster of Paris, essentially forming gypsum rock.

Part 2: When mixed, the temperature increased and the color of the solution was green. Chemical bonds are being broken so energy is being released. The color change is due to the indicator, bromthymol blue, which is green in a neutral solution. Note that the solution will not be green unless exact amounts of vinegar and ammonia are mixed.

Part 3: The temperature decreases with every addition of a teaspoon of baking soda. As sodium bicarbonate (baking soda) is dehydrated, energy is released. When you add water to the sodium bicarbonate, energy is absorbed, and the outside of the cup gets cooler.

Part 4: The solution turned into a white suspension.

2. What do the following three chemical reactions have in common?
   A) hardening of plaster; B) burning gas in your car; C) eating food.
   All are exothermic reactions. All of them give off more heat than they take in. The atoms become arranged into more stable molecules.

3. The heat given off when coal burns can be explained as a chemical reaction in which energy is released to the surroundings. How would you explain what happens in a chemical reaction like baking soda dissolving in water?
   It is a chemical reaction in which energy is absorbed from the surroundings.

4. What forms of energy are evident in these experiments?
   Chemical and thermal energy.

Experiment 2

Heating it Up!

Which Fuel Source Has More Heat Energy?

A Comparison Of The Amount Of Energy Given Off In A Combustion Reaction

Objective:

There are two objectives for this experiment. The first is to compare possible fuel sources for the amount of energy they give off in the form of heat energy. The second is to tell which one(s) are cleaner burning fuels than the others.

Review of Scientific Principles:

We are always looking for alternative energy sources since fossil fuels are nonrenewable resources. There are two questions frequently asked when considering an alternative fuel. How much energy will be released per unit of that resource, and what effects might burning it have on the environment? When we use a resource, such as coal, oil, or natural gas to produce energy, we are breaking the chemical bonds within the substance and rearranging them into more stable bonds. This change results in the formation of different products, such as carbon dioxide and water in the case of combustion, and a release of energy. How can we measure the amount of energy?

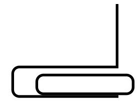
If we tried to quantify it mechanically, we may never know just how much absolute energy is in the resource itself. Therefore, we use the "heating value" of fuels: how using so much of a certain resource (rearranging its bonds into a more stable state) converts to so much heat (motion of molecules). We all hear every day about counting calories. What is a **calorie**? A calorie (cal) is defined as the amount of heat needed to raise one gram of water 1° C. A food calorie actually consists of one kilocalorie, or 1,000 calories. Why do we worry about calories in relation to our weight? Energy conservation! If you feed your body more calories than it can use, it will store the energy in a stable state like body fat for you to use and lose later.

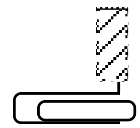
For this lab, we will measure the amount of the temperature change and use that to indicate heat energy. Temperature is defined as the average kinetic energy of all the molecules, and heat is the movement of molecules.

Materials and Supplies:

goggles for each member of the group
1 piece of thick cord clothesline 3 cm long
1 large paper clip
1 soda can with tab still attached per group
one thermometer
teacher has matches - show set-up to get a light
ring stand with ring
stirring rod
400 ml beaker
100 ml graduated cylinder
cold tap water
eye dropper bottles pipette with assigned material in it

Procedure:

1. Bend the paper clip so that it looks like this: 

2. Weave the paper clip in and out of the outer most layer of the clothesline so it looks like this: 

3. Measure 100 ml of cold water with a graduated cylinder and pour it into a soda can.

4. Place the stir rod through the tab of the pop can.

5. Set the stir rod on top of the ring, letting the can hang beneath --see figure below.

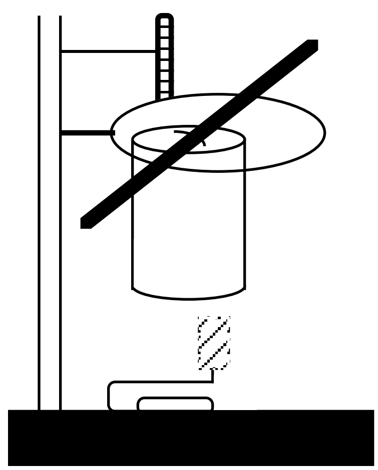
6. Place the thermometer in the can so that
   • it can be easily read;
   • it is in the 100 ml of water in the can;
   • it is supported by a clamp on the ring stand.

9. Put 20 drops of your substance on the clothesline and place it below the can.

10. Adjust the height of the ring so the can is 5 cm above the paper clip apparatus.

11. Measure and record the initial temperature of the water in the data table.

The apparatus should look like this:



12. Have the teacher ignite the clothesline and observe the flame; record your observations.

13. Let the clothesline burn until the flame disappears and place the smoking remains in a beaker of water.

14. Record the final temperature of the water in the data table.

Data and Calculations:

Substance	Initial Temperature ˚C	Final Temperature ˚C	Appearance of fumes from burning
Methanol			
Ethanol			
Vegetable oil			
Peanut oil			
Motor oil			
Kerosene			

1. Calculate the difference in the temperature for all the samples tested.

Methanol
Ethanol
Vegetable oil
Peanut oil
Motor oil
Kerosene

2. Which 'fuels' burnt the cleanest?

3. Which 'fuel' source had most heat energy?

4. Were you able to measure the total amount of energy released? Why or why not -- explain your answer fully.

5. Does the fact that the clothesline may burn affect this comparison of 'fuel' sources? Explain your answer fully.

6. What 'fuel' do we put in our bodies? How is what happens in your body with that 'fuel' similar and dissimilar to how 'fuel' is used in your car?

Experiment 2: Teacher's Notes

Heating it Up!

Which Fuel Source Has More Heat Energy?

Prep Time: 10 minutes
Time: 45-50 minutes

Because of time constraints it works best to 'jigsaw' this lab or have each group do a separate part of this lab; then share their results. Divide the class into six groups (or any multiple of six groups). In order to facilitate this, you'll need to make six clearly labeled 10 ml disposable eye droppers.

Add 10 ml of methanol, ethanol, motor oil, vegetable oil, peanut oil, and kerosene in six different droppers. Label the droppers accordingly. Store upside down in a 50 mL beaker. As you assign each group the material they are to test, point out what table that material is on.

Each group needs to burn the sample they have prepared until the flame extinguishes by itself. (Smoldering samples should be removed and placed in a beaker of water.

Sample Data:

Substance	Initial Temperature ˚C	Final Temperature ˚C	Appearance of fumes from burning
Methanol	29	34	clean burning
Ethanol	28	42	clean burning
Vegetable oil	28	56	sooty
Peanut oil	28	50	sooty
Motor oil	27	55	sooty
Kerosene	23	49	sooty

Calculations:

1. Calculate the difference in temperature for all the samples tested.

Methanol 6 ˚C
Ethanol 13 ˚C
Vegetable oil 28 ˚C
Peanut oil 22 ˚C
Motor oil 28 ˚C
Kerosene 26 ˚C

2. Which 'fuels' burned more cleanly? **Ethanol and Methanol burned the cleanest.**

3. Which 'fuel' source had most heat energy? **Vegetable oil and motor oil released the most heat energy.**

4. Were you able to measure the total amount of energy released? Why or why not ? Explain your answer fully. **No, because some heat energy escaped into the surroundings. Also, energy in the form of light was given off.**

5. Does the fact that the clothesline may burn affect this comparison of 'fuel' sources? Explain your answer fully. **Yes. Since different fuels may release more energy, different amounts of clothesline may burn for each, causing different amounts of heat to be released.**

6. What 'fuel' do we put in our bodies? How is what happens in your body with that 'fuel' similar and dissimilar to how 'fuel' is used in your car? **Food. Food is used for energy to fuel your body processes, such as protein production, growth, and physical activity. Fuel in your car is just used for energy.**

Experiment 3

Half-Life: The Energizer Bunny® Effect

Objective: This experiment will illustrate the principles of a half-life.

Review of Scientific Principles:

The **half-life** of a radioactive substance is the amount of time it takes for one half of a substance to change into something else. After each half-life only half of the original substance remains. During that change some type of "radiation," either alpha (a helium nucleus), beta (an electron), or gamma (high-energy light), is emitted. A substance which undergoes this type of decay is called radioactive. Radioactivity is all around you--from the food you eat to the bricks in the buildings surrounding you. Radioactive elements that occur naturally are considered part of **background radiation.** Background radiation comes from anything that is part of the natural world that is around *all of the time.* Because of this, you can easily conclude that *all* radioactivity is not deadly. Rather, your body is bombarded with radiation every minute of every day, especially if you get lots of exposure to the sun. Several every day ordinary objects are slightly radioactive, including table salt substitute and bananas!

Nuclear power plants do not emit radioactivity. The radioactive material used in nuclear power facilities is contained in the fuel rods inside the core of the reactor. In some reactors the water coolant also becomes slightly radioactive, but has a short half life and is contained inside the plant.

Fortunately, very little high level waste is made per reactor per year. Unlike a coal plant which produces about 15 tons of carbon dioxide, 200 pounds of sulfur dioxide, and about 1,000 tons of solid ash per *minute*, the high level waste from one *year* of nuclear power plant operation produces about 1.5 tons and would occupy a volume of about half a cubic yard, which could easily fit under your coffee table! The amount of high level radioactive waste produced per person from nuclear power for a 70 year life span is about the size of a soda can.

Other things become radioactive in the process of operating a nuclear power plant, however. Objects like water and air filters for trapping radioactive material, rags, gloves, lab equipment, pipes, and mops are considered low-level radioactive waste. They have been used near or in the reactor and were exposed to neutrons. About 25% of all low-level waste comes from hospitals, research labs, and industry. Although the radioactivity in low-level waste is about a million times lower than that in high level waste, it occupies about 1,000 times the volume of high-level waste. Because the radioactivity is so low, low-level waste is buried at about 20 feet underground in controlled areas and allowed to decay.

Practical Applications: How long do we need to store nuclear waste?

Time: 20 minutes

Materials and Supplies:

- 80 M & M's (or 80 Pennies) per lab group
- one box per lab group (the boxes copier paper comes in work well)
- 1 meter stick
- graph paper
- tape
- red pencil

Procedure:

1. Put 80 M & M's "M's up" in a box.
2. Put the lid on the box and shake.
3. Open the box; leave all the "M's up" M & M's in the box, remove all the blank M & M's.
4. Record the number of removed M & M's in the data table.
5. Repeat steps 2-4 more times
6. Write your results on a large table on the board.
7. Plot on graph paper the number of half-lives on the x-axis and the number of **non-decayed** atoms on the y-axis in red pencil.
8. Average the class data on the board.
9. Plot the class data in normal pencil color on your graph in the same manner described above, and be sure to label each of the graphed lines clearly .

Data and Calculations

Number of half-lives	Number of "non decayed" atoms
0	80
1	
2	
3	
4	
5	

Questions:

1. Treat the M & M's as radioactive units. Using your data, how many half-lives does it take to have an inconsequential amount of radioactive material left? Is it ever really gone (HINT: think about the Energizer Bunny®--it keeps going and going and going...)?

2. Suppose you were given $1,000,000. How long would it take to have less than five dollars left if you spent half of it every day?

3. Uranium-238 has a long half life. If 450,000 people live to be 70, how many "soda can" size pieces of nuclear waste will we have to store? How much room would that take up is stacked together?

4. Suppose a material emits 25 rem/year (which causes radiation sickness if felt in a single dose), and has a half-life of 5 years. How many years before it emits only 200 millirem/year, which is approximately the amount of background radiation you receive every year. HINT: 1 rem = 1,000 millirem.

Experiment 3: Teacher's Notes

Half-Life: The Energizer Bunny® Effect

Objective: This experiment will illustrate the principles of a half-life.

Practical Applications: How long do we need to store nuclear waste?

Prep time: 10 minutes
Time: 30 minutes

Sample Data and Calculations (One example) :

Number of half-lives	Number of "non decayed" atoms
0	**80**
1	**44**
2	**22**
3	**9**
4	**4**
5	**1**

<u>Questions:</u>

1. Treat the M & M's as radioactive units. Using your data, how many half-lives does it take to have an inconsequential amount of radioactive material left? Is it ever really gone? **Five half-lives. No; there is always half of the amount left.**

2. Suppose you were given $1,000,000. How long would it take to have less than five dollars left if you spent half of it every day? **17 days.**

3. Uranium-238 has a long half life. If 450,000 people live to be 70, how many "soda can" size pieces of nuclear waste will we have to store? **450,000 * 1 = 450,000**
450,000*(~18 in^2) = 8,100,000 in^2 = 56,250 ft^2 = 6250 yd^2

4. Suppose a material emits 25 rem/year (which causes radiation sickness if felt in a single dose), and has a half-life of 5 years. How many years before it emits only 200 millirem/year, which is the amount of background radiation you receive every year.

HINT: 1 rem = 1,000 millirem.

The easiest way to do this is to divide the amount by 2 for every 5 years.
25,000 mrem / 2 = 12,500 mrem after 5 years
10 years: 6,250 mrem 15 years: 3,125 mrem
20 years: 1,562.5 mrem25 years: 781.25 mrem
30 years: 390.6 mrem35 years: 195.31 mrem

The material will decay to background level after 35 years!

Experiment 4

Nature's Kitchen

Solar Box Cooker

Objective: After performing this experiment, you will be able to design an apparatus to cook food with energy from the sun.

Practical applications: These principles may be useful if you are camping or stranded in the wilderness without a Coleman stove.

Review of Scientific Principles:

Common fuel sources used for cooking include gas, electricity, microwaves, or wood. What if we ran out of all of these sources or if they were unavailable for use? What could we use instead? In this lab we will investigate how to use solar power as a cooking fuel.

The sun may shine all day, but is it warm enough to cook anything? Can we simply put the food outside in the sunshine to cook it? These questions should be considered as you build your solar cooker.

The idea is simple. If you have ever started anything on fire with a magnifying glass, you have used an uncontrolled solar cooker. The solar cooker you will build will concentrate the sun's rays in order to achieve a temperature suitable for cooking food. This heat from the sun must be stored or trapped, in order to reach cooking temperature. In order to trap the heat efficiently, reflectors, a glass or Plexiglas window, and insulation around the perimeter will be used. As you build your solar cooker, think about how it would fit into your lifestyle and how this technology could be used as an alternative fuel source.

Time: 1 class period to build
1-8 hours to cook

Safety Guidelines:

- Temperatures in cooker can be very **high** use extreme <u>caution</u> when opening.
- Reflected sun light can permanently damage eyes. **DO NOT** look directly into reflected light.

Materials and Supplies:

2 large cardboard boxes with flaps (one fitting inside the other with 5 cm on the sides and bottom)
1 piece of cardboard (larger than biggest box)
1 piece of glass or Plexiglas
aluminum foil
clear mailing tape
1 piece of black construction paper (to fit bottom of smaller box)
newspaper
string
stick
scissors

Procedure:

1. Remove the flaps from the smaller box.

2. Make four 4 cm high stacks (3 cm x 3 cm) from discarded flaps for bottom supports.

3. Crumple newspaper into baseball size balls and cover bottom of large box with the supports.

4. Use aluminum foil to cover:
   a. inside of small box.
   b. outside of small box.
   c. both sides of flaps on large box.

5. Put the covered smaller box inside larger box on the newspaper balls and supports.

6. Add newspaper balls between sides of the boxes.

7. Cut black construction paper to fit inside smaller box.

8. Cut flaps of larger box to fit inside the smaller box and cover the space between both boxes. Tape in place.

9. Make a snug fitting lid from the single piece of cardboard and tape (do not tape to large box).

10. Cut three sides of a rectangle in the lid (the same size as the smaller box).

11. Cut the Plexiglas 2 cm larger than the lid's rectangle.

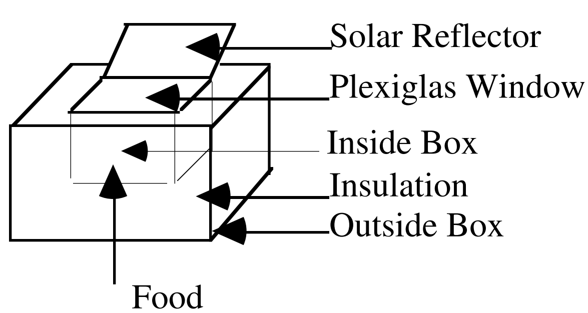
12. Center and tape Plexiglas in lid and put lid on the cooker.

13. Bend the uncut side of the rectangle in the lid to open window and cover inside of the cardboard with aluminum foil.

14. Tape a 10 cm piece of string to the rectangle to open the window.

15. Use a stick to prop open the window to collect the sun's rays.

You are now ready to cook in your solar cooker.



Data and Calculations:

Sample	Time	Temperature

Questions:

1. Identify the collector, storage, and controls on your solar cooker.
   a. collector:

   b. storage:

   c. controls:

2. How does the sunlight cook the food?

3. What parts of the world would a solar cooker work the best? the worst?

4. What are some disadvantages of using a solar cooker?

5. What are some advantages of using a solar cooker?

6. What are some health benefits of using a solar cooker in developing countries?

7. How are solar cookers beneficial to the environment?

8. What other types of materials could be used in the construction of a solar cooker? Would cost have to be a consideration?

Experiment 4: Teacher's Notes

Nature's Kitchen

Solar Box Cooker

Objective: After performing this experiment, you will be able to design an apparatus to cook food with energy from the sun.

Practical applications: These principles may be useful if you are camping or stranded in the wilderness without a Coleman stove.

Time: 1 class period to build
1-8 hours to cook

Safety Guidelines:

- Temperatures in cooker can be very **high** use extreme caution when opening.
- Reflected sun light can permanently damage eyes. **DO NOT** look directly into reflected light.

Questions:

1. Identify the collector, storage and controls on your solar cooker.
   a. collector: **the glass cover that lets the sunlight in the cooker.**

   b. storage: **the newspaper insulation prevents heat from escaping and the food also will absorb the heat.**

   c. controls: **the reflectors direct the sun's rays into the cooking area.**

2. How does the sunlight cook the food?
   The sun's rays are absorbed by the cooker's inside surface and transformed into heat energy.

3. What parts of the world would a solar cooker work the best? the worst?
   Areas that get lots of sunshine on a consistent basis would be the best. Areas where the sunlight is less intense such that it takes a long time to collect the same amount of energy as from a sunny place would be the worst.

4. What are some disadvantages of using a solar cooker?
   Need a lengthy span of available sunlight, longer cooking times, smaller portions.

5. What are some advantages of using a solar cooker?
   There isn't any waste product, and you can cook in the summer without heating the entire house.

6. What are some health benefits of using a solar cooker in developing countries?
   a. temperatures can reach the point to purify water and to kill bacteria and dangerous diseases, but only on sunny days.
   b. eliminates disease caused by inhaling toxins common to food cooked over wood.

c. decrease health problems related to constant exposure to smoke and fire.
d. decrease malnutrition due to the decreased availability of firewood

7. How could solar cookers be beneficial to the environment?
   They could reduce the need of fuel gathering (wood, coal, or gas) that can lead to the destruction of forest and agricultural lands. In addition, much of the waste products from burning fossil fuels would be reduced. However, remember that the majority of our energy is consumed for transportation, not cooking food.

8. What other types of materials could be used in the construction of a solar cooker? Would cost have to be a consideration?
   Answers may vary. Materials should be capable of providing insulation, absorption, storage and reflection.

<u>Teacher Notes</u>

This lab may be done in groups or as an individual project for solar cooker design. Students could experiment with different insulation materials (do not use Styrofoam, they may emit toxic fumes at high temperatures), reflector angles, and general design materials. This could also be a good science fair project, or it might make a fun project for a class competition to see whose cooker can most completely cook a certain type of food in a given time.

Solar cooker should be preheated approximately one hour before using.

Observed Cooking Times

1-2 hours:	rice, fruit, above-ground vegetables, pretzels
3-4 hours:	potatoes, root vegetables, some beans, most bread
5-8 hours:	most dried beans

Energy Quiz

Multiple Choice:

1. Energy efficiency is defined as:
   A. Energy that escapes in an unusable form.
   B. (Energy in bonds broken) - (energy in bonds formed).
   C. The content of energy in a fossil fuel.
   D. The amount of energy extracted from a system divided by the total energy you put into the system.

2. "Fossil fuels" refers to:
   A. coal. B. oil. C. natural gas. D. All of the above.

3. The best type of coal in terms of purity is:
   A. lignite. B. anthracite. C. bituminous. D. subbituminous.

4. Coal liquefaction refers to the process of:
   A. Washing coal to remove impurities. C. Turning coal into syncrude.
   B. Turning coal into natural gas.D. None of the above.

5. The main method of natural gas transportation is:
   A. tankers. B. truck. C. pipeline. D. none of the above.

6. Crude oil is called "sweet" if:
   A. It smells good. C. It removed from oil shale.
   B. It is easy to recover. D. It has $\leq$ 1% sulfur.

7. We use most of our oil products for:
   A. transportation. B. electricity generation. C. home heating. D. industrial uses.

8. Effects of acid rain include:
   A. Deterioration of monuments. C. Damage to lakes and their wildlife.
   B. Damage to vegetation. D. All of the above.

9. Ways we utilize energy from the sun include:
   A. passive solar heating. C. wind power
   B. photovoltaics. D. All of the above.

10. Types of spontaneous radioactive decay include:
    A. gamma emission. C. alpha bombardment.
    B. transmutation. D. nuclear fission.

True/False

1. T F Potential energy is really a type of mechanical energy.
2. T F A BTU is smaller than a Joule.
3. T F Scientists worry that coal reserves may run out in the next 100 years.
4. T F There is only one way to recover oil--drilling.
5. T F OPEC is an organization which regulates the solar power industry.
6. T F The greenhouse effect refers to global warming due the burning of fossil fuels and the subsequent trapping of the waste heat by the atmosphere.
7. T F Solar ponds are a neat idea, but they can't make the water very hot.
8. T F The use and production of biomass is such that eventually, we'll be able to use it for all of our energy needs.
9. T F An accident like the one at Chernobyl could not happen in the United States.
10. T F Ordinary objects are radioactive, and you are bombarded with radiation every day.

Short Answer

1. Name three different types of energy.

2. The law that states that the energy in the universe is constant is the ____.

3. Two ways to mine coal are: and .

4. List 4 products of crude oil:

5. Natural gas is found in .

6. Give one example of geothermal energy on the surface of the earth.

7. An alpha particle is really a .

8. In order for a chain reaction to occur, it is necessary to have a .

9. The type of nuclear reactor that makes more fissile fuel than it consumes is called a ______________ reactor.

10. The amount of radioactive waste could fit under your coffee table.

Energy Quiz Answers

Multiple Choice:

1. Energy efficiency is defined as:
   A. energy that escapes in an unusable form.
   B. (Energy in bonds broken) - (energy in bonds formed).
   C. The content of energy in a fossil fuel.
   D. the amount of energy extracted from a system divided by the total energy you put into the system.

2. "Fossil fuels" refers to:
   A. coal.B. oil. C. natural gas. **D. All of the above.**

3. The best type of coal in terms of purity is:
   A. lignite. **B. anthracite.** C. bituminous. D. subbituminous.

4. Coal liquefaction refers to the process of:
   A. washing coal to remove impurities. **C. turning coal into syncrude.**
   B. turning coal into natural gas.D. none of the above.

5. The main method of natural gas transportation is:
   A. tankers. B. truck. **C. pipeline.** D. none of the above.

6. Crude oil is called "sweet" if:
   A. it smells good.C. it removed from oil shale.
   B. it is easy to recover.**D. it has ≤ 1% sulfur.**

7. We use most of our oil products for:
   A. transportation. C. home heating.
   B. electricity generation. D. industrial uses.

8. Effects of acid rain include:
   A. deterioration of monuments. C. damage to lakes and their wildlife.
   B. damage to vegetation.**D. all of the above.**

9. Ways we utilize energy from the sun include:
   A. passive solar heating.C. wind power
   B. photovoltaics.**D. All of the above.**

10. Types of spontaneous radioactive decay include:
   A. gamma emission.C. alpha bombardment.
   B. transmutation.D. nuclear fission.

True/False

1.**T** F Potential energy is really a type of mechanical energy.
2.**T** F A BTU is smaller than a Joule.
3.T **F** Scientists worry that coal reserves may run out in the next 100 years.
4.T **F** There is only one way to recover oil--drilling.
5.T **F** OPEC is an organization which regulates the solar power industry.
6.**T** F The greenhouse effect refers to global warming due the burning of fossil fuels and the subsequent trapping of the waste heat by the atmosphere.
7.T **F** Solar ponds are a neat idea, but they can't make the water very hot.
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9.**T** F An accident like the one at Chernobyl could not happen in the United States.
10. **T** F Ordinary objects are radioactive, and you are bombarded with radiation every day.

Short Answer

1. Name three different types of energy.
   Answers will vary. Chemical, mechanical, thermal, electrical, radiant, nuclear.

2. The law that states that the energy in the universe is constant is the **first law of thermodynamics.**

3. Two ways to mine coal are: **strip mining** and **deep mining**.

4. List 4 products of crude oil:
   Answers will vary. Gasoline, distillate fuel oil, jet fuel, still gas, lubricants and wax, coke, LPG, asphalt.

5. Natural gas is found in **reservoirs**.

6. Give one example of geothermal energy on the surface of the earth.
   Volcanoes, geysers, hot springs.

7. An alpha particle is really a **helium atom.**

8. In order for a chain reaction to occur, it is necessary to have a **moderator.**

9. The type of nuclear reactor that makes more fissile fuel than it consumes is called a **breeder** reactor.

10. The amount of **high-level** radioactive waste could fit under your coffee table.

Glossary

absolute zero: 0 Kelvin (-273˚ C); the temperature at which all molecular movement ceases.
active solar: energy generated by a photovoltaic cell.
alpha particle: helium nucleus emitted from a heavy radioactive element.
anthracite coal: coal with 90% carbon, very high heating value and very low impurities.
atomic number: the number of protons in the nucleus.
atomic mass: the sum of the protons and neutrons in the nucleus.
atomic mass unit (amu): the weight of one proton or neutron.
background radiation: naturally occurring (i.e. non-enriched) radiation in the world around us to which humans are exposed constantly, including radiation from the sun, bricks, the earth, and naturally occurring radioactive isotopes in food.
beta particle: a negatively charged electron emitted during a nuclear reaction.
binding energy: energy contained in holding the protons and neutrons together in the nucleus of an atom or holding the atoms together in a molecule.
biomass: organic material such as wood, grain, etc. that is a source of renewable energy.
bituminous coal: the most abundant type of coal, which has a high heating value and usually a high sulfur content. Illinois coal is bituminous coal.
breeder reactor: a nuclear reactor in which a fissile fuel is produced from a non-fissile fuel by absorption of a fast neutron.
British thermal unit (BTU): energy required to raise one pound of water one degree Fahrenheit.
boiling water reactor (BWR): nuclear reactor in which the water that moderates and cools the reactor also is used to drive the turbines.
calorie: the amount of heat needed to raise one gram of water by one degree Celsius.
chemical energy: energy stored on the chemical bonds of molecules.
coal: a fossil fuel comprised primarily of carbon formed by the decomposition of plant matter in non-marine environments billions of years ago; a fossil fuel.
coal gasification: process by which coal is converted into synthetic natural gas.
coal liquefaction: the process of converting coal into syncrude, or synthetic crude oil.
containment structure: reinforced enclosure around a nuclear reactor designed to keep all the radioactivity inside and filter it out of the inside atmosphere in the event of an accident; they are tested for susceptibility to tornadoes, earthquakes, airplanes flying into them (really), and explosives.
control rod: rods of cadmium or boron which can be placed in or removed from the core of a nuclear reactor to control the number of neutrons causing a chain reaction by absorbing neutrons.
control system: heat regulation devices in passive solar systems such as insulation, fans, and vents.
crude oil: the form in which oil is initially extracted which is a mixture of hydrocarbons with some oxygen, nitrogen, and sulfur impurities; a fossil fuel.
deep mining: coal mining in which shafts and tunnels are used to extract coal from a seam.
diffuse radiation: solar radiation which can not be focused easily because it passes through cloudy skies.
electrical energy: the energy associated with movement of electrons through a wire or circuit.
electromagnetic radiation: radiation that is emitted in the form of photons, i.e. light.
endothermic: a reaction that takes heat in from the environment, that is, heat is absorbed by the system.
energy: the ability to do work. The source of energy is the rearrangement of chemical and nuclear bonds into a more stable state.
energy efficiency: the amount of energy extracted from a system divided by the amount of energy put into the system in order to recover the energy.

enrichment: the process by which the amount of uranium-235 in a mixture of uranium isotopes is increased from 7% to 2-3%.
exothermic: a chemical reaction which gives off heat to the environment, that is, heat is released from the system.
first law of thermodynamics: the total amount of energy and mass in the universe is constant; energy and mass can be neither created nor destroyed.
fissile material: nuclei that undergoes fission when a neutron is absorbed.
fission: bombarding a radioactive isotope with a neutron in order to split the nucleus into smaller parts, releasing energy.
fission products: isotopes produced when fissile material is split after colliding with a neutron.
flow: the total amount of water moving in a hydropower system per unit time.
fossil fuels: general term referring to fuels that have been generated by "fossilized" plant and animal matter over millions of years, i.e. coal, oil, and natural gas.
fractional distillation: method by which crude petroleum is refined into usable products.
fusion: the process of bringing two light nuclei together to form a heavier nucleus, thereby releasing energy from the loss of mass.
gamma particle: a high-energy electromagnetic photon released during radioactive decay.
gasohol: fuel made by distilling grain, wood, or other plant products into ethyl alcohol and mixing the alcohol with gasoline.
generator: a device consisting of a magnet and a coil of wire that changes the mechanical energy of the turbine into electrical energy.
geothermal energy: energy from the inner core of the earth; specifically from hot, molten rock pushing through to near the surface of the earth heating the water.
greenhouse effect: phenomenon in which oxides of nitrogen and carbon trap the energy radiated from the earth.
greenhouse gases: oxides of nitrogen, sulfur, and carbon as well as CFC compounds which absorb infrared radiation from the earth, causing global warming.
head: term used to describe the height of falling water in a hydropower system.
heat: movement of molecules or atoms.
heat of formation: a measure of the binding energy of a molecule, set such that the heat of formation of O_2 is 0 kcal/mol.
heating value: a measure of the useful energy content of different fuels.
high-level radioactive waste: fission products of a nuclear reaction.
hydropower: energy from flowing water used for mechanical purposes or for electricity production.
insulation: process in which a material slows heat loss or gain.
isotope: nuclei of the same element that have the same atomic number but different atomic mass and neutrons.
joule: one Newton-meter; a unit of work equivalent to 0.239 calories.
kinetic energy: energy of motion, $(1/2)mv^2$.
lignite: "young" coal with high water content, low heating values, and typically many impurities
low-level radioactive waste: other waste products which result from working with radioactivity, such as gloves, mops, and filters.
mechanical energy: energy that can be used directly to do work, either potential or kinetic.
meltdown: a possible situation that may occur when a nuclear reactor core gets so hot (accidentally) that the fuel rods melt and release the radioactive fission products trapped inside.
methanogens: methane-producing bacteria.
MBPD: million barrels of oil per day.
moderator: substance used in nuclear reactors to slow down neutrons so that they can split a nucleus more easily.
multiple barrier containment system: a method of containing high-level radioactive waste in several layers, or barriers, to protect the environment. These include agents to absorb any incident ground water.

natural gas: methane with ~1% other light hydrocarbons; a fossil fuel.
neutron: a nuclear particle with a charge of zero and a mass number of one amu.
nuclear bombardment: hitting a nucleus with subatomic particles like protons, neutrons, or alpha particles.
nuclear energy: the energy stored in the nucleus of an atom which can be released upon fission.
nuclear waste: radioactive active waste resulting from the byproducts of nuclear reactions.
nucleus: the center of the atom where most of the mass is located in the form of protons and neutrons.
oil: a mixture of hydrocarbons formed by the deposition of dead plant, animal, and marine microorganism matter in or near marine sedentary basins.
oil shale: sedimentary rock containing solid organic material that can be converted to crude oil which is called **shale oil**.
OPEC: Organization of Petroleum Exporting Countries.
passive solar heating: using a material to collect and store thermal energy from the sun.
photon: a massless particle of electromagnetic energy (light).
photosynthesis: the production of glucose in a plant from water and carbon dioxide using solar radiation.
pH: a measure of how acidic or basic a substance is by the amount of H^+ ions are in solution.
positron: a positive electron emitted from the nucleus during a nuclear reaction.
positron emission: a type of radioactive decay due to the emission of a positive electron.
potential energy: stored energy in a system which is a function of position or chemical bonds.
Pressurized Water Reactor (PWR): a nuclear power reactor in which the cooling water is kept under high pressure and not allowed to boil until the water passes into the turbine units.
primary oil recovery: a method of oil recovery whereby the oil flows from the well by its own pressure or is pumped out. This method recovers about 30% of the oil in the well.
proton bombardment: the bombardment of a nucleus with a proton in order to effect nuclear decay.
QUAD: an amount of energy equal to 10^{15} BTU.
radiant energy: energy coming to earth from the sun.
radioactive: an unstable nuclei which will decay to a different nuclei and emit radioactivity (an alpha, beta, or gamma) in the process.
rem: a unit of nuclear radiation (dose) equivalent, (**r**adiation **e**quivalent for **m**ammals). An average person is exposed to 300 mrem/year.
renewable resource: an energy resource in the environment which can be renewed if proper care is taken. Examples include hydropower, wind power, biomass, solar power, and geothermal energy.
reserve: the amount of a resource that is recoverable.
reservoirs: large deposits of natural gas.
second law of thermodynamics: the disorder in the universe always increases.
secondary oil recovery: method of oil recovery whereby the well is flooded with high-pressure water or gas, such as CO_2 to push the oil out. Recovers about 10% of the oil in the well after primary recovery.
short ton: 2,000 lbs of coal, which can provide about 26 x 10^6 BTU.
smog: smoky fog that hangs in the atmosphere as a result of burning fossil fuels with impurities, which can originate from the exhaust pipe of your car.
solar pond: a large pond with a salt gradient which traps heat from the sun and may be used to directly heat buildings.
subbituminous coal: coal with 40% carbon and less sulfur than lignite.
surface mining: type of coal mining (also called strip mining) in which layers of land are removed, leaving an open "pit."
syncrude: synthetic crude oil.
temperature: the average speed of all the molecules within a certain area.

tertiary oil recovery: method of oil recovery in which the oil is heated by burning it underground, adding steam, or adding a detergent to scrub it out. Typically recovers only an additional 10% of the oil in the well after primary and secondary recovery.

THERM: a measure of heat energy equal to 100,000 BTU.

thermal mass: a heat storage material, such as water or masonry, used in passive solar heating systems, which radiates heat to the surroundings after the sun goes down.

thermal energy: energy in the form of heat.

thermal neutrons: neutrons in a reactor that have the necessary energy (1/40 of an electron volt) needed to induce fission.

thermodynamics: study of energy relationships involving, heat, mechanics, work, and other aspects of energy and energy transfer.

third law of thermodynamics: all molecular movement stops at absolute zero.

transmutation: radioactive decay induced by particle bombardment.

waste heat: an unusable form of energy which inevitably results from energy transformation.

wind power: energy from the moving air which turns large windmills for electricity generation.

work: a force applied to an object over a certain distance.