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Energy Resource Series for Youth and Adult Energy Programs

5. Solar

by
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Preface

Quite frequently stories and news articles appear in our newspapers and magazines about a vast source of energy surrounding us every day. This is solar energy. It is true that it is a vast source. It is also true that methods proposed today to make increased use of this natural energy require special equipment. This makes the cost extremely high.

The first part of this publication deals with nuclear physics; it is designed for the reader who is serious about learning the basics of sunlight. The reader who is mainly interested in applications of solar energy should begin reading at the section titled Radiation Arithmetic and Geometry.

This is the fifth publication in a 12-part energy resource series designed for the adult and student with a serious interest in the energy situation. Each publication in the series deals with a different energy source and considers the advantages and disadvantages associated with its use.

When necessary, diagrams and/or tables are used to clarify or elaborate upon information found in the text. Questions with answers are included at the end of each publication so that you can test what you have learned.

The author wishes to thank Larry W. Turner, Richard Hiatt and Linda Bach of the Department of Agricultural Engineering, University of Kentucky, for reviewing the text.

The Energy Resource Series for Youth and Adult Energy Programs includes the following publications:

AEES-21 Energy Overview
AEES-22 Definitions
AEES-23 Oil and Gas
AEES-24 Coal
AEES-25 Solar
AEES-26 Wind
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5. Solar

Introduction

Since 1973, when the public became aware that shortages of gasoline for automobiles could drastically affect their personal lives, there has been much interest in solar energy. Many articles have appeared in the popular press about the potential of solar energy, and the federal government has allocated large sums of money for research in this area of energy. Most science textbooks now contain a chapter or two on solar energy utilization. Most engineering colleges offer courses specifically related to energy, and many of these place emphasis on the solar aspect. There is little doubt that the public, in all sectors, is well aware of the sun as a vast source of energy.

It is true that there is an immense amount of energy coming to our earth from the sun. Most people have felt the heat from the sun while in an automobile or while sitting near a window on a clear, cold day. From these experiences, many individuals anticipate that an economical breakthrough by scientists will provide them with access to this energy source. In reality, the process of substituting solar energy for the immense amount of work that fossil fuels now do is formidable; it is difficult, if not impossible, for people today to appreciate how difficult it would be to accomplish this on a nationwide scale.

Radiation Defined

In order to adequately understand solar energy, you must understand the concept of radiation. To do this, we start with the simple, basic facts as they are conceived today by specialists in this field, the physicists. Their concept of radiation starts with the atom. The simplest atom is hydrogen. It has one proton in its center or nucleus, and one electron moving around the outside. This is illustrated in Figure 1.

Physicists believe all protons are exactly the same. The mass of a proton is given in physics books at 1.66 x 10^{-27} kg. The proton is slightly more than 1,800 times as massive as the electron; therefore, the electron is very small. Scientists think that all electrons are exactly alike.

Each proton exhibits a positive electrical charge of one unit, while each electron exhibits one electrical charge but of opposite or negative value. In the physical world, the positive and negative charges attract or draw toward each other, while all positive charges repel or push away from each other. Likewise, all negative charges repel each other.

![A simplified diagram of the hydrogen atom.](image_url)

In an atom, such as hydrogen illustrated in Figure 1, the electron with its negative charge wants to get as close as possible to the proton with its positive charge. The only reason they do not get together is because the electron is whirling around so fast that its centrifugal force keeps it away; in a similar fashion, the moon orbits the earth.

The electron has many discreet orbit levels available to it depending on the energy it possesses. It can move up and down to one of several levels at one time if external energy is put into the electron.

If the electron moves closer to the proton, it must orbit at a faster rate to keep all the forces in balance. Since an electron has less energy at lower
levels than at higher levels, it takes energy or work to make these changes in the orbit's distance and corresponding velocity.

During the past 50 years or so, scientists have found that when external energy is put into an atom, the electron will move to a higher orbit. When the external source of energy is removed, the electron will move back to its original orbit. It gives up energy exactly equal in quantity to that which was put in. Scientists gave the name quantum to this amount of energy.

They now propose that this energy is carried by a massless, particle-like bundle of energy to which they have given the name "photon." The photon, carrying a quantum of energy, is the basis of all electromagnetic radiation whether it be radio, television, radar, microwave ovens, electromagnets, infrared heat, visible light, laser beams, ultraviolet, X rays or gamma rays.

A Radiation Concept

Any person can form a mental concept of a photon. It will probably not be like the one formed by any other person. It does not matter as long as the concept fits all the facts. A photon will never be seen by human eyes. All that can ever be done is to examine the evidence of what the photon does. The concept, based on facts known today, is that all photons are the same and travel away from their source of origin at the speed of light; and depending upon the level of electron orbit from which they were emitted, they vibrate at different rates.

You can visualize a photon as a point which can expand and contract in a plane, such as a sheet of paper, perpendicular to the direction of travel. This expansion and contraction is the vibration; the number of times the photon vibrates per second is the frequency. Photons emitted from electrons moving from very high levels of orbits have higher frequencies of vibration than those emitted from lower levels.

As a photon travels away from the atom of its origin at the speed of light, amazing things happen. A greatly simplified picture of this process is shown in Figure 2. Note that the point or photon expands in a plane in all directions. Remember this plane is moving forward at the speed of light.

Figure 3 is a side view of a photon that vibrates with a frequency of 1,000 kilocycles per second (1,000 kc/s). This is about the center of the standard broadcast radio band. Since "kilo" means thousand, this photon vibrates at one thousand thousand cycles each second or one million cycles each second.

At the speed of light, 186,000 miles per second, this photon travels 0.186 miles while one cycle is taking place, or about 980 feet. The wavelength is then 980 feet or about 300 meters. This is shown at the top of the diagram of Figure 3. During one cycle, the photon expands from point size to a maximum, then contracts to a point again.

Now let's apply the same process to a photon emitted from an orbit farther from the nucleus and assume it to vibrate about 500 trillion cycles per second. This is about the middle of the visible light band. The human eye is sensitive to this frequency...
which means that the millions of tiny rods and cones in the retina of the eye are attuned to this band, or that they vibrate in phase with the incoming photon. In other words, the rods and cones in the retina of the eye act as antennae that are tuned to this band. When photons close to this frequency of vibration reflect from objects, such as a printed page, they bring information which the human eye can sense; we interpret this as vision.

The side view of such a photon is shown in Figure 4. The frequency of this photon is about 500 million times as great as the one shown in Figure 3. Therefore, the number of humps or expansions in the distance covered by the forward movement of the photon each second is 500 million times those of Figure 3. Remember that all photons travel forward at the same velocity, that is, the speed of light.

Fig. 4.—A side view of a photon vibrating at a frequency of 500 trillion cycles per second. This is about the middle of the visible light spectrum that makes up most of the radiation from the sun. Note the difference in wavelength compared to Figure 3.

The picture of the path of this photon through space would be similar, yet quite different, from the radio frequency photon of Figure 3. This comparison is illustrated in Figure 5. Note that each photon travels at the same velocity, the speed of light, and therefore covers the same distance in the same time period. The difference in the paths is caused by the difference in the frequencies.

One very important fact made obvious by the illustration of the two photons is that there is much more energy in the higher frequency than in the lower one. In fact, the energy of a photon is directly related to its frequency of vibration. This fits the physical facts that scientists have observed about photons.

Radio frequencies and even frequencies in the visible light range do not do much damage to living cells. But, starting with ultraviolet and upward, such as X rays and gamma rays, the frequencies can kill living cells causing irritating burns and, if severe enough, can cause the death of plants, animals and humans.

It must be understood that all the space throughout the universe is filled with photons moving in all directions. Photons do not seem to interfere with one another. The beams of light from two flashlights can cross each other and still show up as spots on the opposite walls of a room. Photons in the visible light frequency band can be coordinated so that a large majority are in phase with each other. This is called a “laser” beam. The secret behind this is to cause many atoms to have electrons drop from higher orbit levels to lower ones at the same instant. This in turn sends photons of the same frequencies outward at the same time, or in phase.

One more illustration can help explain where visible light comes from. The filament of an incandescent light bulb is made of tungsten, a special kind of metal. An electric current is forced through this filament. This results in the conductor heating up just like the wires in an electric oven or toaster. But, in this case, the force keeps increasing and pushing the electricity through so that the conductor gets hotter and hotter. The wire actually
becomes white hot rather than just red hot. The temperature of the wire is about 3,000°C (5,400°F). This effect is caused by the extreme agitation of the atoms which make up the wire filament. There are many billions of atoms in a filament 2 inches long. The external energy input, in the form of the electric current, is the actual cause of the wire heating up to white incandescence. This in turn causes the electrons to be elevated to higher levels on most of the atoms. Some of the atoms will be temporarily cooled by being briefly away from the agitation. The electrons of these atoms fall back to a lower level, and this is the source of photon emission that we see. Objects must be in the 4,000 to 5,000°F range to emit photons vibrating in the visible light range.

Gases can burn at temperature levels causing visible flames of different colors. The atoms within the flame are agitated to such an extent that the electrons are elevated in orbit. When some of the atoms cool by moving to the edge of the flame, their electrons drop back, emitting a photon. Some gas flames are cooler than others, about 4,000°F, giving off mostly red and yellow color; while some are in the blue range, closer to 5,000°F. A piece of metal heated by a torch to 1,500°F will appear dull red. Atoms in objects at this temperature emit photons vibrating in the red band or lower edge of the visible light band at about 400 trillion cycles per second.

So far, the basic facts about radiation are as follows. The entire electromagnetic spectrum is made up of photons. These originate when an electron orbiting an atomic nucleus drops to a lower level. Photons travel through space at the speed of light and can have various frequencies of vibration depending upon the orbit level from which they were emitted. Space is filled with these moving photons coming from any object containing energy in the form of atomic vibration.

**The Sun as a Radiation Source**

Now let’s look at the sun as an emitter of gigantic quantities of radiation. Scientists now know that our sun is a star. They know that its energy comes from the familiar thermonuclear reaction called “fusion.” In this reaction, hydrogen atoms approach one another with sufficient velocity to overcome the opposing forces of the positively charged nucleus or proton (Figure 1). When the two protons touch, physical forces just recently discovered take over. These forces have always existed, but scientists have learned about them only in the past 50 years. These forces are strong nuclear forces called binding forces. Refer to AEES-28 Fusion for more detail on the thermonuclear reaction and these strong nuclear forces.

The forces are so strong that the two protons stick solidly together as one unit, forming a new element, helium. When a new element is formed, its total mass is less than the separate parts before they come together. This loss of mass reappears as energy given off as gamma rays—extremely high frequency photons. In the thermonuclear reaction, a vast amount of energy is given off from the very small amount of mass that is lost. Velocities several million miles per hour, aided by pressure or gravity great enough to overcome the tremendous repulsive force of the two protons (0.13 pounds at two diameters distance apart), are only found in the sun or similar stars. It is the high velocity of the particles, representing high temperature, that gives this reaction the name “thermonuclear.”

In actuality, it is found that four particles make up the nucleus of a helium atom, not just the protons. However, the two extra particles have no charge and are therefore called “neutrons.” Their purpose seems to be to help evenly distribute the strong nuclear force and form a stable nucleus. All elements, from hydrogen which rarely has a neutron attached, up to about number 26, iron (Fe), have a neutron for each proton in the nucleus. Above this point, extra neutrons are found in the nucleus. In other words, more neutrons than protons are found in the nucleus. Apparently the more complex the nucleus, the more help the strong forces must have to maintain stability. After uranium (U), number 96, no amount of extra neutrons can make a nucleus stay together for more than fleeting instances of time. Every element is unstable above uranium and cannot be found in nature.

All stars, of which our sun is one, fall within a relatively narrow range of mass. If the mass is too small, the pressure caused by gravity is not great enough to assist in forcing the hydrogen atoms together to form helium. If the mass is too great, the gravitational force overcomes and crushes the interior into an extremely dense mass where thermal energy (not nuclear but friction) raises the temperature above what the nuclear reaction would do, and the mass is forced apart in a gigantic explosion called a “supernova.”

Our sun has just the right amount of mass to cause the thermonuclear reaction energy to balance the gravitational forces. It has been doing this for billions of years and can continue for billions more before imbalance takes place.
The surface of the sun is about 5,500°C (10,000°F). At this temperature, photons are emitted with frequencies averaging 500 trillion cycles per second. This puts them in the middle of the visible light range, and the human eye is tuned to respond to these. Certain portions of the surface are somewhat cooler, and some quite a lot hotter. These portions, however, make up a small percentage of the surface. Because of this, there are some photons emitted of relatively low frequency and some with a much higher frequency. In fact, frequencies all across the spectrum have been detected ranging from low frequency radio to gamma rays. The large majority of the photons emitted, however, are in the visible range, from 430 trillion cycles per second (red) to 750 trillion (violet). Additional quantities are emitted in the infrared range, 30 trillion cps (sensed as heat only) and in the ultraviolet range, 3,000 trillion cps.

A graph of the radiation spectrum of the sun is shown in Figure 6. Note that the large percentage of radiation is in the visible light range. This is because the 10,000°F surface temperatures caused by agitated atoms produced photon emission in that frequency. Any object at this same temperature will produce photons of the same frequency. Note also that there is a little radiation on either side of the visible light band. This is caused by parts of the surface being cooler and some much hotter.

The radiation from the sun travels outward in all directions in equal quantity at the speed of light. A photon leaving the sun's surface can travel for millions of light years, and if it touches nothing in space, the photon can have exactly the same frequency or energy content as when it was emitted.

**Radiation Absorption**

When a photon collides or strikes matter, several things can happen (Figure 7). If the frequency or energy content is exactly right, a photon can hit the electron of an atom of matter giving the electron a boost into a higher orbit, just like one pool ball striking another. This action is exactly the reverse of the action that emitted the photon. The atom that received the energy is agitated and exhibits an increase in temperature.

The transfer of energy from one body to another by radiation is 100 percent efficient so far as the travel of the photons is concerned. As has been
pointed out, photons can travel for eons and never lose energy. The only inefficiency in transfer of energy by radiation comes from the fact that so many photons emitted never intersect matter, but simply travel off through space. This amounts to a tremendous loss in the number of photons leaving a hot object and travelling toward another object, because only a few encounter atoms in the receiving object. Photons can be focused, however, to direct more of them where they can interact with the intended material and, thus, increase efficiency.

As a matter of interest, it should be pointed out that photons do not exist inside atoms like electrons, protons and neutrons do, but exhibit themselves only as a form for conveying bundles (quanta) of energy when an electron falls from a higher level to a lower level. They cease to exist when they collide with matter, that is, strike the electron of an atom and transfer all their energy to it.

A second action that can happen is that a photon can strike a free electron in space and simply impart all or part of its energy to it. This effect is shown in Figure 8. A photon also may strike an electron in orbit with a direct blow and knock it clear out of the orbit. This is called ionization or the photoelectric effect.

A third possibility of the photon transferring its energy is shown in Figure 9. The photon simply disappears. It changes into two identical particles of matter. Each has an opposite electric charge, one positive, the other negative. One is the familiar electron, the other a positron. These two particles of unlike charge immediately attract each other and come together. In doing so, they completely annihilate each other, leaving a quantity of energy with a vibration rate greatly different from that of the original photon. This action is called “pair production.”

Of the three possibilities listed here, the first one is most prevalent as far as radiation in the frequency range emitted by the sun. The other emissions come mainly from radioactive radiation.

Radiation Arithmetic and Geometry

Now let's see how much of the radiation given off by the sun reaches the earth. Imagine a spherical surface surrounding the sun at a distance equal to that of the earth from the sun. This is a radius of 93 million miles. The surface area of any sphere is found by the formula $4 \pi r^2$. Using the radius of 93 million miles, a sphere of this size would have $1.4 \times 10^{17}$ square miles or 110,000 trillion square miles. The earth, as viewed from the sun, would appear as a circle or flat disc 8,000 miles in diameter on the surface of this imaginary sphere. A circle, 8,000 miles in diameter, has 50 million square miles. This is .0000000046 percent of the imaginary spherical surface. This figure represents the amount of the total energy emitted by the sun that is intercepted by the earth.

It is estimated that the total output of the sun is $4 \times 10^{26}$ watts (W) or $5.3 \times 10^{23}$ horsepower (hp). The earth intercepts about $1.7 \times 10^{17}$ W or $4 \times 10^{9}$ hp. The sun’s radiation intercepted by the earth represents about 56,000 times the total U.S. energy use. This fact is pointed out here so that you can compare the effects of our annual energy conversion on the overall earth energy balance.

To get these figures into a more familiar form, consider again that the earth appears as a flat disc when viewed from the sun. Each square meter (just about a square yard) receives 1,400 W or 1.4 kilo-
watts (kW). Remember this is above the atmosphere. Some of the solar radiation is reflected by photons colliding with atoms in the atmosphere. Some is reflected by clouds, and a small bit is absorbed by imparting extra energy to atoms in the air. At the surface of the earth, after the photons have penetrated the blanket of atmosphere, the square meter will receive about 1 kW or about 70 percent of that at the top of the atmosphere. This is only for clear days and during daylight hours. Daylight is considered as beginning about one hour after sunrise and ending one hour before sunset. During other hours, the radiation passes through too much of the atmosphere.

In the preceding examples, the square meter was assumed to be positioned perpendicular to the sun’s rays at all times. Unless the receiving surface is mounted on an elaborately controlled base, it is probably never at a right angle to the sun.

One reason that a tilted surface receives proportionally less radiant energy is shown in Figure 10. It is simply because the quantity of radiation touching it is less; therefore, the intensity on each part of the area is less.

The earth is just the right distance from the sun. If its average distance were less, the radiant energy would probably cause all the polar ice to melt. If it were slightly greater, only a narrow band around the earth could be inhabited. Also, the tilt of the axis plays a necessary role.

As shown in Figure 11, if the earth’s axis were perpendicular to the plane of the orbit around the sun, the poles would never receive direct radiation, and the band of surface at the equator would be much hotter than now, because it would be constantly receiving maximum radiation.

Fig. 10.—A surface slanted with respect to radiation has less energy imposed on it than a surface perpendicular to the radiation.

Fig. 11.—Because it is a sphere, the surface of the earth slopes at various angles to the incoming radiation. This greatly affects absorption of the solar radiation.

Fig. 12.—Because of the tilt of the axis of the earth, the north and south poles receive greater and lesser amounts of radiation as the earth moves around the sun. In the above diagram, the rays from the sun are striking the south pole, and it is winter time north of the equator.

But, with the axis tipped at $23\frac{1}{2}^\circ$ as shown in Figure 12, the poles will point toward the sun for part of the annual trip around the sun. A larger view of this arrangement is shown in Figure 13.

Because of the tilt of the axis, two movements of a flat plate receiver, or any object for that matter, are necessary to keep it pointed toward the sun. Tele-
scopes and cameras, which follow the sun and stars automatically, have gear ratios designed to allow for these movements.

Fig. 13.—In this diagram of the earth’s orbit, it is easy to see how the tilt of the earth’s axis causes the seasons. In positions 1 and 3, the poles receive equal radiation. In position 2, the south pole receives sunlight, which is the same as shown in Figure 12. In position 4, the north pole receives sunlight. It is now summertime in the northern hemisphere.

Look at Figure 14. With the north pole tilted toward the sun, the plane of the equator also is tilted. Any other plane of rotation is tilted the same amount. Notice the plane toward the top of the globe representing the latitude of Lexington, Kentucky. A flat plate at position 1, sunrise, must be rotated toward the east and tilted upward in order to be perpendicular to the sun. At noon, position 2, the plate has no rotation angle but is tilted at less of an angle with respect to the plane. At position 3, sunset, it is rotated toward the west and at the same angle of tilt with respect to the plane at sunrise.

Automatic-following equipment for the two-axis movement is quite expensive. Therefore, many flat plates of a practical nature are placed stationary at an average tilt and rotation angle for the whole year. They thus compromise on a little less efficiency or they enlarge the plate area. This means they face south and are at a rather steep angle, about 60° for Kentucky. The loss in efficiency is not as great as the theory would indicate. This is because the atmosphere causes diffusion of the radiation to take place. This simply means that many of the photons bounce or reflect off particles in the atmosphere, and therefore are not traveling in a direction directly from the sun to the plate. It is estimated that an average of 15 percent of the radiation is diffused or scattered.

With the theoretically impressive figures on the quantity of energy produced by the sun, let’s see what can be and has been done to avail ourselves of it.

How Solar Energy Has Been Used

First of all, we need to be aware of what has taken place in the past. All plants receive their growing energy from the sun through photosynthesis taking place in the leaves. This process has taken place since the first plant grew many billions of years ago. Wind and water power are directly related to heat from the sun. Of course, all the fossil fuels originated in energy from the sun.

The fact that solar energy is spread uniformly is in some cases a great disadvantage and in other cases a strong advantage. In attempting to design a central power station of large capacity, a great disadvantage is immediately encountered, that of collecting enough sunlight for the required output. Most of the expense of such a design is incurred by the gathering equipment. On the other hand, if small, home-sized power equipment is contemplated, the fact that sunlight is evenly dispersed is a great advantage. Regardless of where a home is located, it has access to some sunlight.

The greatest disadvantage to the practical harnessing of solar energy for heat or electricity is intermittency or the occurrence of cloudy days and nighttime hours. There is not much that can be done to alter either of these so engineers must design systems that work around this great limitation. This means discovering some way to receive an excess amount of energy when the sun is shining and storing the excess for use when it is not shining.
Collecting Solar Energy

At the present time, the most practical uses of solar energy appear to be space heating of buildings and domestic hot water production. When used as heat, solar energy is collected more or less directly. That is, no complicated, costly conversion equipment with its inherent inefficiency is needed such as in producing electricity or running cooling equipment with electricity.

The most common type of solar collector or photon absorber is the flat-plate type. This is simply a flat surface, as the name implies, placed to face the rays from the sun. If the surface is black, it will absorb much more radiation than if it were bright and shiny. If you have ever walked across a blacktop pavement on a hot, sunny day, you have experienced this. There is a limit as to how hot such a surface will get even under the direct rays of the sun. As the surface material heats up, it begins to radiate heat itself. Soon a balance is reached between incoming and outgoing radiation, and the material will not get any hotter. If the material is in contact with colder surroundings, the heat will be conducted away, thus reducing the material's temperature. This can happen if cold air touches the surface or if the material is lying on cold ground. To limit this, the surface is usually covered by clear glass so that a thin layer of air is trapped above the black surface acting as an insulator to the surrounding air. Insulating material is placed under the black surface to limit heat loss in this direction. Using these and other innovations, the temperature of the black surface can be increased.

To make use of the heat buildup in the black surface, two schemes are usually employed, one using air and the other water. The water method is to attach with glue or solder small tubes to the back side of the surface. Through these tubes, water is circulated. Heat from the high temperature surface is conducted into the water which in turn can carry the heat through insulated pipes to the radiators throughout the building. A diagram of a system to heat a building is shown in Figure 15. Obviously, the total system must be designed to balance the size of the heat absorbing surface, the size of all the pipes, the speed of circulating the water, and the size of the radiators in the rooms to be heated.

If the sun shone continuously, the design job would be simplified. Then, you would simply match the heating surface to the total building needs. But, since it does not shine continuously, the size of the surface absorbers, which may be limited by the building's physical size and shape, economics, or both, must be increased as much as practical to provide an excess amount of heated water. The heat above what is immediately needed for the building is usually stored in large, insulated water tanks. In practice, a balanced design can store enough excess heat from one clear day of operation to maintain an adequate building temperature for two to four cloudy days. When long periods of cloudy weather are encountered, heat from conventional sources must be supplied.

As can be seen by this example, a conventional heating system must always be installed, and the cost of the solar system added to it. The only saving comes from being able to reduce substantially the amount of conventional fuel used. However, if enough solar systems could be installed in existing buildings and new construction, conventional heating fuel costs could be significantly reduced.

Mediums other than water can be used to carry the heat from the absorber to the point of use. Air is a common one. Air has certain advantages over
water; it does not freeze and there is no danger of leaks. Air is circulated across the absorber plate to collect the heat. The size of the ducts to convey the heat to where it is needed is much greater than required for water so more room must be designed than for a water system.

An insulated bed of crushed stone is usually used for the storage of heat in air systems. The construction materials and methods are usually somewhat simpler in air systems. Material which is readily available and conventionally fabricated makes air systems more attractive for most contractors, as well as do-it-yourself builders.

Storage systems using materials other than water or rocks are being studied. One such system that shows some promise uses a material called Gloubers salt (sodium sulfate decahydrate). This material will form crystals at 90°F whereas water must be at 34°F or below to crystalize. As is well known, substances absorb or give off much more heat when changing from one state to another, for example from a liquid to a solid, than they do, if for example, you just add heat to a liquid. This is called latent heat or heat of change of state. In this process, all the energy going in when heat is being added is used to break down or melt the crystal structure, while the temperature of the substance remains the same.

A brief summary of the types of storage presently used is given in Table 1.

Table 1.—A Comparison of Heat Storage Capacity

<table>
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<th>Btu/lb</th>
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<td>Rocks</td>
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<td>Salts</td>
<td>125</td>
<td>12,000</td>
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Potential Uses of Solar Energy

Cooling with Sunlight

In the attempt to utilize solar energy for heating buildings, we find that we are working directly against nature. It is a natural fact that homes and buildings needing the most heat are geographically located where there is the least sunlight available. When we stop to think about it, that is exactly the reason buildings in these locations need more heat.

But, when we consider cooling of homes, we are working with nature. Homes and buildings that need air-conditioning are always geographically located where there is abundant sunshine, because this is what causes the higher climatic temperature. Even the seasons of the year coincide favorably with the demand for cooling. Some electric utilities report that their greatest load is during the summertime due to consumers running air-conditioning equipment.

It seems then that more effort should be put into ways to utilize solar energy to run cooling equipment. But how can you cool with solar energy which is a natural heat energy? The answer is possibly simpler than you might expect. The same system and equipment used in gas-fueled refrigerators will work. These have been on the market for many years. Many homes have large air-conditioning units operating on natural gas.

A simplified diagram showing the principle of operation of a mechanical and gas-fueled refrigeration cycle is shown in Figure 16. In the mechanical system, a pump turned by an electric motor or gas engine compresses a gas into a liquid. When any gas is compressed, it heats up. In this system, the heat is dissipated immediately to the atmosphere in

![Diagram](image)

Fig. 16.—A mechanical and a gas-fueled refrigeration cycle diagram. The operation of these systems is described in the text. For solar operation, concentrated sunlight by reflectors or magnifying lenses would take the place of the gas flame.

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the radiator. A fan can be used to force the incoming air through this radiator, or it can be placed so natural air circulation passes through it. This is usually done in the gas system since electric power may not be available.

The now-cooled liquid presses against the expansion valve. As it forces its way through this valve, the gas re-expands and, in doing so, cools as it fills the coils of this radiator. The cooled, expanded gas picks up heat from the room air and moves on to the intake of the compressor to start the cycle over again.

The only difference between the gas and mechanical system is that the flame of the gas burner compresses the gas inside the tubes by heating it, and this heat is then passed to the atmosphere in a radiator just like in the mechanical system.

In a solar system, concentrated rays of the sun could furnish the heat instead of the gas flame. Some type of focusing system, such as parabolic dishes (Figure 17) or lenses must be used to get a high enough temperature.

![Fig. 17.—A parabolic disc (a) and cylinder (b). Sunlight striking the highly polished parabolic surfaces is directed toward the center. Thus, several square feet of solar area can be directed toward a very small area and greatly multiply the temperature at that point.](image)

**Electricity Directly From Sunlight**

Aside from space heating and water heating, much effort is being put into the direct production of electricity from sunlight by use of solar cells. These cells are made of silicon, a very abundant element in our earth's crust. These type cells have been in use extensively in the space program. The efficiency is not too great, about 13 percent, but we must remember that this is direct conversion as contrasted with heating water to steam, then turning a generator to produce electricity.

The big disadvantage today is that these silicon cells must be manufactured to extremely critical purity tolerances. This makes the cost excessively high compared to the conventional method of producing electricity. Even if a breakthrough could be made in this area, it is unlikely that solar cells would make a great impact on the nation's total electrical needs.

Again, however, the fact that sunlight is evenly spread may be an advantage. Each individual house could have its roof or yard covered with these cells and furnish a large percentage of its electrical needs.

Storage of electrical energy for use when the sun does not shine looms as the one big insurmountable problem. Right now, storage is possible with batteries. You can readily see how expensive it would be to have enough batteries in each house to store a three- or four-day supply of electricity. Even then these would not cover the long spells of sunless days which in the winter can number weeks. Each house would, therefore, need to be connected to the conventional electrical supply. We are now at the same situation as with heating systems. The home must have installed in it the solar electrical system at extra cost, along with its hookup to the conventional electric power grid, and the only saving is on the days when solar supplies the electricity.

The big obstacle to the practical use of solar energy is its interruption by nighttime or cloudy days. To get around this, engineers have suggested great banks of solar cells on spacecrafts in synchronous orbit around the earth. This is an orbit requiring 24 hours to complete; the satellite appears to stand still above one spot on the earth. These solar cells would be almost continuously exposed to sunlight which in turn would beam energy to earth via microwave antennae. There it would be picked up by large dish antennae, and the electricity sent to consumers via conventional transmission lines. Present projections are that it would take 50 years of concentrated effort before a system of this type could produce an effective amount of energy. The equipment must be much more massive than the communication satellites, because the rate of energy flow must be many billions of times as great.
Conventional Electric Production by Sunlight

One proposed method of producing electricity on earth by solar energy involves the use of many mirrors to focus a large area of sunlight on a relatively small area, and thus heat water in a boiler. The laws of thermodynamics show us that the higher the initial temperature, the more efficient a steam cycle will be. By the use of mirrors and in a sense magnifying many times the amount of sunlight to heat water, the temperature can be as high as it is in a coal-fired boiler. The physical size of a plant can be kept smaller by increasing the operating efficiency.

Parabolic reflectors in the form of dishes and cylinders (Figure 17) can be used to focus large areas of sunlight onto small points or tubes. These points or tubes can contain a heat-carrying medium, such as air, water or special gases in refrigeration systems and can be heated to very high temperatures.

An Overall Summary

Solar energy may be summed up in outline form to help get an overall look at its potential uses (Table 2).

<table>
<thead>
<tr>
<th>Product</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Solar collector, flat and concentrating, to heat water or air that in turn heats buildings or water</td>
</tr>
<tr>
<td></td>
<td>Solar collectors, concentrating type, for ranges and ovens</td>
</tr>
<tr>
<td>Electricity</td>
<td>Solar cells for direct conversion</td>
</tr>
<tr>
<td>Cooling</td>
<td>Solar collector for heat, concentrating type, to turn steam turbines</td>
</tr>
<tr>
<td>Fuel</td>
<td>Solar concentrators to provide the high temperature for the refrigeration cycle</td>
</tr>
<tr>
<td></td>
<td>Increased plant growth in forestry and agriculture to provide biomass for fuel, either by direct burning or conversion to alcohol and methane</td>
</tr>
</tbody>
</table>
Questions

To stimulate thought and greater understanding of solar energy, answer these questions with the best word(s) to make a true statement. Refer to the material when necessary.

1. The center of an atom is called the _________________________________.
2. In hydrogen, only one particle is at the center. This particle is called a(n) _____________________.
3. Around the outside of the hydrogen atom whirls a very tiny particle called a(n) _____________________.
4. The electric charge at the center is ________, and the charge of the small outside particle is ________.
5. Unlike charges always ________________________________ each other.
6. External energy put into an atom can make the electron move to a higher orbit. (True or False) ________
7. The amount of energy required to make the electron move up is called _______________________.
8. Photons are emitted when an electron drops to a lower orbit. (True or False) ________
9. Photons carry or represent a ________________________________ amount of energy.
10. Photons travel away from the atom of their origin at the speed of light. (True or False) ________
11. Photons vibrate as they travel. This is called _________________________________.
12. The frequency of vibration is greater for photons emitted from electrons falling from the high orbit levels. (True or False) ________
13. Photons with higher frequencies have high energy. (True or False) ________
14. Radiation is never dangerous to living things. (True or False) ________
15. Space is filled with _________________________________.
16. Photons of different frequencies interfere or disrupt each other. (True or False) ________
17. The electric current forced through the filament of an incandescent light agitates the atoms to white heat. (True or False) ________
18. An atom of the filament temporarily cooled gives off light. (True or False) ________
19. Any object that is close to 5,000°F has atoms agitated to such a state that they can emit light. (True or False) ________
20. Gases cannot emit light as solids do. (True or False) ________
21. Our sun is a _________________________________.
22. The energy that heats the sun comes from what kind of reaction? ________________________________
23. Stars can be of any mass. (True or False) ________
24. A thermonuclear reaction means that two atoms come together with sufficient velocity to fuse and form a new element. (True or False) 

25. When there is a loss of mass, always appears. 

26. The force that causes the protons, even though of the same charge, to stay together is called . 

27. The surface of our sun is at 5,500°F. (True or False) 

28. The sun emits a majority of photons at frequencies in the visible range. (True or False) 

29. The sun emits no radiation in the low frequency range, such as radio. (True or False) 

30. The sun emits the greatest quantity of energy in the extremely high frequencies of X rays and gamma rays. (True or False) 

31. The temperature of the surface of the sun determines the frequency of radiation. (True or False) 

32. Any object, solid or gas, at the same temperature as the sun's surface will appear the same color. (True or False) 

33. Photons can travel through space for ages and never change frequency. (True or False) 

34. Radiation leaves the sun in all directions. (True or False) 

35. Atoms are filled with trillions of photons. (True or False) 

36. A photon can give up its quantum of energy to another atom if they collide. (True or False) 

37. The transfer of energy from one object to another by radiation is 100 percent efficient. (True or False) 

38. What percent of the sun's total output strikes the earth? 

39. How much energy (watts) reaches a square meter of flat surface on the earth? 

40. What would happen if the earth were a few million miles closer to the sun during all of its orbit? 

41. What causes the seasons on earth? 

42. It makes little difference in the quantity of radiation a flat surface receives whether it is perpendicular to the sun's rays or not. (True or False) 

43. What is one thing that can be done to increase use of solar energy in agriculture? 

44. Can grain, such as corn, wheat, oats, barley and rice be used as a motor fuel? (Yes or No) 

45. At the present time, what is the most practical use of solar energy? 

46. What color is best for a flat surface collector?
47. At the present time, what two mediums are most used to carry heat away from the collector? __________

48. What material is being considered for storage of heat by the change of state (latent) system? __________

49. About how much more (ratio) heat can the latent system store per pound than rocks? __________

50. In heating of buildings, we find we are working against nature. Is this the same with cooling? (Yes or No) __________

51. What material is the main ingredient in solar cells to convert sunlight to electricity? __________

52. In practice, a home must still be connected to a conventional fuel source to supply heat and electric power when the sun does not shine for several days. (True or False) __________

53. Solar panels in orbit can get around the intermittency problem. (True or False) __________

54. For operating refrigeration equipment and heating water in boilers for steam turbines, a high temperature is necessary. (True or False) __________
Answers

1. nucleus
2. proton
3. electron
4. positive, negative
5. attract
6. T
7. quantum
8. T
9. quantum
10. T
11. frequency
12. T
13. T
14. F
15. photons
16. F
17. T
18. T
19. T
20. F
21. star
22. thermonuclear
23. F
24. T
25. energy
26. strong nuclear or binding
27. F (centigrade is correct)

28. T
29. F
30. F
31. T
32. T
33. T
34. T
35. F
36. T
37. F
38. 0.0000000046%
39. 1,000
40. Polar ice would begin melting.
41. tilt of axis
42. F
43. increase land area
44. yes (fermentation)
45. heat source
46. black
47. air and water
48. Gloubers salt
49. 12.5:1
50. no
51. silicon
52. T
53. T
54. T
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