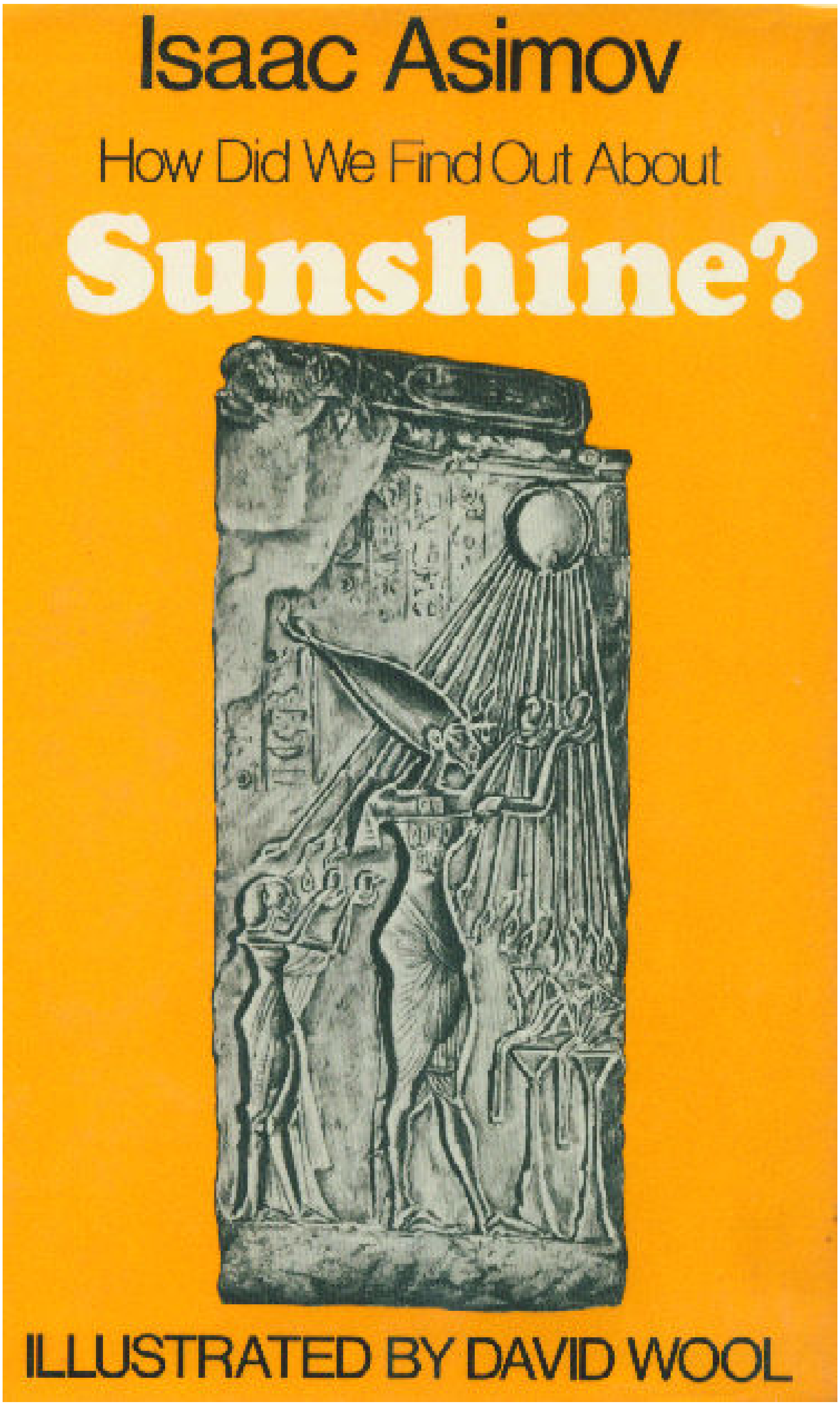
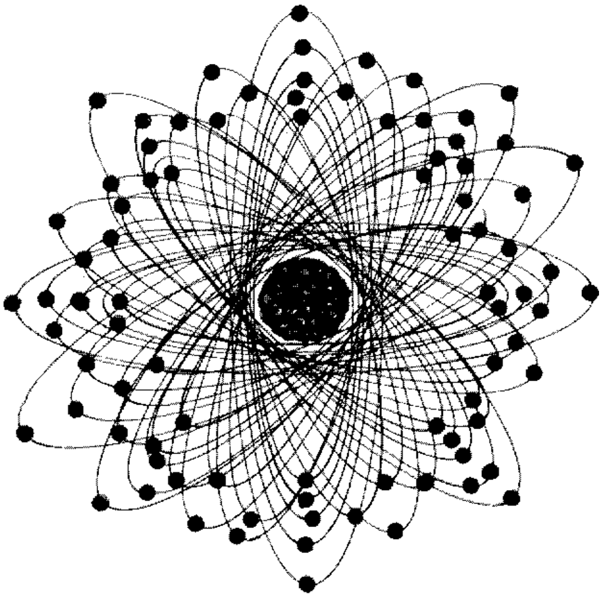


Quite early in history people understood that if the sun did not shine, everything would remain dark and cold and life would come to an end.

What is the sun made of and how can it keep shining on and on and never stop?

Asimov takes us through the discoveries of Galilieo, Copernicus, Cassini, Newton, Helmholtz and other scientists, to the discovery of nuclear energy, which later led to the discovery of hydrogen fusion. Hydrogen fusion produces more energy than any other nuclear reaction. It supplies energy year after year for billions of years.

How Did We Find Out About Sunshine?



Isaac Asimov

Illustrated by David Wool

1. The Sun

HUMAN BEINGS HAVE always been aware of the Sun. They have been grateful for it, too. After the chill and darkness of night, the appearance of the Sun in the morning is a welcome sight.

When the Sun remains low in the sky at noon, it is wintertime. In the cold and gloom of winter it is pleasant to know that the noonday Sun is getting higher in the sky from day to day. That means spring is coming.

Quite early in history, human beings must have understood that if the Sun didn't shine, then everything would remain dark and cold, nothing would ever grow, and life would come to an end. Sometimes the Sun was eclipsed and grew dark in the daytime because the Moon moved in front of it. In ancient times, people thought that meant the Sun had disappeared and they were in a panic until the Moon passed by and the Sun began to brighten again.

Such eclipses are rare, however, and when they take place, they are brief. Except for that, the Sun rises every day and gives light and warmth to the world. There might be clouds hiding the Sun for a while, but even then its light and warmth manage to get through. A cloudy day is not as dark and cold as the nighttime is.

The Sun is so important to us that early in history it was generally viewed as a god. About 1370 B.C., an Egyptian king, Ikhnaton (ik-NAH-tun), proclaimed the Sun to be the only god, and tried to get everyone in the kingdom to worship it.

The Sun doesn't have to become altogether dark to destroy life. If the Sun just dimmed a bit, there would be an eternal winter on Earth and, eventually, all life would die. If the Sun brightened a bit, the Earth would grow very hot and, eventually, all life would die. If the Sun dimmed at some times and brightened at others, weather changes might become so extreme that, eventually, all life would die.

But none of that happens. The Sun shines constantly and evenly day after day, year after year, century after century, for as long as people have existed. To be sure, it is colder in some places than in others, and it is colder at some times of year than others, but the changes are not very great, so that life continues.

Ikhnaton and his Queen worship the Sun

Throughout history, most people have simply taken all this for granted. The Sun was there in the sky and it shone. It rose and set, moved higher in the sky and lower, so that there was day and night, summer and winter, over and over. That's just the way it was.

Most people assumed that gods of some sort created the Sun in order that people might have warmth and light. The gods also arranged day and night and winter and summer out of their superior wisdom, and there was no use questioning the gods.

Yet some people felt like questioning. They wondered, for instance, what the Sun might be made of.

The Sun seems to be simply a ball of light. You can imagine a ball made out of rock or iron or rubber. It would then be made out of a material thing that you can touch and feel. A ball of light would be different. Light is "immaterial." It is not matter; it is not something you can touch and feel. If the Sun is a ball of light in the sky that shines on everything all about it and casts light everywhere, it is something quite special.

It may not seem special in some ways, perhaps. After all, human beings can make little balls of light themselves. Whenever you build a fire, you create flames that give off light and heat just the way the Sun does. At night, you are likely to start a fire in order to supply light and heat in the absence of the Sun. In winter, you might keep the fire going all day, in order to have its warmth.

Or else, you might light a candle or an oil lamp. That produces a much smaller flame. It would not be enough to warm a person in the cold, but it would be enough to light things in the dark.

Still, there are differences between the Sun in the sky, and the fires that human beings start on Earth. For one thing, the Sun is a round ball that doesn't change, while fire on Earth has no definite shape.

Earthly fires consist of flickering, jumping, changing flames.

There is a more important difference, too. Fires on Earth are only temporary. They are produced by burning *fuel,* such as wood, wax, or oil. Once the fuel is all burned up, the fire goes out. If you want to keep the fire going, you have to supply more fuel; you have to put another log on the fire.

The Sun is not like that at all. It keeps shining on and on and on, and never stops.

But perhaps the rules (or laws of nature) are different on Earth than in the sky. The ancient Greek scientist, Aristotle (AR-is-TOT-ul, 384-322 B.C.), thought so.

He felt that the Earth was made up of materials that were constantly changing and decaying. For that reason, if light were produced on Earth, it couldn't last long. The flames leaped and changed, the fuel was used up, and the light went out.

Aristotle decided that objects in the sky were made up of a perfect, unchanging substance that was not like anything on Earth. He called the sky-substance *ether,* from a Greek word meaning "glowing," because he felt that ether had a built-in glow that lasted forever.

Shooting Star

To Aristotle, the Sun seemed a ball of ether, and it needed no fuel to keep on shining forever.

But was Aristotle's notion correct? Were objects in the sky completely different from those on Earth? There were things in the sky that glowed, but didn't glow forever. Lightning flashed and was gone.

Meteors, or "shooting stars," streaked across the sky and were gone. Comets also came and went. All these things, however, Aristotle considered to be part of the air, and not of the sky.

But what about the Moon? It was always changing its shape. Sometimes it was a round circle of light, but other times it was squashed in on one side. It might be a semicircle of light, or even a thin crescent.

It didn't take long for people to see that these changes in shape, or *phases,* were because half the Moon was lit up by the Sun, and the other half was not. The Moon had a day side and a night side, just as Earth did. The shape of the Moon depended on how much of the side turned toward us was in the sunlight. In other words, the Moon was a dark world and didn't glow of itself any more than the Earth did. The Moon was not made of Aristotle's ether.

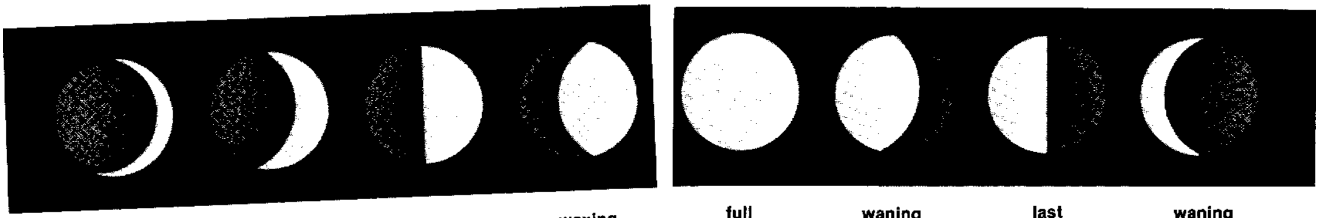
In 1609, an Italian scientist, Galileo (gah-lih-LAY-oh, 1564-1642), built a small telescope. Telescopes made little objects seem larger and dim objects seem brighter. Galileo turned his telescope on the sky and saw the Moon larger and more clearly than he could see it with his eyes alone. Through the telescope the Moon was seen to have mountains and plains. It was a world, like the Earth.

Later on, when he looked at the planet Venus through his telescope, he found that it, too, showed phases like the Moon. It was another dark body that only shone by reflecting sunlight. All the planets were dark bodies that weren't made up of Aristotle's "ether."

Still, the Sun *did* shine by itself. Could it be "ether?"

If so, it should be perfectly clear and unmarked, but Galileo showed that this was not so. With his telescope, he could make out dark spots on the Sun *(sunspots.)* Watching these, he could see that the Sun was turning on its axis, making a complete turn in twenty-six days.

Could it be, then, that the Sun was made of some sort of matter, and not of immaterial light? From Galileo's time on, people began to suspect that was so.

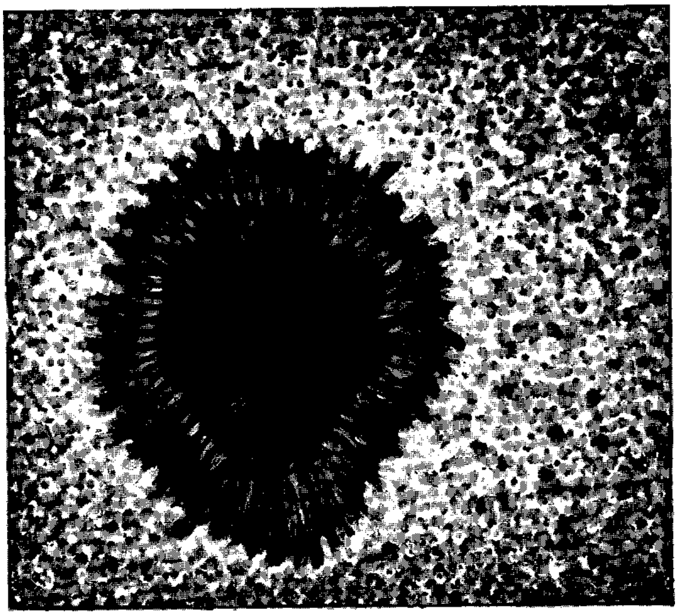


Phases of the moon

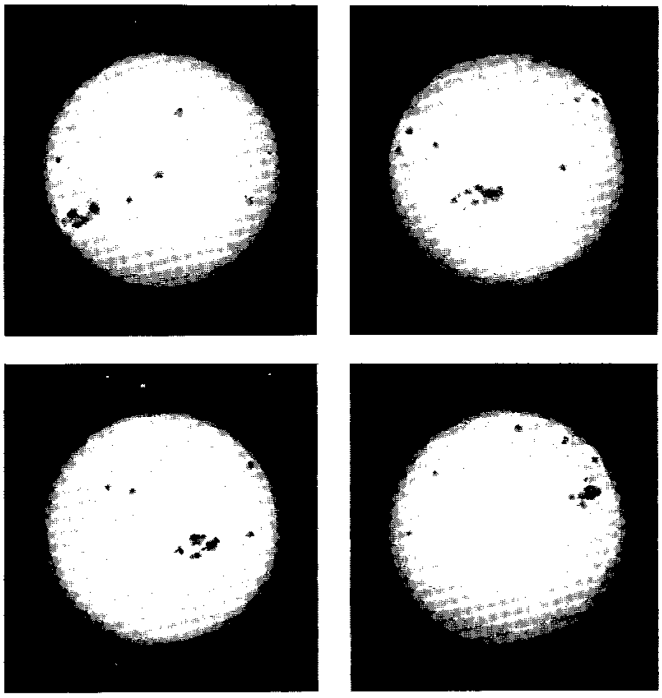
In early times, people thought the Sun went around the Earth, because it certainly looked as though it did. In 1543, however, a Polish astronomer, Nicolaus Copernicus (koh-PUR-nih-kus, 1473-1543), had published a book that gave reasons for thinking the Earth went around the Sun.

By Galileo's time, most astronomers agreed with that notion, and this made the Sun seem more important than ever. Astronomers grew increasingly anxious to find out more about it.

For instance, how far from the Earth was the Sun? Even the ancient Greeks had wondered about that, but they didn't have instruments delicate enough to make the measurements. With the telescope, it became easier.



Sunspot



Sunspots show rotation of Sun in seven days

In 1672, an Italian-French astronomer, Giovanni Domenico Cassini (ka-SEE-nee, 1625-1712), made the first reasonably accurate measurement of the distance of the Sun from the Earth. The Sun turned out to be far more distant than anyone had expected.

The Sun, we now know, is 92,900,000 miles from the Earth. In order for the Sun to appear as large in the sky as it does, when it is so far away, it must be a really huge object.

The Earth itself is a large ball of matter that is 7,900 miles wide. The Sun, however, is a ball that is 865,000 miles wide. It is 109 times as wide as the Earth is.

Then, in 1687, the English scientist Isaac Newton (1642-1727) worked out the mathematics of the *law of gravitation.* Using this, it was possible to make an important calculation. If the Earth is 92,900,000 miles from the Sun, and goes around the Sun in just one year, then the amount of material in the Sun (its *mass)* is 332,900 times the amount in the Earth.

It was no longer possible to look upon the Sun as just a ball of glowing, immaterial light. The Sun was made up of matter — a great deal of matter.

What's more, it was quite plain that gravitation worked according to Newton's mathematics both on the Earth and in the sky. From that point on, scientists were quite convinced that Aristotle was wrong in thinking that the laws of nature were different in the sky than they were on Earth. The laws of nature, scientists decided, were the same everywhere in the Universe.

In that case, scientists had to face an important problem. Nothing on Earth glowed by itself and kept on glowing forever. In that case, how could the Sun, which was controlled by the same laws of nature as Earth was, manage to glow, and to continue glowing throughout history?

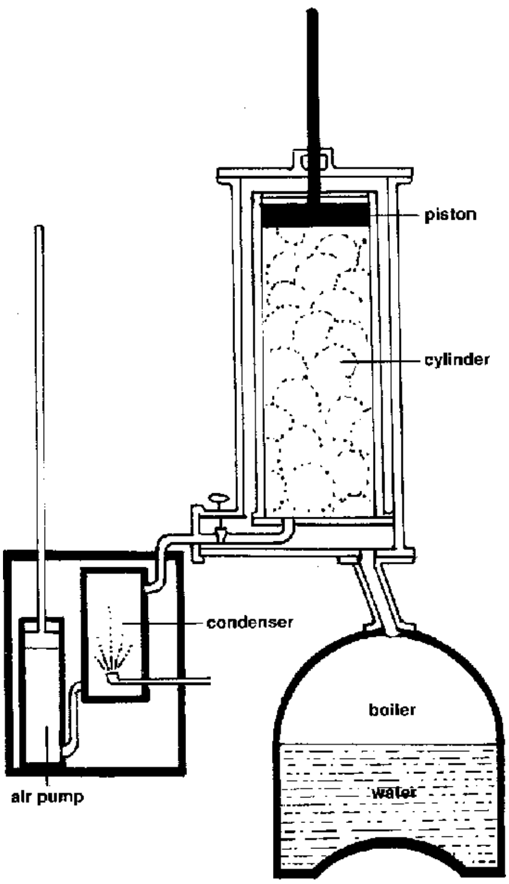
Of course, one could argue that even though the Sun was made up of matter, its matter might be completely different from the matter on Earth. Perhaps it was the nature of the Sun's substance to glow and to continue glowing. Perhaps such matter would do so on Earth, too, if any of it existed here.

Still, it seemed hopeless to get a piece of the Sun's matter in order to study it. Because of that, it must have seemed, in Newton's time that people would never find out what makes the Sun shine.

2. Energy

SCIENTISTS WERE INTERESTED not only in the Sun, but also in the ordinary fires one builds on Earth. If one burns fuel, the heat of the burning will boil water and turn it into steam. The steam expands, and can be made to push rods and turn wheels. In this way, fire can make machinery work.

It is *energy* (EN-er-jee) that actually makes things work. The word comes from a Greek expression meaning "work inside."



Watt's steam engine

In 1764, a Scottish engineer, James Watt (1736-1819), built the first really practical *steam engine,* in which burning fuel could make machinery work. The machinery began to replace human muscle, and this made the modern world possible.

Naturally, this made scientists particularly interested in how energy might be transferred from one place to another. They wanted to know just how much energy could be extracted from fuel. To do this, they learned how to measure amounts of energy more and more exactly.

In the 1840s, an English scientist, James Prescott Joule (JOWL or JOOL, 1818-1889), made many such measurements. He worked with energy in many different forms: light, sound, motion, heat, electricity, magnetism, and so on. He could change one form of energy into another and transfer the energy from place to place, but it seemed to him that, in all such changes and transfers, the total amount of energy never changed.

Other scientists came to this conclusion at about this time even without making careful measurements of the kind Joule was making. For instance, in 1842, a German doctor, Julius Robert Mayer (MY-er, 1814-1878), did.

Since Joule and Mayer were not well-known scientists, no one paid much attention to either of them. In 1847, however, a very important German scientist, Hermann von Helmholtz (HELM-holts, 1821-1894), came to the same conclusion, and this time everyone listened.


A coal-forming forest

Helmholtz is, therefore, usually considered to have introduced the *law of conservation of energy.* This states that energy can be changed or transferred, but cannot be created or destroyed, so that the total energy of the Universe always remains the same.

Joule and Mayer deserve a share of the credit, but Helmholtz perhaps deserves most of it, for he went on to ask an important question.

If the law of conservation is true, then whenever work is done, we have to ask where the energy comes from. The energy in moving machinery may come from steam. The energy in steam comes from the fire. The energy in the fire comes from the fuel.

But in that case where does the energy in the fuel come from?

If the fuel is wood, then it is formed by plants, which absorb energy from sunlight in order to form that wood.

If the fuel is coal, then it is the remains of wood that is a hundred million or so years old. And that wood was formed with the help of the energy of sunlight.

If the fuel is oil, then it is the remains of microscopic animals that got their energy by feeding on microscopic plants that got their energy from sunlight.

Sometimes, energy appears where no fuel seems to be burned. An electric light gives off light and heat even though we don't see any fuel burning. What's more, it keeps on giving off light and heat as long as it remains plugged in the wall, and as long as the switch is on. Where does the energy come from?

If we traced it back, we would find that the energy comes from an electric generator, which produces the electricity. And where does *its* energy come from?

It turns out that a generator usually gets its energy by burning fuel. If the fuel is used up and no new fuel is added, then no more electricity would be formed, and the electric light would go out. All other electrical gadgets would stop working, too. And, of course, the energy of the fuel comes from sunlight.

Some electric generators do not use fuel at all.

They form electricity from the energy of falling water, either in waterfalls or in swiftly flowing rivers. But where does *that* energy come from?

Waterfalls and rivers would stop flowing except that rain is always adding more water to them. Therefore, their energy comes from falling rain. The energy of falling rain comes from sunlight that warms the water in the ocean. Water vapor is formed, which rises high into the air to form clouds, and then falls as rain.

We can trace almost any kind of energy back to sunlight at last. Sunlight is the source of almost every form of energy on Earth.

Once Helmholtz understood the law of conservation of energy, he realized that you couldn't simply stop at the Sun. Where does the Sun get *its* energy from? That was the important question Helmholtz asked. *What makes the Sun shine?*

To begin with, a person might wonder if the Sun is made up of some kind of fuel, and if it also contains something in which that fuel will burn. On Earth, a fuel like coal combines with *oxygen* (OK-sih-jen), one of the gases of the air. The act of combining makes the coal burn and produces light and heat.

What if the Sun were made up entirely of coal and oxygen, then? Imagine a heap of coal and oxygen that has 332,900 times as much mass as the whole earth has. If that mass of coal and oxygen were to start burning, wouldn't it burn for a long time?

It would, but for how long? Suppose that it burned rapidly enough to supply all the vast amount of energy, all the light and heat, that the Sun pours out day after day. In that case, it turns out, that heap of coal and oxygen would all be combined and burnt up in 1,500 years.

That can't be right. About 1,500 years ago, the Roman Empire came to an end, and we know that the Sun was shining for a long time before that.

If the Sun were made up of chemicals that combined with each other to give off energy, the way they do on Earth, then no possible combination could have produced sunshine through all the years of civilization.

In fact, it is not just the years of civilization that we must be concerned about. The Sun must have been shining a long, long time before civilization even arose.

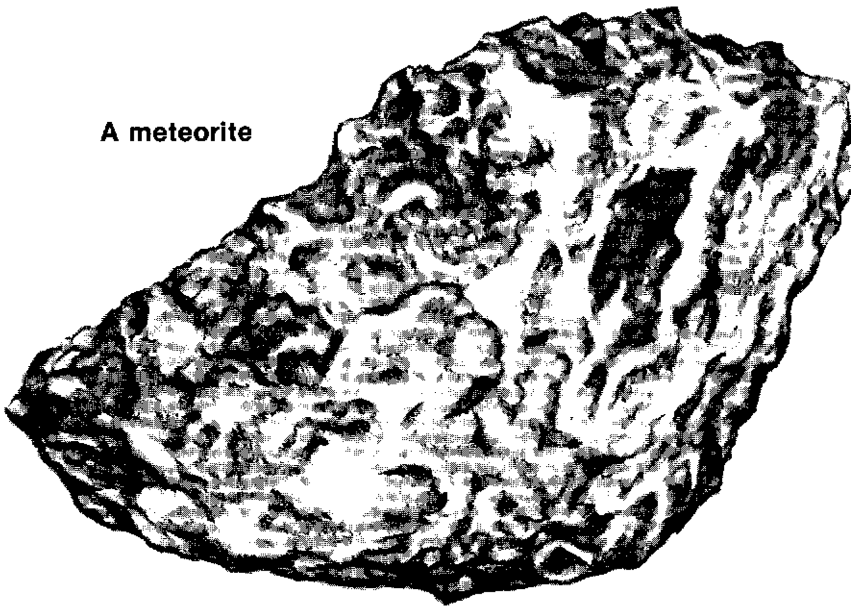
Until about 1750, everyone had thought that the Earth and Sun only came into existence about the time that civilization did. They thought the Earth and Sun had only existed for about 6,000 year's altogether. But then scientists began to find evidence that the Earth and Sun were older than that—*much* older.

By Helmholtz's time, scientists were quite convinced that the Earth must be many millions of years old, and that during all that time the Sun existed in the sky and had been shining as it is today. Helmholtz therefore had to find a source of energy that would last not only a few thousand years, but many millions of years.

One source of energy that might do would be the energy of motion.

The space about the Sun and Earth contains many bits of matter, all circling the Sun and moving at speeds of several miles per second. Most of these bits of matter are just dust particles. Some are larger, as large as gravel, or as rocks, or even, in a very few cases, as large as mountains.

A meteorite



Anything that moves contains energy. If a moving bit of matter collides with an object, its energy of motion is transferred to the object or is turned into another form of energy.

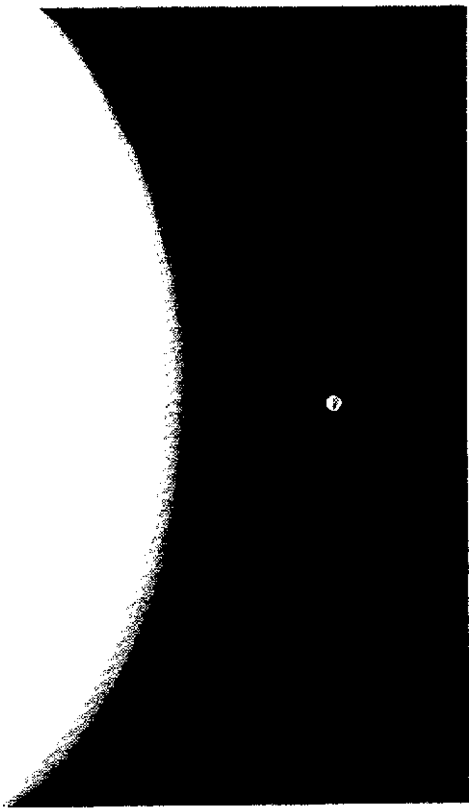
These moving bits of matter from space are constantly hitting the Earth. The tiniest dust particles are stopped by the air almost at once. They float there harmlessly, and very slowly sink down to the ground.

Larger bits of matter heat up as they pass through the air and sparkle as meteors. Generally, they turn completely into vapor while they are still high in the air. A few bits of matter are so large, however, that there is no time for them to turn completely into vapor. They reach the ground, and such objects that have fallen from the sky are called *meteorites.*

Each speeding object that hits the Earth transmits energy to it. However, the total energy is not enough to make much difference.

The Sun, though, is much larger than the Earth is, and it is therefore a larger target for collisions. The Sun also has a much stronger gravitational pull than Earth. For both these reasons, many more speeding objects may hit the Sun than the Earth.

Helmholtz calculated that if about a hundred trillion tons (100,000,000,000,000 tons) of matter hit the Sun every hour, and if the energy of their motion was turned to heat, that would keep the Sun shining as it does. The trouble is that it doesn't seem likely that there is enough moving matter in space to supply the Sun with a hundred trillion tons an hour for millions of years.



Relative size of Sun and Earth

Besides, suppose there were. That would mean that the Sun would increase in mass by a hundred trillion tons every hour. That's not much compared to the total mass of the Sun, but it would mount up, hour by hour. The additional mass would make the Sun's gravitational pull stronger and stronger. Because of that, Earth would move around the Sun faster and faster. In fact, it would mean that each year on Earth would be two seconds shorter than the year before.

A two-second difference would not be much, but scientists, even in Helmholtz's day, could measure time well enough to know that the year was *not* shortening in such a way. The notion that the Sun's energy arose from collisions with particles simply won't work.

But then Helmholtz had another idea. Suppose that the Sun, under the pull of its own gravity, was contracting and getting smaller? Every bit of its matter would be falling toward the center.

This falling substance would be gaining the energy of motion from the gravitational pull of the Sun, and this energy could be turned into the light and heat of sunshine. In this way, the source of the Sun's energy would be its own gravitation.

Naturally, this energy source would come to an end once the Sun's substance had fallen inward as far as possible, but how long would that take?

Helmholtz was able to calculate that if the Sun contracted one inch every three hours, it would be supplied with the energy it needed to maintain its light and heat. And if it is contracting only one inch every three hours, it can continue to contract for millions of year before no further contraction was possible.

If it has been contracting like this all through history, it must have been much larger in the past. Contraction from that original large size to its much smaller present size would have kept it burning for many millions of years in the past.

What's more, the contraction of the Sun wouldn't add to its total substance and wouldn't affect its gravitational pull. That means there would be no change in the length of our year.

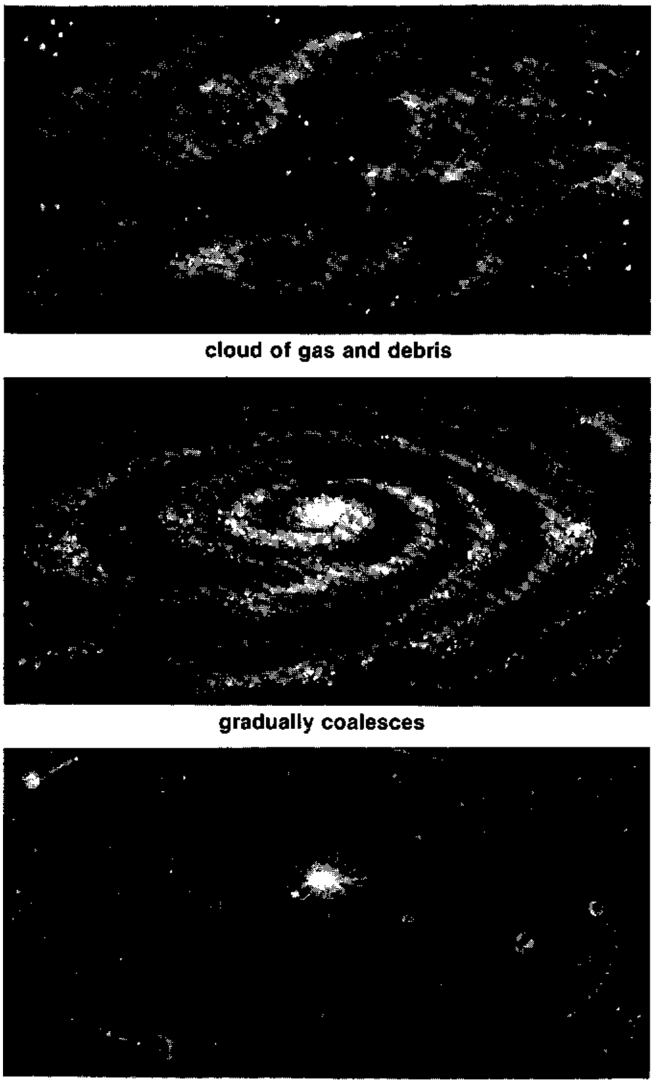
All in all, it was a very clever idea, and for half a century or so, astronomers were satisfied with Helmholtz's suggestion — besides, there seemed no other possible explanation.

3. Age and Substance

HELMHOLTZ'S NOTION DID not please everyone. To some people it didn't seem to make the Earth old enough.

In Helmholtz's time, it was thought that the Sun had started as a vast cloud of dust and gas that had slowly contracted under its own gravitational pull. The cloud was spinning as it contracted and as it grew smaller, it spun faster and faster. Every once in a while, matter was pushed off the edge because of the increasing rate of spin. That matter formed a planet.

According to this point of view, the Earth must have been formed when the Sun had shrunk to a width of 186,000,000 miles. That is the distance across the circle that the Earth makes as it goes around the Sun. If the Sun were bigger than that, the Earth would have had to form *inside* the Sun and that isn't possible.



cloud of gas and debris

gradually coalesces

forming the sun and the planets in orbit

Formation of solar system

If the Sun were about 186,000,000 miles when the Earth was first formed, how long would it take for it to shrink to its present size of 865,000 miles across? If it shrank fast enough to produce the light and heat it does, it would take it perhaps 100,000,000 years to do so.

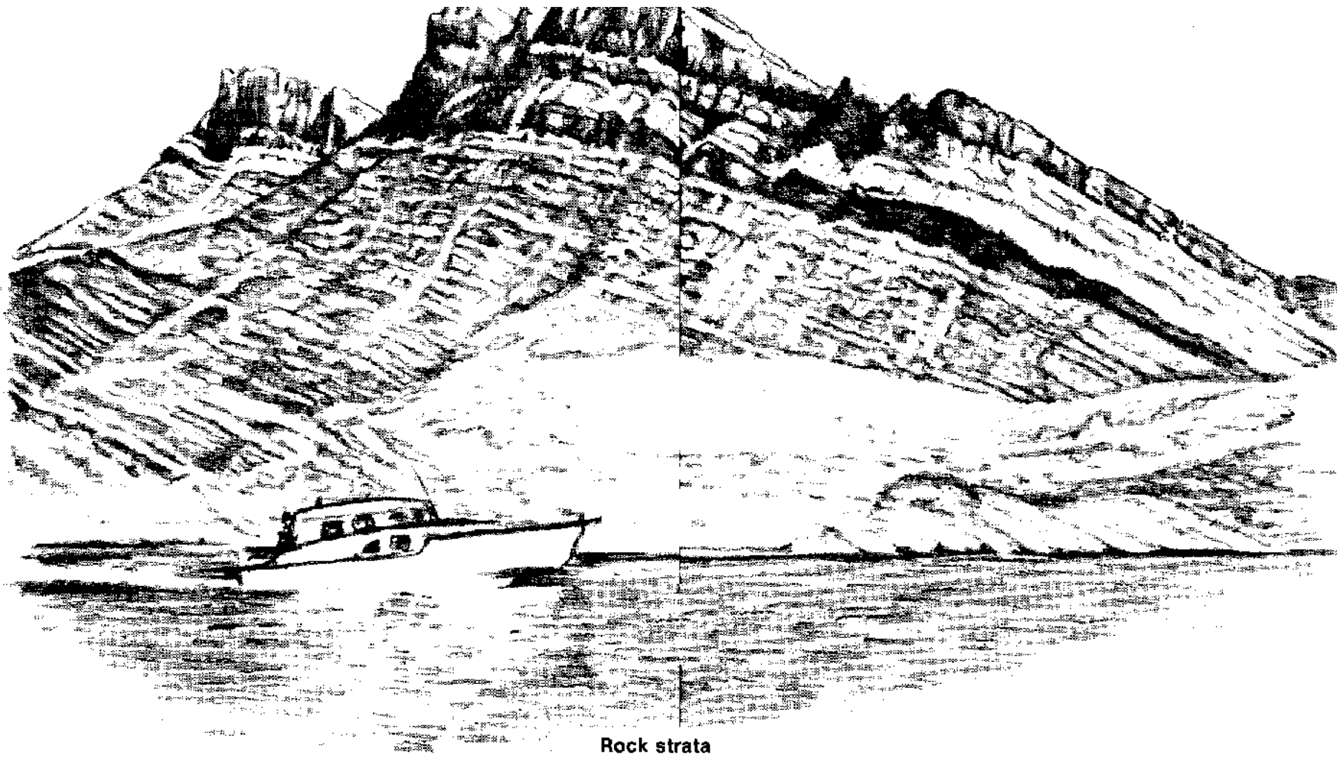
By Helmholtz's theory of the shrinking Sun, then, the Earth could not be more than about 100,000,000 years old. That seems quite a long time, especially compared with the 6,000 years that people a century earlier had reckoned as the age of the Earth.

Still, to some, 100,000,000 years was not enough.

Geologists were beginning to study the rocks of the Earth in detail. They were studying how rocks changed; how they were gradually buried; how the land rose and fell very slowly; how mountains formed; and so on. By studying the very slow way in which changes took place, they calculated how long it would take for a thick layer of rock to form, for instance, or for a mountain to lift upward.

A Scottish geologist, Charles Lyell (LY-el, 1797-1875), published a three-volume book on such things between 1830 and 1833. He made it quite clear that the earth had to develop over a very long period of time, a period that was considerably longer than 100,000,000 years.

It was not only the rocks of the Earth that under-went very slow changes. Living things also changed very slowly. (Such change is called *evolution.)* There were rocky objects found in the earth *(fossils)* that clearly were the remains of plants and animals that had lived long, long before. They were not quite like plants and animals that live today, so it was clear that living things changed very slowly as time passed.



Rock strata

In 1859, an English biologist, Charles Robert Darwin (1809-1882), who was a friend of Lyell, published a book in which he described how such changes in living things came about. He described his *theory of evolution by natural selection.* It was one of the most important books of science ever written, and in time, almost all biologists came to accept the notion of slow evolution.

Evolution, however, is very slow indeed, and 100,000,000 years just isn't time enough. The Earth must be much older to account for the living things that dwell on Earth today.

(As a matter of fact, even the geologists and biologists in Darwin's time did not realize how very old the Earth is. At present, scientists are quite certain that the Earth is 4,600,000,000 years —that's nearly five billion years — old.)

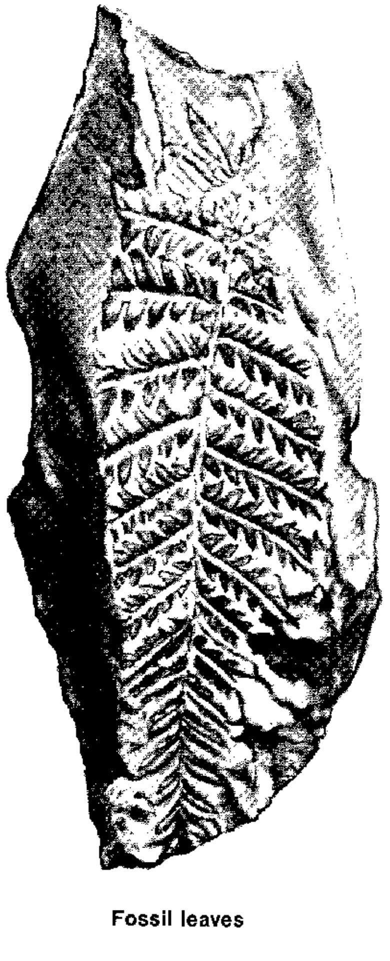
For fifty years, then, the argument continued between astronomers and physicists, who believed in a younger Earth, and geologists and biologists, who believed in an older Earth.

The whole argument rested on what made the Sun shine. The astronomers and physicists insisted that the Sun's contraction was the greatest known source of energy, and that meant the Earth couldn't be very old.

Was it possible, though, that there was some *unknown* source of energy, some source that was even greater than contraction?

Even in Helmholtz's time, scientists had no idea at all what the Sun might be made of. Suppose it were made up of substances that didn't exist on Earth. Who knows what kind of energy such unknown substances might contain?

But how could one find out anything about the Sun's substance? The only portion of the Sun that could be studied close up was sunshine itself. Fortunately, that proved to be enough.



Fossil leaves

Newton had found, in 1666 that if sunlight were passed through a triangular piece of glass *(prism)* the light was bent and spread out into a rainbow of colored light. Newton called the rainbow of light a *spectrum* from a Latin word meaning "ghost" because the spectrum was immaterial light and could not be touched or felt. Any device that produced such a spectrum was a *spectroscope.*

In 1803, an English scientist, Thomas Young (1773-1829), showed that light was made up of tiny waves of different lengths. Each wavelength by itself had a certain color, but mixed together, the result was "white" light.

When light passed through a spectroscope, every different wavelength was bent by a different amount, and it was this that formed the spectrum. The longest wavelengths are of red light and these are bent the least, so that they are at one end of the spectrum. Orange, yellow, green, and blue have shorter and shorter wavelengths and are bent more and more. The shortest wavelengths—those of violet light — are at the other end of the spectrum.

In 1814, a German optician, Joseph von Fraun-hofer (FROWN-hoh-fer, 1787-1826), prepared a very good spectroscope and studied the spectrum carefully. He found, to his surprise, that the spectrum was crossed by numerous dark lines. These lines represented wavelengths that were missing in sunlight. From their position in the spectrum, one could determine exactly which wavelengths were represented.

In 1858, another German scientist, Gustav Robert Kirchhoff (KIRK-huf, 1824-1887), studied those dark lines and considered what they might mean.

By Kirchhoff's time, it was well known that all matter is made up of tiny atoms of different kinds. Each different kind of atom represents an *element,* and dozens of elements were then known. (Today, 106 elements are known.)

Kirchhoff studied the light given off by different elements when they were heated. He found that each element gave off only certain wavelengths of light. No two elements ever gave off the same wavelength. A scientist using a spectroscope to work out the exact wavelengths of light given off by some substance could tell which elements were in that substance. The wavelengths given off are like fingerprints identifying the elements.

Under some conditions, heated substances give off light of all wavelengths, and if such a light is passed through a colder material, some wavelengths are absorbed and this produces dark lines. The cold material absorbs the same wavelengths that it would give off if it were heated. These dark lines also act as fingerprints identifying the elements.

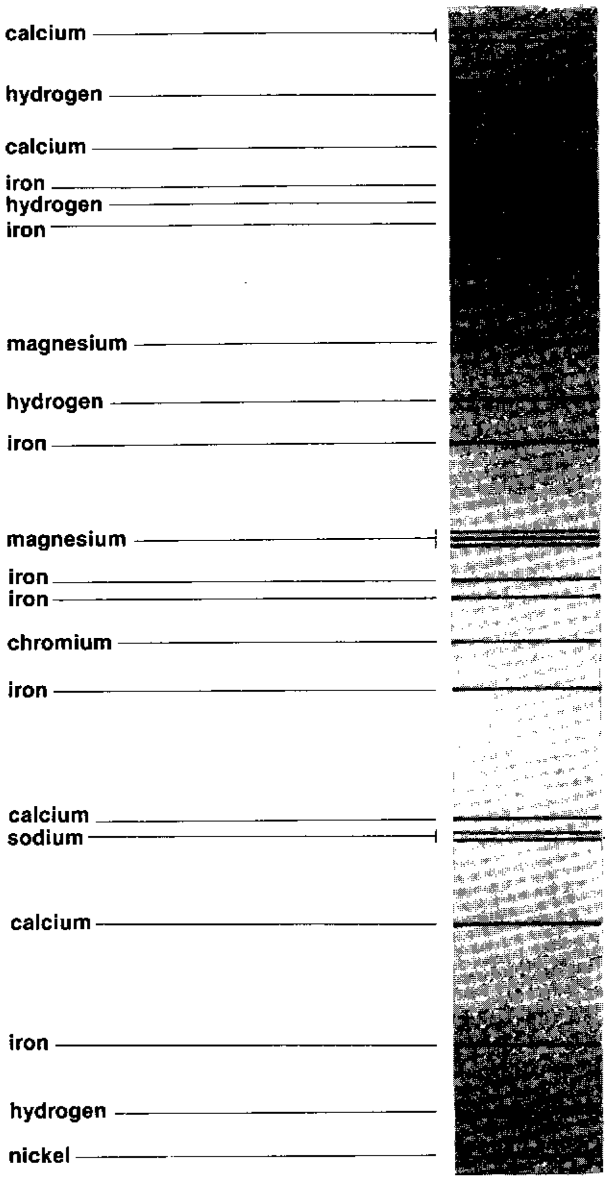
This means that if the spectrum of sunlight were studied, the position of the dark lines could tell us what different kinds of atoms are present in the gases around the glowing surface of the Sun.


Anders Jonas Ångström 1814–1874

This was first done successfully, in 1862, by a Swedish physicist, Anders Jonas Angstrom (AHNG-strom, 1814-1874). He was able to show that some of the dark lines in the Sun's spectrum were those of the common gas *hydrogen* (HY-droh-jen).

Since Angstrom's time, more and more elements have been discovered in the Sun. Hydrogen, however, is by far the most common. It makes up about three-fourths of all the material in the Sun, so it is no wonder that it was the first element discovered there. Almost all the rest of the Sun is made up of helium, another gas. Only about 2 percent of the Sun's substance is made up of other elements.

Hydrogen has the simplest and smallest atom that exists, and helium has the second simplest and smallest atom. These two simple kinds of atoms make up not only 98 percent of the Sun, but are now believed to make up 98 percent or more of the entire Universe.



Part of spectrum of sunlight

Toward the end of the 1800s, then, it seemed quite certain that the Sun was not only controlled by the same laws of nature that the Earth was, but that it was also made up of the same elements.

In that case, there seemed simply no way of falling back on a super mystery-substance. The astronomers and physicists seemed to have won. There could be no greater energy source than gravitational contraction and that meant the Earth could not be very old.

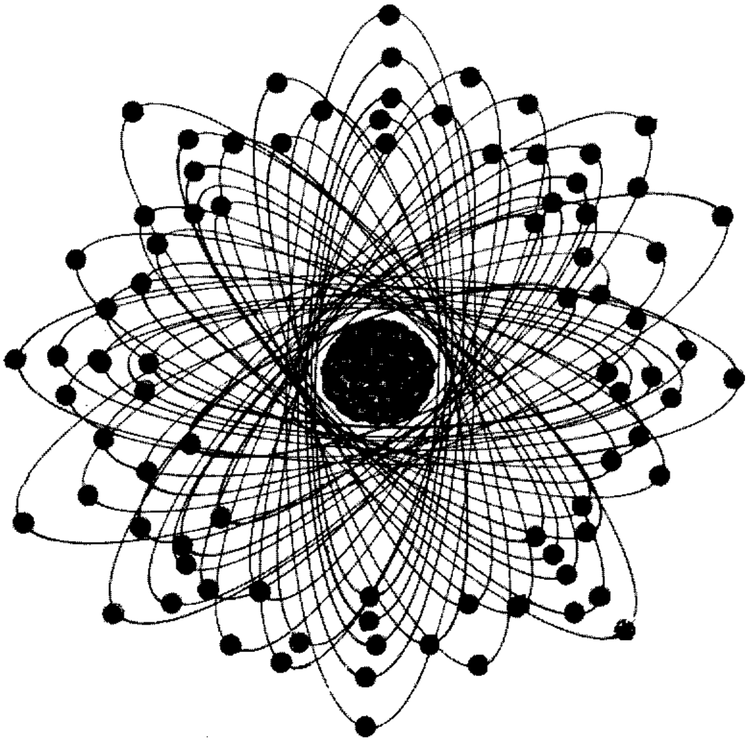
The geologists and biologists were helpless and could not be rescued unless another energy source was found.

4. Radioactivity

THE BEGINNING OF the rescue came in 1895. A French physicist, Antoine Henri Becquerel (beh-KREL, 1852-1908), was studying a substance that contained atoms of the element *uranium.* He found, to his great surprise, that it was constantly giving off radiation that was not like anything that had ever been seen before. Uranium, it turned out, displayed a brand-new kind of behavior unknown till then, which came to be called *radioactivity.*

Uranium was made up of the most complicated atoms then known. Some other elements with complicated atoms were also found to be radioactive, and scientists began to study this new discovery very carefully.

The French chemist Pierre Curie (kyoo-REE, 1859-1906), was the first to measure the energy given off by radioactive substances. He did this in 1901 and was surprised at the large amount of energy given off by a single atom.



Uranium atom

What's more, the energy continued to be given off day after day, year after year, and in some cases with only a very small decline as time went on. A quantity of the element *radium* gave off energy for 1,600 years before the radiation being given off slowly declined to half the starting amount. Uranium gave off energy for the unbelievable length of time of 4,500,000,000 years before the rate of energy production dropped to half. The quantity of energy given off on a particular day wasn't much, but the quantity given off altogether before it was all gone was enormous.

This was all very puzzling, for there seemed to be no place the energy might be coming from. The radioactive atoms just sat there giving off energy. Could it be that the law of conservation of energy was wrong?

In 1905, the German-Swiss physicist, Albert Einstein (1879-1955), was able to find the beginnings of the answer. He worked out the *theory of relativity.* Among other things, this theory showed that matter, or mass, was itself a very powerful source of energy. A tiny bit of mass could be converted into quite a great deal of energy.

Under ordinary conditions, in ordinary matter, only the tiniest quantities of mass were converted, and only ordinary amounts of energy were formed. In radioactive atoms, larger quantities of mass were lost and much more energy was formed.

But *why* was a greater amount of mass converted to energy in radioactive substances? The answer to that came as a result of a new look at atoms.

All through the 1800s, atoms had been thought to be the smallest particles that could exist. There seemed to be nothing smaller.

Some of the radiations given off by radioactive materials turned out, however, to consist of particles that were much smaller than atoms. These were *subatomic* particles. If subatomic particles existed, perhaps the atoms that made up all the matter about us were in turn made up of still smaller objects.

Ernest Rutherford 1871-1937

British physicist Ernest Rutherford (1871-1937), bombarded ordinary atoms with subatomic particles released by radioactive materials. Some of the particles went right through the atoms being bombarded, but some bounced in this direction or that.

From the fraction of subatomic particles that bounced, and from the directions in which they bounced, Rutherford was able to show, in 1911, that almost all the mass of an atom was at the very center of the atom in a tiny object called the *nucleus* (NYOO-klee-us), plural *nuclei* (NYOO-klee-eye.)

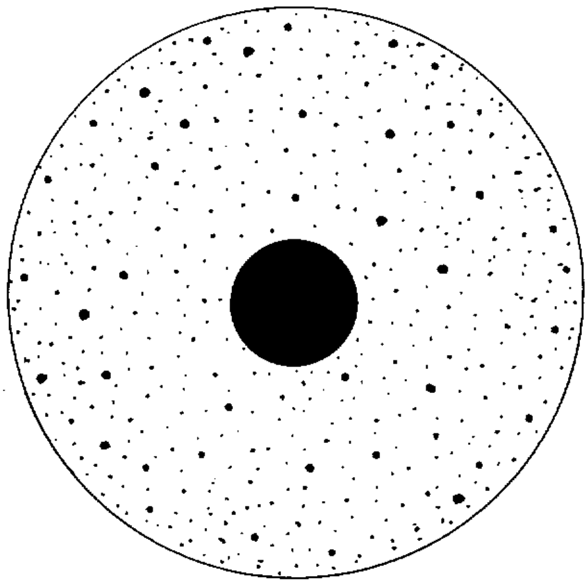
Around this very tiny nucleus, the rest of the atom was filled with a number of particles called *electrons.* The electrons had very little mass.

Ordinary chemical changes, like the burning of fuel, involved the rearrangement of electrons in the atoms. With their small size, electrons had very little mass to lose and produced only small amounts of energy—the amounts we're used to.

Radioactive substances, on the other hand, underwent changes and rearrangements in the particles inside the nucleus. These particles *(protons* and *neutrons)* are nearly two thousand times as massive as electrons. They can lose more mass in rearranging themselves and therefore produce a great deal more energy than electrons can.

In other words, radioactivity involves *nuclear energy.*

Nuclear energy is an enormous source of energy, but mostly it is tied up in atomic nuclei and remains there, so people never knew about it. It was only when radioactivity was discovered, quite accidentally, that the existence of nuclear energy came to be known.



Rutherford's view of an atom

Once it *was* known, however, people quickly realized that nuclear energy might be the source of sunshine. If the Sun were radioactive, then it would produce a great deal of energy. What's more, this energy would be released so slowly that the Sun would not explode. It would, instead, produce its energy at a slow and even rate and do so perhaps for billions of years in the past and for additional billions of years in the future. It seemed an ideal solution.

The trouble was that, at first, radioactivity was only found to occur in a few elements with very complicated atoms. Such atoms existed in the Sun in only very small amounts, if at all.

The Sun simply didn't have enough radioactive atoms to account for more than the tiniest possible amount of the Sun's energy. Radioactivity might be an ideal solution, but it just wasn't *the* solution.

5. Fusion

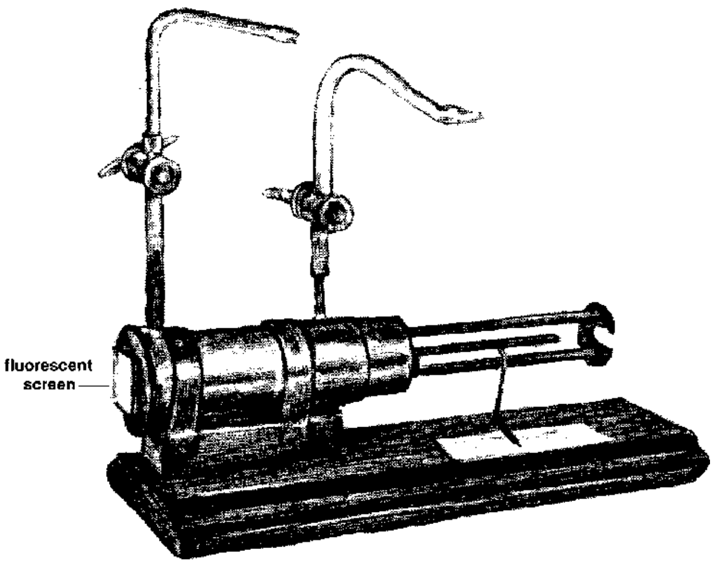
IT TURNED OUT that radioactivity as it exists in nature wasn't the only kind of nuclear change possible. Human beings could produce other kinds, and the first to do so was Rutherford, in 1919.

He bombarded the gas *nitrogen* (NY-troh-jen) with subatomic particles from radioactive atoms. Some of the particles hit some of the nuclei of the nitrogen atoms and rearranged the nuclear particles. That changed them into atoms of oxygen,

What Rutherford had done was to produce a human-made *nuclear reaction.* It was the particles inside the nucleus, rather than the electrons outside the nucleus, that were being rearranged.

In the years that followed, scientists managed to produce many other kinds of nuclear reactions, and it began to seem that something like this might be the answer.

If it was not ordinary radioactivity that supplied the Sun's energy and made it shine, it might be some other nuclear reaction.



Apparatus used by Rutherford to break up nuclei of nitrogen atoms

There was a catch to that.

Nuclear reactions won't take place by themselves. This is sometimes true of chemical reactions, too. For instance, gasoline, coal, or wood will not burn if you just let them sit in the open air. However, chemical reactions can be made to start easily if you apply heat. If you put a match to some fuel, or raise its temperature in some other way, it will burn.

It is not so with nuclear reactions. They won't start, even if you heat them. Scientists are quite convinced that they would not start even if you heated them to the temperature of the Sun's surface, which is about 10,000 degrees Fahrenheit.

The only way human beings can make such nuclear reactions take place is by bombarding atomic nuclei with subatomic particles. These nuclei do give off some energy, but only a tiny fraction of the amount that is used up by the subatomic particles, most of which miss the nuclei. This means that far more energy is spent trying to get nuclear reactions going than one gets out of them.

Besides, most nuclear reactions involve elements that exist in only small quantities in the Sun. And though most nuclear reactions may produce considerable energy, it is not enough to power the Sun.

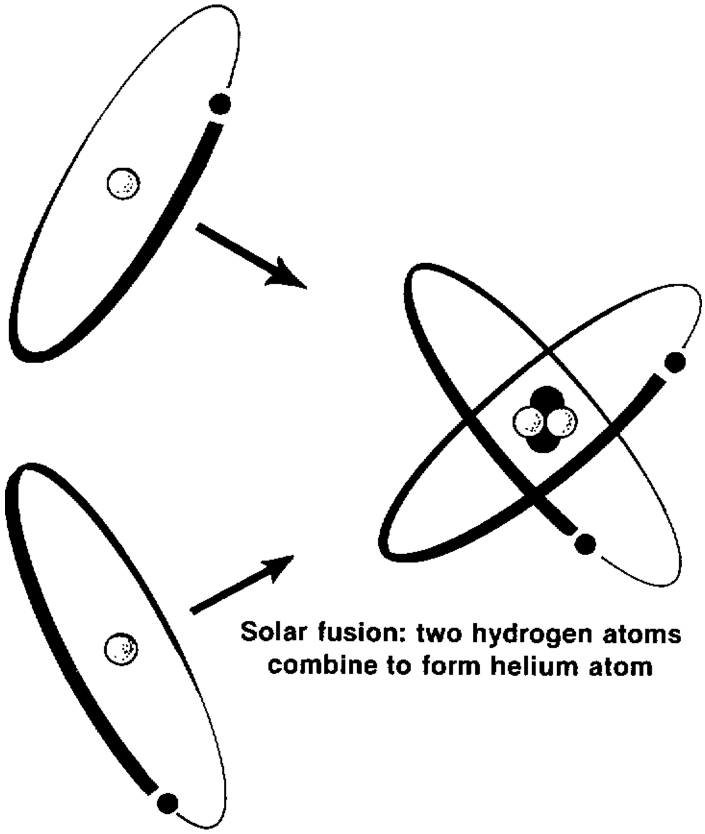
In 1915, an American chemist, William Draper Harkins (1873-1951), pointed out that four hydrogen nuclei might be pushed together so hard that they would cling together to form a helium nucleus. That is, the hydrogen nuclei would be *fused* to form helium. Such a reaction, where a number of small nuclei are fused into a larger one, is called *nuclear fusion.* If hydrogen is involved, it is *hydrogen fusion.*

Within a few years, enough came to be known about nuclear reactions for scientists to realize that hydrogen fusion would produce more energy than any other nuclear reaction they knew about. Furthermore, it was also known that the Sun was mostly hydrogen.

If it was a nuclear reaction that made the Sun shine, then it had to involve hydrogen. It might also be that the reason there was so much helium in the Sun was that it was formed by hydrogen fusion through all the years the Sun had already existed. Calculations showed that there was enough hydrogen in the Sun to keep it shining as it is now for many billions of years.

But there was still a catch. The tiny hydrogen nuclei had to be pushed together with enormous force to make them fuse. To try to supply the force, one might imagine them being heated, for the higher the temperature, the more rapidly the nuclei would travel and the more forcibly they would collide with each other. However, the amount of temperature required would not be the thousands of degrees at the Sun's surface, but many *millions* of degrees.

Even hydrogen fusion seems to be a failure as an answer.



Solar fusion: two hydrogen atoms combine to form helium atom

Meanwhile, an English astronomer, Arthur Stanley Eddington (1882-1944), was wondering about the structure of the *inside* of the Sun.

It was possible that the Sun was a huge ball of gas. After all, hydrogen and helium, which made up 98 percent of its structure, were gases. Inside the Sun, it was possible that the weight of the outer layers could squeeze the gas till it was almost solid. But if that were so, the Sun would have been squeezed into a small ball. It would not be the giant object it is.

But if so, what kept it so large? Why didn't the Sun's own gravitational pull force it into a small ball of matter?

Eddington thought that the one thing that would keep the Sun from contracting would be its high temperature. A high temperature causes a gas to expand. If the temperature were high enough, the gas would expand even against the Sun's own enormous gravitational pull.

But how high a temperature would that take? Eddington made the necessary calculations and, in the early 1920s, decided that the Sun had to be much hotter inside than anyone had thought. It got hotter and hotter, deeper and deeper inside the Sun. At the center of the Sun, the temperature might be as high as 25,000,000 degrees Fahrenheit.

If this were so, hydrogen fusion became possible after all. It wasn't necessary to think of it taking place at the Sun's surface where it was only 10,000 degrees Fahrenheit. It was more likely taking place at or near the center where the temperature was much higher.

At the high temperatures of the Sun's interior, atoms would break up. The electrons would be stripped away and the central nuclei would be bare. The nuclei would be able to come much closer together than they would if they were part of intact atoms. The heat would therefore cause them to collide more frequently, and it would make fusion more likely.

It wasn't enough, however, to say that hydrogen fusion would take place at the center. How fast would it take place? If it took place too slowly, the Sun wouldn't be able to produce as much energy as it does. If it took place too quickly, the Sun would explode.

It was necessary to calculate the rate at which the necessary nuclear changes take place in the center of the Sun where the temperatures and the pressures are so enormous.

In order to do that, a great deal had to be learned about nuclear reactions under laboratory conditions. It might then be possible to calculate what they would be like in the Sun's interior.

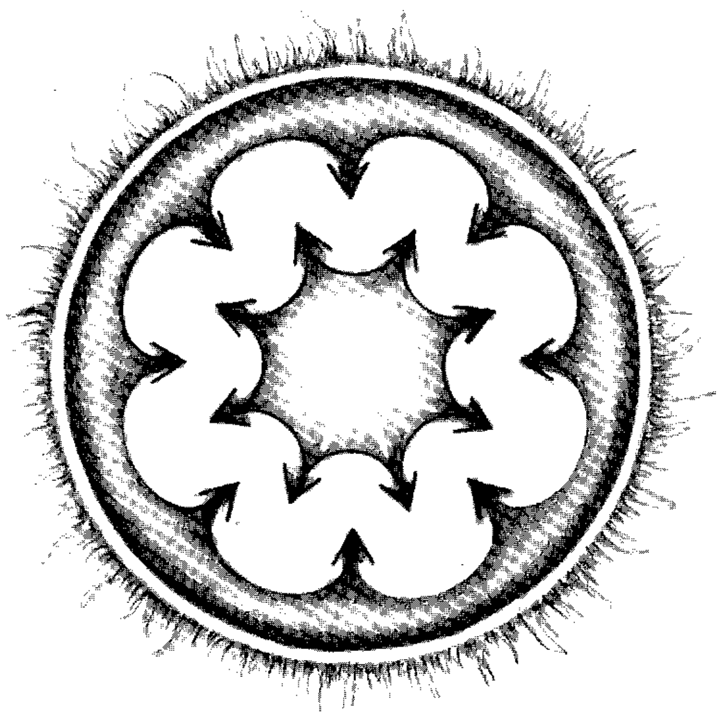
By 1938, enough was known to make such calculations possible. The German-American physicist Hans Albrecht Bethe (BAY-tuh, 1906-) worked them out and found that hydrogen nuclei under the conditions at the Sun's center would undergo a series of nuclear reactions. These would produce helium in the end, and would also produce just the right amount of energy to account for sunshine.

At about the same time, a German physicist, Carl Friedrich von Weizsacker (VITE-sek-er, 1912-), worked out the same calculations and got the same results.

The problem was solved at last. Scientists had discovered that what made the sun shine was hydrogen fusion.

Even hydrogen fusion doesn't last forever. The Sun has been shining for nearly five billion years, and it still has plenty of hydrogen left. Eventually though, after another five billion years, perhaps, it will run low enough in hydrogen to undergo changes that will make life impossible on Earth — but that's far off in the future. We don't have to worry about that now.

There does remain a puzzling matter.



Pressure from inside the Sun balances the pull of gravity.

The kind of nuclear reactions that go on at the Sun's center, producing helium out of hydrogen, also produce some very tiny particles called *neutrinos.* Neutrinos are so tiny they have no mass at all, and they are scarcely disturbed by the presence of matter.

As soon as neutrinos are formed at the Sun's center, they start moving at the speed of light and go through matter just as though it weren't there. They go off in all directions and reach the Sun's surface in 2.3 seconds. They then streak out into space. Those which happen to be aimed in the direction of Earth reach it in eight minutes and then pass right through the entire planet (and through us, too, if we are in the way).

A few neutrinos, a few out of many trillions, are indeed stopped by an atomic nucleus here and there. An American physicist, Frederick Reines (RINES, 1918-), was one of those who first detected neutrinos from nuclear reactions on Earth in 1956. Later, he wondered if he could detect them from the Sun, too.

A mile deep in an abandoned mine, he set up a device for detecting neutrinos. The reason for working deep underground is that other types of particles cannot penetrate that much soil and rock. Therefore, any particles that can be detected would be neutrinos.

Reines used a very delicate device but knew he would only be able to detect very few of those tiny particles. He calculated exactly how many he ought to detect and, to his surprise, he detected even fewer than he expected. He detected only one-third as many as he should have.

He went over his device and over his calculations, and could find nothing wrong. He just detected fewer neutrinos than he should. This has been going on for years, and the neutrinos always remain too few.

Some physicists call this "the mystery of the missing neutrinos," and to this day, they are not sure how to account for it.

There is no doubt that hydrogen fusion makes the Sun shine, but there seem to be some details about the nuclear reactions at the Sun's center, or about the neutrinos themselves, that are not quite right.

Scientists will keep thinking about the matter, and they will continue experimenting, till what isn't quite right is made right. Then they will know even more exactly than they do now just what it is that makes the Sun shine.

end