ISAAC
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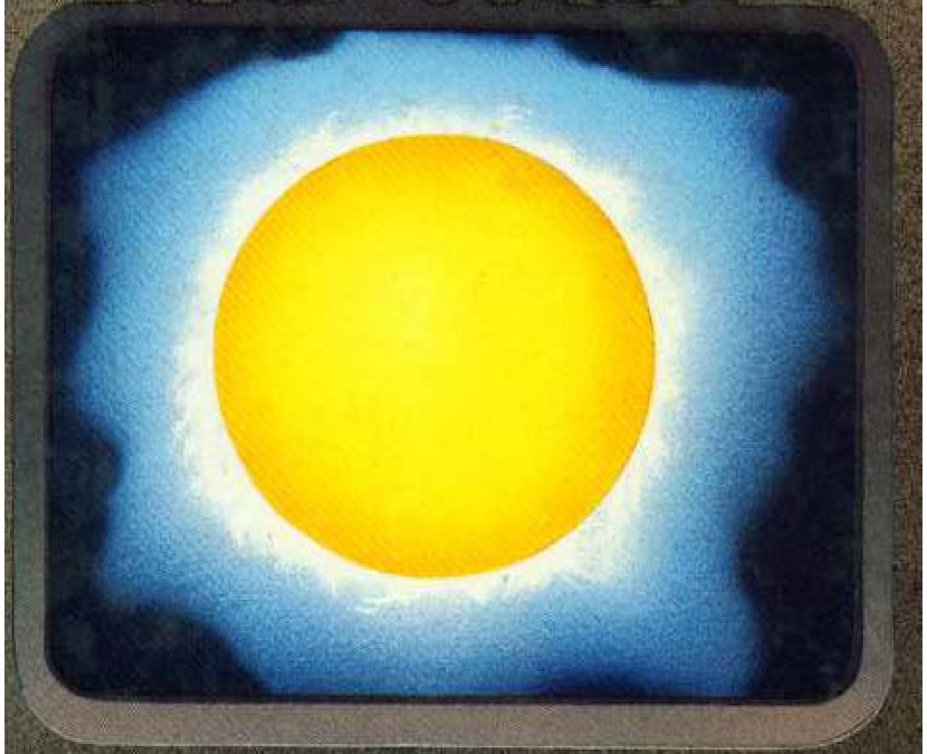

How we found out about

ENERGY

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ISAAC ASIMOV

Contents

1. Energy

Everybody considers energy so important these days that you might think the word was known even in ancient times. But it wasn't. The word was invented less than 200 years ago by an English scientist named Thomas Young. He used it for the first time in 1807.

Energy is something that makes it possible to do work, and work is something that takes effort. Lifting a heavy object is work. So is lifting a light object, but that is less work. Lifting an object a long distance is more work than lifting it a short distance.

The heavier an object is and the further you have to move it against some pull, the more work you do.

Energy goes along with work. The more work you do, the more energy you need to do it with. The more energy you have, the more work you can do.

In fact, Thomas Young made up the word "energy" from a Greek expression that means "work inside". Energy is something that has "work inside it". You can use that energy and get work out of it.

Even though ancient people didn't use the word, they had the *idea* of energy. They knew that doing work took effort and made you feel tired. They knew that the more

work you did, the greater the effort and the more tired you got.

If they had known the word, they might have said, "You only have so much *energy* in your body. The more work you do, the more energy you use up and the more tired you feel."

What the ancient people didn't realise was that making use of energy was the *only* way of doing work. They thought there were strange powers that could do work without an effort and without getting tired.

The ancient Greeks told tales of musicians who played so beautifully that stones danced and moved into a wall by themselves. In *The Arabian Nights*, Aladdin had a wonderful lamp that could give him anything he wanted. The genie of the lamp could build a castle for him in the twinkling of an eye. That didn't make the genie tired because he used magic instead of energy.

It's not really surprising that people made up these tales. Work was so hard that everyone longed for some way to do it without wearing a person out. But no one ever actually saw anything done by magic and no one ever did anything by magic. Any work that was ever done took energy, and if people did it, it took effort and made them tired.

For the most part, you think of work in connection with living beings. People do work, and so do animals such as horses, donkeys, or cattle. Often, though, objects that have no life in them can also do work.

The wind can blow ships across the water. The river current can move rafts downstream. The tide can lift heavy ships. If a catapult is released, its lever moves and a heavy stone is thrown into the air. That heavy stone can hit a wall and smash it.

Whenever something that is not alive does work, it is because it is in motion. Still air, still water, still rocks don't move anything or smash anything. It is moving air, moving water, moving rocks that do the work.

Since motion does work, motion must be a kind of energy. We could call it "motion energy", but in 1856, an English scientist named Lord Kelvin called it "kinetic energy". That's really the same thing, for "kinetic" is from a Greek word meaning "motion".

The faster an object moves, the more work it can do, and the more energy it must therefore have. If you make a hammer move slowly, it will just tap a nail and push it into wood only a little way. If you move that same hammer more rapidly, it hits the nail harder and drives it further into the wood.

We can also see that a heavier, or "more massive", object has more kinetic energy than a less massive one moving at the same speed. A large, heavy hammer will drive a nail further in with each blow than a small light hammer will at the same speed.

Sometimes even a motionless object can become capable of doing work. Imagine a rock sitting on the edge of a cliff. If a gust of wind blows it off it starts falling. It starts moving downwards, in other words, and that means it suddenly has kinetic energy. As something falls, it moves faster and faster, so that it gains more and more kinetic energy. Finally it hits the ground, and it can do work as it hits—smash something, for instance.

The rock doesn't seem to have any energy when it is just sitting at the edge of the cliff. It doesn't do any work. But it can gain kinetic energy when it falls off the cliff. We can say that the rock at the edge of the cliff has energy that is just waiting for the right conditions to show up.

In 1853, a Scottish engineer named William J.M. Rankine called the energy of anything that could start falling "potential energy".

The higher an object is above the ground, the longer the distance it can fall and the greater its potential energy. After all, an object falling only a short distance doesn't have a chance to speed up very much and to gain much kinetic energy. It lands with only a small thump and can do very little work. The object had little potential energy to start with.

An object falling from a great height has a chance to gain a great deal of speed and therefore a great deal of kinetic energy. It can then do a great deal of work when it lands, because it had a great deal of potential energy to start with.

You probably know from your own experience that you can get hurt more when you jump from a high wall than from a low one. From a high wall, you hit the ground harder.

The ancient people would have been puzzled if anyone had spoken to them of kinetic energy or of potential energy. They didn't know the words. Still, they had the *notion*. They built ships with sails to take advantage of the wind's energy. They let the running water of a river turn wheels that then did work for them. They knew perfectly well that a rock dropping from a height could do damage, and that a person jumping from a height might hit the ground hard enough to break a leg or even be killed.

Just the same, having a notion isn't enough. If you want to understand energy properly, you have to study it carefully. You have to make exact measurements and notice how those measurements fit together.

The ancients weren't able to make the kind of careful measurements that were needed to develop a real understanding of energy. That didn't come until modern times.

2. Mechanical energy

Since motion is a kind of energy, you might begin to find out about energy if you studied motion carefully. The first person to study motion carefully was an Italian scientist named Galileo Galilei. He is usually known by his first name only: Galileo.

In the 1590s, Galileo experimented by letting balls roll down slanted grooves and measuring the distance they rolled in a given time. Accurate clocks hadn't been invented yet, so he timed the rolling by counting the drops of water that leaked out of a can with a hole in the bottom.

He was the first to show that balls moved faster and faster as they rolled down an inclined plane. He was able to work out two simple mathematical formulae that could be used to calculate how fast an object would be moving after it had dropped for a certain length of time down an inclined plane. You could also use these formulae to calculate the distance it had fallen.

If you know that a ball moves faster and faster as it falls, you also know that it keeps gaining more and more kinetic energy. In Galileo's time, scientists still didn't have a clear idea of kinetic energy. Eventually, they learned about kinetic energy and then they were able to use Galileo's formulae.

Years before he experimented with rolling and falling balls, Galileo had made a different discovery. In 1581, when he was only 17, he was attending religious services in a cathedral when he noticed a chandelier swinging in the draughts of wind.

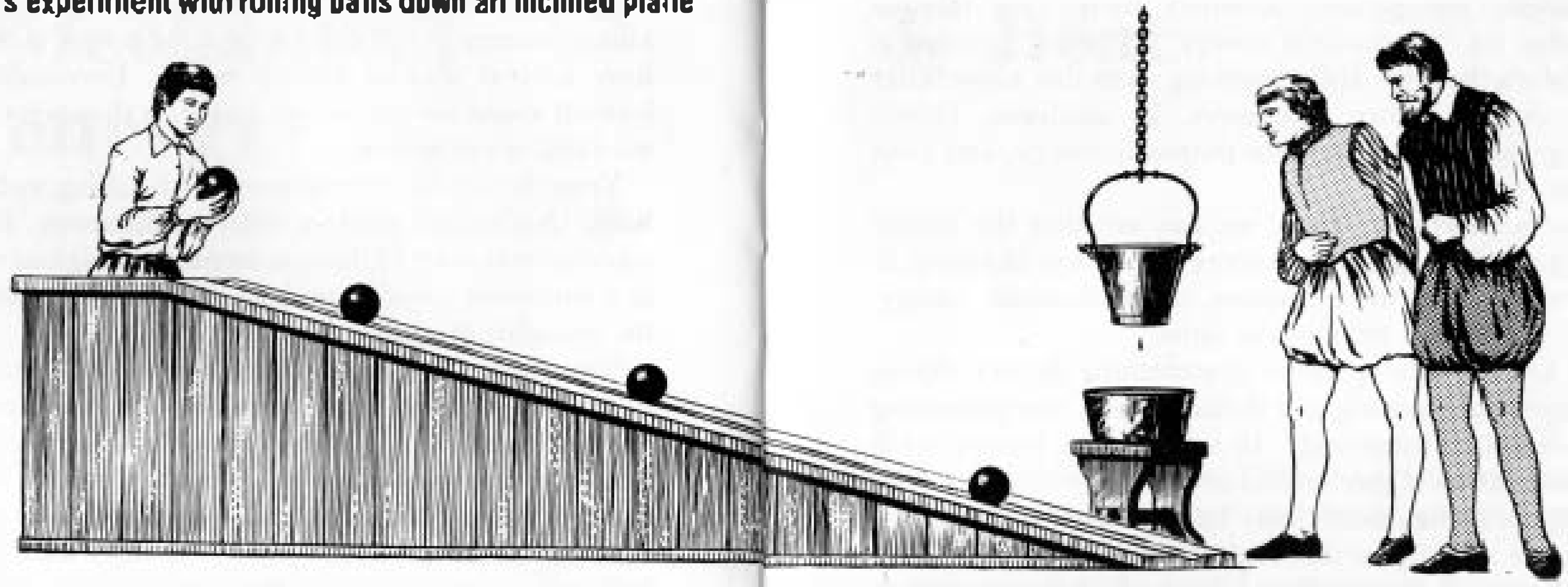
Sometimes it swung back and forth just a little way; sometimes a long way, according to how the gusts of wind caught it. It always took the same time to go from end to end of its swing, though, whether it swung through a small distance or a large one. (Galileo timed it by means of his pulse, and he was so busy counting that he must have missed hearing the service.)

In this way, Galileo discovered the way a pendulum works. Pendulums keep time in their swings so well that about 70 years later they were used to build "grandfather clocks". These were the first accurate clocks ever invented.

Suppose you want to find out how a pendulum works. You could make one for yourself. Tie a piece of string to anything that's above the ground; a shower-curtain rod, for instance. Then tie something fairly heavy to the other end; a pocketknife, for instance. Then let it swing.

It goes to one side, then to the other, back and forth, over and over. As it goes up on one side it moves more and more slowly, until it comes to the top of its swing. There it stops moving for an instant. Then it begins to move back down, faster and faster. By the time it reaches the bottom of the swing, it is moving quite quickly. Then it begins to move up in the other direction, and slow it

Galileo's experiment with rolling balls down an inclined plane



moves more and more slowly again.

As the pendulum rises on one side and moves more and more slowly, it has less and less kinetic energy. Since it is rising higher as it does so, it has more and more potential energy. By the time it reaches the top of its swing, it has no kinetic energy at all because it isn't moving. It has the most potential energy it ever has, though, because it is then as high as it ever gets and has the potential of falling.

When the pendulum comes down again, it starts gaining kinetic energy again as it moves faster and faster. At the same time it loses potential energy because it moves lower and lower. At the bottom of the swing, it is moving fastest and has most kinetic energy, and it is at its lowest point and has least potential energy.

As a pendulum swings, first it loses kinetic energy and gains potential energy, then it gains kinetic energy and loses potential energy—over and over again. The two kinds of energy keep changing one into the other, back and forth, back and forth.

The working of a pendulum was one of the first observations that gave scientists the notion that different kinds of energy could be easily changed back and forth.

What's more, you can see that as the energy switches back and forth from one kind to another, the total doesn't increase. The pendulum always goes up to the same height on each side of the swing.

Eventually, in fact, scientists learned how to calculate exactly how much kinetic energy and how much potential energy a pendulum had at each point in its swing. They found that the kinetic energy *plus* the potential energy was always the same. The amount of each kind of energy was constantly changing, but the *total* amount of energy was not.

Kinetic energy and potential energy are lumped together as "mechanical energy". That is because in machines there are always moving parts that move faster and slower, higher and lower. In machines, kinetic energy is often turning into potential energy, and back again.

For a pendulum, then, we can say that the kinetic energy and the potential energy are always changing in amounts. The total amount of mechanical energy, however, always remains the same.

When the total quantity of something doesn't change as objects are moving and shifting about, that something is said to be "conserved". In a pendulum, then, there is "conservation of mechanical energy".

Suppose this doesn't only happen with a pendulum? Suppose any object that experiences changes in kinetic and potential energy always keeps the same amount of mechanical energy. We would then say this was a "natural law". We would say the pendulum behaved as it did because of the "law of conservation of mechanical energy".

Here is another common example of this law:

Suppose you dropped a glass marble on a smooth tile floor. It will gain kinetic energy and lose potential energy as it drops. But then it will hit the floor and bounce. It will move upwards, losing kinetic energy and gaining potential energy as it rises. If it rises to the same point from which you let it drop, the total mechanical energy has not changed. In fact, the total mechanical energy has remained the same at every point in the fall and in the bounce back.

We could say, the bouncing glass marble also shows the workings of the law of conservation of mechanical energy.

3. Heat

Throughout the 1600s and 1700s, scientists kept arguing about motion and energy and never got the law of conservation of mechanical energy quite clear. The chief trouble was that the law of conservation of mechanical energy didn't really work. It wasn't a true natural law.

If you let a pendulum swing for a long time, it will make smaller and smaller swings, and eventually it will stop. The bouncing glass marble will make smaller and smaller bounces until it is just lying on the ground. In other words, the total mechanical energy always gets *less*. Sometimes it gets less only very slowly, sometimes it gets less very rapidly—*but it always gets less.*

Suppose you shove a wooden object across a waxed wooden floor. The object slides along, but the floor is level so that the object never changes its height. It never increases its potential energy. If the law of conservation of mechanical energy was right, then the object could never decrease its kinetic energy. It would have to keep sliding along forever at the same speed.

But that's not the way it works. The wooden object slows down as it slides. Finally, it comes to a halt.

No matter what we do, mechanical energy is never conserved. It always changes, and it always changes in the same direction. It always gets less.

The reason mechanical energy gets less is because of "friction"—that is, the rubbing of one object against another. A wooden object travels only a short way over a rough wooden floor before it comes to a halt. The rough wooden floor produces lots of friction, and the sliding object uses up all its kinetic energy overcoming the friction.

If it was moving over a smooth wooden floor, the wooden object would slide a longer distance before stopping. It would slide still further if it was moving over ice.

A pendulum has to rub against the air as it swings. This rubbing is called "air resistance" and it is a kind of friction too. Then, too, the string used to attach the pendulum to something rubs against whatever it is attached to.

If we could imagine a world without friction, then mechanical energy *would* be conserved. Imagine a pendulum swinging in a place where there is nothing at all, not even air (a "vacuum"). If there was no friction at the string's end, it would then swing forever. An object sliding in a vacuum along a perfectly smooth floor would travel forever.

In the real world, though, friction *does* exist. That means that mechanical energy is always disappearing. Where does it go? Does it disappear into nothing at all? Or does it change into something else—into another form of energy, perhaps?

One thing that friction produces is heat. If you rub your hands you make them warm. If you rub two sticks together in the right way, you can make them so hot that you can start a fire. Does heat have some connection with energy?

In the 1700s, many scientists thought heat was a kind of substance that they called "caloric" from a Latin word for "heat". They thought that caloric could flow easily from one object to another: a hot object contained a great deal of caloric, and when it was put near a cold one, some of the caloric flowed from the hot object to the cold; the hot object cooled off and the cold object warmed up.

That seemed to make sense—but suppose you start with two objects that are both cool. Neither has much caloric, but if you rub them together, both grow warm and contain more caloric. Where did the extra caloric come from?

One person who puzzled over this question was an American named Benjamin Thompson. At the time of the American Revolution, he left America and never returned. In Europe, he was made a noble and was known as Count Rumford.

In 1798, Count Rumford was in Germany where he was supervising the manufacture of cannons. In order to make a cannon, you begin with a block of metal and bore a long hole into it. The hole is gouged out with a sharp, rotating piece of a harder kind of metal.

Naturally, as you gouge out the hole, there is a lot of friction between the rotating piece of metal and the block of metal into which the hole is being bored. Both pieces of metal get very hot and have to be kept cool by pouring cold water over them all the time.

Rumford thought about this and wondered where all the heat was coming from. Some scientists thought that when pieces of metal flaked off from the cannon as the hole was formed, the caloric in the metal was released and poured out. But how much caloric could there be?

All the metal was cold to start with, and yet as the boring continued, the metal could be made hot enough to boil endless amounts of water.

Rumford tried using a dull piece of metal to do the boring. That didn't cut off any pieces of metal, so no caloric could get loose. Did this mean that the metal wouldn't get hot? No! It *did* get hot and even faster. Heat just poured out of those metals for as long as he kept boring.

Rumford thought that heat might be a kind of motion. The motion of the burning bore, ordinary kinetic motion, was turning into another kind of motion that was heat.

Heat wasn't the motion of an entire object, Rumford thought. It was the motion of all the tiny little pieces of which the object was composed. These tiny little pieces were so small you couldn't see them, and they moved through such tiny distances that you couldn't see the motion.

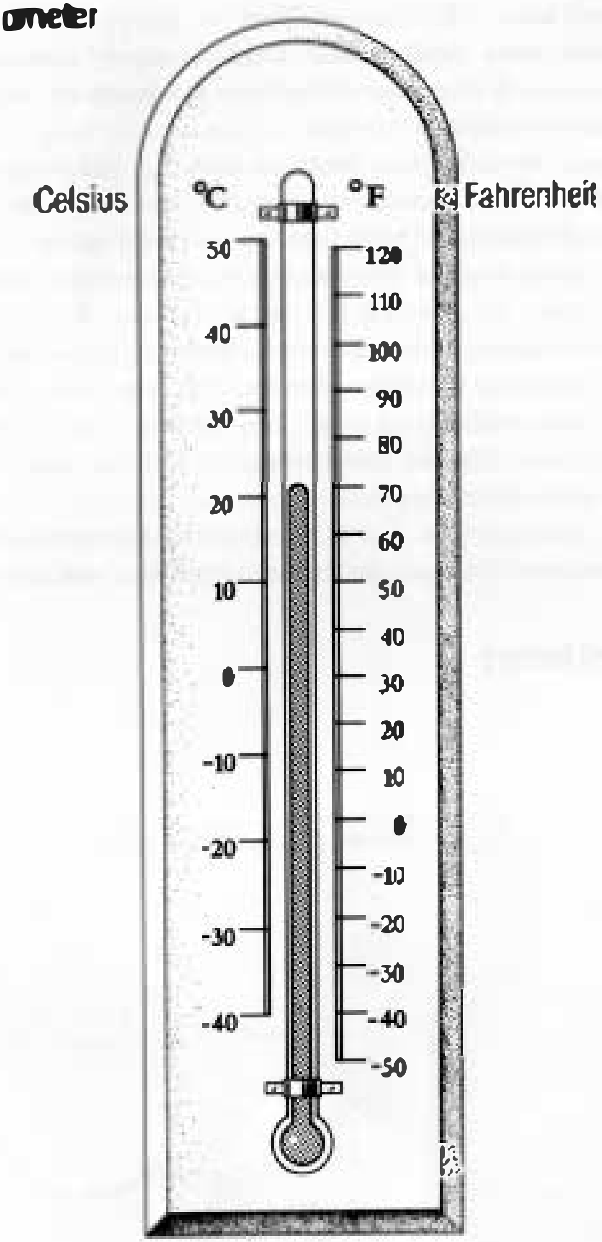
What's more, they moved in all directions, back and forth. All the motions in all the different directions cancelled out, and the whole object didn't move.

According to Rumford's notion, when friction causes an object to stop swinging, bouncing, or sliding, its kinetic energy has not disappeared. Its kinetic energy has just shifted from the whole object to all the little parts that make it up, and all the little parts of whatever it rubs against.

When Rumford first suggested this, very few scientists believed him. How could there be parts of an object so small you couldn't see them, moving in all directions through such tiny distances you couldn't see the motion? It sounded silly.

In 1803, however, only 5 years after Rumford's experiments, an English chemist, John Dalton, came up with

Thermometer



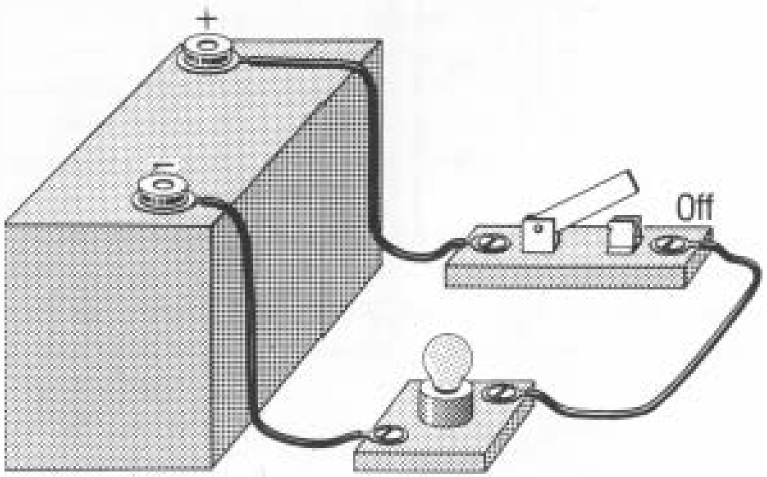
another idea. He showed that a great many things scientists were finding out could be easily explained if you supposed that everything was made up of tiny little parts that he called "atoms".

Atoms were far too small to see, but the concept of atoms became so useful to scientists that more and more of them began to believe that atoms really exist.

Scientists worked out careful experiments to find out what atoms are like. As the years went on, they learned more and more about the tiny atoms. It began to make more and more sense to suppose that heat was made up of the tiny motions of these tiny atoms. The faster the atoms moved in all directions in any substance, the hotter that substance was.

You can tell how hot a substance is by measuring its temperature with an instrument called a thermometer.

Dry cell battery



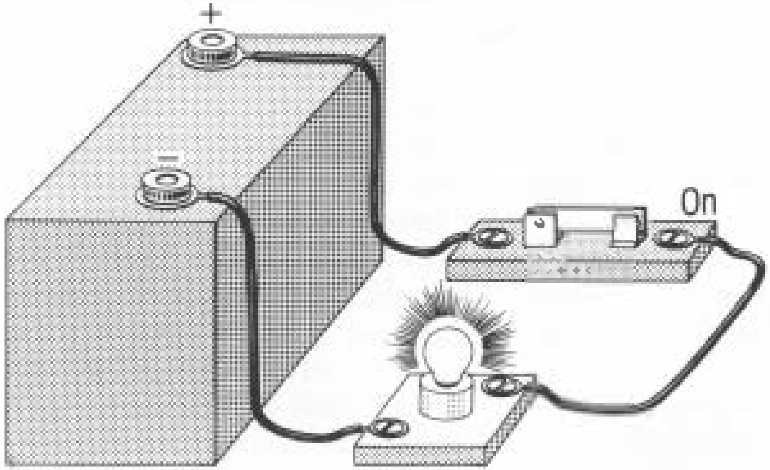
By the 1800s, very good thermometers had been invented to measure temperature, and they were very useful to scientists who were interested in energy.

Once heat was looked at as a kind of kinetic energy, scientists could take another look at the law of conservation of mechanical energy. The reason it didn't work was that some of the mechanical energy was always being changed into heat, which is *another* form of energy.

Instead of just saying that kinetic energy can turn to potential energy and vice versa, we can say that any form of energy can turn into any other kind of energy.

For instance, ordinary kinetic energy can turn to heat. Also, heat can turn to ordinary kinetic energy; for example, when the hot steam in a kettle makes the cover move up and down.

There are other forms of energy. Light, sound,



electricity, magnetism can all do work and are all forms of energy. They can be changed back and forth. Electricity can produce light in an electric bulb or sound in an electric bell. Electricity can produce magnetism. Magnetism can produce electricity. Heat, light, and motion can each produce electricity.

Chemicals can produce sound and kinetic energy when they explode, or light and heat when they burn, so there is "chemical energy", too. Also, light, heat and kinetic energy can produce certain chemical changes and thus become chemical energy.

By the middle 1800s, it was clear that scientists could make sense of energy only if they considered it in all its forms.

4. Conservation of energy

A big question remains. If we take *all* the kinds of energy there are in the world, and add them up, is the total always the same? In changing energy from one form to another, does any of it ever disappear altogether? Does any of it appear out of nothing?

A German scientist named Julius Robert Mayer was the first to consider this question. He was a ship's doctor, travelling to distant lands, and he had considerable time to start thinking about the subject.

It occurred to him that if people could measure the way in which kinetic energy turned to potential energy and back again, they could also measure the way in which mechanical energy turned to heat. In 1840, as an experiment, he had a horse pull away at a machine that stirred a thick mixture in a large pot. He calculated how much energy the horse put out and how much heat appeared in the mixture.

In measuring how much mechanical energy created a particular amount of heat, he measured something called "the mechanical equivalent of heat". In 1842, he wrote a paper in which he explained this.

He also went on to say that he thought any kind of energy could be transformed into any other, but that the total energy always remained the same. He thought this included even the energy of living things.

According to Mayer's theory, we could suppose that the energy of sunlight is transformed into the chemical energy of food inside green plants. When animals eat the food of green plants, this chemical energy is changed into the chemical energy in animals.

Mayer thought that the energy of sunlight evaporated some of the water in the ocean and that this vapour finally fell as rain, which collected in rivers. The energy of sunlight was thus transformed into the energy of running water.

The energy of sunlight also heated up some parts of the ocean and the air more than other parts. The hot parts rose and the cold parts moved in to take their place. In this way, the energy of sunlight was transformed into the energy of wind and of ocean currents.

Plants that gained their energy from the Sun sometimes decayed in such a way as to form coal. We can now dig up coal that was formed hundreds of millions of years ago. Its chemical energy comes from the sunlight of that period. When we burn the coal, that chemical energy turns into light and heat.

Tiny sea-animals sometimes die and decay in such a way as to form petroleum. The energy of petroleum comes from the plants those tiny sea-animals ate, and therefore from sunlight.

Suppose energy can shift from one form to another but never changes its total quantity. In that case, energy is conserved. What Mayer was maintaining in his paper

was that there is a "law of conservation of energy".

Mayer had a great deal of trouble getting people to pay attention to his theories. Most people who read the paper at all just put it aside and forgot about it. After all, how could anyone know just how much energy of sunlight went into the wind and into coal, and so on? It seemed to them that Mayer just had a very lively imagination.

Poor Mayer was so depressed about the way in which people ignored his scientific contributions and about various family troubles that in 1849 he tried to kill himself by jumping out of a third-storey window. He just hurt his legs, but he was put into a mental institution for a while. Finally, he was released, but he did no more scientific work.

In the 1860s, however, the scientific world came to realise the value of Mayer's work, and everyone began to praise him. In 1871, he received the Copley medal, one of the highest honours a scientist could get in those days.

One of the reasons that Mayer had received so little attention was that he had done only one experiment. He had only done the experiment with the horse stirring the thick mixture.

An English scientist, James Prescott Joule, approached the problem in a different way.

He had had a sickly childhood, but he was the son of a rich brewer, whose beer was selling very well. Joule was privately educated and he was allowed to fix up a home laboratory for himself.

He became very interested in measuring things, and through the 1840s, he worked at measuring exactly how much heat was formed when a certain amount of a particular kind of energy was used. He tried almost every form of energy he could think of.

He churned water with paddles, for instance. Then he churned mercury with paddles. He forced water through small holes to heat it by friction. He let gases expand and then squeezed them again. He passed electric currents through various objects to heat them up.

He was so fascinated by such measurements that he was even busy with them on his honeymoon. He made himself a special thermometer and used it to measure the temperature of the water at the top and bottom of a waterfall his new wife and he visited. He wanted to know if the energy of the falling waterfall was turned into heat at the bottom end and, if so, how much heat was produced.

By 1847, 5 years after Mayer's paper, Joule had satisfied himself that the same amount of energy, no matter what kind it was, always ended up as the same amount of heat. He had measured, much more exactly than Mayer had, the mechanical equivalent of heat.

What's more, if energy was transformed from one kind to another without gaining or losing, then that fitted in with the law of conservation of energy.

Joule wrote up all his findings in a paper and tried to get it printed. However, he was not a professional scientist. He was just a rich brewer (his father had died by then, and Joule was running the brewery). Scientists weren't sure if they could take him seriously, so they refused to print his paper.

Joule had a brother who worked on a newspaper, however. He got his brother to persuade the newspaper to print his entire paper. That gave some people a chance to read it. Then, when he made a speech about it, some scientists became interested. In a couple of years, everyone was taking Joule's work quite seriously.

About the time that Joule was getting his paper printed, a German scientist, Hermann L.F. von Helmholtz, had come to the conclusion that energy was conserved. In 1847, he wrote a paper explaining his ideas.

Helmholtz was a professor, but he too had trouble getting his paper printed. In the end, he did. His clear explanation and Joule's measurements finally won out. Three men together, Mayer, Joule, and Helmholtz, all working in the 1840s, established the law of conservation of energy, which states that energy may change from one form to another, but that the total amount in the Universe is always the same.

There is a special branch of science that deals with the way energy is transformed from one form to another, how all forms of energy can be transformed to heat, and how heat moves from one place to another. It is called "thermodynamics" from Greek words meaning "heat-movement".

Everything in that science depends on the law of conservation of energy, more than on anything else. For that reason, the law of conservation of energy is sometimes called "the first law of thermodynamics".

It's even more than that. Scientists usually consider the law of conservation of energy to be the most important of all the rules that describe how the Universe works.

Once people understood the law of conservation of energy, they realised there was no use expecting magic to work. How could stones dance into a wall, or a flying carpet go through the air, or a palace be built by making magic passes in the air? Where would the energy come from?

5. Entropy

Suppose you had a supply of energy. Would that be all you needed to do any amount of work? After all, the law of conservation of energy says it can't be destroyed. You would just change it from one form of energy to another and then to another and then back to the first perhaps, and so on forever. And with each change, you could just keep on getting work out of it. Or could you?

It turns out that you can't. Energy never disappears, but not all of it can be turned into work.

The first person who saw this point was a French scientist named Nicolas L.S. Carnot. He did his work in 1824, long before the law of conservation of energy was finally worked out. Carnot wasn't trying to check whether that law existed. He was interested in a smaller problem. By 1824, steam engines were being used for more and more purposes. In steam engines, water is heated to boiling, and the steam that is produced collects in a chamber. As more and more steam gets into the chamber, it builds up strong pressures. When the steam is allowed to puff out of the chamber it does so with such a push that it can move rods, turn wheels, and thus do work.

The steam engine had been invented over 50 years before Carnot's time, but although it had been improved, it still worked very poorly. The energy started in the burning wood or coal that boiled the water. It ended in the work being done. But only about 5 per cent of the original energy of the burning wood or coal ended in work. The other 95 per cent was wasted in heating up the surroundings and did no work.

Carnot was interested in seeing whether there was any way of improving this. He pretended that a steam engine could be made perfectly so that it lost no heat at all. When he did that, his mathematics showed that even then you could never turn *all* the heat into work.

In the steam engine there is steam at a high temperature in the boiler and water at a low temperature in a cooling chamber. The water is first heated to steam by burning fuel, then the steam is changed back to liquid water in the cooling chamber.

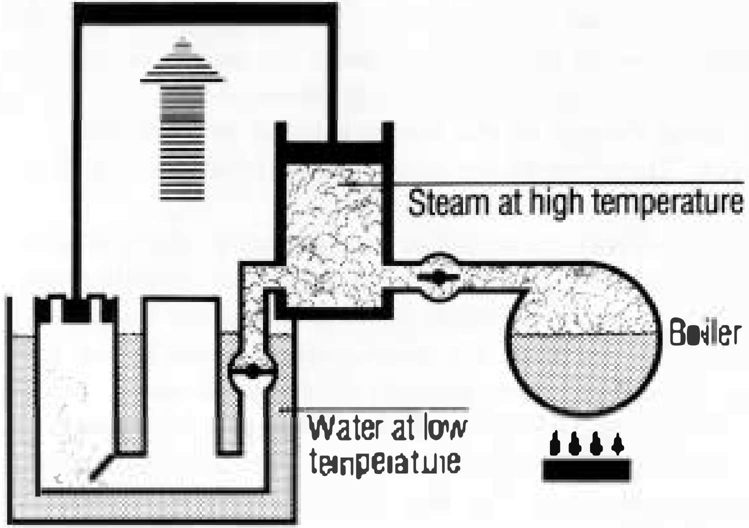
Carnot showed that the amount of energy that could be turned into work depended upon the *difference* in the two temperatures. The greater the difference, the more of the energy (but never all of it) could be turned into work. The smaller the difference, the less of the energy could be turned into work. If the entire steam engine was at the same temperature, so that there were *no* differences, then no matter how hot the steam engine was, *none* of the energy could be turned into work. If you were to try this by experiment, you would find it to be true.

Unfortunately, Carnot died while he was still a young man, only a few years after he did this work and for a while it was not followed up.

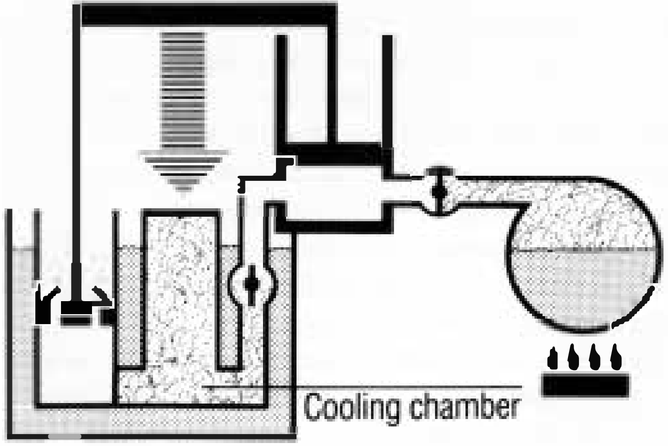
By 1850, however, Carnot's work began to seem very interesting. A German scientist, Rudolf J.E. Clausius, began to consider the idea.

Steam engine

Intake stroke



Power stroke



He didn't deal just with the heat in a steam engine and its different temperatures. He considered all kinds of energies, and he studied all kinds of work. (Clausius was the first scientist to define the word "work" carefully, so that it could be used properly in mathematical formulae.)

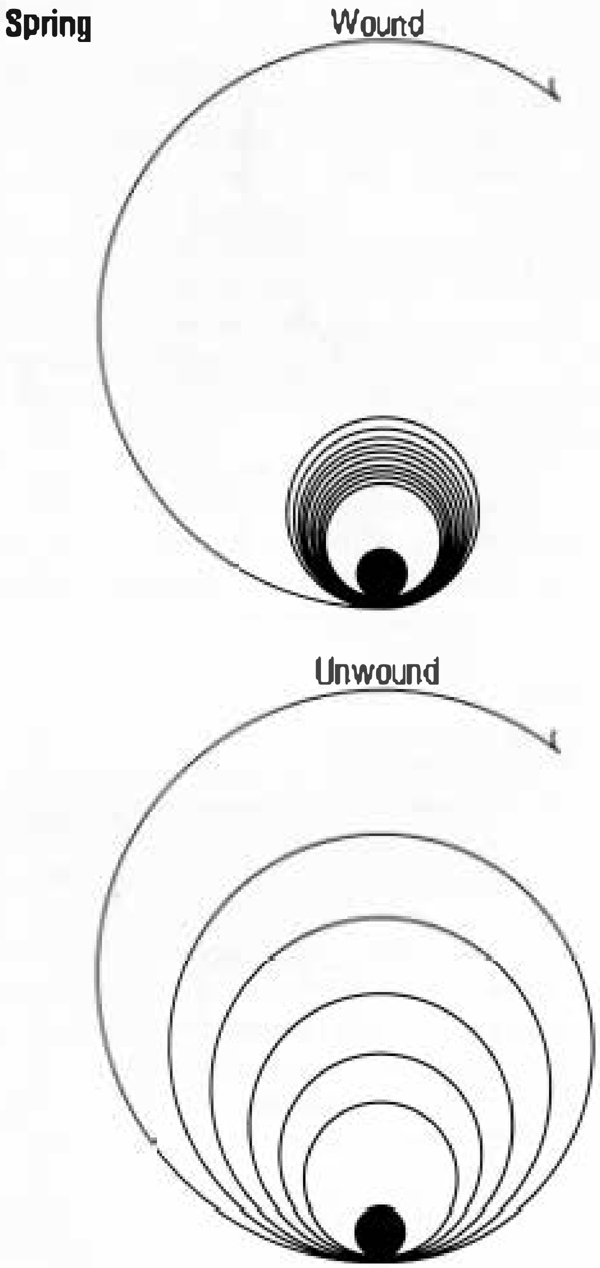
Clausius showed that the only time you could turn energy into work was when the energy supply you were using was not evenly spread out. Whenever you had some device in which a lot of some kind of energy was present in one part and only a little in another part, then you could get work out of it.

As you got work out of such a device, the energy began to even out. As the energy evened out, you got less and less work out of it. Finally, when the energy was all evened out, you could get no more work out of the device. The only way you could make that device continue to do work would be to force some of the energy back into one part, leaving the rest with only a little energy.

In a wind-up clock, for instance, a lot of energy is present in the spring. This energy-filled spring does work by turning the hands of the clock. As it does the work, though, the spring unwinds. Finally, it has no more energy than any other part of the clock, and the clock stops. It will only go if you wind it up again.

Clausius worked out a mathematical expression that represented the amount by which the energy had evened out. He called this amount "entropy". The more energy evens out in some device, the higher its entropy. When the energy evens out altogether, so that all parts of a device have the same energy level, its entropy is at a maximum.

Clausius pointed out in 1852 that entropy is always increasing; energy is always evening out. Even if you can



reverse the process and make energy become uneven again, it takes energy to do that. It takes energy to wind up a clock, for instance.

Whatever is done to concentrate energy in one place and decrease entropy there, it always increases entropy in another place—in your own body, if you are winding the clock. The entropy increase in one place is always found to be greater than the entropy decrease in another. If you include everything, then entropy is always going up.

In that case, is everything on Earth running down like a clock? The Earth's entropy is increasing. Then why hasn't everything on Earth run down by now?

The answer is that everything on Earth is always being wound up again by the energy of sunlight, so that for thousands of millions of years, Earth has been full of the kind of energy-unevenness that can be turned into work.

But then, is the Sun running down? Clausius thought it had to be. The Sun and all the stars are running down, and finally, a long time from now, everything in the Universe will be all run down. Entropy in the whole Universe will be at a maximum, and no more work will be possible.

The notion of how energy is always evening out, so that less and less can be turned into work, is another very important rule in thermodynamics. It is not quite as important as the law of conservation of energy, but almost.

If the law of conservation of energy is the first law of thermodynamics, the rule that entropy always increases and that everything is always running down can be called "the second law of thermodynamics".

6. Nuclear energy

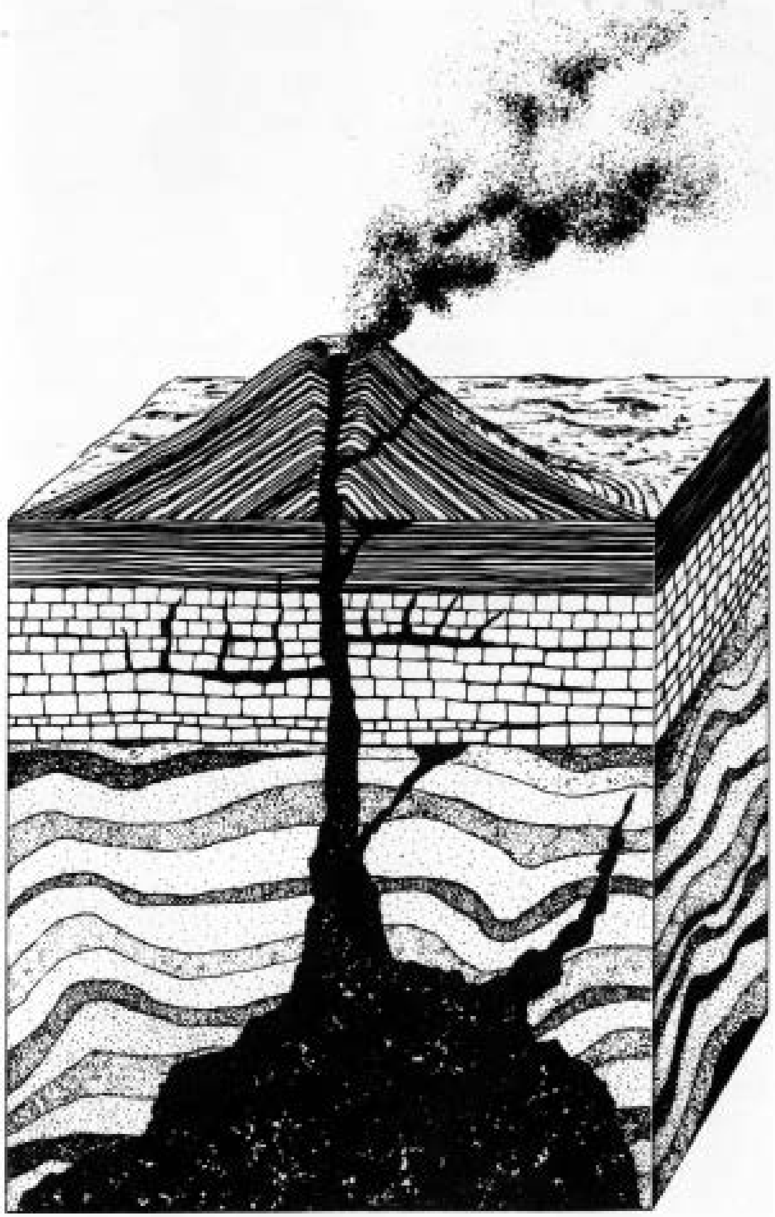
Once the law of conservation of energy was worked out, all the energy problems on Earth could be explained. It could be seen how all the forms of energy could be transformed back and forth, and where they all came from.

Some energy, like the energy of volcanoes and earthquakes, came from the heat deep inside the Earth. Some, like the energy of the ocean tides, came from the energy of the Earth's rotation.

Almost all forms of energy we meet with on Earth, however, can be traced back to the energy of sunlight The Sun has been shining exactly as it does now for all the thousands of years of human history on Earth. It must have been shining exactly as it does now for many, many millions of years before human civilisation began. Where did all that energy come from?

Could the law of conservation of energy be true only for the Earth? Could the Sun's energy come from nowhere?

Helmholtz, one of the three men who worked out the law of conservation of energy, began to think about this in 1854. He thought the Sun's energy had to come from



Cross-section of a volcano

somewhere. The Sun couldn't be burning like a huge bonfire. Ordinary chemical energy would only keep it going for 1,500 years at most.

Helmholtz wondered if meteors might be falling constantly into the Sun. The kinetic energy of their motion might be the source of the Sun's energy. This didn't work, though. If that was the case, the Sun would get more and more massive and its pull on Earth would get stronger. The Earth would move faster and faster about the Sun—and it doesn't.

Then Helmholtz wondered if the Sun might be slowly shrinking. All the parts of the Sun might be falling towards the centre. The kinetic energy of *that* fall could be the source of the Sun's energy. If that was true, the Sun's mass wouldn't change.

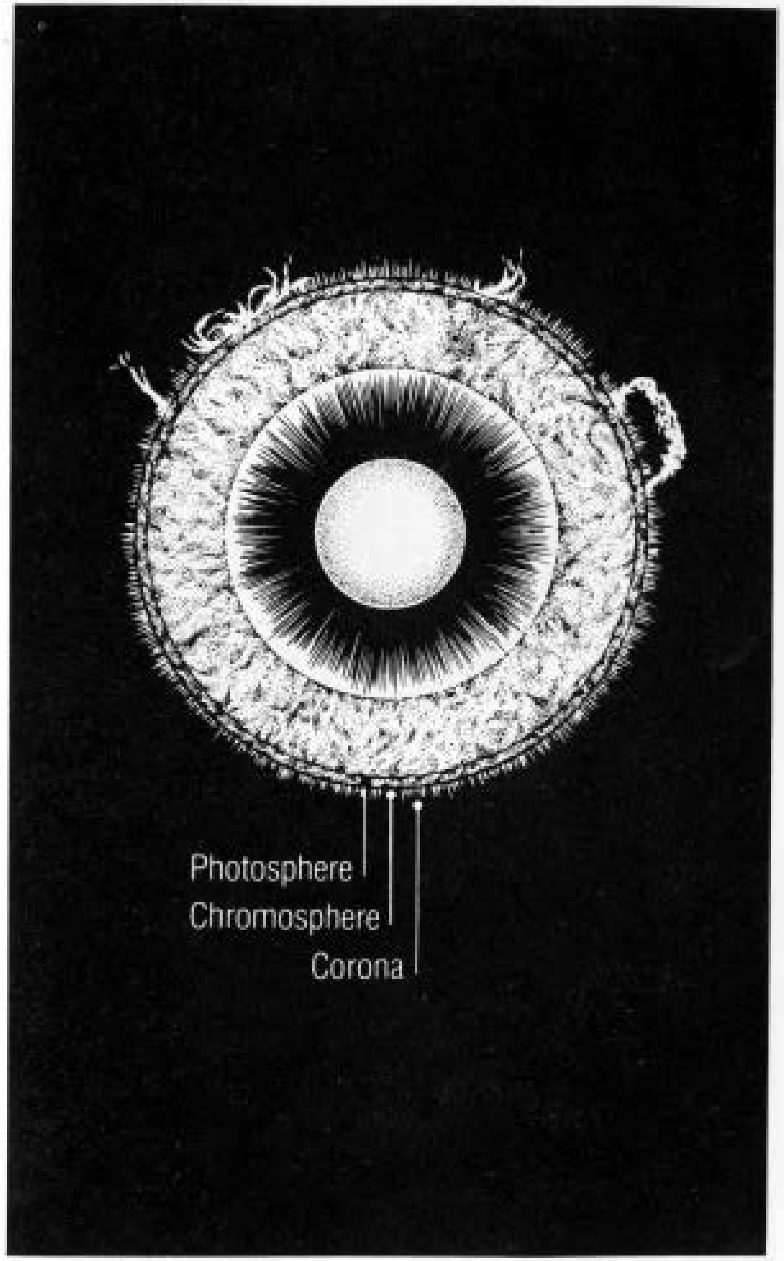
For the rest of the 1800s, it seemed to many scientists that shrinking was the answer to the question of the Sun's energy. Other scientists, however, were unhappy about the notion.

Suppose the energy coming from the Sun did come from the shrinking of the Sun. In that case, less than a hundred million years ago, the Sun must have been so big that the Earth, if it moved about the Sun at its present distance, would have been *inside* the Sun. The Earth couldn't have formed until the Sun had shrunk enough to make room for it to move about outside the Sun.

This meant the Earth would have to be less than a hundred million years old. Scientists who studied the Earth's structure, however, were sure that this couldn't be so. The Earth had to be much older than a hundred million years.

Then, in 1896, a French scientist, Antoine Henri Becquerel, found that a rather rare metal, uranium, was

Cross-section of the Sun



"radioactive"; that is, it was always giving off tiny speeding particles, much smaller than atoms, with a great deal of kinetic energy. It also gave off a form of energy something like light.

In 1900, a New Zealand-born British scientist, Ernest Rutherford, figured out how much energy was given off. He calculated it for a particular radioactive metal, radium, which gave off more energy in this way than any substance known before. He showed that a gramme of radium would give off enough energy every hour to heat a gramme of freezing cold water to its boiling point. In the next hour it would do the same, and in the next, and so on, for many hundreds of years.

Where was the energy coming from? Was the law of conservation of energy wrong? Rutherford thought not. He suspected there was some form of energy inside the atoms that scientists did not know existed.

Rutherford experimented with the speeding particles that shot out of the radioactive atoms. He let them pass through ordinary atoms and they seemed to pass through as though there was nothing there. Every once in a while, though, one of the particles hit something and bounced back.

By 1911, Rutherford was able to announce that atoms were made up mostly of empty space. Throughout most of the atom's structure, there were only occasional very light particles called "electrons". At the very centre of the atom though, there was a tiny, massive region that Rutherford called the "atomic nucleus".

Scientists went on to study the atomic nucleus and found that it was made up of particles called "protons" and "neutrons". Atoms are joined to each other by means of the electrons in their outer portions. When atoms are pulled apart and rearranged, energy is

released. It is this energy, involving electrons, that is "chemical energy".

When the protons and neutrons of an atomic nucleus are rearranged, energy is also released. This energy, involving the nucleus, is "nuclear energy".

There is much more nuclear energy than there is chemical energy. A certain number of atoms shifting the particles in the nucleus will deliver many, many times as much energy as that same number of atoms shifting their electrons in their outer sections.

Now, at last, there seemed a new route by which to discover the source of the Sun's tremendous, continuous energy.

In 1924, an English astronomer, Arthur Stanley Eddington, worked out what the material at the Sun's centre must be like. He showed that it would have to be very hot. It would have to have a temperature of millions of degrees.

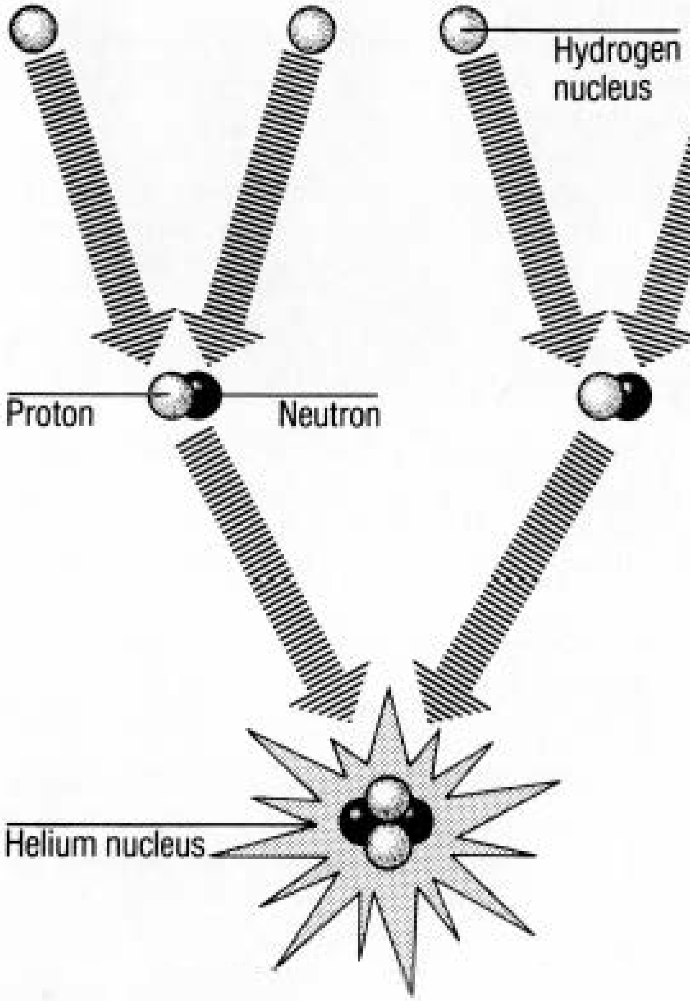
Then in 1929, an American astronomer, Henry Norris Russell, analysed sunlight in such a way as to be able to show that the Sun consisted mostly of a substance called hydrogen.

Using such information, a German-American scientist, Hans Albrecht Bethe, tried to work out what kind of nuclear changes might be going on in the centre of the Sun. In 1938, he showed that the Sun's energy had to come from the fusion of two hydrogen atoms to form one helium atom. This is called "nuclear fusion".

Scientists now agree that the Sun is changing hydrogen nuclei to helium nuclei, and there is enough hydrogen in the Sun to account for its having shone through all the 5,000 million years that the Earth has existed.

Of course, some day, the Sun's hydrogen will be used

Hydrogen fusing to form helium



up, but that won't be for at least 8,000 million years more.

The nuclear fusion that produces the Sun's energy also produces the energy of all the other stars. The law of conservation of energy is true not only on Earth but all over the Universe.

Are there still other kinds of energy that are even greater than nuclear energy? Scientists can't say that there aren't, but since 1900, they haven't found any new kinds of energy they don't already know something about.

7. People and energy

Far back in early cave dweller days, the only energy human beings used was the chemical energy of their own bodies.

As human beings gained more knowledge and learned new ways of doing things, they used the energy of their tame animals. They also used water currents and wind to move their ships.

Long, long ago, they learned how to use the energy of fires, burning wood or fat for fuel. Fire was used for more and more things as time went on. It was used to warm people in the winter. It was also used to give light at night. It was used to cook food, to make metals, glass, and pottery.

As fire was used more and more, more and more wood had to be used for fuel. For a long time, it didn't matter because every year more trees grew and that made up for the wood that human beings used.

But by the 1700s, so much wood was being used that in some places trees didn't grow fast enough to make up for what was being burned.

In Great Britain, the wood shortage was severe, and it was here that a sudden new and greater need for fuel arose. During the 1700s, the steam engine was invented. For the first time, the chemical energy of fuel was converted into the kinetic energy of moving rods and turning wheels that made things move.

More and more steam engines were built and used to run machines in factories and move ships across the water and locomotives over land. As a result, there was a great change in people's lives. This period was called the "Industrial Revolution".

There just wasn't enough wood in the world to supply the energy needed to keep all those steam engines going. In the 1700s, Great Britain began to use coal instead, because it was a more plentiful fuel.

More and more coal was used throughout the 1800s. Of course, very little new coal is being formed, so that once the coal that is in the ground gets used up, there won't be any more. Still, there are millions of millions of tonnes of coal in the ground all over the world. That is enough to last for hundreds of years.

People have learned new ways of using energy. In the 1800s, the chemical energy of burning fuel was used to turn wheels between the poles of a magnet. It was found that the energy of motion past the magnet was changed into the energy of an electric current. Electric currents were used for telegraphs and telephones and for every kind of electric motor to do work for human beings.

All this electrical power was made possible by burning more and more coal.

It is hard to dig up coal, however, and hard to get it from the mines to the factories. In the 1800s, people learned how to drill oil wells. Oil is a liquid, not a solid like coal. It is easier to get oil out of the ground than to get coal. It is also a lot easier to move oil from place to place through pipes. Oil is also a lot easier to burn.

Towards the end of the 1800s, new kinds of engines were invented that burned petrol. Such engines are called "internal combustion engines" and these are used in automobiles, trucks, buses, ships and aeroplanes. The petrol they use comes from oil.

Throughout the first half of the 1900s, more and more of these engines were used and more and more oil was being burned. Oil was being used instead of coal to heat houses and to produce electricity. By 1950, more oil was being burned than coal.

The trouble is, though, that there is far less oil in the ground than there is coal. What's more, more of the oil is to be found in just one certain part of the world—the regions around the Persian Gulf.

Now oil is beginning to run short and people are using it more and more every year. The price is going up and there is the danger of shortage. In 30 to 50 years there may be no oil left at all.

What will people do for energy when that happens?

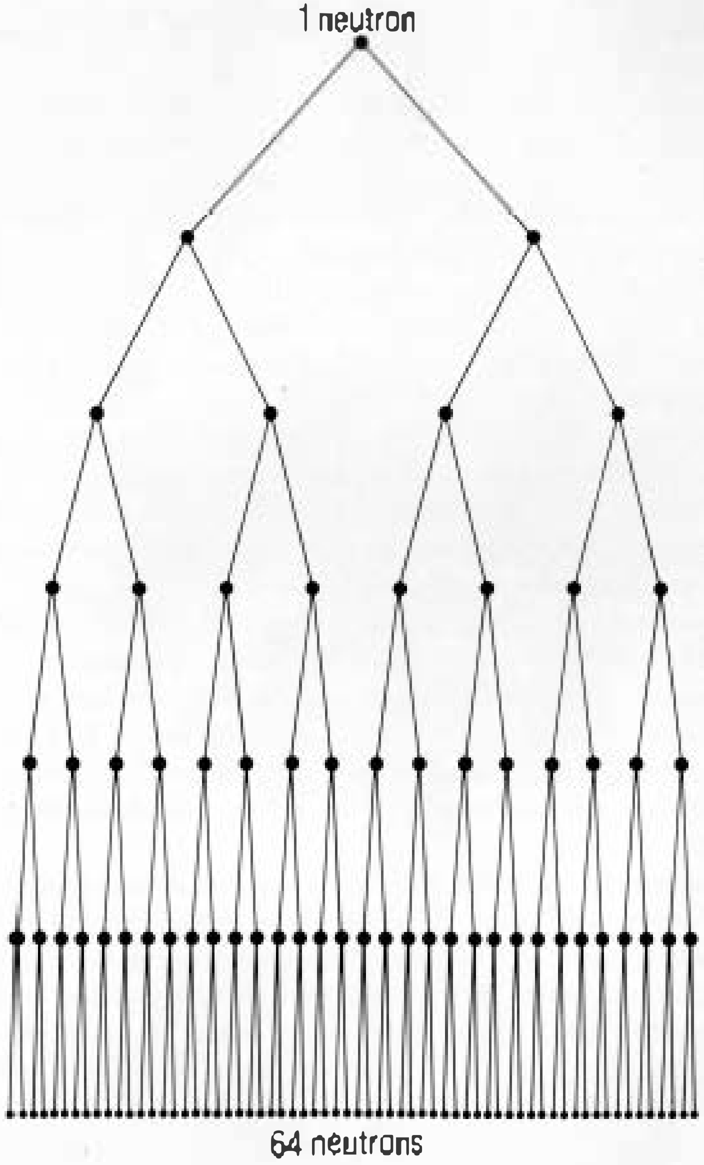
They can go back to coal. Coal, however, is still hard to get out of the ground and difficult to move from place to place. Oil can be formed from coal and from certain kinds of rocks, but it would then be very expensive.

Besides, oil and coal both fill the air with soot and with irritating chemicals when they burn. This is "air pollution" and it is bad for human health.

Are there sources of energy besides the chemical energy of coal and oil that we can use? What about nuclear energy? The only nuclear energy found on Earth was the radioactivity of certain substances. For many years that was very hard to put to use on a large scale.

In 1939, however, the German scientist, Otto Hahn,

Fission chain reaction



found there were ways of making the uranium nucleus break in half ("nuclear fission"). He found that this released even more nuclear energy than ordinary radioactivity did.

In the United States, scientists got to work at once to see if nuclear fission could be made to yield a great deal of energy. At the end of 1942, the problem was solved by people working under the leadership of the Italian-American scientist, Enrico Fermi.

Fission bombs (also called "atomic bombs") were built as a result. These bombs, using nuclear energy, created far more destruction than ordinary bombs using chemical energy.

After the Second World War, nuclear fission was used to build power plants that could produce energy without explosions. This nuclear energy could be used to produce electricity for peaceful purposes. There are now fission power plants all over the world.

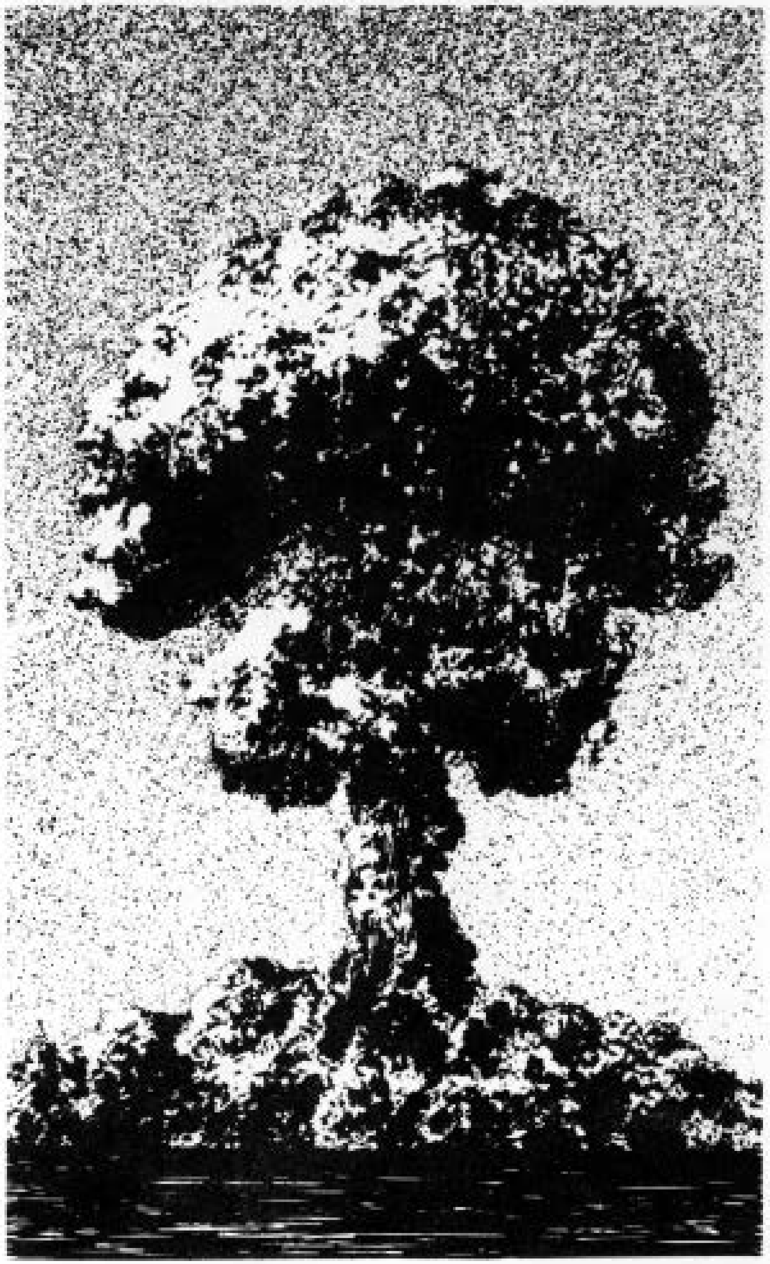
Nuclear fission is not really the best answer to the energy shortage, though. For one thing, it makes use of uranium and other similar metals that are not very common. For another, once the uranium nuclei break in two, very dangerous radioactive atoms are left behind. Scientists are not sure how to dispose of these atoms safely.

So scientists are still looking for another energy source.

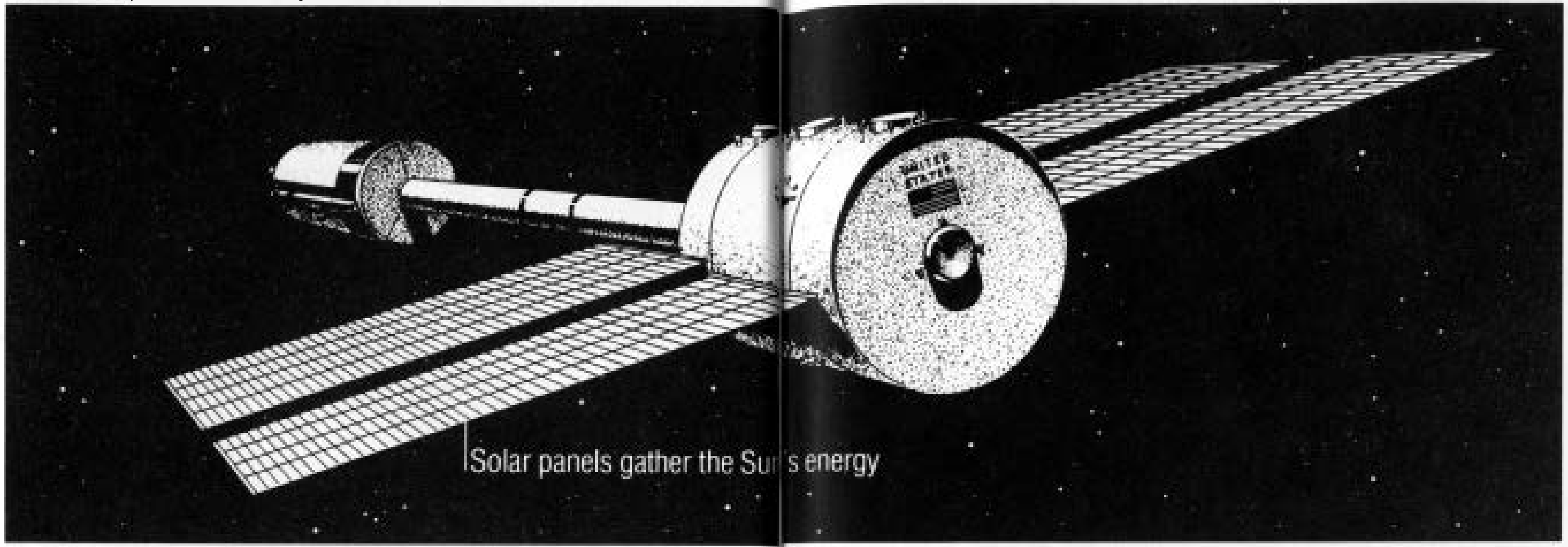
People could make more use of the energy of wind and of water currents. They could use the energy of the rising and falling tides. They could use the energy of the heat inside the Earth. They could make use of the energy of sunlight where is falls on desert areas and where its energy is otherwise wasted.

These kinds of energy could last for millions, or even thousands of millions of years, once scientists find out

'Mushroom cloud' after atom bomb explosion



Artist's impression of a space station



how to build the right kind of power plants to make use of them.

Another possibility is to make use of nuclear fusion, the kind of nuclear energy that powers the Sun and the other stars.

There is a great deal of hydrogen on Earth, and if scientists learn how to make its nuclei change to helium nuclei—much as this change takes place in the Sun—that would be a source of a great deal of energy. This, too, could last for millions of years.

Scientists have been hot on the trail of nuclear fusion for 30 years, and many people think the problem is about to be solved.

So there may be no real permanent energy shortage. It will take a little time, but scientists will probably find new sources of energy that will make it possible for people on Earth to live comfortably—provided we keep our planet livable and don't destroy our civilisation by nuclear war.