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SCIENCE IN YOUR LIFE

By John Pfeiffer

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CHAPTER I

MORE POWER TO YOU

THERE is a shaft in the side of an ancient Egyptian pyramid. At the beginning of every year, when the Nile started overflowing, Sirius, the dog star, rose in the sky. The pyramid was so located that the rays of this star traveled straight through the shaft's opening and down along the stone corridor until they lit the head of the dead Pharaoh in his tomb.

The Egyptians had to know a good deal about mathematics and astronomy to build a pyramid in this way; yet we have no records of their scientific wisdom. The laws they used for building and calculating are unknown to us, and, indeed, they were unknown to most of the Egyptians. Science was the closely guarded secret of priests and soothsayers.

Modern science has machinery that could build a thousand pyramids in the time it took hundreds of thousands of sweating Egyptian slaves to build one—and it has no secrets. The bars to knowledge have been let down. Almost anyone who wants to study science can find good courses he can afford. Anyone at all can use the libraries where the world's store of scientific knowledge is set down in books. And the machinery of science, which took thousands of years to develop, is at your service every hour. We buy science. It is no longer the business only of scientists and those others who study for the pleasure of it, but a part of everyone's practical equipment for understanding the world he lives in.

The heaviest load a human being ever lifted with his hands weighed about 1,400 pounds. Yet, you yourself can lift a 300,000-pound locomotive and swing it through the air with the greatest of ease—if you use a derrick. The world's record for the 100-yard dash is a bit under ten seconds; but with an airplane going 440 miles an hour you would be doing the hundred in half a second flat.

As it has increased our power and speed, so science has vastly improved our senses. The most keen-eyed among us cannot make out the features of the landscape more than a few miles away. But if you peered through the new California telescope with its seventeen-foot lens and slowly turned the controls with your fingers, you would be able to bring the moon—which hangs 250,000 miles out in space—5,000 times closer. You would see the jagged edges of the moon's volcanic craters and its mysterious canals, almost as clearly as if they were only fifty miles away. If you are interested in very little things, instead of those that are far off, there is a microscope so powerful that it could make this exclamation point ! seem as large as the Washington Monument. With it your eyes could watch billions of bacteria wriggle in a single drop of water.

You could increase your sense of hearing 10,000-000,000,000 (ten million million) times by the use of an amplifier. While you usually have to strain to hear whispers in the next room, with this device you could distinctly hear a mother putting her baby to sleep 3,000 miles away, and the baby's crying would sound as loud as a riveter's pneumatic drill across the street. The clinking of beer mugs in Berlin across the Atlantic Ocean would make a thunderous noise to your science-aided ears.

By the use of such amplifiers man, whose hearing is naturally far less keen than that of many animals, has made himself the world's best listener. The eagle, symbol of keen vision, would seem pitifully weak-eyed if pitted against a man with a telescope. Human muscles, by means of labor-saving and weight-lifting machinery, are made thousands of times more effective than the strength of elephants. Man has become king of the animals because he has, by centuries of thought and experiment, come to understand the forces of nature, and how they behave, so well that he can produce many of them, turn them off and on, and make them do his work.

Besides explaining nature and putting it to work, science is one of man's ways of sharpening his wits and improving his mind. It is nothing new; man has always tried to do great things with his explanations or theories. But, through education, science is now trying to create a new and better type of mind, an open mind that is prepared to throw away one explanation and try another. The earth's first "scientists" could not do this.

Thousands of years ago, according to a story found so often in ancient records that it seems to be true, it rained so hard that there was a great flood that did terrible damage. To explain the deluge, the men of one tribe said the sky was a huge water tank, and when all the windows of the sky opened at once, so much water poured out that their fields were ruined and their homes destroyed. Now this is not such a bad theory; and if it were correct there should be some way to prove it.

To do this the tribe's "scientists" reasoned as follows: "If we built a tower to the sky and chopped a small hole in the heavenly vault, we could let the waters drip out gradually and not all at once. This would prevent floods."

So the tribe started building a tower. Perhaps they got up as high as a four-story house, but it is unlikely they did any better. Still, these men were true scientists; they were not content with a mere theory. They tried to test out their belief by attempting a system of flood control.

In the attempt, many builders fell from the crude tower and were badly crippled. This made the tribesmen so angry that, instead of calmly and scientifically discarding their water-tank theory or trying a more practical experiment, they blamed their failure on jealous gods. One day they sent some of their best soldiers to shoot arrows against the sky gods—and, according to their story, the arrows came down stained with blood.

Such myths were the result of the same sort of anger that makes a child kick something it has tried to move and found too heavy. Modern scientists, like the tribesmen, are human beings; they make mistakes, and sometimes their theories turn out to be wrong. But instead of "seeing red" they discard their unsound theories and set their minds working on better ones. It is not stubbornness that drives science on, but an open-minded curiosity.

This forward drive expresses itself in two ways. "Science" is a blanket word which we can use to cover not only the efforts of research workers in their laboratories and theorists like Einstein who spend most of their lives working with difficult mathematical symbols and ideas more difficult still, but also the labors of engineers and technicians who develop the machines and devices which make living more pleasant and convenient for you. Men who looked behind the face of Nature to study such everyday matters as heat, sound, light, electricity, and magnetism have contributed a steady flow of facts and working principles which, in the hands of others whose job was to increase our strength and the power of our senses, have led to dynamos, airplanes, telescopes, radios, and television sets.

Attempts to explain nature have been more successful along some lines than along others. And the practical results in certain fields have been far more important in changing the way we live. The following chapters tell the story of how men came to understand the tremendous part motion plays in the workings of the universe, and how that understanding now serves us every day of our lives.

Chapter II

CLIMATE TO ORDER

ONE of the first puzzles that spurred scientists' curiosity to action was the nature of the thing fire produces—heat. Here was something necessary to life but unexplained. Without heat eggs could never hatch, buds would never blossom, and trees would always be brown and leafless. Heat not only develops new life, but also keeps life going. Without the sun's rays, plants would die; without plants, plant-eating animals would die, and all the meat eaters—including man—would soon starve to death.

Too much heat, of course, is a bad thing. At tem-

peratures well below the world's hottest—136 degrees in the shade—people may suffer from sunstroke and drop unconscious to the ground. Since the sun can produce such effects even though it is 93,000,000 miles away, there must be something pretty tremendous going on up there to produce all that heat. It is, of course, burning that goes on, and men had a chance to study this force-releasing power in nature on a small scale right on their terrestrial home grounds.

The problem was to find what goes on in a burning lump of coal, chunk of wood, or container of petroleum that makes it able to do work. In the days when all the world's work was done by men and beasts, the problem did not matter very much. But with the coming of machines it began to take on a practical importance that has grown greater as the years passed. For instance, the first steam engine used steam pressures of less than 14,000 pounds a square foot, and the people complained that such forces were dangerous. Explosions might burst machines and send red-hot pieces of iron hurtling through the air. Today some of the steam engines that run the propellers of large ocean liners produce pressure of 144,000 pounds per square foot, and there are practically no explosions. These modern engines, and many other aids to living, such as air-conditioning equipment, were developed only after men had spent years studying heat—and its opposite, cold.

Just as heat is associated with life and comfort, so cold is a symptom of death. There is no life in the frigid valleys of the moon. Most of the life on earth is confined to the warm band around the middle; the nearer you approach the poles, the fewer living things you find.

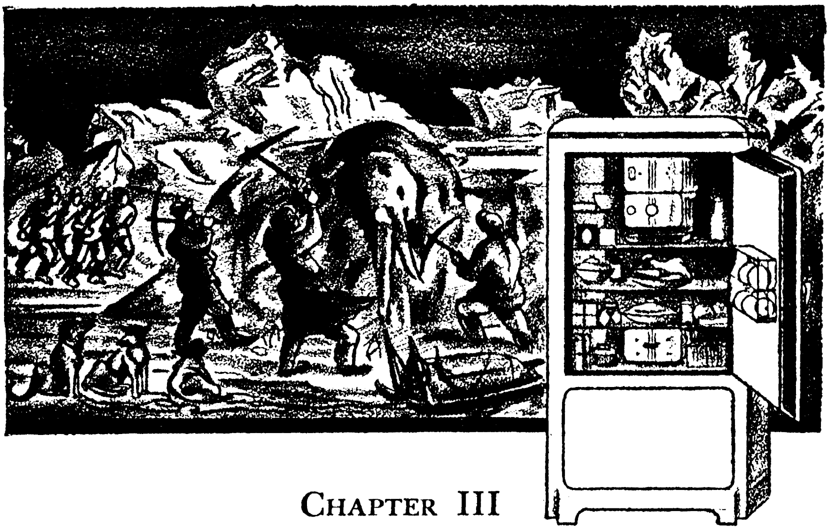
But even cold can be made to serve man. Some years ago, hunters were wandering over the blizzard-swept plains of northern Siberia and discovered something that looked like a large black rock, surrounded by ice. When parts of the ice were chopped away, the hunters found a mammoth, a great animal shaped like an elephant but covered with long, shaggy hair. The beast's flesh was in perfect preservation; its tusks were like new. All of which astounded scientists because they knew that the last mammoth had died thousands of years ago.

There was only one possible explanation for this. One day, centuries before the pyramids were built, the mammoth had gotten stuck in the snow and was slowly surrounded by thick walls of ice. Since bacteria, the microscopic animals that live on dead things and produce decay, can't live in ice, there were none of the hungry microbes to eat the mammoth and he "kept" through the ages.

For hundreds of years people have been saving food in the same way that the Siberian weather saved the mastodon for future generations. Ice in a tightly closed box makes a climate as cold as Siberia's. Some modern refrigerators use gases that expand and take heat away from the air around them to lower the temperature. Both up-to-date cooling devices and plain iceboxes chill food-spoiling microbes into a harmless, motionless condition.

But man's greatest problem is still to keep himself warm and find sources of machine-running heat. The earth's coal and other heat-supplying substances are limited. By the year 3039 these materials may be completely used up. To provide against that day scientists have recently turned to the sun in their search for a new source of heat. The flaming gases of the sun send out heat in amounts hard to imagine. If you burned 400,000,000,000,000,000,000,000 tons of coal in a gigantic furnace you would get the amount of heat that reaches the earth every year; and our share, of course, is only a small part of the heat the sun sends through space in all directions. To scientists it seems a great waste to let so much power fall unused; and they have already built machines to harness some of it.

Standard equipment for any Boy Scout's kit is a magnifying glass to focus the sun's rays on a piece of paper and produce a fire. Machines using this principle have been built to snare sun heat, and some of them will grill pork chops in ten seconds flat. This may seem like a puny effort; it may even remind you of the sky-chopping tribesmen. But scientists are in earnest about this problem. And they are equipped now with the knowledge needed to attack it, because others before them had spent years and years finding out what heat is.



CHAPTER III

WEIGHING HEAT

WHEN you wake up winter mornings and turn on the radiator in a cold room, heat flows into the chilly space and pretty soon you can dress comfortably. If you were seriously bitten by the bug of scientific curiosity, you might start puzzling about what it was that flowed from the radiator and warmed your body. Since it is not a thing you could see or handle you would have to start by studying hot things and cold things and the way things change between cold and hot.

Something is happening in a warm room that was not happening in a cold one. You can put your hands over the radiator and feel the heat as it rises to fill the room, and such evidence might make you believe that heat is a substance like water, and that it has to be taken from one place in order to get somewhere else. But this ability to be moved is not the only characteristic of a substance. Substance is definitely limited and gets used up; the more water you take out of a bucket, the emptier it is. Furthermore, substances include all kinds of things from a lump of coal to the flesh of your body, and all of them have weight. So in order to test your substance theory of heat, you would have to try an experiment that would give definite proof that heat also has weight.

As simple a test as you could find would be to weigh a cold tin pan or pot and then weigh the same object when it was red-hot. If the hot metal weighed more than the cold metal, your belief or theory would be correct and you would say truly that heat is a substance, which flows like water from one place to another. If, however, the metal weighed the same when hot as when cold, you would have to change your opinions. Scientists tried similar experiments.

They made many fires and warmed metals to a faint glow and strained their eyes reading the pointers on delicate scales. No squad of detectives seeking an escaped criminal ever worked harder than did these men in their laboratory search for that supposedly weighty substance—heat. They heated some things slowly and others rapidly, but after trying every conceivable trick, the best weighing apparatus they had still told them the same thing—an object weighs the same, whether hot or cold.

At this dead end, the best scientists did the common-sense thing and threw the substance theory overboard. Science, however, like politics, has its die-hards who grow stubborn when they are stumped. Some acted like a detective who goes to a spot where he thinks a dead body should be and, finding nothing, can only scratch his head in bewilderment. At last the die-hards admitted that heat did not weigh anything, but said it was a substance anyway. This idea of a weightless material made little more sense to clear-thinking researchers than it does to you, and a clinching experiment finally convinced most of the unyielding scientists that they were wrong.

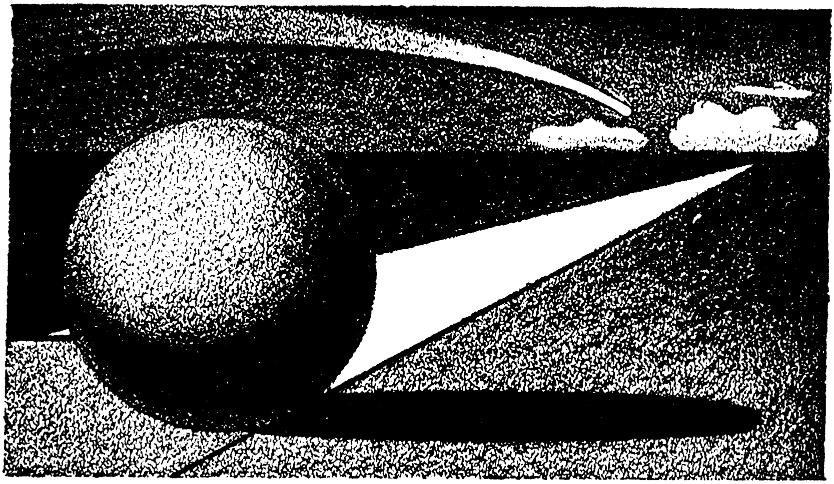
In the eighteenth century, Count Rumford, a New Englander living in Germany, was supervising some workers as they used a blunt bore to drill the barrel of a brass cannon. He noticed that the friction of the rotating bore rubbing against the cannon produced heat. If heat were a substance, the cannon should take its share from some other place—in other words, some near-by thing should get cooler. But the surrounding air and the boring instrument got almost as hot as the cannon.

To settle the matter, Count Rumford bored a hole in a chunk of metal under water where no air could reach the apparatus. Soon the water began to boil;

and it kept on boiling as long as the bore was rotating and drilling into the metal. Again, this is not how a substance would act. A substance gets used up or turns into something else, as coal burns to ashes and smoke. But as long as the bore kept turning, enough heat was produced to boil the water, though the metal grew no lighter.

These experiments showed that, whatever heat might be, it was not a substance because it was weightless and inexhaustible. At this stage of the game most scientists were left without a theory to explain heat and were frankly baffled. Of course, they knew that the idea of producing heat by motion was not new. Thousands of years ago primitive men made fire by rubbing sticks together; but before it was possible to explain how and why this happened, scientists had to retrace their steps and turn to the work of other men who had not been thinking about heat at all. These students of nature were busy with matter, the stuff that makes up all things, including those that move.

This problem apparently took researchers far away from the subject of heat. First someone studied how balls roll down inclines; then telescopes were focused on the stars; finally men began to study the ninety-odd different chemicals (scientists are sure of ninety-two but believe that there are probably several more) that in various combinations make up every material known. All the clues gathered from these seemingly disconnected bits of work had to be examined and put together in a certain way. Scientists had to do some expert trail-following before they could track heat down. And the trail was not a simple straight-line path. It started with a study of motion and finally ended with the scientific explanation of heat that is now helping men to harness the power of the sun.



CHAPTER IV

ON THE LEVEL

A PERSON can get great pleasure out of hearing simple reasons for a complicated problem. By calling fifty million Frenchmen "France," newspapers make things easier for themselves when they talk about the European situation. Politicians have simple explanations for evils they are going to wipe out or difficulties they are going to solve. Salesmen always have equally simple explanations ready to help you use that washing machine or electric razor.

Science also makes complicated matters simpler in many cases, but not for the purpose of making them easy to talk about or fooling the public with halftruths that are often falser than downright lies. To arrive at an explanation of nature and to find ways of controlling nature, scientists spend years studying some part of it bit by bit, by experiment and observation. Still other years pass while they compare results. Finally, by the most exact and careful thinking, they form what they have learned into principles—and these also must be tested.

So it often seems, in the early stages, that science is making a simple matter more complicated. In the case of heat, for example, all you have to do to keep warm is to make a fire or turn on the radiator. Since heat is a common thing, easily taken for granted, it may seem foolish to worry about what it is. But the men who looked behind the familiar everyday facts of heat and cold made one of the first and most important steps in a search for knowledge that has given us devices ranging all the way from air conditioning to telescopes that probe the star-filled depths of space.

Motion, too, is a commonplace thing and seems, at first glance, to be too simple to be worth investigating. But scientific thinkers had started taking heat's behavior apart even before Count Rumford's cannon-boring experiment showed that motion had something to do with it. Since motion is what happens when that weighty, solid stuff called substance goes from one place to another, the first problem was to find what produced it. That looked easy. To cut the grass in your back yard, you have to push your lawn mower. The harder you push, the faster it will go; if you get tired and exert less force, the mower slows down. When you stop pushing, the lawn mower stops, too.

From such simple observations it was argued that force produced motion: If the force against an object remained the same, the body moved with a constant, unchanging velocity; if the force grew larger, the object moved faster; if it grew smaller, the object moved slower. A thing like a rock on the ground, they believed, was motionless because no force was acting on it.

This theory of motion was put forward by a Greek philosopher about 380 B.C.; by the time the year 1638 rolled around, it had been drilled into the minds of people for more than two thousand years and was accepted as sound common sense. But the belief that the world is flat was also considered common sense at one time, and it took centuries before men's "common sense" was changed and they became convinced the world was round.

Similarly it was quite a while before the force-produces-motion theory was replaced; for years the few who dared disagree with it were laughed at, stoned, or burned at the stake. But the old belief was not practical. As long as a force could be seen acting upon a moving object—a child pushing a hoop along, for example, this theory fitted the facts. But as soon as the force and the moving object became separated—as when a hoop goes forward on its own—one had to imagine some sort of mysterious power running along behind to keep it going.

In 1638, an Italian named Galileo published a new theory of motion that contradicted twenty centuries of reasonableness and began a new age of science and invention. In the two thousand years before Galileo, there was no organized science; most men lived in small wooden houses and sailed in small wooden ships. In the three hundred years after his work, men have carried on research that has resulted in twelve-hundred-foot skyscrapers and airplanes that can cross the Atlantic Ocean in seventeen hours.

Galileo's experiments were not startling. He rolled balls down inclines, found how fast they would go. But his choice of equipment was genius, for the force that pulls a ball or any other dropping object to the earth is always the same, but a ball will roll down various inclines at different speeds. By changing the slope of the incline, Galileo could make balls roll faster or slower while the force that moved them remained steady and unchanged.

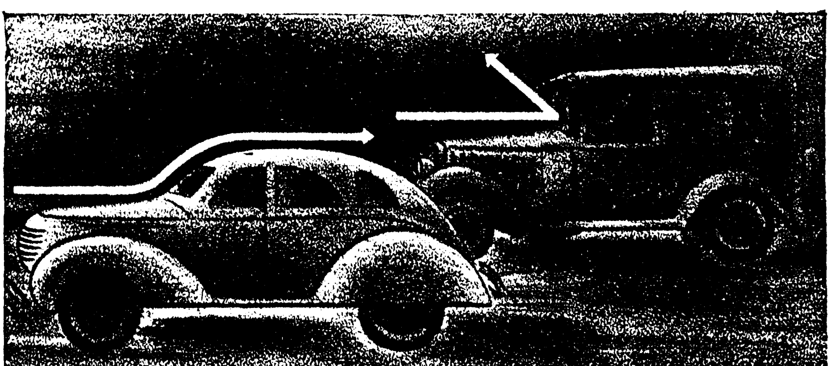
He demonstrated the well known fact that the farther a ball rolls downhill, the faster it rolls. But like many another scientific examination of a commonplace fact, his experiments showed something else that proved very important. The increase in the velocity with which the balls rolled always proceeded at a regular rate. If, on a certain incline, a ball traveled five feet in the first second, it rolled fifteen feet in the second, and twenty-five feet in the third; that is, its velocity increased ten feet each second. When Galileo made his inclines less steep, he found that this regular increase in velocity also grew less; a ball that rolled two feet during the first second traveled six feet in the second and ten feet in the third.

From those experiments Galileo was able to predict how fast a ball would travel along any incline, and how much its velocity would increase during each second. Since the increase in velocity became less and less as the inclines were made more nearly level with the ground, a ball on an absolutely flat runway should keep on doing as it did at the beginning; it should neither increase nor decrease its velocity because no force was then acting on it. It was clear enough that this was actually what happened in the case of a ball that had no motion given it at the start; naturally, a ball that was simply laid on the runway stayed right where it was put. But the inclines also showed that a ball set rolling by a push or some other force should keep on moving without any change in velocity. If it was started at ten feet per second, it should keep on at that rate forever, in a straight line.

Force starts motion, but from then on a ball (or any other piece of matter) goes on its own; on the other hand, a ball at rest will not move unless some force starts its going. Together these two points make up Galileo's now famous principle of inertia, the gist of which is that matter acts in an almost human fashion. When you're sitting in your easy-chair and someone asks you to go down to the corner and buy a beef-steak for supper, you may be so comfortably settled that you hate to get up. It may even take the force of an angry voice to start you. If you act like this, you are exhibiting the leave-me-alone trait of all matter, which will not move of its own accord. But once some force starts it going, it tends to keep right on, never hurrying, never slowing down, never changing its direction.

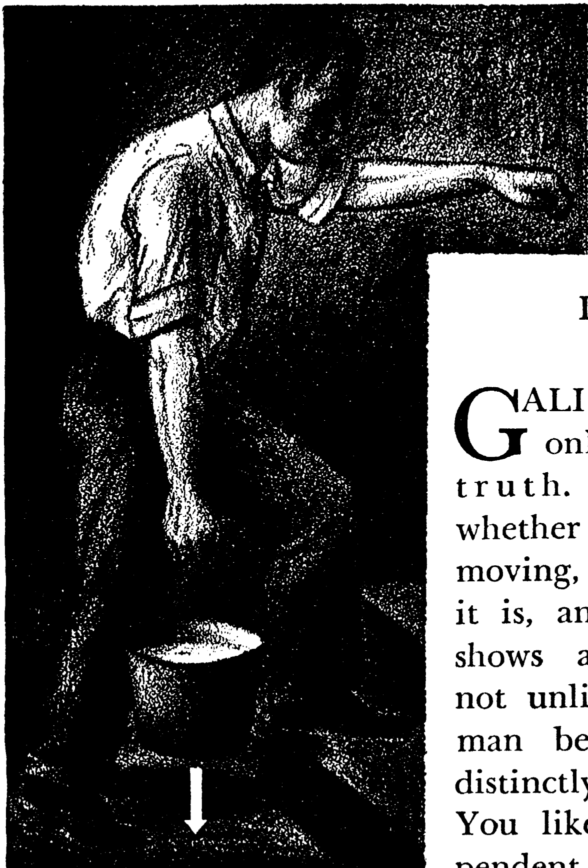
The fact that moving things usually do come to a stop unless some force drives them onward does not make Galileo's principle untrue. They are stopped by forces that resist their motion, as every automobile driver has observed.

If you are driving along a straight, level road in an old-model car with poor bearings and disconnect the motor gears from the rear wheel axle, the car will slow down and stop very shortly. But a modern car, in which the velocity-decreasing forces are lessened by good bearings, will roll much farther.



If your car has a streamlined body, so that it cuts through the air as a torpedo cuts through water, you will roll farther still. If you throw out the clutch on a level road on a mountain top where there is less air and therefore less resistance, you will go an even greater distance. And if it were possible to try the experiment with a frictionless automobile in a vacuum tube, you would go forever.

By showing motion to be like a "habit" of matter when once it is started, Galileo gave science an entirely new approach to nature and helped to clear up some important puzzles. Instead of believing that a strange force kept a rock rising after it left the hand of a thrower, scientists now understood that the stone would naturally tend to go up forever in a straight line, if it were not for a force that held it back. This force is Mother Earth's great love for her own—gravity—by which she pulls things back to herself with invisible apron strings. But it was not until many years after Galileo died that men learned how gravity works.



Chapter V

LOOKING UP

GALILEO discovered only part of the truth. An object, whether it is at rest or moving, tends to stay as it is, and in this way shows a stubbornness not unlike that of human beings. You are distinctly an individual. You like to feel independent, to be free to do what you want to do when you want to do it. Yet, because there are other people, you and most of the world's 2,000,000,000 persons are organized in nations. They have to pay taxes and obey laws. Matter, too, enjoys some freedom and yet has to obey laws. Every object in the universe would either remain at rest or move in a straight line forever—if there were no other objects. But the universe is a society of countless stars, nebulae, meteors, and planets and smaller objects. They are so well organized that they do not go about crashing into one another.

Galileo was the first man to use a telescope to study the citizens of the sky, and one of the first things he saw was the planet Jupiter with four moons circling around it. No man had ever seen this sight before. The Italian may have been overwhelmed by what his crude telescope showed him, and may have realized in a burst of intuition that the earth with its single moon was only a drop in the cosmic bucket. But although he put inertia—the tendency of bodies to act on their own—into a scientific law, he did not study organized groups of matter, such as the planet-moon systems which he himself had observed. It was an Englishman, Sir Isaac Newton, who looked for order in the skies and discovered that the same force which makes large things weigh more than small ones of the same material, and causes you to gasp for breath when climbing uphill, also keeps planets and satellites in their courses.

In a tug-of-war, you pull against the force of another person; in carrying a bucketful of lead bars, you pull against the attracting force of gravity; against the tendency of things to get together. Even the smallest piece of iron, copper, or any other substance, exerts a pull on objects around it, but this joining force is so small in such cases that there is no noticeable effect.

But just as a large nation is more powerful than a small one, so a large chunk of matter is more powerful than a small chunk, gravitationally speaking. The earth is a solid body eight thousand miles in diameter, and therefore it exerts a tremendous pull of attraction for thousands of miles around it. This is why things drop to the ground, balls roll down inclines, and why you have to fight gravity all the way when you climb uphill.

The more lead you have in a bucket, the greater is the metal's urge to get closer to the earth, and the more strength you need to hold it. When your butcher puts a steak on the scales, he is measuring the earth's attraction for the beef. Weighing, in other words, is a way of measuring the earth's gravitational force.

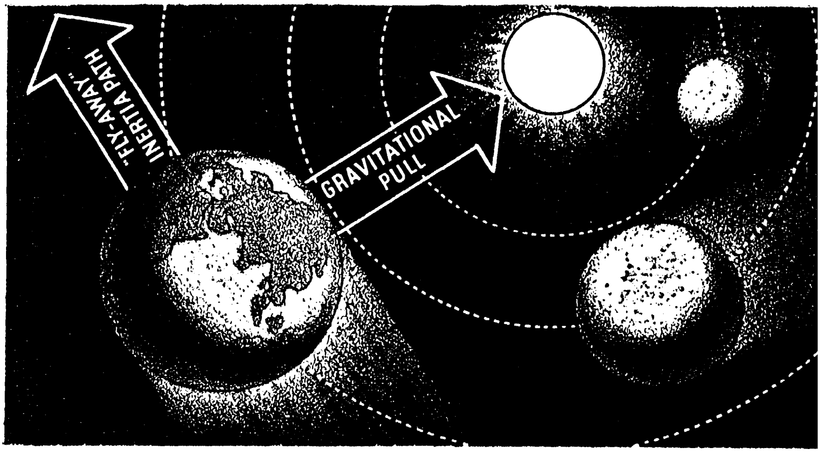
Newton was the first human being to recognize all these facts—but he went further. By combining Galileo's theory of inertia with his own theory of gravitation, he explained why heavenly bodies revolve about one another. Even if you have never seen a child tie a rubber band to a rock and then swing the rock around in circles, you can believe it is a nerve-racking experience. At any moment the band may break or the knot slip and the rock shoot off through the air, perhaps to break a window. But as long as the band holds the rock, it will continue to go round and round in a circle.

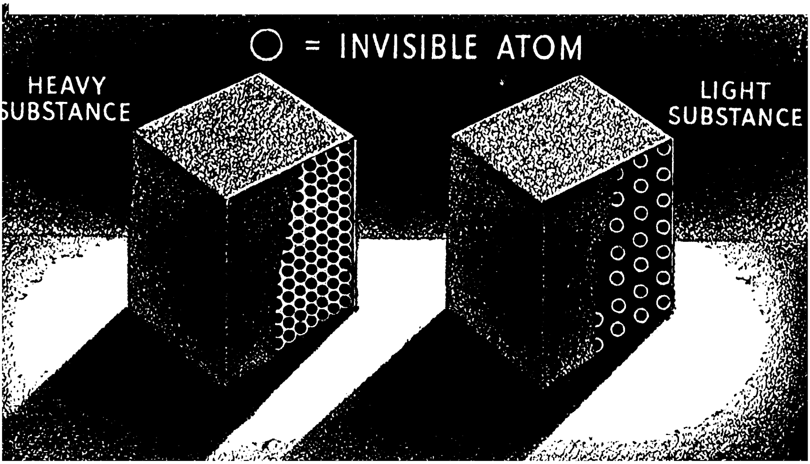
In a similar way the moon revolves about the earth, because the earth's pull (gravitation) is like an invisible rubber band and counteracts the moon's inertia, its tendency to go off in a straight line, which is so powerful that it would break a steel cable three hundred miles in diameter. The huge sun with a diameter of 864,000 miles exerts enough of a tug on the eight planets to keep them all circling around it in orderly orbits.

But if the gravitational herd instinct of matter were the sole force of nature, all bodies would smash into each other and the result would be a cosmic traffic jam. If, on the other hand, the inertial I'll-do-as-I-please tendency in matter held full sway, the universe would be a chaos of runaway bodies. Order in the universe—as in the world of politics—is a matter of compromise. Neither gravity nor inertia has the upper hand in the solar system; both have some leeway, and each helps keep the other in check.

When men had found the laws that govern the two forces which maintain the balance that keeps order in the universe, it became possible not only to account for motion, but to predict motion and to tell, more exactly than before, where heavenly bodies would be at any time in the future. Astronomers could calculate tides in advance by studying the moon's gravitational pull on the earth's waters. They were able to predict eclipses so accurately that today it is known that a partial eclipse of the sun will occur in 1940 on April 7th at about 3:38 Eastern Standard Time, and be visible—weather permitting—throughout the United States.

It was a great day in scientific history when Newton discovered gravitation, combined it with inertia, and showed that motion could be a result of these two forces which together control batted baseballs, whirling tops, mighty tides, falling stars, and the entire solar system.





Chapter VI

THINGS YOU NEVER SAW

IT IS apparently a far cry from predicting eclipses to explaining heat, but the scientific sleuths were getting somewhere. From a study of solar-system motions they finally went on to study the stuff that moves—and gets hot: matter. No sooner had they discovered gravity than they learned that this earthward-pulling force weakens as the distance from the earth's surface increases.

When a child leaves home, the influence of its parents lessens considerably. Similarly as you climb uphill and leave the earth's surface, the downward pull of gravity against you becomes smaller; you grow slightly more "buoyant" and weigh less as a result. Your sweat and muscular effort are the price you pay for overcoming the tug of gravity, and if, by some miracle, a one-hundred-and-sixty-pound man stepped onto a scale four thousand miles above the earth where gravity's attraction is comparatively small, he would weigh only forty pounds. If the same man could stand the sun's heat, he would weigh 4,464 pounds on that star's surface because the sun is many times larger than the earth and hence its tug is much greater.

Weight, then, is a varying thing. When you say something weighs ten pounds, you mean it weighs ten pounds close to the earth's surface. But while the weight of a ten-pound object may lessen as it is taken farther from the earth (and from the earth's gravitational influence), it still contains the same amount of matter. In other words, the amount of matter an object contains, its mass, remains constant although its weight may change with position.

On the earth's surface, however, objects weigh the same if they contain equal amounts of matter—if their masses are the same. This fact is part of another puzzle, for objects of the same mass are not always the same size. A cube of lead one foot on each side weighs about seven hundred pounds on the ground; but it takes seventy cubic feet of balsa wood—enough material to fill a large crate—to make a load of seven hundred pounds. Yet since the single cubic foot of lead and the seventy cubic feet of wood weigh the same, they must contain equal amounts of matter.

Those persons who had been used to thinking that equal amounts of matter filled equal amounts of space were considerably worried by this state of affairs. They wondered how the same quantity of substance could take up either one cubic foot or seventy.

But any practical-minded housewife knows that the same number of persons that fills a large room comfortably, will overcrowd a small one. One might think about matter in the same way. The cubic foot of lead could contain many trillions of tiny particles jammed close together, while in the seventy cubic feet of balsa wood the same number of particles might be grouped farther apart.

Scientists came to a similar conclusion by investigating all the non-living materials they could find on earth. And since you cannot tell much by looking at a large chunk of rock or other matter, they crushed the materials and sorted out the parts. This part of the research was fairly simple: your druggist can take a lump of the yellow element, sulphur, and grind it to fine powder. But they did not know how far this process could go—whether you could keep on grinding a particular material and making it finer indefinitely.

There were long arguments about it, but there were also experiments which showed that matter was composed of particles even finer than those produced by the best grinding tools. The experimenters found that substances were made up of very small particles of matter which they called molecules, and if you broke up the molecules you had something different. You had two or more materials instead of the one you began with. For instance, they found that water molecules can be broken up into oxygen and hydrogen.

The particles into which molecules can be broken, they called "atoms," from the Greek word for "indivisible." Atoms too can be broken up, but they tend to remain whole much more than molecules do. Also, some materials are made of only one kind of atom: sulphur is such a material, oxygen is another. Scientists have found ninety-two altogether, of which they are sure, and several more of which they are still doubtful. They call these materials in which the atoms are all alike, "elements."

By combining in various ways, these elements make up all the matter that has yet been discovered on earth and in the heavens; all solids, liquids, and gases, from rocks and oceans to the glowing tails of comets.

But even the non-living part of nature is always changing—even solid iron rusts away in time—and it seemed as if atoms and molecules must be on the move. To test this idea, comparatively large particles a few thousandths of an inch across, such as grains of pollen, were mixed with water and studied under microscopes.

Instead of staying quietly in one spot or sinking to the bottom, the grains bounced back and forth; they moved continually in an agitated sort of way.

When trees outside the window bend, you conclude that the wind is blowing, though you cannot see it, hear it, or feel it. Scientists concluded that the pollen grains were being struck by swift-moving water molecules too small to be seen.

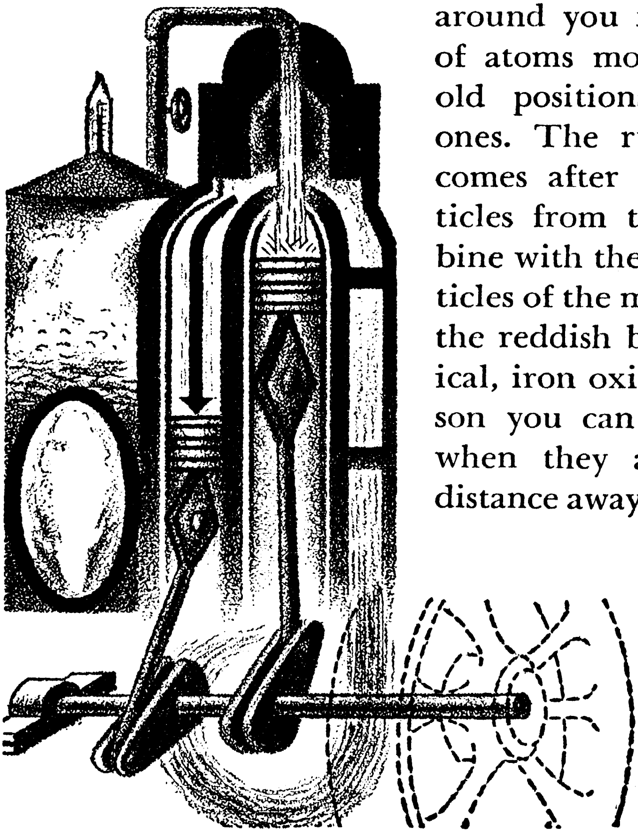
To test this idea still further they measured just how far each grain moved in a straight line before it darted off on another angle in its zigzag path. You would bounce farther if you were hit by a moving van than if a light coupé hit you; so these measurements gave scientists a chance to estimate the weight of the bombarding particles. They estimate that one water molecule weighs .000000000000000000000001 (this is read one-septillionth) of an ounce, and an average water drop contains 2,000,000,000,000,000,000,000 (two sextillion) molecules.

According to the theory of atoms and molecules all substances are built of such small particles. But this belief is obtained at a great price. People must believe that their eyes aren't really seeing the world around them, because the particles of matter are too small to see either with eyes or with microscopes. The sense of touch is false because what seems solid to you is actually a mass of atoms with gaps between them. To justify such conclusions, the atomic theory had to be extremely useful—and it was. When this idea was born, men had what they needed to explain heat and cold.

CHAPTER VII

MADHOUSE OF MOLECULES

THE atoms composing all matter do not sit in one place. Like the people on city streets, they hurry back and forth continually. Every change you see around you is the result of atoms moving out of old positions into new ones. The rust on iron comes after oxygen particles from the air combine with the surface particles of the metal to form the reddish brown chemical, iron oxide. The reason you can smell roses when they are quite a distance away is that some



of the particles composing the flowers drift from the petals to your nostrils, where they combine with other atoms to produce odor sensations. Melting snow, autumn leaves, all the countless changes in nature, result from atoms that do not stay put.

Since some days are warm and others are cold, heat, too, is a changing thing, and men soon found it also was a direct result of moving atoms. According to the atomic theory solids are composed of trillions of bodies which are as firm in their positions as the girders of a skyscraper and are packed so close together that they are visible. Since particles of liquids are not fixed in such rigid positions and are farther apart than the particles of solids, fluids not only flow and refuse to hold any shape unless kept in by walls or banks, but are often a cross between visibility and invisibility; that is, you can see through some of them. Most gases (such as the oxygen in the air) are completely invisible because their molecules are on the loose, being separated by what are for them vast distances. If you have an air-filled tube and use a suction pump to force out most of the air particles, you can create a partial vacuum, a space almost entirely empty. When you open cans of vacuum-sealed coffee or tennis balls, the hiss you hear is the scramble of air molecules rushing in to fill the container.

Scientists interested in the problem of heat found gases and their free-moving particles a most fascinating study. They discovered that the faster gas molecules whiz through space, the hotter things become.

Old-time boilers used to burst under the force of high-pressure steam, and such pressures were found to be caused by countless molecules colliding against steel plates at breakneck speeds and bouncing off with unlessened vigor to knock other particles against the boiler walls and eventually hit the metal barriers again themselves.

For gas particles are the rebels in the society of matter, and it takes strong containers to keep them from causing explosions in their efforts to break out into the open. Every enclosed gas is a madhouse of molecules trying to escape their boundaries. About 5,300,000,000 collisions occur every second in the air of your room, and when you raise the temperature a few degrees there are more. Turning on your radiator is simply a way of pushing air molecules into greater activity.

With this picture of rapidly moving particles, heat began to mean something. For the first time science realized how Count Rumford could produce heat by drilling a hole into his cannon. The rubbing of the borer on the brass started a series of collisions between the particles on the surfaces where they touched and jarred some of the firmly set atoms out of position. This caused many more particles than there are people on earth to fly into violent though invisible activity and finally produced enough heat to boil the water.

For centuries men saw the sun moving across the sky, birds flying, and nature's creatures changing, and accepted it as part of nature's great show. But with the atomic theory came a whole new idea about the importance of motion. Motion, they now realized, is heat; more heat is faster motion and more atomic collisions. But if activity is heat, inactivity is cold. A gas or liquid whose molecules are not on the loose, but move comparatively slowly, is cold and may be frozen. The molecules of water have some freedom to move, and so water flows; but ice molecules are chained and enslaved. This is the condition of the particles making the icebergs and snowdrifts at the Poles and in Siberia. If you could see the particles in tropical air, you would find them smashing into each other in a frenzy of restlessness. The air of ice-bound countries, however, has comparatively slow-moving, sluggish molecules.

The lowest temperature possible would occur when the particles of a substance were completely motionless. This temperature, known as absolute zero, has been calculated to be about minus 469 degrees. Nothing approaching this motionless state is known in nature. Even in solids, atoms are quivering to a small extent. In laboratories, however, scientists have come within one degree of absolute zero.

Rubber can be stretched because the positions of its molecules are easily changed and have a comparatively large leeway of motion. But at super-low temperatures rubber becomes brittle. If you tried to erase a pencil mark with this frozen rubber, it would rip the paper like tin.

If the tissues of your body were frozen into rigidity they would not be of any more use to you than a piece of brittle rubber. An absolutely motionless animal would be a very dead one. Plants move, though often too slowly to notice. If the particles that compose all matter were motionless, the universe would be a vast expanse of cold, dead matter; and in the actual world heat, motion, and life are inseparably connected.

Yet the heat that makes life possible introduces a strange paradox into science. The surface of the life-giving sun is a swarming inferno of countless particles flying at random in a complete hubbub of motion. Yet science, logic, and all of the order man has brought about, from government to train schedules, is made possible by this solar chaos. Without the heat-giving activity on the sun's surface, men and their scientific and logical thoughts could never exist—there would be no such thing as man-made order.

CHAPTER VIII

THE BODY'S INSTRUMENTS

THE universe is a place where powerful forces are competing for the control of every bit of matter; the curved paths of the planets about the sun are the result of a balance between gravitation and inertia, and even unmoving objects are subject to the strictest laws. The can of coffee on your kitchen shelf is constantly being tugged toward the floor by gravitation, and the shelf has to be firmly attached to the wall to overcome this same force. The most quiet forest scene is actually seething with invisible atomic motions which produce, among other things, the heat that is life.

The equipment that connects you with this strange world of atoms, gravitation, and inertia is the common senses—touch, smell, taste, sight, and hearing. When you stroke a cat, the fur touches some of the 500,000 small areas on your skin that are sensitive to touch and pressure, and nerves from these regions send the impression "soft" to your brain. Several thousand pits in your tongue serve as taste detectors; and you pick up odors from a region less than half an inch in diameter in the upper part of the nose. Through sense organs such as these come all of man's ideas about nature.

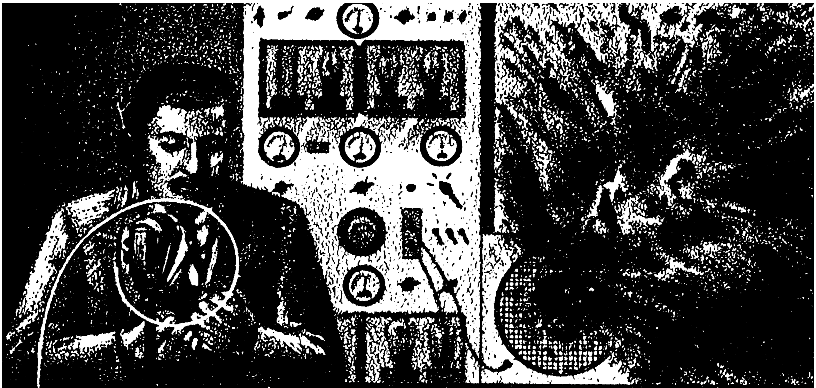
Scientists, therefore, had to study the body's receivers before great practical benefits grew out of the new understanding of motion, matter, and energy. To illuminate rooms it was necessary to know a great deal about light and how it enables us to see; before the phonograph and talking pictures could be developed men had to solve the puzzle of what sound is and how it works the delicate machinery of the ear. Some of science's greatest gifts to man have come through a study of sight and hearing, the most used senses, and the problem of sound proved the simpler of the two.

Millions of years ago when all things lived in oceans, one species of fishlike animals sported a pair of slight depressions, tiny punched-in marks on each side of their heads. These were the first ears. As animals learned to live a landlubbing life, their ears became more and more complex, until sensitive hearing organs such as man's developed.

But man's hearing is not the best on earth. Many animals have hearing ranges that include tones you cannot catch. A hummingbird launches notes higher and higher up the musical scale until there is utter silence. But even then the bird's beak is wide open and its head is lifted back in a singing position. This puzzled men and made them conscious of certain limitations in themselves.

Perhaps the greatest hearing riddle of all, however, was posed when a primitive tribesman first shouted "Hello!" at a friend and heard his own voice bouncing back at him. The Greeks had a goddess for it: a beautiful nymph who tried to trick the gods, and was punished by being forced to repeat the last parts of the phrases people spoke. She was so unhappy that she slowly pined away until only her voice was left. Her name was Echo.

Legends served to fill in gaps of knowledge and expressed a great awe of nature, but you can't run machinery with myths. Scientists knew that hearing and other senses did more than put people into touch with nature. The senses are safeguards of life. You detour away from the smell of a skunk, take warning from automobile horns, and avoid danger signs and red flags. The main thing that has kept researchers working is a strong curiosity, but they have also had the hope that the power of man's senses could be increased, and with it man's control over nature and his ability to do more things, and do them better.



LIGHTING MATCH . AMPLIFIER . AMPLIFIED . . . .

CHAPTER IX

LOUDER THAN EVER

MEN were quick to observe that sound had something to do with vibrations. If you pluck the string of a guitar, it quivers back and forth and produces a definite note. When you strike a tuning fork and hold it near your skin, you feel a tickling sensation as long as the sound lasts. It was soon found that all sound is the result of motion, not the straight-line motion of a bullet or the curved motion of a planet or even the chaotic motion that is heat, but the regular to-and-fro shaking motion of something vibrating.

The faster gas molecules move as they bounce off the walls of a boiler or some other container, the higher the temperature rises. Similarly, the faster a violin or piano string vibrates, the higher the note it produces. But the ear is not built to pick up all such vibrations. If a string vibrates fewer than 20 or more than about 20,000 times a second, most people cannot hear anything. Careful experimenters, however, have succeeded in measuring the number of vibrations a second, the frequencies, of various familiar sounds.

The quivering cords in the throat of a young robin may bring forth notes with a frequency of 15,000; the house cricket's chirp, caused by vibrations of its wings, has a frequency of 4,600; and a piccolo's high C is the result of 4,096 vibrations a second. These and countless other sounds are well within the range of human hearing. Some other animals hear a great deal more than we. Dogs, for example, prick up their ears attentively for "notes" with frequencies as high as 80,000.

When any one of the tones hearable to man hits the eardrum, it vibrates at exactly the same rate as the quivering or shaking object that produced the sound. This "sympathetic" vibration is one of the prime requirements for normal hearing. As soon as scientists learned that sound can be transferred from one vibrating thing to another, they began to put the principle to work, usually to man's benefit though often to his annoyance.

If you examine the grooves in a phonograph record with a strong magnifying glass, you see tiny lines shaped like the wavy sides of those hairpins that are supposed not to fall out. These curly roads were made by a needle vibrating in response to the voice of a singer or the reeds and strings of instruments. When you play a record the needle of your machine is made to vibrate in exactly the same way because it must follow the grooves. These needle vibrations, in turn, are carried to a thin metal plate like an eardrum, which by its throbbing sends out the recorded sound. Though Caruso is long dead, the vibrations of his voice, carved in wax, will make music as long as there are ears to listen.

Perhaps even more remarkable is the amplifier, whose sound-magnifying powers were briefly described in Chapter I. This supersensitive device makes use of a sound pick-up similar in principle to a radio microphone, but far more delicate. An artificial eardrum trembles in response to the feeblest vibration, and the motion is transferred to an electric current. This current may then be made billions of times more powerful.

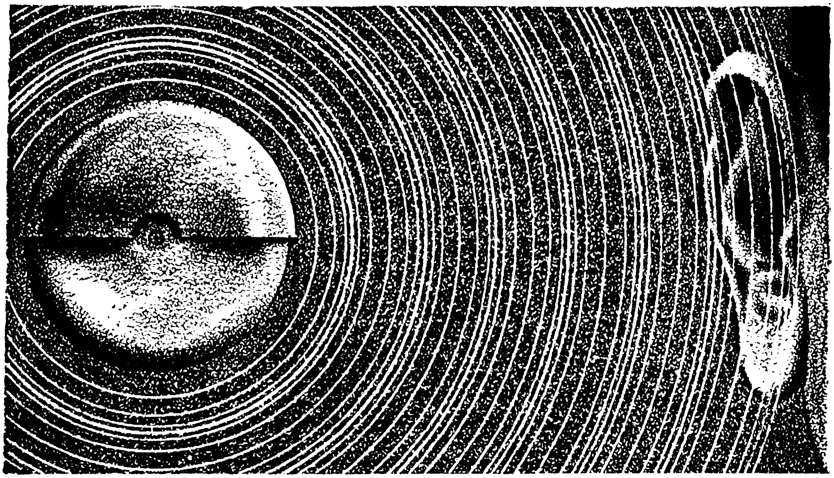
In a telegraph office the dot-dash of messages coming in from distant places by electricity is, as you know, the result of the motions of a ticker or sounding key. Instead of moving a key, however, the current of an amplifier causes a metal plate to vibrate back and forth vigorously, and produces a sound many times louder than that of the vibrations originally picked up. Amplifiers can make the voice of a soft-spoken man into a shout loud enough to be heard by every person in a large auditorium. If you put the amplifier near an anthill, the footsteps of one insect as it scurries along sound like the heavy tread of a marching army.

There are 37,500,000 telephones in the world; 19,600,000 in the United States. In these devices there is again the familiar metal plate or diaphragm, which throbs with the sounds of your voice and sends these vibrations in the form of electric currents over miles of wire. In the telephone receiver the currents produce a quivering motion in another diaphragm, which faithfully reproduces your voice.

The control of sound has come so rapidly that the telephone, amplifier, and phonograph are taken for granted. But it was not so long ago that these devices were considered the ideas of crackpots. In an eastern newspaper of 1865, the following editorial appeared:

> A man about 46 years of age . . . has been arrested in New York for attempting to extort funds from ignorant and superstitious people, by exhibiting a device which he says will convey the human voice any distance over metallic wires so that it will be heard by the listener at the other end. . . .
>
> He calls the instrument a "telephone" which is obviously intended to imitate the word "telegraph" and win the confidence of those who know of the success of the latter instrument. . . . Well-informed people know that it is impossible to transmit voice over wires . . . and that, were it possible to do so, the thing would be of no practical value. . . .

Probably a good many people read this bit of news and agreed heartily with the person who wrote it, but most of them lived to change their opinions. Just eleven years later a crude telephone was demonstrated to the Emperor of Brazil, who picked up a receiver, heard a voice, and muttered: "My God, it talks!" If the Emperor had been introduced to the radio or to a television set, he might have fainted dead away. But to give you, or any modern, the thrill of experiencing the unbelievable, it would be necessary to produce some such marvel as motion pictures in which the audience could touch the film stars.



CHAPTER X

WHAT YOU HEAR

THERE are no emperors left in the western world, and very few people ignorant enough to be astonished by a telephone. In the fifty-three years since the ruler of Brazil first heard a voice sent along a wire we have come to depend on devices that increase the power of our hearing almost as much as upon our ears. But before these devices could be developed to their present efficiency there was much experimenting to be done, not only to find out the exact frequencies of various sounds, but to discover how sound itself travels from one place to another.

Men knew well enough that thunderclaps always follow lightning, and reasoned that sound takes a longer time to get across a given space than does light. Yet there were no experiments to measure the exact speed of sound in air until gunpowder had been invented and cannon were used in warfare. By noting how long it took the sound of a gun to arrive after the flash was seen at a measured distance away, this speed was first calculated; and today it is known to be about 1,120 feet a second. Guns were developed in the World War that could send shells seventy-five miles. You would have to wait six minutes to pick up the sound of the gun, even though your ears were sensitive enough to hear, at a distance of seventy-five miles. And if the gun were aimed in your direction you might never hear a sound, because the shells would take only three minutes to cover the distance.

To find how sound travels across space, men first rang a bell in a small jar from which the air could be pumped. As they pumped more and more air out of the jar, the sounds from the shaking bell became fainter and fainter, until a high-degree vacuum had been produced. Then, with the bell still swinging, there was no sound at all. Further experiments showed that sound could travel through water, oil, and other substances, as well as through air, but it could never cross a vacuum.

Such research showed that sound must have a medium, something through which to travel and that usually, as it journeys from a whistle or some other source to your ears, it goes through air. So scientists began studying what happens when sound passes through the air you breathe.

Air, like water, resists motion. And according to the atomic theory air is simply thinned-out matter. So it will take power to move air just as it takes the power of an engine to move an automobile made of dense, solid matter. If you smack the top of a large bass drum, the tight-stretched skin trembles back and forth at, say, fifty vibrations a second. The power of this violent quivering produces a like motion in the air. When the skin of a sounding bass drum is on the upward part of a vibration, it pushes against the air above it, and this air then exerts a push on the surrounding air. When air is pushed, it behaves very much as water does when moved by your hand or the passing of a boat; waves go out from the spot where the pushing takes place.

Since the drum skin has a frequency of fifty vibrations a second, it will push upward against the air fifty times every second—or once every one-fiftieth of a second. While it moves down and then up again, the push it has given the air will be sent along through space, somewhat in the way one falling domino results in the falling of all dominoes in a long line, at the rate of 1,120 feet a second. (Sound always travels at this rate, no matter how far it goes, or what the frequency of the vibrations that produce it.) Since the time between pushes is one-fiftieth of a second, each sound wave will travel twenty-two feet before the drum skin vibrates upward to push again. Scientists sum this up by saying a sound wave with a frequency of fifty vibrations per second has a wave length of twenty-two feet. Higher frequency waves have shorter wave lengths; some of those produced by musical instruments vibrating 11,200 times a second are only one-tenth of a foot long. After the playing stops, and with it the wave-pushing power of the instrument, the waves already in the air will travel a long distance before they die down entirely.

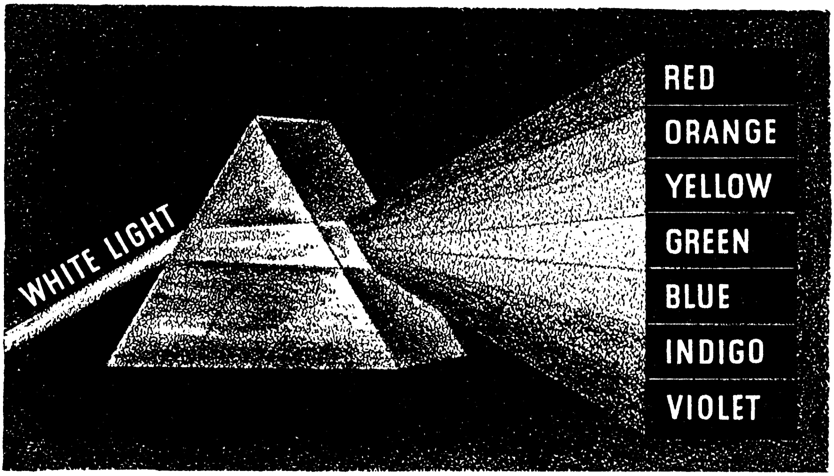
Normal air pressure upon all parts of your body, including your ears, is about 15 pounds to the square inch, and when each of the regular air waves set up by some vibrating source of sound strikes your delicate eardrums with an added pressure of a few hundred millionths of an ounce, you can detect the pulsations—you "hear" a sound. As the wave pressure increases, the sound gets louder. When the waves exert a pressure of about one-fifteenth of an ounce on your eardrums, the force is about all these miniature drum skins can stand. Higher pressures may break them. If, instead of hitting such flexible surfaces as eardrums, sound waves strike against a rigid surface of rock, they are reflected back like a series of ripples bouncing off a steep bank and traveling back over the surface of a pool. Such reflections you hear as echoes.

Scientists know that the greater the number of waves that press upon the eardrum per second—that is, the greater the number of vibrations in the note's original frequency—the higher the pitch of the note produced. Furthermore, notes increase in loudness when the sound waves exert a greater pressure.

As the theory of sound has been worked out in further detail, men have learned to control sound in the inventions already described. But when it comes to that variety of sound called noise man's control is by no means complete. By building special walls that are so poor a medium that a sound wave will not travel through them, it is possible to soundproof a room or two; but such quiet spots are rare, especially in a large city.

Although anti-noise leagues have been formed and drivers are sometimes fined for honking horns unnecessarily, it seems that there will be noise as long as there are cities. Noise is the price paid for activity. It is a product of machines which are designed, not to give out pure musical tones, but to do work quickly and efficiently.

Sound under control may appear as music; sound on the loose is noise. But either kind of sound is the result of motion, and men began to see the importance of motion in connection with the senses as they learned more and more about our most useful means of receiving news of the outside world—sight.



CHAPTER XI

MORE THAN MEETS THE EYE

ABOUT 85 per cent of everything we find out about comes to us through our eyes. The story of civilization itself can be told in the development of man's ability to record things in visible form; first crude pictures, then writing, then printed books, photographs, television. There would be no science, as we know it, without microscopes and the hundreds of other instruments which add to the natural power of the eyes, and the written reports that make every new experiment known throughout the world. Perhaps the most important thing that the growing ability to use our power of sight has accomplished is to make knowledge the common property of all civilized people. In the great days of Egypt, when men wrote in pictures on stone and clay, it was easy for priests to guard their mysteries of pyramid building and astronomy. Today, scientists could not keep the rest of us from reading about their discoveries if they wanted to—which they do not.

Just as a man without food is starving, so one without light is blind. The fact was too commonplace to be worth thinking about until people began asking: "What makes us see? What is this stuff we call 'light,' and what does it do?" Scientists are still working on the problem, but they have already found a good part of the answer. One of the most important hints came from the study of heat.

It was easy enough to see that light and heat are connected in some way. Light often accompanies heat, as on a winter evening when you make yourself a warm fire. And even when you do not want it, heat is produced along with light. After you have read for a while, the bulb in your lamp is often too hot to touch. In fact, one of the greatest problems facing modern engineers is to get light without heat. If scientific theory is anywhere near correct, they have a very difficult job on their hands.

As you raise the temperature of a soldering iron, the particles of which it is made move faster and faster. If you raise the temperature high enough, that is, increase the rate of motion of the atomic particles, the iron gives off light, becoming red-hot. It seems as if this red light must be the result of the same motions that produce the iron's heat. Scientists believe that it is, but there is some difference between the motions that produce heat and those that produce light. This is shown by the fact that the hot air around the iron does not give off light, though its atoms are moving at furious speeds.

The atoms of air, which is a gas, as you remember, are free to move in chaotic, zigzag paths. But the atoms of iron and other metals are more tightly bound to one another and act like dogs on leash. So, as the rising temperature of the soldering iron sets them moving, they are pulled back time after time; in other words, they vibrate millions of times each second, though the distance through which they move is so short that no eye can see them quivering.

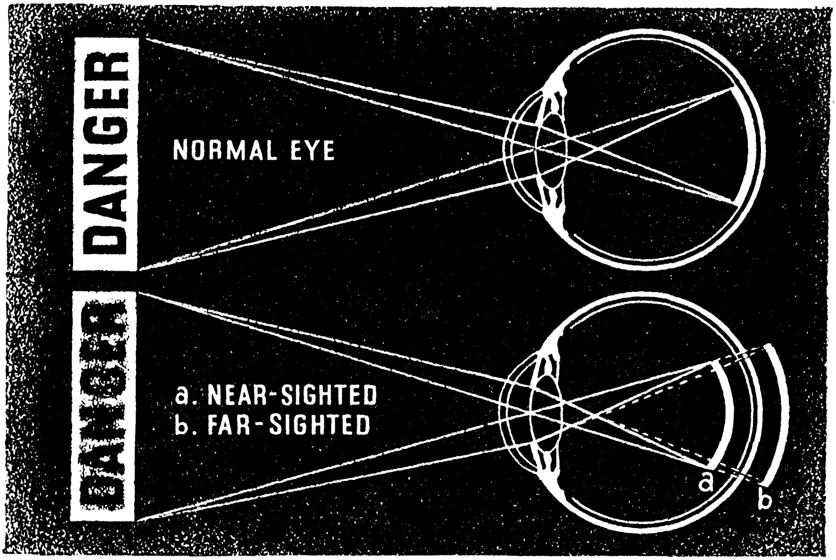
When the temperature of a metal reaches a certain point, red light is given off. Increasing the temperature makes the metal glow white-hot. Newton, the discoverer of gravitation, did an experiment that helped explain this change in the color of light. Though it is so simple that a child can repeat it, the experiment is one of the most important in the history of science.

If you take a prism, almost any triangular, solid piece of glass, and place it in a sunny window or in front of an electric lamp, white light will not come through. Instead, a spectrum, the colors of the rainbow arranged in ribbonlike, up-and-down strips, will appear on the wall of your room. The prism separates the red, orange, yellow, green, blue, and violet which together make up white light.

Before Newton's experiment, it had not been known that sunlight is a mixture of the entire range of colors; and this fact provided one hint as to why a red-hot metal may become white-hot. As the temperature rises, the metal particles vibrate faster, and the faster vibrations produce a mixture of colors which we always see as white. Furthermore, since red is the first color to appear, it is produced by the slowest light-giving vibrations; other colors are the result of more rapid movements. Studies of light frequencies show that atoms quivering at the rate of about five hundred trillion (500,000,000,000,000) vibrations a second produce red light, and as atoms move faster, orange, yellow, green, blue, and violet are produced in that order. The range from deep red to violet (frequency, one quadrillion) includes all the colors visible to man.

Whatever colors you see, all of them result from the vibration of atomic particles at tremendous rates. So a universe submerged in absolute-zero coldness would be dark and colorless as well as heatless, because such a temperature would mean that no atoms were moving.

Careful study of light showed scientists that motion is even more important than they had imagined. Without vibrating atomic motion, the light that makes all seeing possible would not exist. The universe would be pitch-dark.



Chapter XII

BENDING LIGHT

WITH the understanding that light is essentially motion, has come man's ability to produce almost any kind of illumination he wants. The dancing atoms in a powerful searchlight throw out a beam that will catch a raiding airplane half a mile up in the night sky. The Christmas-tree effect of the neon advertisements in our downtown streets is created, not by paint on the glass through which light shines, but by particles vibrating at the speeds which produce red, green, or any color that is wanted.

Control of light production has enabled us to see better than ever before, but the greatest increase in the power of man's vision has come from knowledge of the way in which light behaves; that is, an understanding of the way it moves, and what happens when it strikes our eyes.

You see trees, rocks, and buildings because the light from street lamps or the sun is reflected from them to your eyes, as sound waves bounce back from rocks to become echoes in your ears. But all things do not reflect light. The first scientist to become curious about substances that let light through was probably some skin-clad tribesman who chipped off a thin piece of mica and held it before his eye.

He certainly could not see very well. Some of the light bounced off the mica, and the rays that did get through showed him a twisted picture of the landscape. For when light, which travels in a straight line whenever it can, enters any transparent substance, it is bent. No doubt you have seen the sword-straight beams from a searchlight bend when they strike a cloud, and slanting rays "break" at the surface of a lake and turn sharply downward as if trying to reach the bottom as quickly as possible.

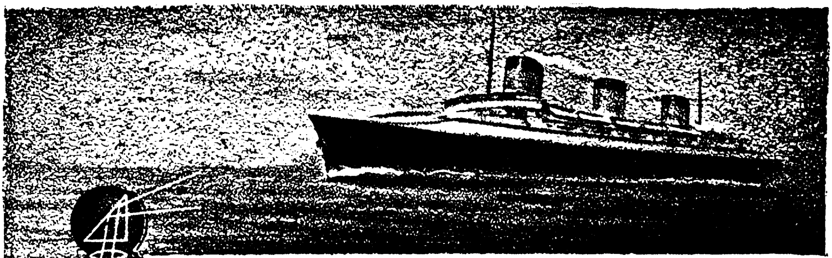
No one knows how long ago glass, the most useful of transparent substances, was first made. But from that time onward man has become more and more skillful at bending light to his will. He has been urged on by the fact that human eyes often fail and need the light-bending power of glass to aid them.

The glass of your automobile headlights bends the light from the bulbs and spreads it into a fan that covers the whole width of the road. A spotlight falls on a smaller area but illuminates it much more brightly, for the light is concentrated into a sharp, narrow beam. Normal eyes are equipped with lenses which have much the same effect as the glass in a spotlight—but in reverse, of course, for the light comes in through them instead of passing out. They bend the entering light so that it all is focused on one very small spot on the retina, a sensitive region behind the eye's lens, which serves the same purpose in vision that a film serves in taking a photograph.

But the eye lenses could not be composed of rigid material such as glass, because they have to change shape to properly focus the light from objects at different distances. They are made of a jellylike substance, so that their shape can be changed by small muscles. They may be made short and thick, like an almost round almond, when you look at near-by objects. When you look at distant scenery, they are stretched out until they are long and narrow. This ability of human lenses to change their shape so that you can see things clearly is one of nature's mechanisms that man has never been able to duplicate.

Eye lenses, however, like arteries and some other body tissues, may harden with increasing age. They become so stiff that they no longer adjust for near objects but remain in the long and narrow shape that only focuses light from far away on the retina.

Eyeglasses make inefficient eyes able to see normally and leave man just about at par. But scientists want vaulting poles, not crutches. The eyes of primitive priests saw the stars as strange gods and built myths around them; a few curious persons, however, thought that heavenly bodies might turn out to be more or less like the earth if they only had some device that would make vision so powerful that distant objects would look close.



CHAPTER XIII

FOR A CLOSER LOOK

HAVING found that they could bend light to order with eyeglasses, men were on the way to bringing far distant worlds within reach of their eyes. During the early seventeenth century, about the time ships were setting out to explore the coast of that mysterious continent Colum-

bus had discovered, the Dutch became the foremost makers of glasses in all Europe. One of these lens grinders, the story goes, stepped out one day to test two new pairs of glasses by daylight. When he held one in front of the other, a foot or so apart, he was astonished to see the faces of his friends across the street appear large and clear, as if they were close in front of him.

Very shortly afterward, someone found that it was handier and more efficient to put two lenses into a tube, and by the 1630's telescopes had been developed far enough for Galileo to see four moons circling around the planet Jupiter. But the men of that time were not ready to build such instruments as astronomers now use to study whirling pinwheels of gas billions of miles away that are called nebulae, or watch the changing patterns on Mars, which may (or may not) mean that grass grows there. They had first to learn a great deal about how light must be bent to make far-off things seem nearer and larger.

The apparent size of things depends on the way the light rays that come from them focus in our eyes. A matchstick an inch away reflects rays that focus in the same manner as those from a pine tree some distance off; therefore match and tree appear the same size. The two lenses of a telescope bend the light from a distant star so that it falls on the eye in the same way as light from a silver dollar one foot in front of you. So the star seems as big as a dollar. Light from the moon can be bent so that it reaches your eyes in the same way as light from some other large object floating near by, like a balloon ten feet off, in which case you see only a small patch of the moon but see it very clearly.

Men working with bits of ground glass also found that a mirror shaped like a shallow bowl collects and concentrates light so that the image of any light source, from a candle to a star, appears much brighter. Modern telescopes are huge mirrors that collect light from heavenly bodies and reflect it into lenses which make stars far fainter than those in the Milky Way appear large to the peering eye of the astronomer.

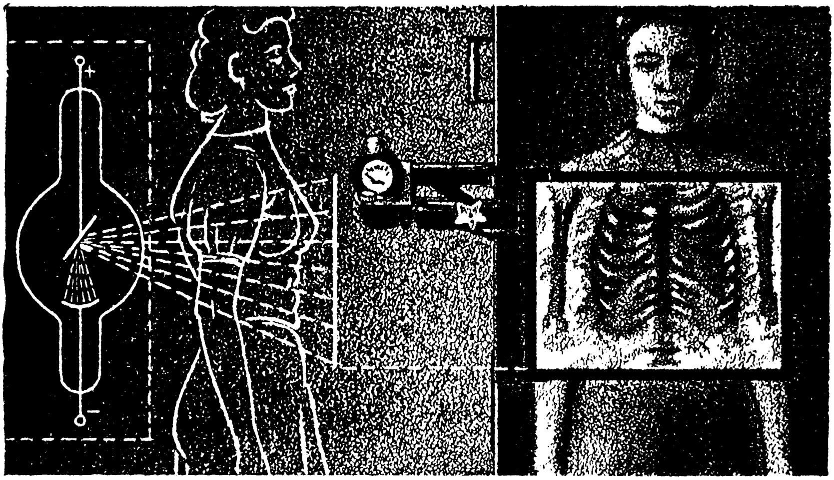
Not long after telescopes began to probe the mysteries of outer space, the Dutch lens makers developed another light-bending instrument, the microscope, and looked for the first time into Nature's closer, more intimate secrets. With this double increase in the power of vision, secrets and mysteries grew clear before men's eyes and became realities that could be studied, experimented upon, and controlled. A drop of water, for example, had seemed no more than a silver bead to men's naked eyes. A Dutchman put one under his microscope, saw that it was swarming with tiny animals, and the turning point had come in man's fight against disease. He had seen for the first time the creatures that attack us and make us ill.

The lenses of microscopes, like those of telescopes, "bring closer" things that are beyond the range of the naked eye. The average microscope makes a disease germ appear about two thousand times larger than it actually is; the new two-hundred-inch telescope in California magnifies a star five thousand times. But stars are millions of miles away while the objects you want to look at through a microscope can be brought as close to the probing lenses as you wish. Because of this vast difference in distance, microscopes are most effective when they are made small and compact, with their lenses comparatively close together. Microbes and the smallest blood vessels of the human body reflect too little light into the eye. By sharply bending light that would otherwise miss the eye and focusing it properly, a microscope causes the eye to see and the object to appear much larger than its real size.

The value of a greater power of vision has been wonderfully increased by the development of the camera, which also was made possible by men who studied light and how it behaves. Chemists discovered that silver chloride turns black when light strikes it, and that other chemicals behave in a similar manner; and finally they developed the sensitive coatings that make modern photographic film so wonderfully quick and sure to take and hold an image. Meanwhile, men who understood lenses were developing bits of glass that bent light so that it fell on a film much as your eyes' lenses focus rays on the retina. You see with the part of the retina on which light falls. A picture is made on the part of the film that light strikes, which turns dark while all the rest remains unaffected.

With a microscope or telescope a scientist can study nature only while he has his eyes glued to the instrument. He cannot keep on looking very long at a time, for the work is very tiring. Also, he is not always certain of what he has seen, and someone else may make different observations of the same thing. But a photograph can be studied at leisure, and photographs made by a competent scientist leave no room for argument. What a camera's mechanical eye sees through a microscope or telescope is pretty sure to be real.

Of course, the fun people get out of moving pictures and candid cameras is not the least of the gifts that students of light have given to us. But in adding up the benefits that have come through the increase in man's power of vision, the scientific work it has made possible must come first. Without the microscope, the microbes that cause disease would never have been discovered, and many of us would not be here to enjoy anything. Without the telescope the circling of the planets could not have been observed so closely, and the study of motion that led to an understanding of heat and light might have been abandoned, leaving civilization to mark time during the last three hundred years.



Chapter XIV

LIGHT GETS THERE JUST THE SAME

WE ARE not yet at the limit of our seeing power; scientific progress is literally pushing man toward finding new eye-aiding instruments and improving those he already has. But even top-notch scientists are not sure what light is or how it gets from one place to another.

There is plenty of evidence to suggest that light, like sound, travels in waves. Sound is produced by vibrating strings or other objects; light, by vibrating atoms. Changes in the rapidity of vibrations that produce sound cause changes in tone, and changes in the light-producing motion of atoms cause changes in color. Furthermore, echoes and mirror images show that both sound and light can be reflected from some surfaces.

Although these and other similarities convinced some men that the two forces traveled in waves, experiments also showed differences between light and sound. When the first domino in a long row falls and knocks down the piece in front of it, this starts off a series of falls down the whole line. Similarly, a sound wave is the result of pushed air that jars the air near it, and the pushes are passed along through space until a final push sets your eardrum vibrating.

But, though light may consist of waves, they are not "pushes" passed along through the air. A side-to-side motion sets them going. If you shake one end of a loose rope, snakelike waves move along it toward the other end. In much the same way light waves are moved through space; they quiver from side to side at right angles to the direction of their motion.

Sound and light differ in another way. Whereas the former travels 1,120 feet a second in air, light goes at such a tremendous rate that for centuries men thought it took no time at all in getting from one place to another. When apparatus was finally made to measure its speed, light was found to travel about 186,000 miles a second; and, as far as we know, nothing else in the universe goes so fast. Astronomers use the term "light year" (the distance light goes in a year—about 6,000,000,000,000 miles) in speaking of star distances. In spite of this tremendous speed, light from the really distant stars takes thousands of years to cover the space between these islands in the universe and the telescopes of man.

But there is a third difference between light and sound: sound will not travel through a vacuum—light will. Situations like this worry scientists as much as votes worry politicians. Sound waves need air or some other material as a medium, and it seems reasonable that light waves, too, should have a medium that will shake back and forth, carrying the motion of the waves along through space. But a perfect vacuum contains nothing—not even a lone atom—and it is hard to believe that light can cross such a void. This is a puzzle today.

Some scientists hold that even a "vacuum" is filled with a mysterious, undetectable substance called "ether." They do not believe that the ether is a solid, liquid, or gas, strictly speaking; but many first-rate scientists feel that they need to assume the existence of this ghost material to explain the passage of light across the vast spaces between the stars. Though these great areas are not quite empty, containing gases which are found on earth, very delicate measuring equipment and subtle mathematics are necessary in order to discover anything there. In the gases between the stars the atoms are at least a million billion times as far apart as those of air, which as you know, is simply "thinned-out" matter.

Feeling that such thin stuff could not possibly serve as a medium through which light waves can travel, many scientists believe that all space is filled with a sea of ether, and that when an atom vibrates, it ripples this ocean as a thrown rock ripples the surface of a pond. The ripples are light: you see when they hit your eyes.

But the ether, if it exists, is not the private property of light. For each ripple of visible light, which is produced by atoms vibrating between five hundred trillion and one quadrillion times a second, there are many waves that you cannot see.

Atoms, as you remember, are like people in always being on the go, but they are also like human beings in that they cannot be regimented and made to move at the same rate. After you light your gas stove, the iron grating over the blue flames becomes hot. Men found that this heat was not the kind resulting from the chaotic motions of gas molecules hemmed in by four walls, although it can warm you just as well.

When iron gets hot, its atoms also start moving, but with regular back-and-forth motions slower than the five hundred trillion vibrations a second necessary to produce red light. These quivering particles set up "infra-red" (below the red) waves which make you feel hot when they strike your skin. As you keep on heating iron, many of its atoms vibrate faster and faster until some have a frequency of five hundred trillion—and the metal becomes red-hot. More heat may make the iron white-hot. Since white is a combination of all colors, this simply means that the iron atoms are vibrating at all rates from the comparatively slow motions that produce red, orange, and yellow light to the one-quadrillion frequency of violet light.

The sluggard atoms in white-hot iron vibrate less than five hundred trillion times a second and send out infra-red heat waves at the same time that the fast-steppers are producing visible light waves in the ether. Similarly, electric light bulbs in your home become hot after shining awhile. In fact, all light-producing sources, from the spotlights in theaters to airport searchlights, give off large amounts of heat in the form of infra-red waves.

Infra-red waves and light waves, however, have many things in common. Both travel 186,000 miles a second, both can pass through a vacuum, and both affect photographic plates. Modern seamen make good use of this last similarity. On a foggy night the light from a lighthouse beacon does not reach ships. But the beacon also sends out infra-red rays which whiz right through light-stopping mists, and officers of ships equipped with special photographic plates that register when hit by these waves are warned just as well as if they could actually see the beacon.

Particles vibrating faster than the one-quadrillion frequency of violet light may also produce invisible waves in the ether. Some atoms in the sun vibrate up to seventy quadrillion (70 followed by fifteen zeros) times a second, producing invisible ultraviolet (above the violet) waves that cause sunburn and kill germs. By making the molecules of certain gases tremble in special tubes, men imitate the sun and manufacture lamps that tan the skins of city dwellers, and kill the microbes that may lurk in hospital operating rooms.

There seems to be no upper limit to the rate with which atoms can vibrate. If millions of high-speed atomic particles are made to strike headlong against a metal target in a tube, they set up waves in the ether with frequencies even above those of ultraviolet rays. Because these X-rays can penetrate flesh and blood but are stopped dead by bone, doctors shoot them at your body and place a special photographic plate behind you. Since the spots on the plate directly behind your bones are "shielded," but the rest of the plate is affected, photographs of your skeleton are produced.

Not only do infra-red, ultraviolet, and X-ray radiations pass through a vacuum and travel with light's speed of 186,000 miles a second, but their waves, like those of light, are transverse. It was little wonder that scientists grouped all these waves together, since they are all caused by vibrating atoms and all need that peculiar ether as a medium through which to travel.

Light is the only visible member in a family of radiations, all of which man has learned to use—one of them, X-rays, giving his eyes the added power of looking through solid walls. But all our knowledge of rays would have been useless if men had not found out how to produce and control a force capable of making atoms vibrate at the proper speeds—electricity.

CHAPTER XV

WHAT ATOMS ARE MADE OF

NIGHT life became democratic when men learned how to produce the kind of light they wanted. If an aviator could have flown over London or Berlin a hundred and twenty-nine years ago, he would have looked down on darkness pricked here and there with a glow coming from a place or great house where money was being lavished on hundreds of candles. Cities were practically blacked out every night, and books were little used because people had to strain their eyes to read after the sun went down. But the new knowledge gathered by students of light could never have been put to use if other workers had not studied electricity, the only force of nature that can be efficiently used to make atoms vibrate at light-producing speeds.

Judged by the form in which electricity was first noticed—and that must have happened a long time ago, possibly in Egypt or Babylon—it gave little promise of becoming one of man's most valuable servants. Someone rubbed a piece of glass with fur and brought the glass quickly near a wisp of cloth. The cloth moved toward the glass and stuck to it. When the glass was lifted, the wisp still stuck.

Other experiments show this peculiar behavior even more clearly; when hung by a thread, a ball of pith (the core of a dried potato) makes a good indicator. If you take a glass rod, rub it on your coat sleeve and bring it near, the ball, pulled by an invisible attracting force, will suddenly swing toward the rod. But if you let the ball hit the rod, a strange thing will happen. The ball will suddenly swing away from the rod. It is plain that when ball and glass touch each other some sort of force flows from one to the other, causing repulsion instead of the previous attraction.

If gravity worked like this, and you jumped to the ground from a chair, you would quickly be repelled from the floor upon touching it and dangle in midair. This two-way force was called "static" or "motionless" electricity when men found that there was another type that flowed through wires. But even then they could not explain it.

For a long time atoms were supposed to be solid, indivisible chunks; but studies of certain of those ninety-odd elements that make up all matter showed this idea to be false, and as scientists discarded the belief in a one-piece atom they learned more and more about electricity.

The atoms of substances such as radium explode automatically, and the infinitesimally small fragments of these explosions have been carefully studied. They were found to consist of two kinds of particles, called "protons" and "electrons." A proton weighs about one septillionth of an ounce; an electron is "lighter," weighing about 1/1840 of a proton.

There is a connection between these particles and static electricity. A proton attracts an electron, but repels another proton. Similarly electrons tend to move toward protons but away from other electrons. In this world of fragments below the size of atoms, birds of a feather do not flock together—opposites attract. This source of attracting and repelling forces can explain what happens in the experiment with a glass rod and a pith ball.

In most of the world's substances there is one electron for every proton; so it is not usual for two objects either to attract or to repel each other. But if a few electrons are brushed off from some substance, as happens when a glass rod is rubbed on the coat sleeve, this leaves a few "discontented" protons that want either their lost electrons or some others. The protons in the glass do more than yearn, however; they actually exert an attracting force for electrons—

a kind of atomic mating urge. Any electrons near by will flow toward these protons, and if they happen to be part of some light bit of material, such as a pith ball, the whole object will move toward the glass. If the pith ball hits the glass, it surrenders a few electrons but not enough to go around among the waiting protons. This leaves both glass and pith with "unmated" protons, which repel each other and cause the ball to swing sharply away.

Compared to electrons, protons are bulky particles. Like fat persons, they do not move much, and the lighter electrons are the particles that are shifted from one material to another in a static electricity experiment. When a substance loses electrons, it has an excess of protons and is said to have a positive (+) charge. When a substance gains electrons, so that they outnumber the protons, it has a negative (–) charge. Since these two kinds of particles make up atoms, and atoms make up all matter, it became clear that all substances are charged with electricity.

They also realized that electricity, unlike gravitation which always attracts, is a two-way force that sometimes attracts and sometimes repels. Furthermore, while gravitation pulls a thing to the surface of the earth, man has no control over it—he cannot turn it on and off. Electricity's double forces, however, could be created artificially by rubbing, and showed promise of serving man. The power lines that run across country landscapes show how this promise has been fulfilled.

Chapter XVI

QUICK AS A FLASH

STATIC electricity has been little help to man except as a clue to bigger things. But its connection with the electricity that moves in currents is vividly shown in lightning. The attracting and repelling forces between positive and negative electricity (between protons and electrons) gave men an explanation for the bolts which had seemed the mysterious and terrible expressions of a god's anger.

During a storm countless trillions of electrons, herded by forces in the atmosphere, may gather in some cloudy region in spite of the fact that electrons tend to repel one another. However, the vast charge of negative electricity thus suspended in the clouds has a powerful repelling action on the electrons below and drives great numbers of them from a section of the earth, leaving "unmated" protons. As time passes, more and more electrons gather in the clouds, and more and more electrons are driven away from the ground beneath them. This region of no man's land acquires a large excess of protons, a strong positive charge, and the stage is set.

Suddenly the breaking point comes. The electrons in the sky are so strongly attracted to the protons below (protons, as you remember, are heavy and do not move readily) that they leave their perch and stream madly toward the earth. The sudden leap from air to ground is a flash of lightning.

For centuries men dreamed of controlling this force that can split trees, shatter houses, and kill anything it strikes, and putting it to work for their own benefit.

The first step was taken when they found that electricity will flow from batteries, which are combinations of chemical solutions and solids that act on one another in such a way that electrons are freed and move in regular processions. For instance, when a rod of black carbon and a sheet or plate of zinc are put into a solution of water mixed with ammonium chloride, the carbon sheds electrons into the water and becomes positively charged. The lost electrons migrate to the zinc plate, giving it a negative charge. When you attach a wire to the piece of zinc, the metal's surplus store of electrons (which originally escaped from the carbon) flow into the wire and along it until they come to the end and can flow no longer.

These "dammed" electrons, like those in a cloud before a lightning flash, are eager to escape, and when a wire into which they flow from the zinc plate is brought close to a wire attached to the electron-lacking or positively charged carbon, they jump the gap. This tiny leap may make a crackling sound and appear as a spark. Such jumps of electrons are small-scale lightning flashes; they may produce electrical shocks strong enough to kill a man. By connecting the wires from carbon and zinc to one another, you can obtain a steady flow of electrons away from the negative (—) zinc plate to the positive (+) carbon rod. This is an electric current, and the zinc-carbon-chemical combination which produces it is known as a cell. Many such cells are combined to make a battery such as those which supply the headlights and other electrical equipment of automobiles.

In a wire, electrons act like solid bits of matter; they knock against the atoms that make up the metal, set them in motion, and produce heat, just as a stream of bullets passing through a machine gun heats up the barrel. This might have prevented electricity from ever becoming useful, for billions of electron "bullets" pass a given point every second. But men studied the heat produced by currents and learned to control it for our advantage.

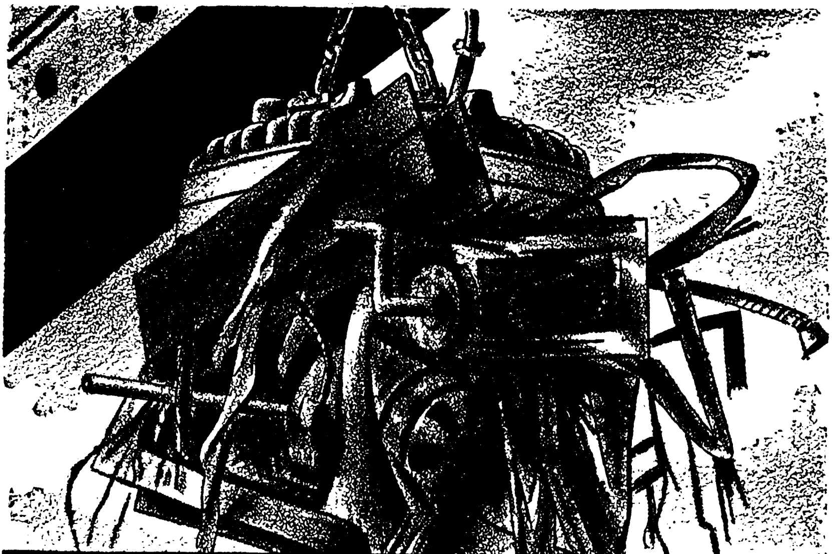
They found that they could run currents through wires of copper and bronze without warming them very much, and these two metals therefore carry our electricity from place to place. Certain metals can be made to heat just enough to cook a meal, and still not melt.

When an electric stove glows red, the atoms in its coils are moving back and forth at the lowest speed that gives light, three hundred million to four hundred trillion times a second. When scientists found a metal whose atoms could be speeded up to four hundred and thirty trillion or more vibrations per second, and still not melt, they were able to produce white light for everybody.

The light bulbs that illuminate your rooms consist of a wire—called a filament—that glows to a white heat when electrons pass through it—1,000,000,000,000,000,000 of them a second. Other bulbs, such as those in neon signs, contain gas instead of a filament, and electrons passing through hit billions of gas particles and cause them to produce light. One gas-filled tube announced recently in California is perhaps the best man-made light source: although each tube is only half an inch long, a handful of them could light all the airports in the United States.

You cannot get away from electricity. If you shuffle your feet across a thick rug, you may become a "wire" and pick up enough electrons to become negatively charged. If you touch someone after this, you can feel a real shock as the electrons jump from your skin to his. When you cross a street at night and see a car approaching, the automobile's headlight and beams affect certain cells in your eyes so that they send extremely small electric currents via nerve pathways to the brain. The result of this split-second telegraphic message is that you jump out of the way.

But currents as small as those in your body, and even the far more powerful currents produced by batteries, were not potent enough to satisfy man's desire for more strength. So far he had succeeded only in producing electricity strong enough to light a bulb and toast a piece of bread. But batteries wear out. They are almost useless to supply the world's homes with light or to provide a steady source of electricity for large-scale projects. Scientists were a long time in finding a way to produce electricity in quantities, for they had first to study and control another force that seemed at first to have nothing at all to do with it.



62″ ELECTROMAGNET. LIFTS 40 TONS OF SCRAP STEEL

Chapter XVII

WATCHING THE COMPASS

ACCORDING to one myth, magnetism received its name from a shepherd named Magnes who found that whenever he passed a certain spot of ground in his pasture, the iron-covered end of his staff was strongly attracted and tugged by an invisible force. Digging to discover why this should happen, Magnes found a large chunk of magnetic, iron-containing rock. What puzzled the shepherd, and puzzled other men for many centuries afterward, was how the iron bars that could pick up nails and other articles differed from ordinary iron. The magnetic metal was filled with some force that drew all iron toward it with invisible fingers; but men didn't learn much more until they launched into a study of magnets and developed the idea of a magnetic field.

The word "field," which usually brings to mind long stretches of flowers and grass, has a special meaning for physicists. To them a field is not a bit of scenery, but a space in which a force acts. When a diver springs from a board, he throws himself into a part of the vast gravitational field that surrounds the earth and extends many miles skyward. Because of the pull of the earth's gravitational field, he lands in the water, and all things fall when they lose support. Every magnet similarly attracts ordinary iron that comes near. It was found that the field of a bar magnet is strongest at the ends and weakest at the middle.

The earth is a vast magnet, having its most powerful fields near the South and North poles. The small, light needle of a compass is also a magnet, one end of which is called its north pole because it points toward the earth's North Pole—its south pole, of course, being the end that always points toward the earth's South Pole. Long before magnetism was understood, men used this instrument to guide their wooden ships of commerce and war. They found that any bar magnet balanced delicately enough would act as a compass.

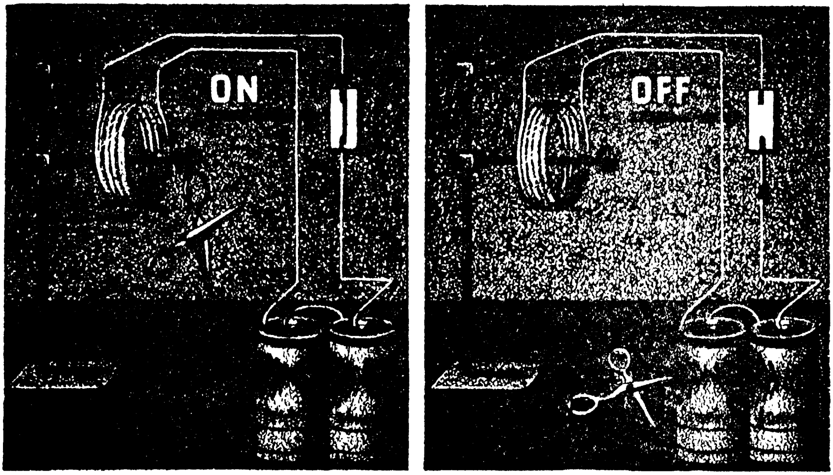
If you bring the north-seeking end of one bar magnet close to the south-seeking end of another, the two will be attracted strongly and come together with a "click." If you try to bring the north poles of two powerful bar magnets together, you have to exert a good deal of effort; and they separate when you relax. Two south poles will resist and tend to move apart when you attempt to make them touch. In other words, opposite magnetic poles attract one another, like poles repel.

Nature plays a similar trick in static electricity. Positively charged protons repel one another; electrons and their negative charges repel one another; but oppositely charged protons and electrons attract one another. In their study of magnetism scientists were introduced to a peculiar force that acted like electricity, sometimes bringing things together and sometimes keeping them apart. When men study a force, they are interested in controlling it: they want to create it or get rid of it at their own sweet will. This scientists succeeded in doing with electricity when the battery was invented; and the next objective was to see if it were possible to influence the coming and going of magnetism.

It is easy to magnetize an iron bar by stroking it with a magnet; but why this simple motion should do the trick, scientists could not tell. They were no less mystified to find it possible to take the attracting power out of an iron magnet by knocking it sharply against some hard surface. The best clue researchers had to the puzzle of magnetism, however, came from other experiments. If you pick up a nail with a horseshoe magnet and then heat the magnet, it will slowly lose its attracting power; finally the nail will drop to the floor. Since heat is accompanied by atomic motion, this test indicated that magnetism might be due to some peculiar arrangement of iron atoms, and that the heating shuffled the particles into positions such as they had in non-magnetic iron.

But these were only hints, and the situation looked hopeless when men tried another type of experiment. To study north and south poles separately, they broke a bar magnet in two, hoping to end up with one north and one south pole. But instead each of the halves had a north and a south pole, and was a small-scale model of the original magnet. Splitting the two halves into quarter bars gave a total of four magnets with two poles each.

Scientists were as amazed as a farmer would be on chopping his pet hen into four pieces to find he had, not four lumps of meat but four live, miniature hens. Moreover, although they could create and destroy magnetism within narrow limits, the forces they worked with were too small to help men in their daily work. Until magnetism became man's slave, scientists couldn't rest; and this power in nature was useless until they learned what produced it.



Chapter XVIII

PULLING TOGETHER

IN ELECTRICITY and magnetism men had two things which they could produce in the laboratory but could not supply on a large enough scale to satisfy man's need for power. These were the only two forces known that worked in opposite ways, both attracting and repelling, and it seemed they must be connected in some way. So many workers searched for such a connection that they would have found it very shortly; but it was by an accident that a tie-up was finally discovered.

A Danish physicist left a battery and a compass close together in his laboratory. One day when he attached a wire to the terminals of his battery, the near-by north pole of the compass needle was deflected to one side just as it would have been if a large magnet had approached it. There were no iron magnets around, and the Danish researcher was certain that the only thing which could move a bit of magnetized iron like the compass needle, without touching it, must be some other magnetic field.

He was correct. The wire carrying that stream of electrons called an electric current actually had a magnetic field around it; but, when the current was switched off, this field disappeared. Apparently magnetism was a result of the motion of millions of those subatomic particles called "electrons."

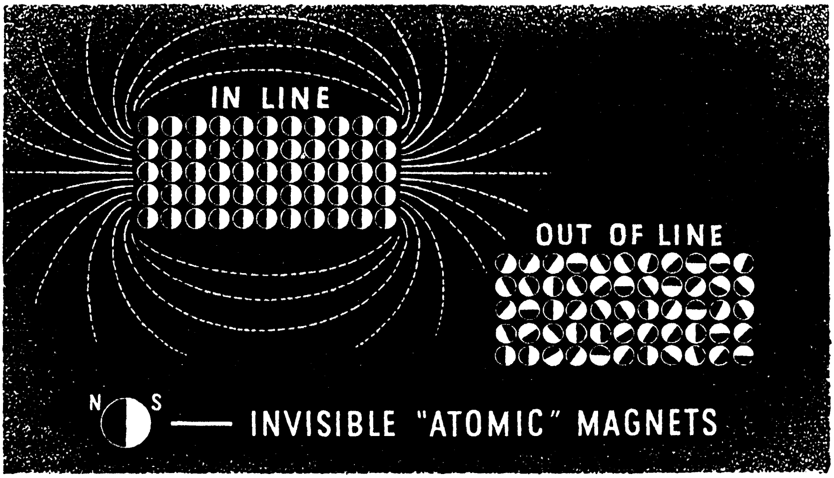
But, though electrons flowing along straight wires produce magnetic fields, they are not like those around bar magnets. To obtain a field with north and south poles, experimenters found they had to bend wires in loops and set the electrons swirling in merry-go-round courses. If you hold a compass before a loop of wire with its ends attached to the terminals in such a way that the streaming electrons circle in a counter-clockwise direction, the compass needle's south-seeking end will point directly at the loop's center. By changing the wires to the opposite terminals, you change the current's direction and cause the electrons to flow clockwise, and then the north pole of the compass will point at the loop's center.

Since compass needles are attracted by magnetic poles, there must be a north pole to exert a pull when the south-seeking end points at the center of the loop.

By merely changing the direction of the circling electrons, you change this invisible pole to a south pole. Without strengthening the current you can make it produce a magnetic field twice as strong by making two loops of the same wire; and a many-looped coil will have a field many times more powerful. Scientists found that if they wound such a coil around a bar of iron the combination became an extra-powerful magnet.

When men combined the knowledge gained from working with electromagnets with that gained from studying the pieces of atoms, the nature of magnetism became clearer. They found that the electrons and protons composing matter are arranged like miniature solar systems. At the center of the atom is a nucleus or bundle of matter, consisting mostly of protons, around which one or more electrons circle in moonlike orbits. These electrons have, on a very small scale, the same effect as electrons whizzing through a wire loop. They produce magnetic fields with a north pole on one side of the atom and a south pole on the other.

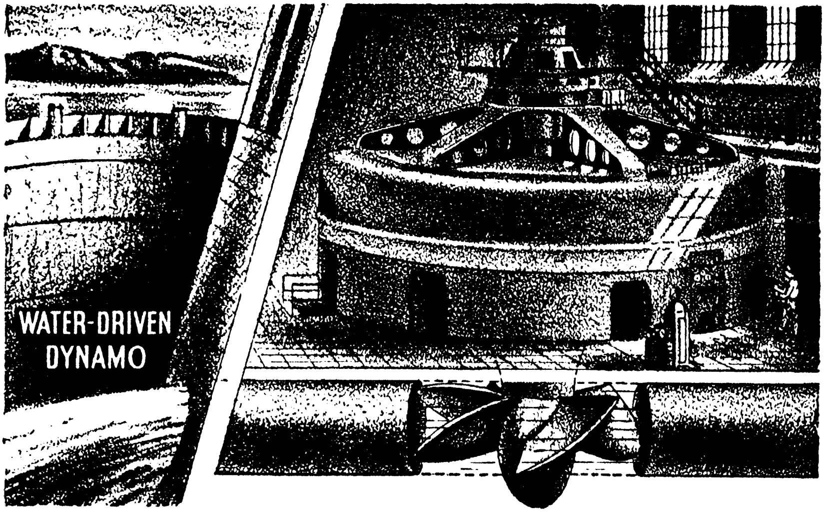
Since all substances are composed of atoms and all atoms are solar systems of electrons circling about protons, all substances are magnetic to a very slight degree. But materials like magnetized iron exert real force because their atoms are arranged so that the electrons all circle in orbits parallel to one another, like so many wheels turning on one axle. Many loops in an electricity-carrying wire make a strong magnet of an iron bar; and in the same way the atoms in a piece of iron, lined up so that they act as many tiny loops, will combine their small fields to make a single large one, with south pole at one end and north pole at the other.



Using this theory, men had no difficulty in explaining the coming and going of magnetism. When magnets were banged against hard surfaces or heated, the positions of their atoms changed so that the particles no longer worked together. It was as if the persons on one side of a tug-of-war suddenly started pulling in all directions at once, and therefore lost their power. Magnetism was the result of atomic cooperation. Atoms in an unmagnetized iron bar were not working together; when the metal was stroked with a magnet the particles lined up, their electrons circled in parallel paths, and the impotent iron became a magnet in its own right. Breaking a bar magnet in two didn't change the position of the atoms in either place—the electrons went right on circling parallel to one another in the separate parts, so that each still had a north pole at one end and a south pole at the other.

These explanations showed that magnetism was just another example of a simple but tremendously important occurrence in nature—motion. Every moving electron produces a magnetic field of some sort. A Danish physicist showed men how to use electricity to make magnets; it was not until they learned a new way to set electrons in motion that electricity changed men's ways of living all over the civilized world.

The greater the number of electrons speeding through a coil—that is, the greater the current—the stronger the iron's magnetic field becomes. In this way it is possible to make artificial magnets that are much stronger than natural ones; and their attracting power depends only upon the limits of electricity-producing devices. When men learned how to turn magnetic fields on and off, like water, they were able to develop much of the modern equipment for living. The most important part of your doorbell is a piece of iron with a coil around it. When a caller presses the outside button, electricity runs through the coil and magnetizes the iron, which attracts a ringer, pulls it downward and bangs the clapper against the bell. Doctors use special electromagnets to take shrapnel from wounded soldiers and to extract bits of iron or steel from people's eyes.



CHAPTER XIX

POWER ENOUGH

THE magnetism produced by battery electricity sets doorbells ringing. But today scrap-iron factories may use massive electromagnets that pick up tons of metal at a single time and have more power and working speed than a whole crew of laborers. Batteries could not efficiently supply all of the electricity that is the lifeblood of these timesaving lifters; it would take too many of them, and they wear out too fast. In the heavy work of modern industry, batteries are as out of date as wood-burning locomotives. It is dynamos that make it possible to produce vast floods of electricity instead of comparative trickles and give us eye-saving electric light and the strength of a thousand arms.

The dynamo grew from a simple experiment. Men who wanted to find a way of making electricity without batteries started wondering why, if electricity could produce magnetic fields, magnetic fields would not produce electricity. The man whose wonderings first brought results was Michael Faraday, the son of an English blacksmith. Lacking a scientific education, he read books about physics and chemistry on his own and developed one of the most productive curiosities a man ever had. In 1831, at the age of forty, he discovered that—without a battery—a moving magnet would produce electricity in a piece of wire.

One way of showing this is to take a coil of wire and attach the ends to an electricity-measuring device with a needle as an indicator. Then if you grasp a strong bar magnet and thrust it into the open space inside the coil, the needle will jump sharply, indicating that the magnetic field has set the wire's electrons moving. Electricity flows while you are pushing the magnet into the coil, but when you stop the inward thrust, the current will stop too. As you withdraw the bar magnet, a current will flow through the coil in the opposite direction, and will stop when the magnet is completely withdrawn. By moving the bar magnet in and out of the coil of wire, you can set up an alternating current—so called because it changes direction in the wire every time you change the direction of the magnet's motion.

Faraday's simple experiment was one of the most important in the entire history of science. This way of making electric currents without batteries was developed and improved to a point where it gave man a more useful power than he had ever possessed before. Scientists discovered that moving a magnet in and out of a coil was not the only way to produce an alternating current; it can also be done by keeping the magnet still and moving the coil back and forth with the bar magnet inside it. But it is much simpler for engineers to produce a rotating motion than a shuttlelike motion, and men found that, if they set a rectangular wire loop on an axle and spun it in the space between two stationary pieces of magnetized iron (one a north pole and the other a south pole), they could produce an alternating current similar to that obtained by Faraday in his experiment with a coil and a bar magnet.

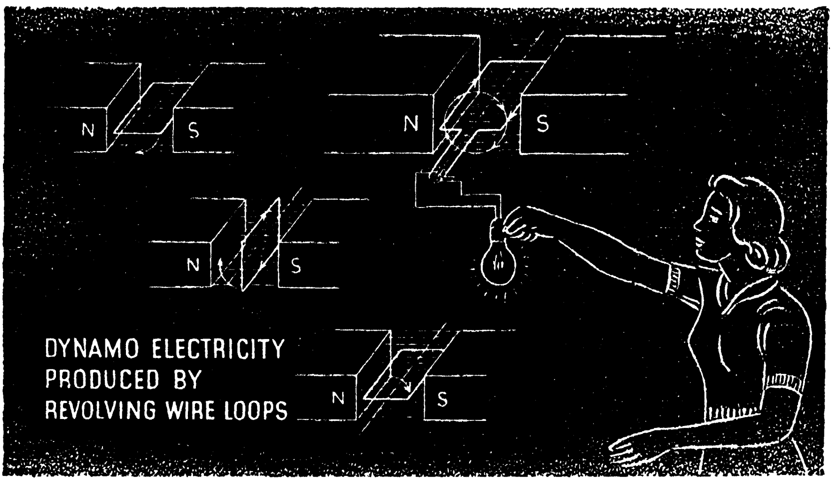
The power of this current depends on the strength of the magnetic attraction between the pieces of iron, the number of loops spinning between them, and the speed at which they spin. If you have 100 such loops coiled around a spinning cylinder, the electricity produced will be 100 times greater than if you had only one, and this is the principle back of dynamos that supply electricity to light your home and run your radio.

Before dynamo electricity is sent out, however, engineers play a clever trick to make it do one final job for them. They make it flow through wires coiled around the pieces of iron that form the dynamo's own magnetic poles. Since electricity running through a wire coiled about a bar of iron increases the iron's magnetic field, the field between the dynamo's two poles is thus increased, and the wire loops spinning in this space twine faster. In other words, the very current it produces is made to increase the dynamo's power.

Dynamos generate so much energy that one power plant can send electricity to tens of thousands of persons. The loops of wire can be made to rotate by steam-engine power or by using the force of falling water to spin the modern water wheels called turbines. The nation's huge dams are in effect artificial waterfalls, and the pressure of dammed water whirls loop-rotating turbines at terrific speeds.

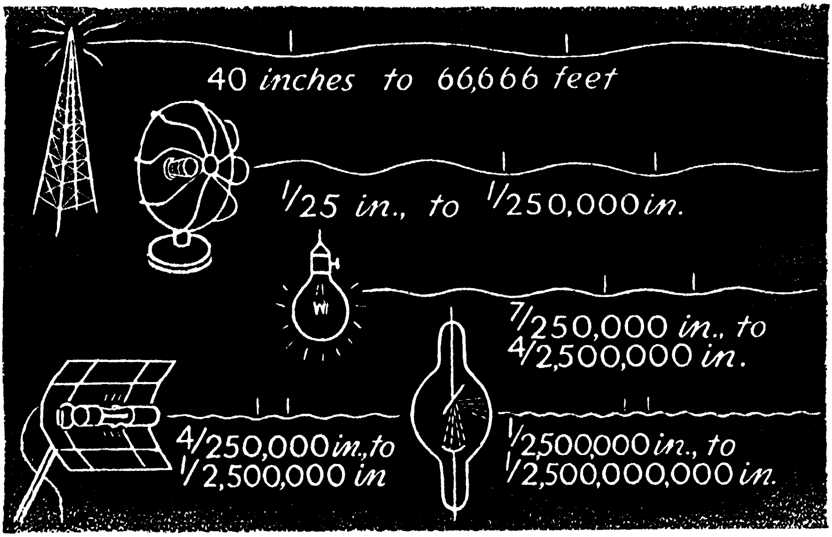
Dynamo electricity can also be used to run electric motors, which are simply dynamos in reverse. Men found that if they placed a loop of wire between the north and south poles of two permanent bar magnets and then, instead of turning the loop, ran an alternating current through it, the loop would spin on its own. Scientific theory can explain this.

The alternating current makes the loop a magnet whose poles change from north to south and back again each time the current changes its direction. When the loop's north and south poles are opposite the permanent north and south poles of the motor's magnets, there is a powerful repelling force between like poles. Since the motor's magnets are fastened in place the loop has to move; and since it is set on a shaft it turns. But no sooner has it made about a half-turn than the alternating current changes direction, reversing the loop's poles so that they are again opposite the like permanent poles of the motor. Again there is a repelling force between the permanent



magnets and the loop, which is given a powerful "push." Since alternating currents switch direction many times a second, the loop may spin rapidly and with great power. Motors built on this principle run three fourths of the nation's machinery.

This work of researchers, who kept their eyes open and found how to use the mysterious force that made the "wise iron" (as the compass once was called) point north, has changed our way of living more than any war or revolution history has seen. When men had a big job to do before the nineteenth century, they had to have a thousand slaves, many teams of horses, or steam engines right on the spot where the work was to be done. But, just as modern plumbing makes it possible to turn on a faucet and get plenty of water although a lake or city reservoir may be miles away, so dynamos send electricity over miles of wires to run heavy machinery at places distant from power plants. Like the light that makes possible all our modern night activities, from flying to reading, power is on tap wherever we need it. But even this gain in useful strength and ability to use our senses has not been enough: we have also learned how to do without connecting wires and send electricity across "empty" space.



Chapter XX

POWER IN THE AIR

THE electrons that hang in clouds before a lightning flash do not have the same sort of attracting and repelling power as magnetized bars and loops through which a current is flowing. But although static electricity is possible without magnetism, there is no such thing as magnetism without electricity. Iron is magnetic because of the currents of billions of electrons circling about atomic nuclei; a wire loop becomes magnetized only when electrons are streaming through it. Scientists therefore know that all magnetic fields are actually electromagnetic fields, because the two forces are present together.

Faraday started research that led to the invention of the dynamos that supply electricity for iceless refrigerators and electric stoves. But he also started something even more spectacular, for the moving magnet with which he first induced electricity did not touch the wire; it simply moved near the coil. In other words, some electricity-producing force was sent through a bit of emptiness. There was not even a jump of particles, as there is when a spark leaps from one wire to another.

Men soon found that energy could travel much greater distances. At Princeton University a scientist stretched a wire between two poles and strung up a second wire several hundred feet away. Then he ran a strong alternating current through one of the wires, which produced a strong electromagnetic field all along its length. When he tested the other wire he found, as he had hoped, a small alternating current accompanied by an electromagnetic field, though this wire was not connected with any source of electricity. Current and field both disappeared when he shut off the electricity in the first wire.

Such experiments brought new problems. The electrons in a wire have a small but measurable weight. They must be pushed to move. When a current in one wire causes electrons to move in a wire one hundred feet away, a pushing force is transmitted across space in some way. Faced with such facts, scientists went back over all they knew about waves—how they are produced by atomic motion, and how they may travel invisibly through space.

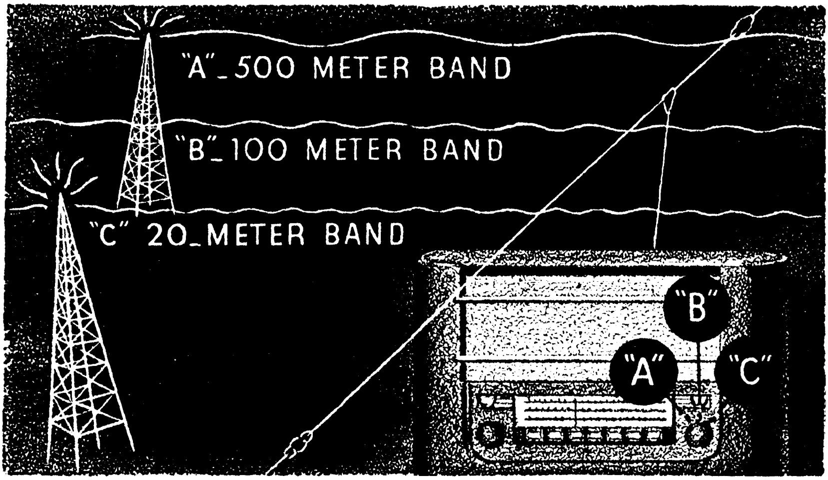
Further research showed that electric currents may also result in waves that pass energy from one place to another, but they have the power to push the lightweight electrons in wires instead of moving human eardrums, like sound, or changing the chemical coat of a photographic film, like light. Studies of these waves revealed that, like light waves, they have no trouble at all in passing through vacuums.

Also like light waves, the waves set up by electric currents travel 186,000 miles a second. The scientists who believe the ether exists hold that all vacuum-penetrating waves pass through this ether and belong to one large family of waves. There is another similarity between current-produced waves and those of the "ray" group—a likeness that has proved most important to man's convenience, pleasure, and safety.

An alternating current in a wire such as the one the Princeton scientist used to send energy across space is a regular back-and-forth motion of electrons. You can actually see them shuttling to and fro in the sparks that are often used to send out radio messages and programs. To the naked eye these miniature lightning bolts appear to be a one-way leap of electricity across a gap, but special photographs show them as electrons actually jumping back and forth thousands of times a second.

This means that current-produced waves, like light waves, are caused by vibrating particles. They cannot, however, be produced by heating a wire, but only by a current which changes the direction of its flow many times a second. And the vibrations are not by any means so rapid as those that produce rays. Electrons moving back and forth only sixty times each second may start waves on their journey through the ether, and their upper limit of a few trillion vibrations per second is still below the frequency that produces infra-red rays.

When light, electric currents, and magnetism were first found to be the result of moving electrons, scientists became more than ever impressed with the importance of motion in nature; for sound, too, is the result of vibrations. Wherever there is motion there is a force; and wherever there is a force man is likely to be trying to put it to work. By applying their hard-won knowledge of magnetism and its relation to other forces, scientists have given us the power to make ourselves heard anywhere in the world, whether anybody wants to listen or not.



CHAPTER XXI

SINGING WAVES

IT WAS a long step from the Princeton experiment in sending the waves of an alternating current a few hundred feet to modern radio. It took time to develop efficient ways of putting to work what had already been learned. But the main problem was not, as one might think, increasing the range of the waves, for the distance they will travel depends chiefly upon the strength of the alternating current vibrating in the overhead wires from which the waves go out; and men could already build dynamos that would furnish sufficient power.

But in order to broadcast words and music, scientists had to take advantage of the fact that all traveling waves are produced by vibrations. Each sound sets up its own characteristic wave in the air, and they had to find some way of changing these different air motions into electrical motions which would each correspond to a sound. Then they could run these special currents into the overhead wires that send out radio waves. Just as each different electron motion in a flowing current may correspond to an air motion (a sound) so each radio wave corresponds to the electron motion that produced it.

Fortunately, scientists were able to apply the experience gained in developing the telephone. A radio microphone is equipped with a metal plate similar to that in a telephone mouthpiece. It is like an eardrum in that it vibrates back and forth when pushed by the slight, rhythmic air motions of sound. But instead of sending messages to the brain, this motion of a telephone or microphone plate produces changes of a current in a wire. In other words, while your voice causes vibrations in the air when you shout to a friend across the street, the words you speak into either of the two instruments influence the motions of electrons in a wire.

The waves going out from a broadcasting station's overhead wires carry these vibrations, so that the main job of your receiving set at home is to change them into air waves which carry them to your ears and so reproduce the original sound. Since radio waves from a broadcasting station produce an electric current in your receiving set, as they did in the Princeton scientist's second wire, the thing to be done is to produce a change from one type of motion to another, a change similar to that which takes place in a telephone receiver. That is, electron motion must cause a piece of metal to vibrate and send out sound waves. In both telephone receiver and radio set, this is managed by means of a magnetic field. The pulling power of the field changes in response to the slight differences in the current, so that the metal is made to vibrate at different rates and push the air with different degrees of power. Since tone depends on the frequency with which sound waves follow one another, and loudness depends on their strength, the original tone is reproduced.

But radio waves become weaker, the farther they travel. They are usually weary travelers when they reach your set, and lack the strength to move even the delicate mechanism of the loud-speaker which pushes sound waves through the air. Before radio became the useful thing it is today, scientists had to develop a remarkable instrument—the amplifier tube. Though you can buy one for a few dollars, it is amazingly delicate and efficient. It juggles electrons so effectively that a thin trickle of current set up by incoming radio waves is built into a stream millions of times larger and more powerful. With such tubes men have built amplifiers that make the light footsteps of a hurrying roach sound like a horse galloping, and the gnawing of a worm inside a grain of wheat so loud as to drown out the voice of a professor lecturing to his class. Every radio set has at least one amplifier tube, and several other tubes which control tone and other qualities.

The fact that every radio station sends out waves of a different frequency makes it possible for many stations to be on the air at the same time. Electrons vibrating at any rate from 10,000 times a second up to 3,000,000,000,000 times a second can be used. When you turn your dial to "75" you adjust your set so that it responds only to a station that happens to be sending waves produced by electrons vibrating 750,000 times a second. All the waves produced by electrons vibrating within a certain range of frequencies are the "broadcasting band," which is divided up among various stations. On your dial the highest broadcasting frequency, 1,500,000 vibrations per second, is represented by "150"; the lowest, 550,000, by "50."

Some waves not in the broadcasting band are reserved for aviators who report weather conditions to landing fields; other waves carry the S O S calls of sinking ships. Still others carry police calls or the messages of amateur broadcasters, or "hams." Certain waves not now used in commercial broadcasting have been set aside by the federal government for use by schools for educational programs. The important thing about all electromagnetic waves is that they can produce electricity and hence magnetism at a point distant from their source. Once these forces arrive where they are needed, they can be changed into other types of motion and put to work at very different tasks.

If mechanical motion is called for, electromagnetic waves may be sent to the radio receiving equipment of pilotless airplanes, where the currents they produce are amplified and made to turn on electric motors. The motors control the levers and wheels that guide the plane's flight as efficiently as a flesh-and-blood aviator. When broadcasters want to make people see as well as hear, electromagnetic waves are made to set up currents in television sets. The currents in turn start particles vibrating at light-producing speeds on special screens and thus duplicate the effect of light reflected from the people and things that you meet in real life.

The wireless transportation of force across empty space represents man's greatest increase of his strength and senses; he can send his image miles through the air and throw his voice to any corner of the globe. And the persons who made it all possible were men who could not be satisfied to accept the world as they found it, or explain it by stories of gods, giants, and the ghosts of beautiful girls, but asked nature questions in the form of experiments—and who kept on asking until they got the answers.

When you come home at night, switch on the electric lights, and turn on your radio for music or the latest news bulletins, you are calmly reaping the benefits of centuries of work. Galileo and Newton began modern science with their studies of moving matter and forces in space; later researchers continued by showing how heat and atoms were related and demonstrated the nature of sound and light waves; the research of Faraday and others taught men how to "pipe" electricity to farms, homes, and factories, and how to send radio waves through the air.

Heat was found to be atomic motion, and at the source of all waves scientists found moving, vibrating matter. Active atomic particles had been whizzing back and forth for millions of years, giving life and destroying it without any control except by the laws of matter and motion. All earth's creatures were at the mercy of Nature until man learned how to make some bits of matter—electrons in wires, atoms in light globes, molecules in the air, etc.—move regularly whenever he wanted them to. The main accomplishment has been to control natural happenings that had never been controlled before, and if man bends Nature to his will in the future as in the past, he will develop new tools that may make television sets seem as old-fashioned as a buggy seems today.

Chapter XXII

THE POWER TO KILL

ALL the slaves of ancient Egypt could not do the work of a single power plant. The Westinghouse Company is building three huge dynamos for the government that will supply enough electricity to completely light New York City and Chicago. While Roman orators had to have extra-strong lungs to speak to large audiences, modern leaders can address thousands through amplifiers that throw their voices to the farthest seats of huge stadiums, and by means of radio sway multitudes they never see. The Greeks sent fleet-footed runners from town to town to spread news of a victory, but today we hear reports of the fall of a city while its streets are still echoing with the tread of the conquering army. A man is broadcasting from Warsaw while the Germans come pounding in; he is silent for a moment and his listeners, thousands of miles away, can hear the sirens screaming over his head, warning of an air raid.

These and many more examples of present-day power and speed are the results of research, of the seemingly useless doings of men like those who got interested in why cannons grew hot in the boring and why compass needles were deflected by electric currents.

The curiosity that is science is going full force today. Physicists are using thousands of dollars' worth of complicated equipment to hurl atoms against other atoms and break them into bits. While atom-smashers bombard matter, mathematically minded researchers calculate the number of electrons in the universe, biologists spend hours studying the heartbeats of oysters, and chemists test the efficiency of artificial rubber and wool made from milk.

The tremendous forces at our command today will seem insignificant to our children's children. Although human curiosity no doubt began 20,000,000 years ago when a four-footed apelike animal first tried to see what it would be like to walk on two feet, the most productive and scientific how-does-it-work spirit began only three hundred years ago when Galileo rolled balls down inclines and discovered the principle of inertia. And the earth still has millions of years to go.

Advances to date, however, have been made by a comparatively few scientists among the hundreds and thousands that have spent their lives studying nature. Just as there are great lawyers, average lawyers, and bad lawyers, so there are great, average, and bad scientists. The best researchers know this, and they also know that progress has often been held up many years and even decades by men who were prominent in their day and stuck to false beliefs with mulelike stubbornness. Scientists who think they have found the answer to how the universe runs are as foolish as politicians who believe they have discovered the perfect form of government.

But the best among them realize that they haven't a clear idea of how quivering electrons in one wire can make the electrons in another wire thousands of miles away quiver with the same frequency, and that the ether is a half-myth, useful in explaining such unruly facts, but never weighed or measured or in any way proved to exist outside men's minds. And they know that this is but one of hundreds of problems yet to be solved before the universe is explained. They know that forces now unharnessed will one day be brought under man's control.

But, ether or no ether, you still have more power at your command than the greatest kings of ancient times. The main problem is: How is this power going

to be used? Scientists the world over are growing more and more concerned over the fact that much of their work helps improve military equipment. Contrasted to the long-lasting and steady power of dynamos is the momentary and shattering power of explosives. While steamships are built to get you across the ocean faster, and transoceanic flights make newspaper headlines, other men quietly proceed to build more powerful guns, faster and deadlier bullets, and ship-destroying torpedoes.

If the United States enters the war, you or your relatives will be using weapons that represent science's greatest advances along military lines. There has even been serious talk of using bacteria in warfare, on the theory that if physicians can subdue germs they can also nourish them, breed them, and spread them through enemy countries.

Scientists are worried about such things, but they are only a small group among 130,000,000 citizens in the United States. Science is everybody's business because it affects everybody's business. In a democracy each of us has his right to a say about how laboratory knowledge is going to be used. But we need to understand enough science to know what it may do to others and ourselves if used destructively, and how it can improve the lot of all men if used intelligently.

Many people look at a radio set or read overwritten but breath-taking accounts of new inventions in their newspapers and gasp, "I'll never understand that!" But it is puzzling out the explanations of nature that requires a lifetime of study and labor. Once knowledge is gained, it does not require a superman in a white coat to understand it; and, unlike the closely guarded knowledge of the old-time priests, the facts of science are about as secret as the private life of a motion picture star. Scientists are ready to explain their work. Libraries have experts at your service to help you find the books you need. And schools of all degrees, having given up the idea that learning is child's play, now stand ready to put knowledge within reach of everyone who wants to have a share in running this world which science has made complicated while it was making it more comfortable.

When more men study science its attitude of experimenting, instead of arguing, may spread to nonscientists; and the misuse of power may some day be outlawed by people who think in this way. In the course of its development along useful lines science has increased the power to kill; but this power need not be used in the future. Only three centuries separate Galileo and television. And there are still millions of years to go.

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