Isaac Asimov

How Did We

Microwaves?

LUSTRATED BY ERIKA W. KORS

How Did We Find Out About Microwaves?

Isaac Asimov

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Colors and Waves

IN 1665, A twenty-three year old English scientist, Isaac Newton (1642–1727), was playing with light.

He pulled all the curtains shut in his room, on a sunny day, so that it was quite dim. Through a little chink cut out of a curtain, a narrow beam of sunlight shone into the room.

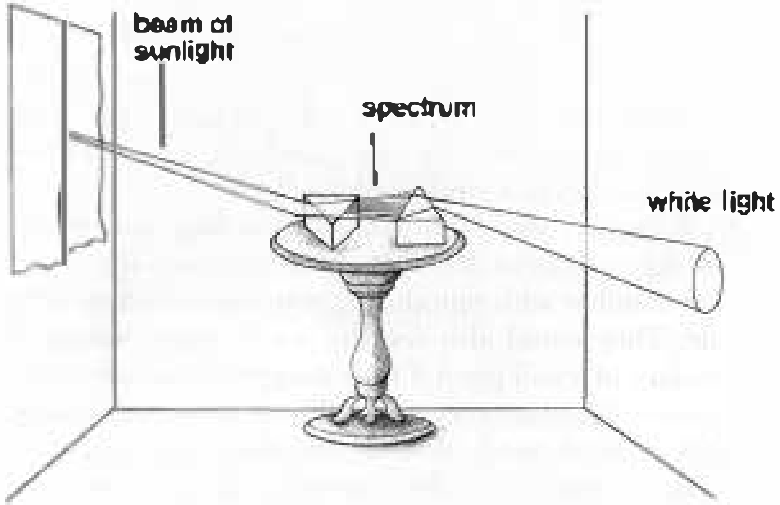
Newton allowed this beam of sunlight to pass through a triangular piece of glass called a *prism* (PRIZ-um). The light beam bent in its path as it went through the prism. The beam was *refracted* (ree-FRAK-ted).

The light came out of the prism traveling in a slightly different direction than it went in and shone on the wall behind. If the prism had not been in its path, the beam would just have made a white round spot on the wall. But the prism was there, and the beam of light had spread out and formed a rainbow. At one end the light was red. As one's eye passed along the band of light, it turned, little by little, orange, then yellow, then green, then blue, and, finally, at the other end, the light was violet.

You can see colors all around you, but usually they're part of solid objects. You can feel them. The colors on the wall that Newton had produced, however, could not be felt. They were in the light itself, not in anything solid. Your hand could have gone through the colored light as though it had been a ghost. In fact, Newton called the band of colored light a *spectrum*, the Latin word for ghost.

Where did the colors come from? Newton felt that what our eyes see as white light is actually a mixture of colors. When white light passes through a prism and is refracted, the different colors are refracted by different amounts. The red light is refracted least, the violet light is refracted most, and the others are refracted by amounts in between. That separates the colors and spreads them along a strip instead of placing them together in a small circle.

To see if this was so, Newton let the light pass through the prism, and then, before it could reach the wall, he let it pass through a second prism with the point of the triangle facing the opposite way from that of the first prism. The light had been bent one way when it went through the first prism, but now it bent the opposite way when it went through the second prism. The colors separated as they went through the first prism and they came together again as they went through the second prism.



Newton's experiment with prisms

When the light had passed through *both* prisms, what appeared on the wall was just a circle of white light. To Newton, this was proof that the colors, mixed together, added up to white.

But why should there be different colors of light? Why should they bend by different amounts in passing through a prism?

To answer that question it might help to know what light is made up of, but no one in Newton's time could be sure. Still, there were two possibilities.

It was possible that light might consist of a stream of very tiny particles, all moving very quickly in a straight line. It was also possible that light might consist of a stream of very small waves, all moving very quickly in a straight line.

Scientists were familiar with the way bullets traveled in a straight line over short distances. They were also familiar with sounds that consisted of waves in the air. They could also see the waves move across the surface of a still pond if they dropped a pebble into it.

One thing was very noticeable about waves, though. They could bend around obstacles. You can watch water waves do it. You know too that you can hear someone around a corner, so the sound waves must bend around that corner.

On the other hand, bullets don't bend around a corner, and light doesn't either. If someone is around the corner, you can't see him. Light moves right past the edge of an obstacle, still going straight.

For this reason, Newton thought light had to consist of a stream of small, moving particles and *not* of waves.

Christian Huygens

Not everyone agreed with him. There was a Dutch scientist, Christiaan Huygens (HY-genz, 1629–1665), who thought light consisted of waves. He argued that small waves didn't bend around obstacles as easily as long waves did. If light consisted of *very* small waves, it would hardly bend around obstacles at all.

Most scientists, it turned out, sided with Newton because, as time went on, people realized he was a very great scientist. In fact, scientists today almost all agree that he was the greatest scientist who ever lived.

Still, even the greatest scientist can be wrong sometimes.

The person who settled the matter was a British scientist, Thomas Young (1773–1829). He was a man who was learned in all sorts of ways.

He was a doctor, to begin with. Then, too, he wrote articles for *The Encyclopedia Britannica* on all sorts of subjects. He was even the first person to begin to work out the meaning of the ancient Egyptian writing. Despite all that, he is best remembered for his experiments with light.

Young had studied sound, and he knew that when two sound waves intersected, or crossed paths, one would sometimes cancel out the other. In one sound wave, the air carrying the wave might be moving in just as air was going out in the other wave. In the combination, the air wouldn't move in either direction, and there would be silence. If the sound waves were of different lengths, the longer wave would overtake the shorter and, for a while, the air would move in and out at the same time in both waves. The sound would then be louder than normal. Then the two sound waves would fall out of step into silence again, and so on.

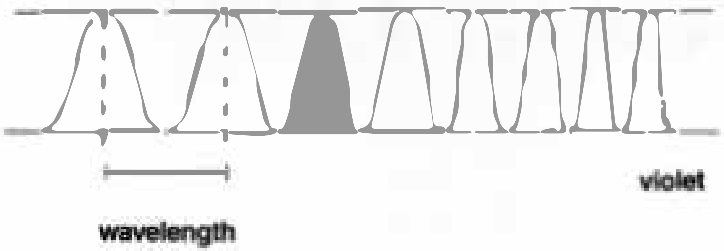
The result is that when two sound waves meet you might hear silence, then sound, then silence, then sound. These are called *beats* and they can be unpleasant to the ear.

If light consisted of streams of particles, this couldn't happen. One particle couldn't cancel out another.

In 1801, Young experimented by sending a beam of light through two different narrow slits, one very close to the other. After the beams passed through the slits, they spread out slightly and, by the time they had reached the wall, the two beams had overlapped.

You would suppose that where two beams of light overlapped, there would just be that much more light so that the wall would be brighter than in places where the beams did not overlap.

Not at all. Where the two beams overlapped, there were alternating stripes of light and dark. The beams of light canceled out in spots and added to each other in spots. They did this alternately, just like beats in music.



When two beams of light cancel out, we say that they *interfere* with each other, or that there is *interference*. The stripes of light and dark are therefore called *interference fringes*.

That settled it. Huygens was right and Newton was wrong. Light consisted of tiny waves. What's more, from the width of the interference fringes, Young could calculate how long the wave might be. This is called the *wavelength*. It turned out that a wavelength of light is in the neighborhood of 1/50,000 of an inch. This means that if you had a beam of light 1 inch long, it would consist of about 50,000 waves, one after the other.

Not all light waves are the same length. Red light has the longest waves and violet light the shortest. The shorter the wavelength, the more the light is refracted. That is why a prism separates the colors.

The red light all the way at one end of the spectrum has a wavelength of 1/32,000 of an inch. The violet light at the other extreme end of the spectrum has a wavelength of 1/64,000 of an inch. The other colors have wavelengths in between, and they get shorter in the order in which the colors appear: red, orange, yellow, green, blue, indigo, and violet.

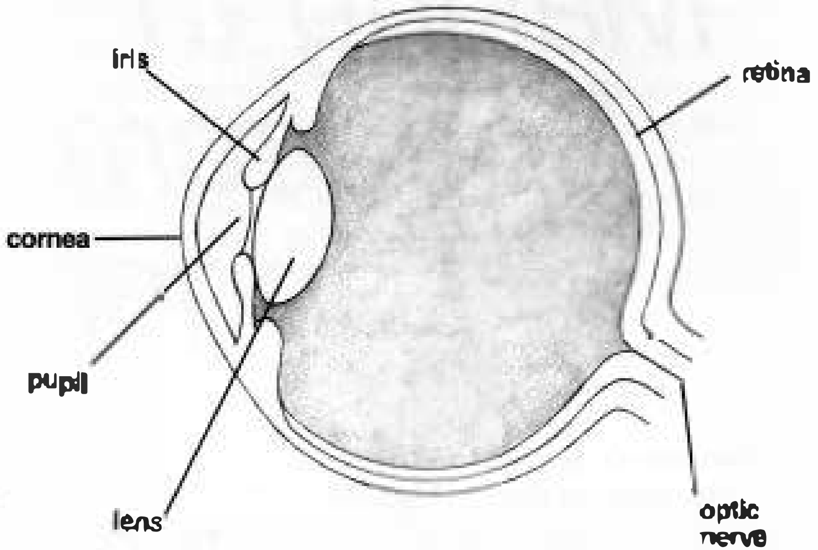
2

Making the Spectrum Longer

WHY DO WE see light and color?

The retina of the eye is a patch of thin tissue on the inside of the back of the eye. In the retina are different chemicals that absorb different bands of wavelengths of light. When all the wavelengths reach the retina, all the chemicals are working, and we see white light—ordinary light. When some wavelengths reach the retina in large amounts with others in small amounts, some chemicals work more than others and we see one color or another.

Is it possible that some wavelengths of light don't affect any of the chemicals in the retina, so that we simply don't see them?



It would seem not, because if wavelengths are present anywhere in the spectrum, we see them. One color or another, we see them.

That seems to settle the matter. Besides, the fact is that people before the 1800s never even thought about the matter. Light was simply something you saw if your eyes were in good working order. How could there be light that you couldn't see?

But then something turned up through the experiments of a German-British scientist named William Herschel (HER SH-ul, 1738–1822). He was best known for being an astronomer. For instance, he discovered the planet Uranus in 1781.

However, good scientists are interested in many things, and Herschel grew interested in the spectrum.

The sun delivers two things to us. It delivers light, which we can see, and heat, which we can feel. As everyone knows, at night it not only gets dark, it also gets colder.

Herschel wondered if the heat was delivered along with the light. One way to tell would be to put the bulb of a thermometer in the spectrum and see if the temperature went up.

It did!

Herschel wondered if different parts of the spectrum delivered different amounts of heat. He put the bulb of the thermometer in the violet part of the spectrum, then in the blue part, then in the green part, and so on. He found that the temperature went up in all of them, but the closer he got to the red end of the spectrum, the more it went up. The temperature went up most in the red itself.

That was a little surprising. Herschel may have felt

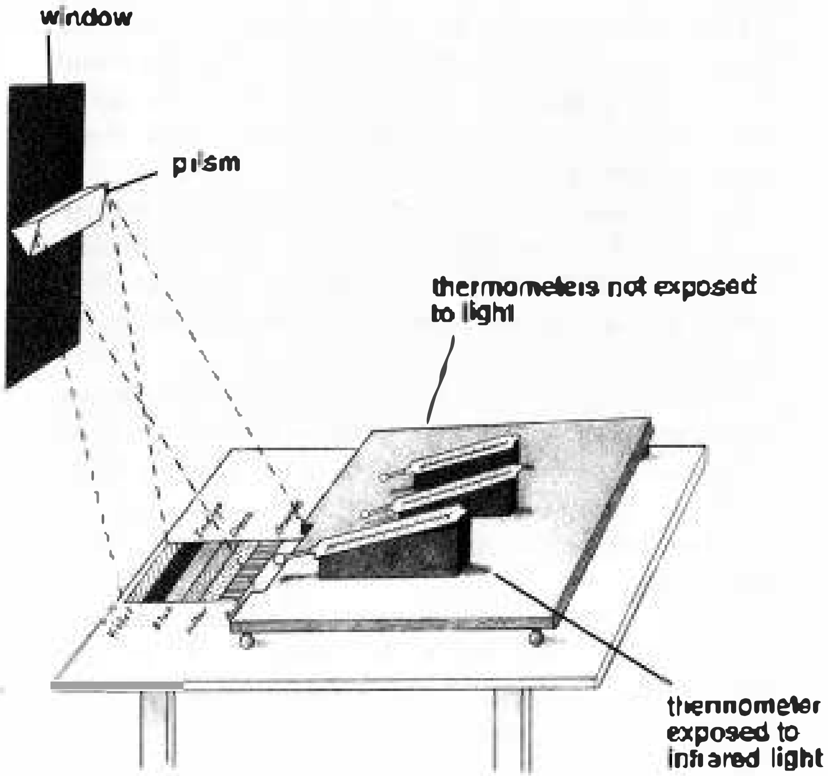


Diagram of Hershel's experiment

that the temperature should have gone up highest in the middle of the spectrum. Next he wondered what would happen if he put the bulb of the thermometer *beyond* the red end of the spectrum, where there was no light at all. He expected that the temperature wouldn't go up at all out there.

He was wrong! The temperature went up even farther than in the red light. The sun was delivering heat even where it was not delivering light. Herschel could only suppose that there were two kinds of rays from the sun, light rays and heat rays. It would seem, then, that there were two spectra, a light spectrum that we could see, and a heat spectrum that the thermometer could detect. The two spectra overlapped, but they seemed to be partly separate, too.

The next year, in 1801, a German scientist, Johann Wilhelm Ritter (1776-1810), tried something else.

It was known that light caused certain white chemicals that contained silver to break apart. Little grains of silver metal appeared in the chemicals. Since silver, when divided into little grains, looks black, the chemicals darkened in the light.

Ritter soaked strips of paper with a solution of the chemical and placed them in different parts of the spectrum. In the red band of the spectrum, there was no darkening. As he looked at the strips of paper farther and farther toward the violet end, however, there was more and more darkening. In the violet band, the paper darkened much faster than in ordinary sunlight.

Because he had heard of Herschel's experiment, Ritter put a strip of soaked paper *beyond* the violet, and it darkened faster even than in the violet. Could it be that the sun also delivered chemical rays? Were there three kinds of rays, and three kinds of solar spectra, one which you could detect with the eye, one with thermometers, and one with chemicals?

It was all pretty confusing until Young's experiments on light interference were reported and scientists realized that light consisted of waves.

It then seemed pretty clear that rays existed with waves even longer than those of red light, and that the chemicals in the human retina couldn't react to such long waves. In the same way, there were waves even shorter than those of violet light, and the chemicals in the retina couldn't react to such short waves, either.

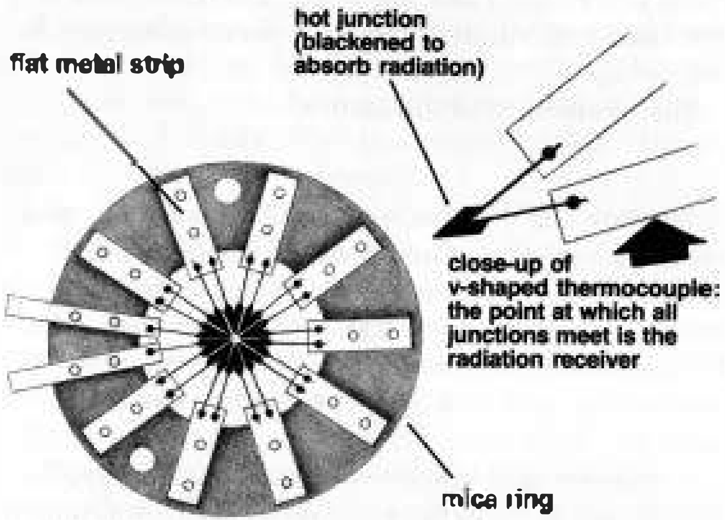
This meant that we can only see part of the spectrum, the part from red to violet. The whole spectrum stretches past the red and past the violet, but we can't see those extremes.

The part of the spectrum that reaches past the red is referred to as *infrared radiation*. *Infra* is from a Latin word meaning below. If we view the spectrum as running from violet on top to red at the bottom, the *infrared* is *below* the red.

The part of the spectrum that reaches past the violet is referred to as ultraviolet radiation. *Ultra* is from a Latin word meaning beyond and the ultraviolet is, indeed, beyond the violet end of the spectrum.

How could one make sure, however, that the infrared was really just like ordinary light, except for its longer waves, if one couldn't see it to study it?

Fortunately, a delicate way of measuring temperature was worked out in 1830. It was called a *thermopile*. This was a series of strips of two different metals that produced electric currents when one end was



Enlarged view of a modern thermopile

heated. Very weak electric current could be easily measured, so very small amounts of heat could be detected.

An Italian scientist, Macedonio Melloni (mel-LOH-nee, 1798–1854), improved the thermopile so that it could follow the infrared radiation as delicately as the eye could follow ordinary light. Then, since infrared waves didn't pass through glass as easily as ordinary light did, Melloni made lenses and prisms out of rock salt. Infrared waves went through rock salt very easily.

In 1850, he was able to show that infrared waves behaved just as ordinary light waves did. Infrared could be reflected and refracted. You could even take two beams of infrared and have them show interference fringes.

That really settled the matter.

But how far did the spectrum extend? Was there anything beyond the infrared and the ultraviolet?

The answer to that came as a result of the work of a British scientist named James Clerk Maxwell (1834-1879). Actually, he was interested in electricity and magnetism, and that brought him to the matter of light.

Electricity and magnetism had been known, in a simple way, even to the ancient Greeks. It was only in the 1800s, however, that scientists learned how to make an electric current run through wires (see *How Did We Find Out About Electricity?* by Isaac Asimov, Walker, 1973).

In 1820 it was found that if an electric current traveled through a wire, the wire could be made to act like a magnet. Then, too, if a magnet were pushed through a coil of wire, it could start an electric current going through the wire.

Electricity and magnetism had always been thought of as two separate things, but it looked more and more as though they were closely related.

That was what interested Maxwell. He wanted to study how this relationship worked.

He spent about nine years working on the problem, and by 1873, he had worked out four simple mathematical rules. These four rules described everything

that electricity and magnetism did, and they are called "Maxwell's equations."

If Maxwell's equations are correct, it turns out that it is impossible to have electricity without having magnetism too; or to have magnetism without having electricity. Actually, the two make up one thing, which is called *electromagnetism*.

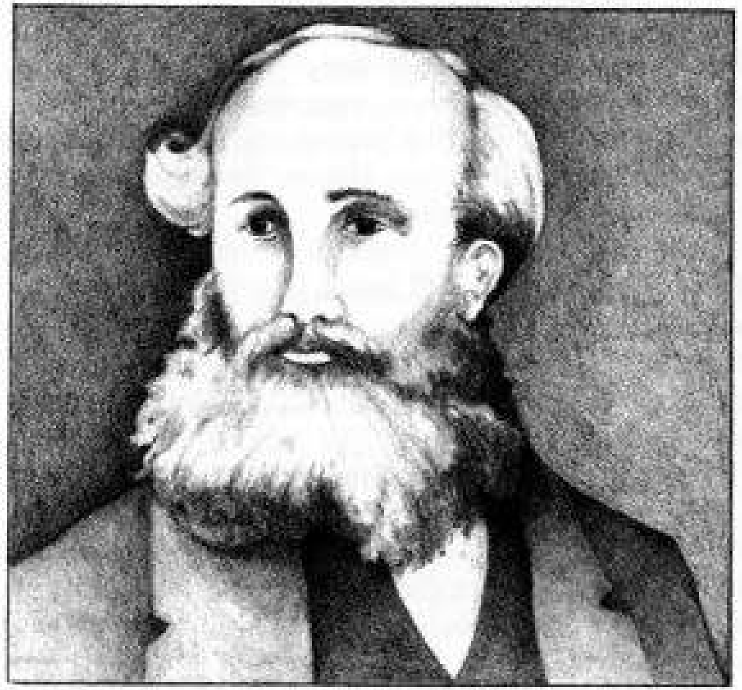
Maxwell showed that as soon as electricity came into being, it produced magnetism, which in turn produced electricity, which in turn produced magnetism, and so on. So the electromagnetic field leapfrogs outward in all directions. This spreading outward is *electromagnetic radiation*.

From his equations, Maxwell could work out how fast this radiation should travel. The speed was enormous—about 186,300 miles per *second*. That happens to be just the speed at which light travels. Maxwell decided, therefore, that light was an electromagnetic radiation.

But why does light come in different wavelengths?

Electromagnetic waves start because something carrying an electric charge is oscillating (AH-sil-lat-ing): that is, moving back and forth. Each time it moves back and forth, it creates a wave. Suppose the charge oscillates 60 trillion times a second. That means that when the radiation has traveled 186,300 miles (which takes it one second), there are 60 trillion tiny waves along that length of light. Each wave is 1/50,000th of an inch long. This is the wavelength of a visible beam of light.

In Maxwell's time, it wasn't known what existed inside the atom, if anything. Nowadays, though, we know there are electric charges inside the atom and



James Clerk Maxwell

they oscillate rapidly enough to produce light. The charges in all the different kinds of atoms oscillate with different rates, so that light of all the different wavelengths is formed.

Maxwell pointed out that nothing in his equations said electric charges could only oscillate at certain rates. They could oscillate so quickly that there could be electromagnetic radiation with wavelengths smaller than ultraviolet, or the electric charges could oscillate so slowly that there could be electromagnetic radiation with wavelengths longer than infrared.

3

Radio Waves and Microwaves

SCIENTISTS ARE ALWAYS dissatisfied if they have to suppose that something exists because the mathematics says it must. By predicting something, the mathematics tells them what to look for. Then scientists want to *find* what has been predicted.

Maxwell's equations said there could be electromagnetic radiations with wavelengths far beyond the infrared in one direction and far beyond the ultraviolet in the other direction. The thing was to locate that radiation.

The first to succeed was a German scientist named Heinrich Rudolf Hertz (1857–1894).

In 1888, Hertz set up an electric current that oscillated very rapidly. He had two metal balls separated by a small air gap as part of the circuit. The electricity surged into one ball. When it reversed direction, it surged into the other ball, then, when it reversed again, into the first ball again, and so on. Each time it surged into one ball or the other, a spark would flash across the gap.

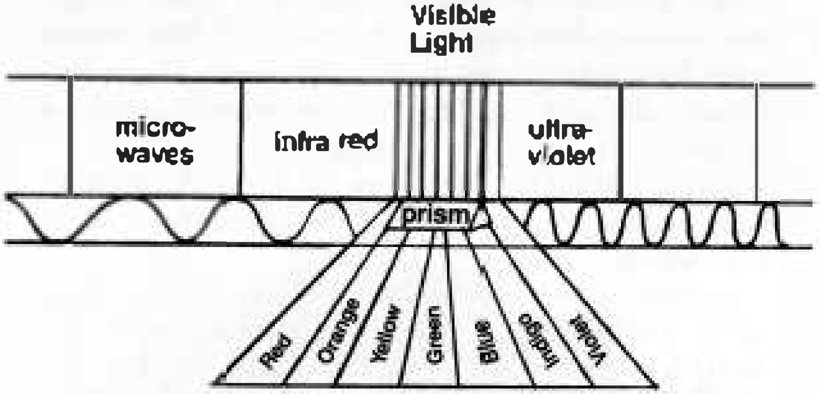
Hertz felt that if Maxwell was right, electromagnetic radiation should appear while the circuit was oscillating. This radiation should have a wavelength much longer than infrared. But how could he tell whether this was indeed happening?

To detect the electromagnetic radiation, Hertz used a simple loop of wire with a tiny gap in it. Just as the oscillating electric current produced radiation, so the radiation (if it were present) should set up an oscillating electric current in the loop of wire.

It did! Tiny sparks crossed the gap in Hertz's detecting loop. He carried it from place to place in the room. In places where the wave was way up or way down, the spark appeared—the farther up or down, the brighter the spark. Where the wave was neither up nor down, but in an intermediate position, Hertz had no spark. In this way, he could tell that the wavelength of the radiation produced by the oscillating current was 2.2 feet long, or well over a million times as long as the wavelengths of light.

These very long waves of electromagnetic radiation were called *Hertzian waves* at first. Later on, however, they came to be called *radio waves*.

Infrared waves, as they grow longer and longer, become radio waves. There is no sharp division between the two kinds of waves. For convenience, scientists use 1/25th of an inch as a dividing line. Wavelengths less than 1/25th of an inch are infrared waves (and if they're small enough they become light waves). Wavelengths more than 1/25th of an inch are radio waves.



Radio waves can be any length—a few inches long, a number of yards long, or many miles long. You can divide radio waves into long-wave, short-wave, and very-short-wave, if you wish. The very-short-wave radio waves are usually called *microwaves*. *Micro* comes from a Greek word meaning small.

Microwaves have wavelengths of anywhere from 1/25th of an inch to about 6¼ inches.

Once scientists knew about radio waves, they began to wonder if such waves could be used to send signals a long distance. For the previous fifty years, people had been sending messages by telegraph. That meant wires had to be strung along poles across whole continents, and cables had to be placed across the bottom of oceans.

Perhaps, if radio waves were used, people wouldn't have to depend so much on all those expensive wires and cables.

In 1890, a French scientist, Edouard Branly (bran-LEE, 1844–1940), invented a better detector than Hertz had used. Branly could detect radio waves at a distance of 150 yards. The British scientist, Oliver Joseph Lodge (1851–1940), improved the detecting device even further, so that he could detect radio waves at a distance of half a mile. He also sent out the radio waves in dots and dashes so that he could transmit a message in Morse code.

The most successful experimenter, however, was an Italian scientist, Guglielmo Marconi (mahr-KOH-nee, 1874–1937). He found that he could send out more powerful signals and receive them more easily by making use of long vertical wires called *antennas* (the same word for the long feelers that insects have on their heads).

By 1896, Marconi could detect a signal at nine miles. Could he do better still? After all, radio waves traveled in straight lines, and the surface of Earth's globe curved downward. After nine miles, the radio waves ought to just pass through the clouds and into outer space.

Guglielmo Marconi

Fortunately, there is a layer of charged particles high in the atmosphere. This layer is called the *ionosphere* (eye-ON-uh-sfeer) because charged particles are called *ions* (EYE-onz). The ionosphere reflects radio waves. Radio waves can bounce back and forth between the Earth and the ionosphere and, in this way, travel around the curve of the globe.

Marconi went to the southwest tip of England on December 12, 1902, and sent out radio wave signals from a balloon. Those signals were detected in Newfoundland on the other side of the Atlantic Ocean. Marconi had sent a message across the ocean without cables, just by radiation. For this reason, Marconi is considered to be the inventor of *radiotelegraphy* (telegraphy by radiation). This word was soon shortened to *radio*.

A few years later, a Canadian-American scientist, Reginald Aubrey Fessenden (FES-en-den, 1866–1932), learned how to make a radio wave vary in such a way that it took on the outline of a sound wave. Sound waves could then produce radio waves that followed the variations in the sound waves. At the other end, the shaped radio waves could be turned into those sound waves again. In that way, technicians could make the radio speak and play music. On December 24, 1906, music was sent over the radio for the first time.

Other improvements followed, until we had the radios and television sets of today.

Microwaves, the very short radio waves, had no particular uses until the 1930s. Then the question arose of detecting objects at a distance by means of radiation.

This is not strange to us because we detect objects at a distance in just this way. We see light that is reflected by distant objects. The resulting image allows us to judge what shape and color an object has, and about how far away it is.

We can't see things under the ocean, however, because light doesn't penetrate very far into water. Sound waves do, but sound waves are so long they aren't reflected by small objects under water. They curve around them instead.

Suppose, though, that very short sound waves are used, sound waves too short to be heard. Such sound waves are *ultrasonic* (from Latin words meaning beyond sound).

In 1917, a French scientist, Paul Langevin (lahnzh-VAN, 1872–1946), worked out a method for sending a pulse of ultrasonic waves down into the ocean and detecting the reflection. From the reflection, he could tell the size and shape of whatever it was that did the reflecting. From the time it took for the pulse to reach the object and return, the distance of the object could be calculated. This system was called *sonar*, an abbreviation of "*so*und *na*vigation *a*nd *r*anging," where ranging means "telling the distance."

During World War I, Langevin worked on sonar as a system for detecting German submarines under water. By the time sonar was in full operation, however, the war was over, and the Germans had been defeated. Sonar was used for scientific purposes after the war—to study the bottom of the ocean.

In the 1930s, it looked as though a new war with

Germany might come, and now it was airplanes that were an enormous danger. It was necessary to know if unseen airplanes were flying toward you at night, or flying above the clouds. Sonar wouldn't do. It was far too slow.

Electromagnetic radiation was needed that would travel at the speed of light. The waves couldn't be too long, or they wouldn't be reflected by airplanes. They couldn't be too short, or they wouldn't penetrate far enough through the atmosphere, especially if mist, fog, or clouds were in the way. It turned out that microwaves were just right—not too long, not too short.

Scientists had to figure out a way to send out pulses of microwaves and then to receive the reflection. They also had to learn to measure the difference in time between the outgoing pulse and the returning reflection, even though that was only a tiny fraction of a second. This enabled them to compute distance and size of an object.

By 1935, thanks mostly to a British scientist, Robert Alexander Watson-Watt (1892–1973), the system was made to work. Since it used very short radio waves rather than very short sound waves, it was called *radar*, an abbreviation of "*radio detection and ranging*."

War came in 1939 and, in 1940, wave upon wave of German planes attacked Great Britain. This was called the Battle of Britain. The Germans had more planes, but the British had radar and could always tell when the planes were coming and where they were. The outnumbered British planes were always on the spot, so that Germany lost the Battle of Britain, and even-

World War II coastal radar station

tually, they lost World War II, just as they had lost World War I.

Once World War II was over, radar and microwaves could be used for everyday purposes. Police used radar to measure the speed of cars so that they could more easily crack down on speeders. Airports used radar to spot planes in flight. This made it possible for them to organize takeoffs and landings without danger of collision.

Even in the home, microwaves came to be used.

Ordinary cooking involves heating objects over fires or over red-hot electric coils. Large quantities of infrared radiation are released and this transfers heat to the material being cooked.

Infrared radiation, however, doesn't penetrate very deeply into food, so that the heat only reaches the outside. The heat from the outside seeps into the inside only slowly. A turkey, for instance, must be roasted for a long time before the interior is heated properly.

Microwaves, however, with their longer waves, can penetrate objects more deeply. They can go right through a slab of meat, for instance, distributing heat to the interior of the food, not only to its surface. Many homes now have microwave ovens for the rapid preparation of food. Supermarkets provide food that is especially packaged for microwave cooking.

4

Planets and Microwaves

AFTER WORLD WAR II, radar could also be put to scientific use. For instance, the microwaves making up radar can be reflected by meteorites as well as by airplanes. Ordinarily, we can see meteorites only at night when they are heated white-hot as they pass through the atmosphere. We see them as shooting stars, which cannot be viewed by daylight any more than ordinary stars can. With radar, we can detect meteorites in daytime as well as at night.

Targets even farther off can be reached. In 1946, for instance, a radar beam was bounced off the Moon, and its echo was detected. In later years radar beams were bounced off Venus, Mercury, Mars, and Jupiter. Radar beams were even bounced off the sun.

The importance of these experiments is great. By measuring the time between the emission of the microwave pulse and the detection of its reflection, scientists could tell the distance of heavenly bodies. This method was far more accurate than any other up to that time.

What's more, radar could tell us things about the planets that we never knew before.

Suppose we begin by considering that, when a small body revolves around a large one, the large body sets up tides in the smaller one. The tides create friction, which slows down the smaller body's rotation around its axis. Eventually, the small body, as it revolves around the larger body, turns only one side to it. Thus, the Moon always turns the same face to Earth as it revolves around it.

Astronomers have thought for many years that Mercury faced only one side to the sun as the planet revolved around it. That side was thought to be forever extremely hot, while the other side, always in darkness, was thought to be extremely cold.

Can we tell that for sure now? Yes, for every object gives off electromagnetic radiation. The hotter the object is, the shorter the waves it gives off. An object has to be very hot to give off light waves that we can see. Cool objects give off longer waves that we cannot see, such as microwaves.

In 1962, astronomers could detect microwaves given off from Mercury's dark side. The microwaves were so short, and were present in such quantity, that it was clear Mercury's dark side was much warmer than had been thought. Therefore, it had to be warmed by the sun at least now and then.

Astronomers then sent a beam of microwaves toward Mercury and studied the reflection. If Mercury were turning on its axis, the microwaves would be slightly distorted and carry that distortion when they came back. From the size of the distortion, the rate at which Mercury is rotating could be calculated.

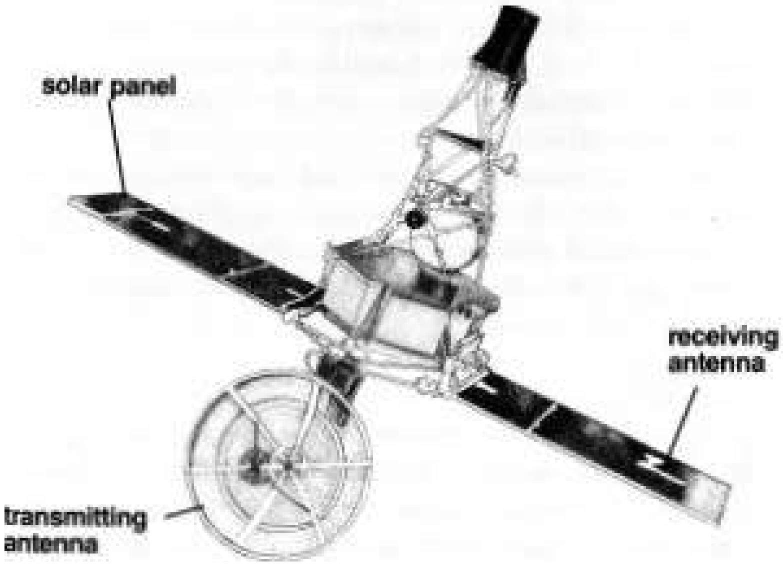
If it turned out that Mercury was rotating on its axis once in 88 days, just the length of its revolution around the sun, that would mean one side of Mercury would always face the sun.

In 1965, scientists discovered from microwave reflections that Mercury turned once in about 58⅔ days. That means it turns slowly with respect to the sun and every part of its surface gets sunlight at one time or another.

The planet Venus proved even more surprising. It is closer to us than Mercury is, and it is larger. Therefore scientists can study its dark side more easily than Mercury's. In 1956, it was found that Venus gave off microwaves in an amount that made it seem hot indeed.

Of course, Venus has a thick atmosphere and Mercury has none. Perhaps Venus's high clouds might be hot while the solid surface below was cool. In 1962, however, an American rocket probe, *Mariner* 2, passed near Venus and measured its microwaves. There was no question after that. The surface of Venus was hot everywhere, hot enough to melt tin and lead.

Scientists had suspected from Venus's thick clouds that it might be a very watery planet and only mildly warm, like Africa, perhaps. But microwaves told us



Mariner 2

that Venus is far too hot to live on and that its surface is absolutely dry.

Because the cloud layer is so thick and unbroken, no astronomer had ever seen the surface of Venus, and with no surface visibility there were no markings that could be watched as Venus turned so as to measure its rotation period. Some scientists thought Venus might turn in 24 hours as Earth and Mars did. Some thought it turned in 225 days, which is the time of its revolution around the sun, so that it showed only one side to the sun.

Both views were wrong. Microwave reflections, in 1962, showed that Venus rotates in 243 days, so that every part of it is exposed to the sun at some time or other, like Mercury. What's more, the planet rotates from east to west, while the other planets revolve from west to east.

Microwaves could reveal still more where Venus was concerned. In 1978, an American probe, *Pioneer Venus*, passed close to Venus and went into orbit around it.

The probe sent out beams of microwaves that passed through the cloud layer without trouble and were reflected from the solid surface of Venus. By studying the reflections of those microwave beams, scientists could calculate the nature of the planet's surface, in the same way as by studying light reflections. Of course, microwaves are much longer than light waves, so that Venus is seen in a fuzzier way.

The microwave reflections show that about five-sixths of the surface of Venus is made up of formations high above the average surface. The remaining one-

Mobile television unit
with microwave antenna

sixth is low and may have been filled with water when the planet was young.

On the continental areas, there are two large plateaus that bear mountain ranges. These possess mountain peaks that are higher than any on Earth. Some of those mountain peaks may be volcanoes, but they seem to be extinct.

5

The Universe and Microwaves

MICROWAVES REACH US from beyond the solar system, but the discovery of that fact came about by accident.

Long-distance telephone calls across the oceans were making use of radio waves. It often happened, in such calls, that radio waves from outside sources caused interference. The outside radio waves introduced crackling noises called *static*, which made conversations hard to hear.

The Bell Telephone Company wanted to find out where the interference was coming from so that they could find ways of removing it. In 1931, they gave the job to an American engineer named Karl Guthe Jansky (1905-1950).

Jansky set up a device that would receive radio waves. He knew that there would be some coming in from thunderstorms, from aircraft passing overhead, from nearby electrical equipment, and so on. Such problems were being worked on. Jansky was trying to find other sources of radio waves that weren't being taken into account.

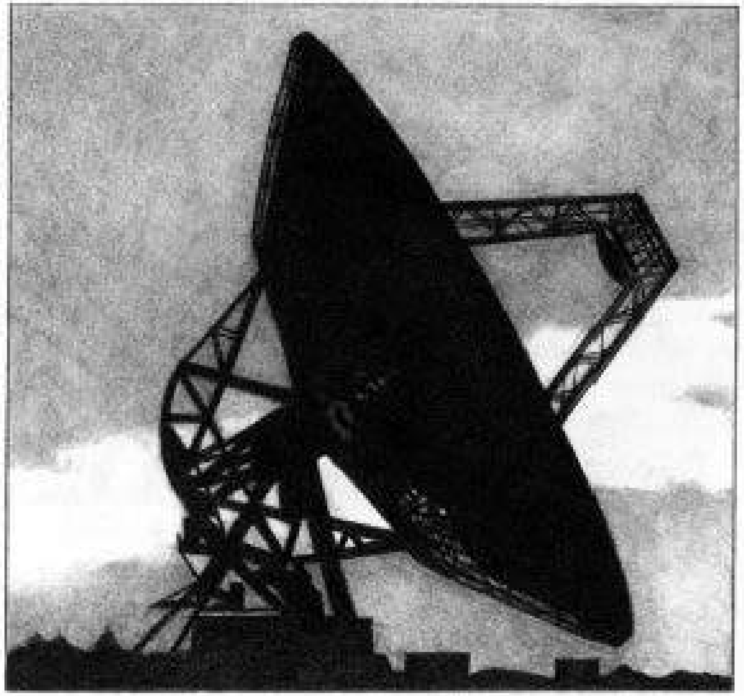
Jansky did detect a new kind of weak static that was very steady and that didn't come from any of the usual sources. He was surprised to discover that it was coming from the sky overhead. In fact, it seemed to be coming from the sun.

Why not? The sun gave off all the wavelengths of electromagnetic radiation; it was bound to give off radio waves, too.

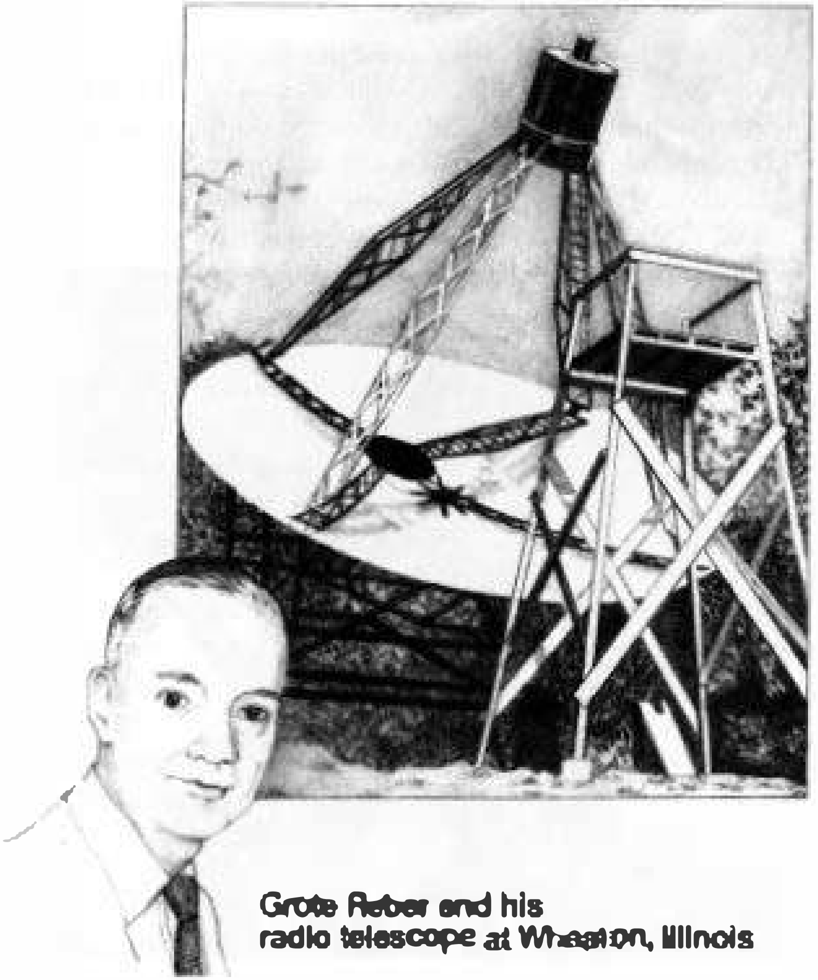
Jansky followed the source of the static from day to day, and it began to appear that it did not come from the sun after all. The source gained on the sun and appeared to be ahead of it, farther and farther, each day. It gained about four minutes on the sun each day.

As it happens, the stars gain on the sun by four minutes each day. It must be, then, that the source of the static came from somewhere outside the solar system, from some place in the stars.

As Jansky kept on watching, he decided that the static waves came from somewhere in the direction that the American astronomer Harlow Shapley (1885-1972) had shown, twenty years before, to be the location of the center of the galaxy. The radio waves, in other words, seemed to be coming from the center



Radio telescope



Grote Reber and his radio telescope at Wheaton, Illinois

of the collection of a couple of hundred billion stars that includes our sun.

In December, 1932, Jansky reported his findings. Radio waves were coming from the center of the galaxy, which we now know to be 30,000 light-years away.

This discovery created considerable excitement. The *New York Times* put the news on the front page. Yet scientists did nothing about it. There was only one who tried, and he was an American radio amateur, Grote Reber (born 1911). In 1937, he built a dish-shaped reflector in his backyard in Wheaton, Illinois. It received radio waves from the sky and reflected them to a detector in the center. This was the first *radio telescope*.

In 1938, Reber began to study the sky for sources of radio waves. He even made a "radio map" of the sky and published it in 1942. The results were very fuzzy, but Reber did more than anyone else at that time.

As it happens, very few kinds of electromagnetic radiation can get through the Earth's atmosphere. Ordinary light can do so, of course. Most ultraviolet light and still shorter wavelengths do not get through the Earth's atmosphere, however, and neither do most infrared or long radio waves. It's as though the band of ordinary light is a window in the atmosphere through which we can detect the universe.

There is a second window, though—the microwaves. These can pass through the atmosphere easily. The longer radio waves, if they start from Earth, bounce off the ionosphere and disappear into outer space. That's why microwaves weren't used in radio.

In the same way, long radio waves from outer space bounce off the ionosphere as they come toward us and never reach our instruments. Microwaves, however, pass right through the ionosphere and reach us. The radio waves detected by Jansky and Reber were microwaves.

Why weren't scientists more interested in microwaves from outer space? The answer is that, since microwaves weren't used in radio, instruments had not been devised to detect them and study them.

The development of radar in the 1930s, however, meant that such instruments were then devised and constructed. After World War II, when radar was not secret anymore, those instruments could be used by scientists. In the 1950s, radio telescopes were built and radio astronomy became extremely important.

Since a radio telescope deals with waves that are over a million times as long as light waves, a radio telescope must be over a million times as wide as an ordinary telescope to "see" as clearly.

There is a way of getting around that, however. Two small radio telescopes set miles apart can be made to act so completely and exactly together that they will behave as though they were one radio telescope miles across. In this way, radio telescopes can now be built in large groups that see even more clearly and sharply than ordinary telescopes can.

Radio telescopes give scientists information that ordinary telescopes can't possibly give. A distant galaxy may look perfectly quiet and peaceful when it is viewed by ordinary light. When it is viewed by a radio telescope, however, there may be large quantities of microwaves coming out of its center. Or there may seem to have been an explosion that sent large quantities of microwave-emitting material out of the center to either side.

Such galaxies are now called *active galaxies*. Even ordinary galaxies are more active than we dreamed before the days of radio astronomy.

At the center of our own galaxy, Jansky had noted radio waves in his first discovery. Now we know that there is, indeed, a very small spot at the very center of the galaxy that gives off large quantities of microwaves.

Scientists think there is a black hole at the center of our galaxy (see *How Did We Find Out About Black Holes?* by Isaac Asimov, Walker, 1978). Perhaps there is one at the center of every galaxy, but we might never have suspected this except for microwaves.

Most stars are so far away that their microwaves cannot be detected at such distances. We only detect the microwaves from our sun because it is so close to us.

Some stars, however, do send out enough microwaves to detect. These were called *radio stars*. They seemed so unusual that they were studied very carefully by ordinary telescopes and some seemed to have a certain fuzziness. It seemed that they might not be ordinary stars, so they were referred to as *quasi-stellar* (from Latin words meaning star-resembling). The phrase was soon shortened to *quasar*.

The light from these quasars was analyzed carefully, and the details of their spectra seemed very odd. It was not till 1963 that the Dutch-American scientist, Maarten Schmidt (born 1929), puzzled it out. The spectrum seemed odd because the quasar he was studying was moving away from us at an enormous speed. All the quasars were moving away from Earth at enormous speeds.

Scientists think that the faster an object moves away from us the more distant it is. If so, the quasars are unusually far away. Even the nearest quasar is one billion light-years away, and some have been discovered that may be seventeen billion light-years away.

Quasars seem to be extremely active galaxies. Their very centers, which are ablaze with activity, are all that can be seen, even in a telescope, at their great distance from us. The outer parts of the galaxy cannot be seen. That is why the centers look merely like faint stars. But for the microwaves they send out, scientists would never have thought of them as in the least interesting.

We see the farthest quasars as they were about seventeen billion years ago, for that is how long it takes their light to reach us. They existed, as we see them, in the very early days of the universe. If we knew more about these distant quasars, we might know more about how the galaxies of stars, which fill the universe, formed and took shape.

Certain radio stars give signs of twinkling, of sending out microwaves, in small, rapid bursts. A British astronomer, Antony Hewish (born 1924), designed a radio telescope that would detect such rapid bursts or twinkles. He set up 2,048 separate receiving devices spread out over an area of three acres.

In July, 1967, one of Hewish's students, Jocelyn Bell, noticed a very rapid pulsation of microwaves. The bursts were much more rapid and more regular than they had expected.

Hewish called the object a *pulsating star*, and this was eventually shortened to *pulsar*. In 1968, the Austrian-American scientist, Thomas Gold (born 1920), pointed out that it might be a very small, very dense object called a *neutron star*. Such an object would contain as much mass as an ordinary star, but it would have all that mass squeezed into a ball only eight miles or so across. Scientists now think that view is correct.

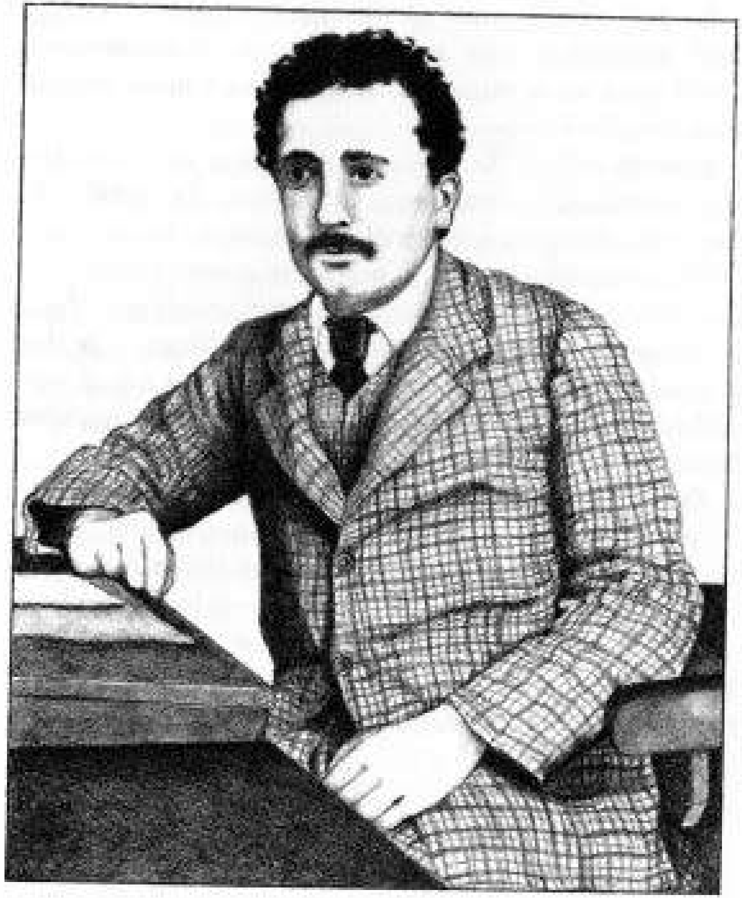
Pulsars rotate very rapidly, making a complete turn in just a few seconds at most, sometimes in a few tenths of a second. Recently, pulsars that rotated in a few thousandths of a second have been located.

If it hadn't been for their burst of microwaves, which sweep past us each time a pulsar turns, these peculiar stars might never have been discovered.

Since the 1920s, scientists have felt that the universe might have originated some time about fifteen or twenty billion years ago. It started as a tiny point of matter that exploded in a "big bang."

The universe is still expanding, and the galaxies are hurrying away from each other as a result.

But did it all really happen? In 1948, a Russian-American scientist, George Gamow (GAM-ov, 1904–1968), pointed out that if the big bang did happen, then there should be a faint background of microwaves coming equally from all parts of the sky.



Albert Einstein

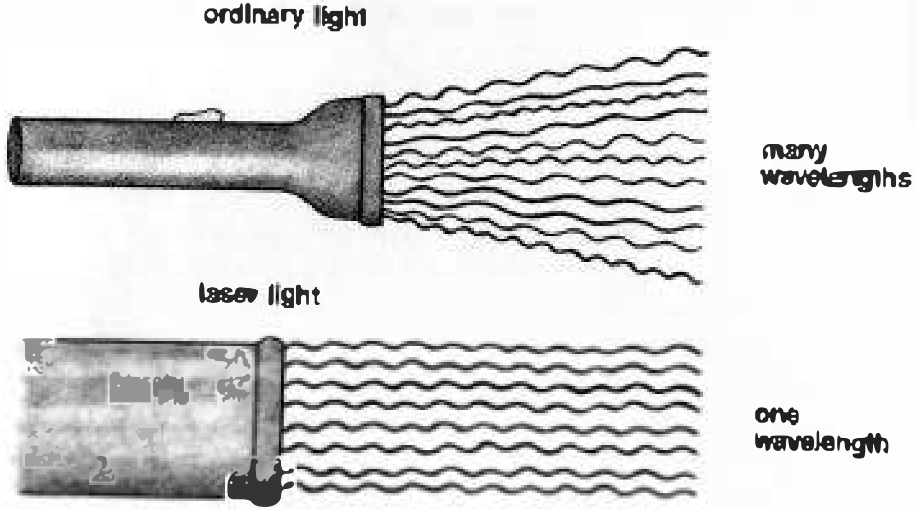
In 1964, a German-American scientist, Arno Allen Penzias (born 1933), and an American scientist, Robert Woodrow Wilson (born 1936), actually detected this microwave background. This is the best evidence we have that the big bang actually happened. If it weren't for the microwaves that were detected, no good evidence for the big bang might ever have been obtained.

In 1917, the German-Swiss scientist, Albert Einstein (1879–1955), pointed out that if a molecule were in a high-energy state and it was bumped by a wave of radiation, the molecule might give off some of its energy as radiation. The radiation it gave off would be in the form of a wave exactly the same size and direction as the wave that had bumped it. These might hit two more molecules and there would then be four, and then eight, and then sixteen, and so on.

The first wave would start a whole flood of waves all of exactly the same wavelength and all moving in the exactly same direction. This is called *coherent radiation*.

In 1933, an American scientist, Charles Hard Townes (born 1915), constructed a device in which a bit of microwave radiation produced a flood of the same microwave radiation. Townes called this "microwave amplification by stimulated emission of radiation" and this phrase was abbreviated to *maser*.

What could be done for microwaves could be done for other kinds of radiation, like that of ordinary light. An American scientist, Theodore Harold Maiman (born 1927), built a device in which a bit of light produced a flood of the same kind of light. This was



"light amplification by stimulated emission of radiation" or, a *laser*.

Both masers and lasers have proved very useful to scientists. In everyday life, lasers have produced new and superior kinds of music records, for instance, and new and superior kinds of printers for home computers.

And it all started when Newton passed a beam of light through a prism.