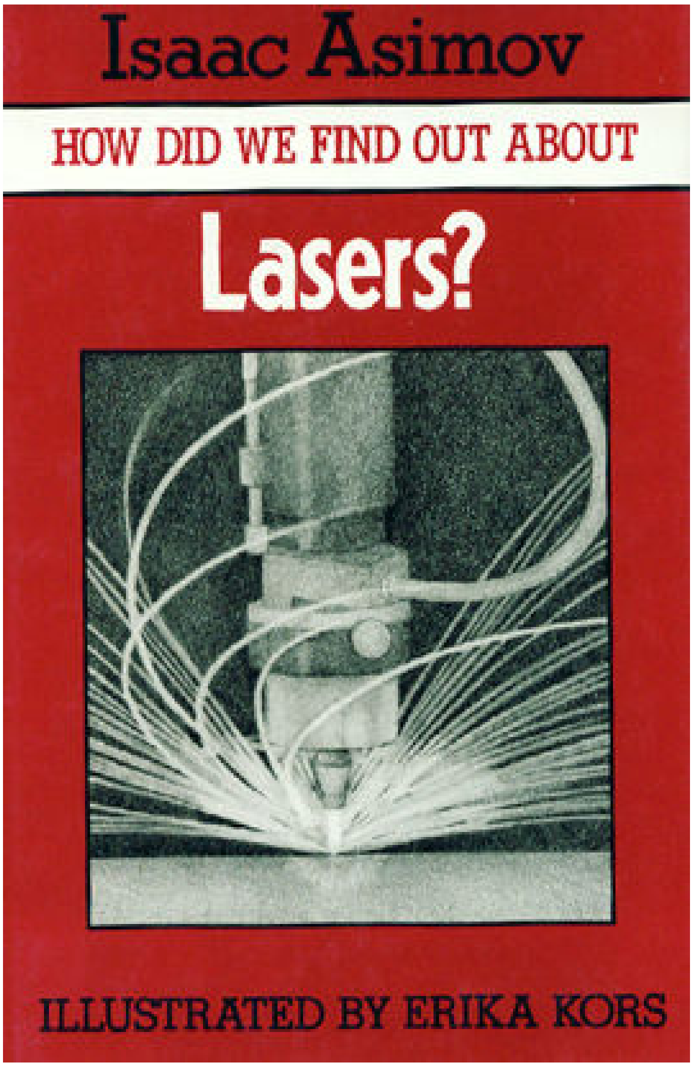


What is this marvellous ray that can read supermarket prices or mend a damaged eyeball? How can the same kind of light ray bore through steel and print a delicate picture?

It took Max Plank's quantam theory, Einstein's creative thinking, and Charles Towne's experiments in the 1950's to put us on the track of making such a powerful beam of light.

Light, which usually spreads out in all directions, needed to be forced into focus. Then one kind of wave length needed to be stimulated to be strong and straight. The device that was created to accomplish this work in the laser.

How it all happened is a real adventure story. The men who made it happen found out a great deal about light on the way to the laser.

Here you'll discover that laser really stands for** *Light Amplification by Stimulated Emission of Radiation*, **and learn about the many wonderful things it can do. And more waiting to be discovered.

1. Waves

THE LIGHT WE see consists of a stream of tiny waves. It takes about fifty thousand of these *light waves* to stretch across the distance of an inch. That means that each wave is about 1/50,000 of an inch long. This is a *wavelength.*

Before we go any further, let's describe the wavelengths without using inches. We use inches here in the United States, but everywhere else in the world, *meters* (MEE-terz) are used. Scientists everywhere, even in the United States, use meters.

One meter is equal to 39.37 inches, or about SVi feet. That is a pretty long distance, but meters can be divided into smaller units, just as we can divide yards into feet and feet into inches. A yard is divided into three feet, and a foot is divided into twelve inches. A meter, though, is always divided by even numbers such as ten, or a hundred, or a thousand. That is what makes the *metric system* (MET-rik) more sensible than the one we use.

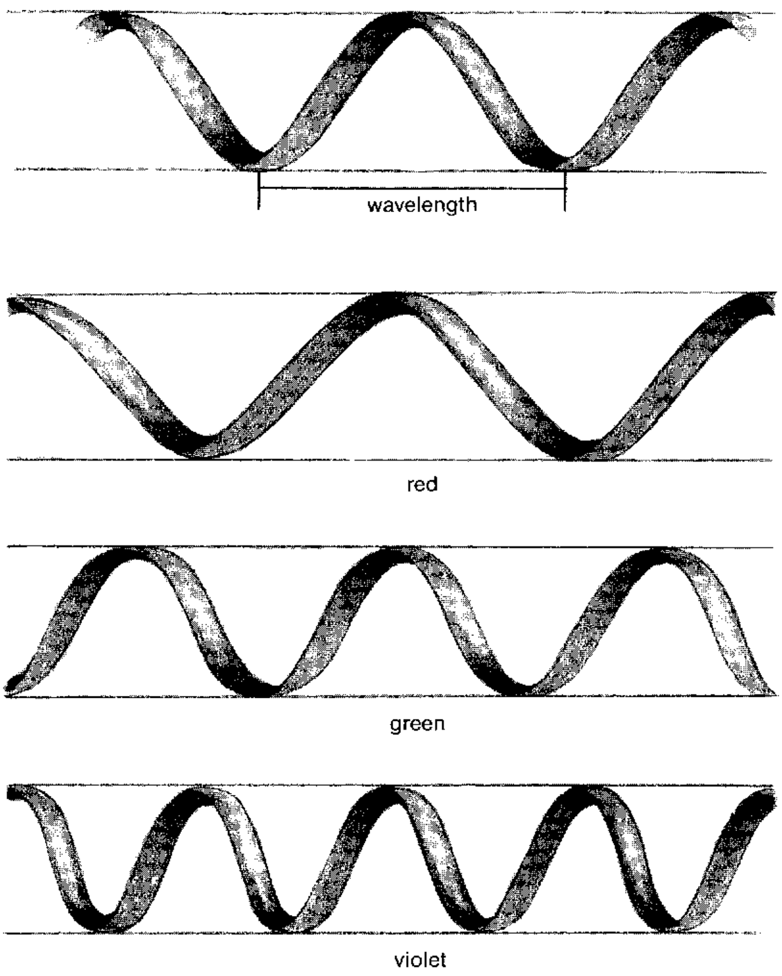
So we have:

1 *centimeter* (SENT-ih-MEE-ter) - 1/100 of a meter, or about 2/5 of an inch.

1 *millimeter* (MIL-ih-MEE-ter) - 1/1000 of a meter, or about 1/25 of an inch.

1 *micrometer* (MIKE-roh-MEE-ter) - 1/1000 of a millimeter, or 1 millionth of a meter.

1 *nanometer* (NAN-oh-MEE-ter) - 1/1000 of a micrometer, or 1 billionth of a meter.



Differences in wavelengths

A light wave is about 500 nanometers long. That's the same as saying 1/50,000 of an inch, but scientists all over the world prefer to use nanometers.

Of course, not all light waves have the same length. Some are a little longer, some a little shorter. We can tell the difference just by looking, because light waves of different lengths produce light that seems of different colors to our eyes.

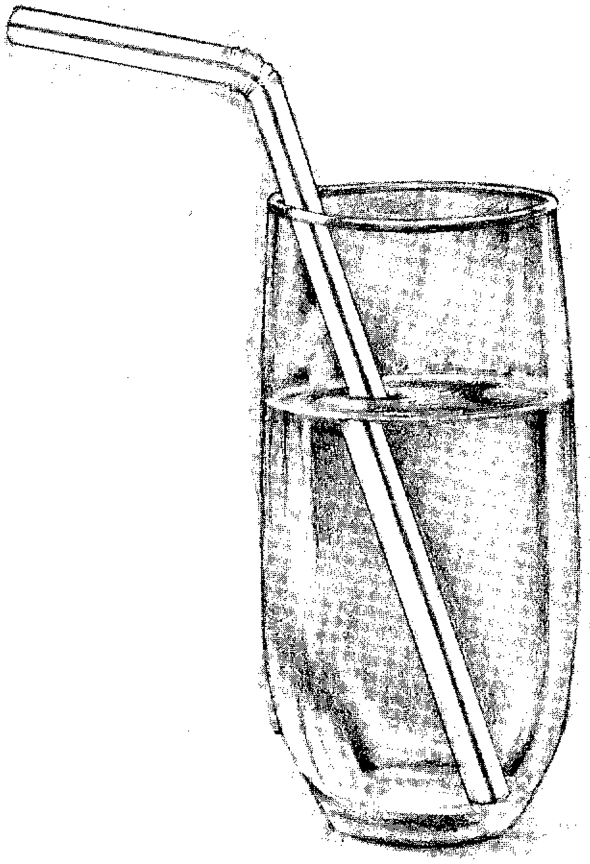
The longest wavelengths that we see look deep red to us. Those wavelengths are 780 nanometers. The shortest wavelengths we see look deep violet to us, and those are 390 nanometers. In between are the other colors: orange, yellow, green, and blue.

Each color has a small spread of wavelengths and, as the wavelengths change, the colors fade into one another. There are no sharp divisions. If we make a little table of the average wavelengths of different colors of light, it looks like this:

red	700 nanometers
orange	600 nanometers
yellow	580 nanometers
green	520 nanometers
blue	450 nanometers
violet	410 nanometers

Light bends slightly when it passes from air into water or glass. The shorter the wavelength, the more it bends. Sunlight is a mixture of all wavelengths, all colors, but when it passes into tiny drops of water in the air, the different wavelengths bend by different amounts and the colors all separate. That's what happens when we see a rainbow in the air. Water droplets have separated the wavelengths, and we see bands of color blending into one another.

But those are only the wavelengths our eyes can see.



Light bending as it passes from air to water

There is light with wavelengths longer than 780 nanometers, but our eyes just don't have the ability to see it. The same is true of light with wavelengths less than 390 nanometers. Yet such extra-long and extra-short light waves do exist.

In 1800, the extra-long light waves were discovered by a German-born, British scientist, named William Herschel (HER-shel, 1738-1822). Those extra-long light waves are called *infrared rays* (IN-fruh-red, meaning "below the red"). Infrared rays can have wavelengths of from 780 nanometers all the way up to 10 million nanometers, or 1 centimeter, which is the same thing.

In 1801, the extra-short light waves were discovered by a German scientist named Johann Wilhelm Ritter (RIT-er, 1776-1810). Those extra-short waves are *ultraviolet rays (UL*-truh-VY-oh-let, meaning "beyond the violet"). Such ultraviolet rays have wavelengths of from 390 nanometers down to about 10 nanometers.

But where does it stop? How short can the waves get? How long?

In 1873, a British scientist, James Clerk Maxwell (1831-1879), showed that electricity and magnetism were different ways of dealing with the same thing. The combination is called *electromagnetism* (ee-LEK-troh-MAG-neh-tiz-um).

Objects that carry electricity or objects that are magnetic produce an *electromagnetic field* that fills the space around them. This electromagnetic field can produce waves of *electromagnetic radiation* (RAY-dee-AY-shun). The kind of light we see, as well as infrared rays and ultraviolet rays that we don't see, are all examples of such electromagnetic radiation.

Maxwell argued that such radiations could come in any wavelength from thousands of meters down to tiny fractions of a nanometer.

In 1888, a German scientist, Heinrich Rudolf Hertz (HURTS, 1857-1894), discovered very-long-wave radiation. These waves came to be called *radio waves,* and some of them are indeed thousands of meters long. In American measurements, it means that some radio waves have wavelengths of miles.

The shortest radio waves, those that are just a little longer than the longest infrared rays, are *microwaves* (MIKE-roh-wavez). The wavelengths of microwaves are anywhere from 1 millimeter long to 150 millimeters. (In inches, that would be anywhere from l/25th of an inch to 6'/4 inches.)

In 1895, another German scientist, Wilhelm Kon-rad Roentgen (ROINT-gen, 1845-1923), discovered very-short-wave electromagnetic radiation. He called it X *rays,* and its wavelengths turned out to be anywhere from 10 nanometers down to about 1/1000 of a nanometer.

The next year, a French scientist, Antoine Henri Becquerel (beh-KREL, 1852-1908), found that certain elements, like *uranium* (yoo-RAY-nee-um), were constantly giving off radiation. Another French scientist, Paul Ulrich Villard (vee-YARD, 1860-1934), found that among the radiations given off by uranium was a kind of electromagnetic radiation with wavelengths even shorter than those of X rays. The new radiation are the *gamma rays* (GAM-uh), which have wavelengths all the way down to 1/100,000th of a nanometer, or less.

Here, then, is a list of the different kinds of electromagnetic radiation, from the longest waves down to the shortest:

radio waves

microwaves

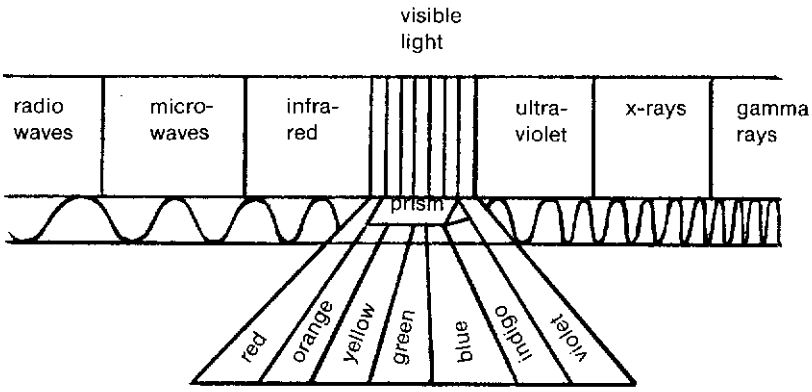
infrared rays

visible light

ultraviolet rays

X rays

gamma rays



Different kinds of electro magnetic waves from smallest to longest

2. Radiation and Energy

LIGHT is a form of *energy* (EN-ur-jee). Energy is anything that can do work, and light can do work.

A beam of light seems to pour out energy continuously, just as though it were a stream of water. The energy might seem as though it could be broken up into smaller and smaller bits forever. The stream of water looks like that, too, but we know that water is made up of tiny atoms that are far too small to see, and that atoms are the smallest bits of ordinary matter.

If water looks as though it pours out in a steady stream but is really made up of tiny atoms, is it possible that energy is really made up of tiny chunks of some kind, too?

A German scientist, Max Karl Ernst Ludwig Planck (1858-1947), was wondering about that in 1900. He was trying to work out the way in which hot objects give off electromagnetic radiation of different wavelengths. Why do they give off more of one kind of wavelength than of another kind?

A number of scientists had tried to work out an explanation and to use that as a way of describing how the wavelengths ought to come off. However, their descriptions never fit what was really so, and a scientific explanation that doesn't match reality is useless.

All the other scientists, however, had tried to work things out by supposing that energy just poured out continuously and didn't consist of little chunks. Planck thought: What if those little chunks are there?

He put that possibility into his thinking and found that he was able to work up a description of how hot objects produced radiation of different wavelengths. His description matched what was really so.

Planck wondered just how much energy there was in each little chunk, so what he worked out is called *quantum theory* (KWAN-tum, from a Latin word meaning "how much?"). Planck found that the amount of energy in each chunk was extremely tiny. That's why it took so long for scientists to realize those chunks were there.

In 1918, Planck received a Nobel Prize for this work.

Max Plank in his study

Eventually, each little chunk was called a *photon* (FOH-ton). One very important thing that Planck found out was that the amount of energy carried by a photon was different for electromagnetic radiation of different wavelengths. The shorter the wavelength, the greater the energy of the photon.

For instance, violet light has a wavelength about half that of red light. This means that a violet-light photon has twice the energy of a red-light photon. For this reason, violet light can do more work. Even though a particular beam of red light and another of violet light might have the same total energy, the violet light comes in larger photons, and that's what counts.

Suppose, for example, someone threw a pound of powder at you. You wouldn't feel a thing. If he threw a pound of pebbles at you, you would feel each pebble. If he threw a one-pound piece of rock at you, he might hurt you very badly.

One of the kinds of work light does is to darken the chemical on photographic film, so that you can form a picture on it. The red-light photons are so small that, with ordinary film, nothing happens to the chemicals. That's why films are often developed under red light. You can see what you're doing and the film isn't affected. With shorter-wavelength light, the film would be darkened at once.

Naturally, wavelengths that are longer than red light carry still less energy. Infrared rays have less energy than visible light. Microwaves have still less energy, and radio waves have the least energy.

It works the other way at the other end of the spectrum. Ultraviolet rays, with shorter wavelengths than visible light, have more energy. X rays have still more energy, and gamma rays have the most energy.

We can feel the increase in energy as wavelengths grow shorter. Radio waves are all about us because radio and television stations broadcast them, but they are too low in energy to harm us. Sunlight, on the other hand, darkens our skin. If we have very fair skin, sunlight might even burn our skin.

Exposure to sunlight over a considerable period, especially to the shorter wavelengths of sunlight, can cause skin cancer. There are ultraviolet rays in sunlight, and those do most of the damage.

X rays and gamma rays are even more dangerous. Doctors and dentists use X rays to study the situation in tissues inside your body. However, they expose you as briefly as possible. Gamma rays are even more dangerous.

Whenever any object is surrounded by material that is cooler than it is, the object gives off electromagnetic radiation that cools it down. When an object is surrounded by materials that are warmer than it is, the object absorbs the electromagnetic radiation being given off by the other material, and it warms up. Electromagnetic radiation always goes from a warmer place to a cooler place, evening out the temperature.

So everywhere in the universe, photons are flying from one object to another. Some are being given off all the time, and this is called *emission of radiation.*

Objects giving off photons give them off in a variety of wavelengths, but some wavelengths come off in greater quantities than others. Usually, there is some intermediate wavelength that comes off in greatest amounts. Wavelengths that are longer or shorter come off less frequently. Wavelengths that are much shorter or much longer hardly appear at all. This was all explained by the quantum theory.

Suppose an object gets hotter and hotter. Naturally, as it does so, it gives off more and more photons. What's more, as it gets hotter and hotter, the photons it produces have more and more energy, on the average. That means that the intermediate-wavelength photons that are given off most frequently are of shorter wavelength in hot objects than in cold objects.

Thus, very cold objects give off only photons of radio waves and microwaves. By the time an object is as warm as the human body, it is giving off mostly infrared rays.

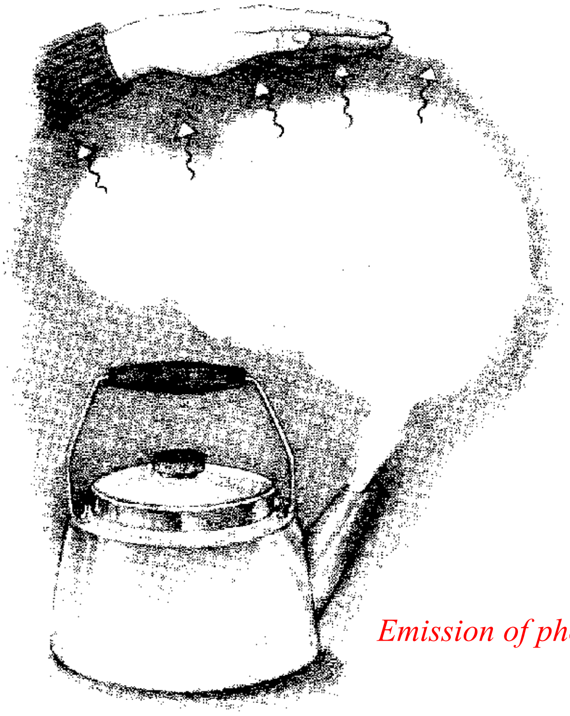
A kettle of boiling water gives off a great deal of infrared rays, and if you put your hand near the kettle (not on it, of course), you can feel the rays as heat. Your hand is cooler than the kettle, so it absorbs the infrared-ray photons, and that warms your hand.

If you were to heat something very strongly, then, eventually some photons of visible light would begin to be given off. Mostly there would be the longer light waves, so the object would be *red hot.* If it were heated further and further, more and more visible-light photons of shorter and shorter wavelength would come off and the object would be *white hot.*

The surface of the sun is white hot. If you build a bonfire, that fire is not as hot as the sun's surface, and the flames seem to be yellowish or even orange.

In any object, the various atoms and combinations of atoms contain energy, and they are always moving around and jostling each other. The jostling transfers photons from atom to atom and sends some into the outside world.

Generally, each atom gives off a photon of some particular wavelength in such a way that it is moving in some particular direction. Another atom may give off a photon of a different wavelength in a different direction.



This means that in any object, we have photons spraying outward in all directions and over a whole range of different wavelengths. This is true of sunlight, of bonfires, of candles, of electric lights, of hot kettles, of everything. You wouldn't think there was any other way in which photons could be given off.

Emission of photons as an object becomes hotter

3. Masers

IN 1917, A German scientist, Albert Einstein (1879-1955), thought about the way photons are given off. It seemed to him that a particular type of atom or group of atoms could pick up a photon of just the right size to send it to a higher level of energy, one that would just fit its structure. The atom or group of atoms would then be *excited* and, sooner or later, it would give up the extra energy and would produce a photon of just the size that had excited it. Different atoms would give up those photons at different times and in different directions.

But suppose you could get all the atoms in a given material excited. All of them would have this extra energy. And suppose that a photon would now come along of just the right size to excite them. It would hit an atom, but it wouldn't excite it because that atom was already excited. Instead, the photon would cause the atom to give up its own extra photon at the moment it was hit. The photon it gave off would be exactly the size of the photon striking it, and the second photon would move off in exactly the same direction as the first.

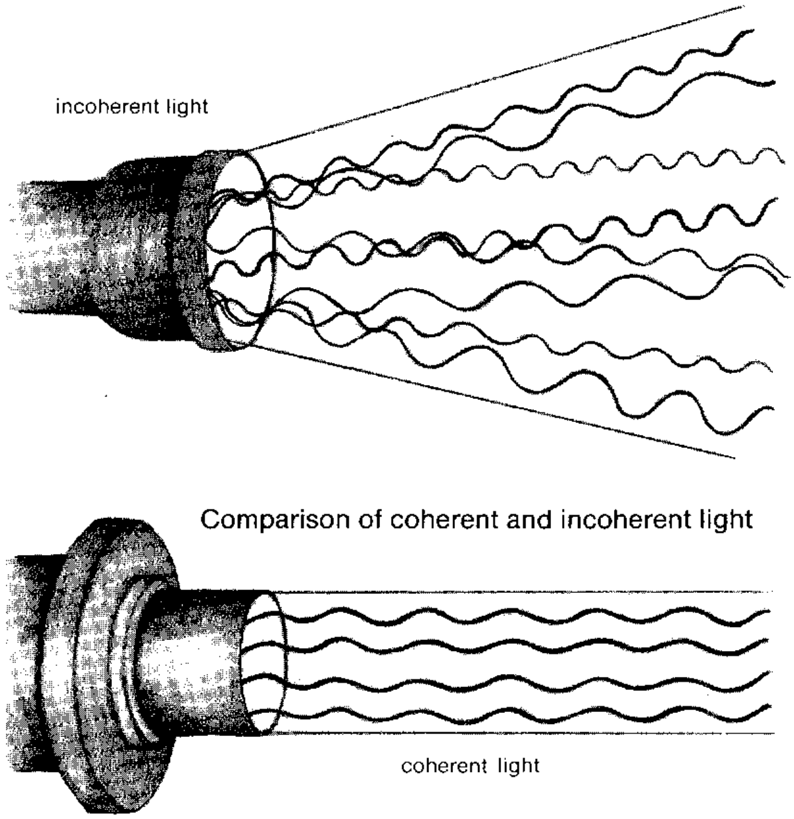
Now there would be two photons of the right size, and they would hit two other atoms and produce two more photons. Then the four would hit four other atoms and there would be eight, and so on, and so on. All this would happen very quickly so that, before you could blink your eyes, billions and billions of photons would be produced, all of the same wavelength and all moving in the same direction.

This is not the ordinary kind of emission of radiation that you see in a bonfire or in the sun, where the photons fly off every which way and at every wavelength. It is the kind of emission that happens when excited atoms are struck by a photon of just the right size. The atoms are *stimulated* by the photon, so this kind of emission is called *stimulated emission of radiation* .

What's more, though yon start off with a single photon, you end up with countless numbers. You might not detect the single photon to begin with, but the vast numbers of photons you produce are easy to detect. The original photon has been magnified or *amplified* into a much larger display of energy. When this happens, you can speak of *amplification by stimulated emission of radiation.*

Ordinary radiation, with its photons moving in every which way on every which wavelength, doesn't stick together. It tends to spread out. Even if you use a curved mirror so that all the rays of light are reflected in the same direction, as in a flashlight or in an automobile light, the light still spreads out quickly. Such light is *incoherent* (in-koh-HEER-ent), meaning "doesn't stick together." It is also *polychromatic* (POL-ee-kroh-MAT-ik), meaning "in many colors" or "in many wavelengths," Stimulated emission of radiation, however, has all the same wavelength. It is *monochromatic* (MON-oh-kroh-MAT-ik), meaning "one color" or "one wavelength. " Also, since all the photons are moving in the same direction, the light hardly spreads out at all. It is *coherent* (koh-HEER-ent), meaning it "sticks together. "

Einstein was a theoretical physicist. That means he tried to work out in his mind and on paper what ought to happen if Planck's quantum theory was correct. Rut suppose Planck's quantum theory wasn't completely correct. We should set up an experiment and see if we actually do get stimulated emission of radiation. We have to see if reality matches the theory.



Comparison of coherent and incoherent light

In 1924, experiments were conducted that showed there could indeed be stimulated emission of radiation and that such radiation would indeed be coherent and monochromatic.

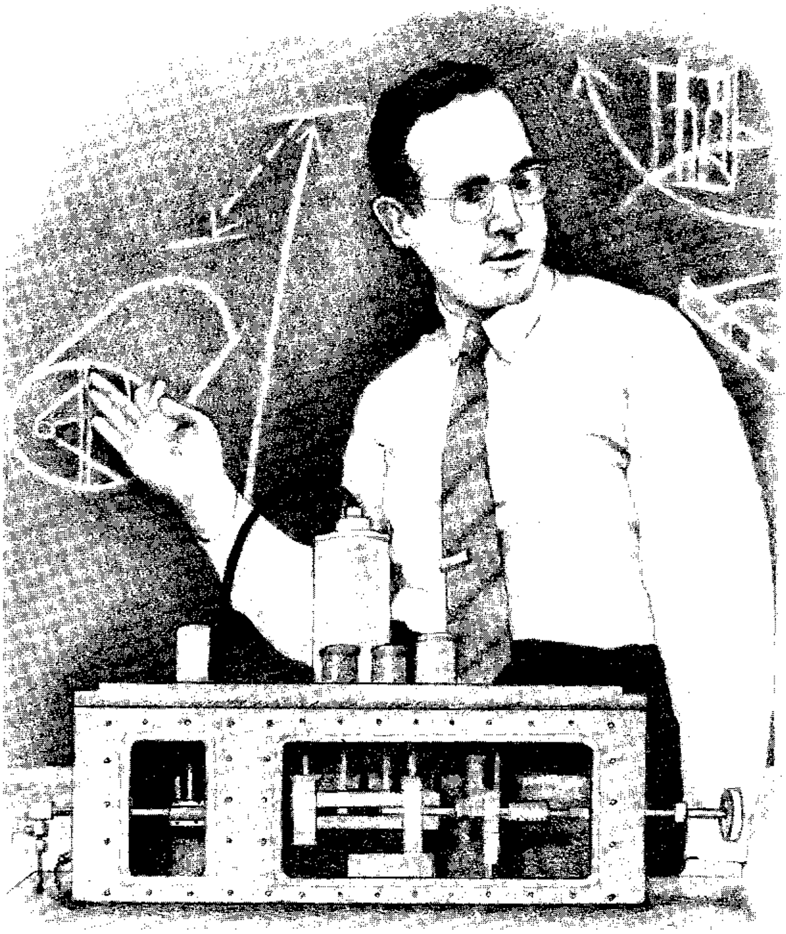
But how could you produce real quantities of such coherent radiation? It doesn't sound as though it would be easy. After all, there is a great deal of radiation in the universe about us, but it is all incoherent. That makes it look as though ordinary emission is easy to produce and stimulated emission is hard.

The reason stimulated emission is hard to create is that once you stimulate atoms to absorb particular photons; they don't hang on to those photons very long. You can't seem to get enough atoms excited and keep them excited long enough to stimulate them.

This seemed so clear that, for a long time after scientists knew that stimulated emission of radiation was possible, no one tried to bring it about in an important way.

But then, in 1951, an American scientist, Charles Hard Townes (b. 1915) was trying to figure out a way of producing a strong beam of microwaves. It occurred to him that the molecule of a gas called "ammonia" would absorb a microwave photon of just the size he was interested in. If enough ammonia molecules could be excited and if they could be stimulated, he would get a strong beam of microwaves.

Townes realized that it wouldn't be possible to excite all the ammonia atoms and keep them excited just by heating them. Other methods would have to be used. An electric current might do it, or a beam of light, or a chemical reaction. If he could do it, then he could stimulate the excited ammonia and get his large beam of microwaves.



Charles H. Townes explaining his ammonia maser

Not until December 1953 were Townes and his students able to devise a successful instrument. Inside it, the ammonia molecules could all be excited and made to hang on to their extra photons till a photon of the right size was sent in to make them all let go at once. That was amplification by stimulated emission of radiation, but since it involved microwaves, it was *microwave amplification by stimulated emission of radiation.*

Even scientists don't like to say all that every time they want to talk about the device, so Townes took the initial letters of the long words: m-a—s-e-r. He called it a *maser* (MAYZ-er).

At about the same time, two scientists in the Soviet Union were also working on schemes for setting up a maser. One was Alexander M. Prokhorov (proh-HOR-ov, b. 1916) and the other was Nikolai G. Basov (BAS-ov, b. 1922). In 1964, a Nobel Prize was shared by all three—Townes, Prokhorov, and Basov—for their work on the maser.

The first masers that were built gave off only brief pulses of microwaves. Once the atoms or molecules were excited and then stimulated, all the extra photons would be emitted and, in a fraction of a second, there would be no more excited atoms or molecules in the maser. The molecules would have to be excited again before they could be made to emit radiation again.

But in 1956, a Dutch-American scientist, Nicolaas Bloembergen (BLOOM-ber-gen, b. 1920), got the idea of using a molecule that would have three energy levels. There would be the ordinary level at the bottom, then an excited level above that, and then a still more excited level above that.

If you have such a three-level maser, you can pump the molecules from levels one to level three. A photon of the proper size will drop the molecule from level three to level two, releasing a flash of microwaves. The molecules would then drop from level two to level one but would be immediately pumped up to three again. One kind of photon could do the pumping and another kind could do the stimulation. They could work together, without interfering with each other, so that the maser stays excited and continues to emit.

Bloembergen was the first to build a "continuous maser," and, in 1981, he was given a share of the Nobel Prize for this.

Remember that masers are amplifiers. Suppose a maser is exposed to radiation from space. If a photon happens to come along that is at the proper energy level, it will excite a beam of microwaves from the maser. Scientists would find it much easier to detect the beam than the original photon. This makes a maser a very sensitive *detector* and helps astronomers learn more about what goes on in space.

Of course, a particular maser might detect only photons of certain energy, but different kinds of masers were quickly manufactured. Some made use of one gas or another. Some made use of solid materials. Actually, then, microwaves of a great many different wavelengths can be detected by one type of maser or another.

Remember, too, that the microwave beams produced by masers are coherent. They don't spread out very much even over long distances. A beam of such microwaves, aimed in the right direction, can travel all the way to Venus without spreading much. It will hit Venus and be reflected, and the *microwave echo* can then be detected when it returns to earth.

Microwaves travel at the speed of light, and we know the speed of light very exactly. The time between the emission of the beam and the detection of the echo is the time it takes the microwaves to go to Venus and back at the speed of light. (It's only a matter of minutes!) That tells us exactly how far away Venus was at the moment the microwaves struck its surface.

In fact, measuring astronomical distances by microwave beams is the best way of doing it that we have yet discovered. Astronomers now know the orbits of the planets more exactly than ever before.

Venus has a thick layer of clouds that covers the entire planet at all times. We can't see through the clouds, even with the best telescopes, so until recent years no one had any idea what the solid surface of Venus was like. They couldn't even tell how fast Venus was turning or in which direction.

Microwaves, however, can pass right through Venus's clouds and hit the solid surface. There they are reflected and pass through the clouds again so that the echo reaches us.

A beam sent out by a maser is monochromatic and is all the same wavelength. If Venus's surface were perfectly smooth and motionless, the beam would be reflected with no change in its wavelength. However, if the planet is turning, the surface is moving, and that produces a change in the wavelength. The faster it is moving, the greater the change. Through studying microwave echoes, scientists were able, in 1962, to calculate the exact way and speed in which Venus was rotating. They never knew that before.

Then, too, if the surface of Venus is uneven, if it has mountains and ravines, that also affects the microwave echo. Such beams have actually been used to locate those unevennesses. In 1978, a probe was put into orbit around Venus, and it worked out a map of Venus's surface by microwave echoes.

Microwave beams have reached farther than Venus. They have touched Mercury, Mars, the sun, Jupiter, and so on. In 1989, microwave echoes were detected after a microwave beam was bounced of Titan, a large satellite of the planet Saturn, which is thirty-five times as far from Earth as Venus when Venus is closest to us.

Titan is the only satellite that has an atmosphere, and that atmosphere is so thick and hazy that even a probe wasn't able to tell us anything about its surface.

The microwave beam, taking about 2Va hours to go to Titan and back, could pass through the clouds and give us information about the surface. It was sent out on three different days, hitting different parts of Titan's surface each day, since the satellite turns. The echo on the first and third days was very weak, as though it had hit liquid. On the second day, it was strong, as though it had hit solid material.

It may be, then, that Titan, like Earth, has both oceans and continents. But, of course, the materials making up Titan's oceans and continents are surely far different from those making up Earth's surface.

4. Lasers

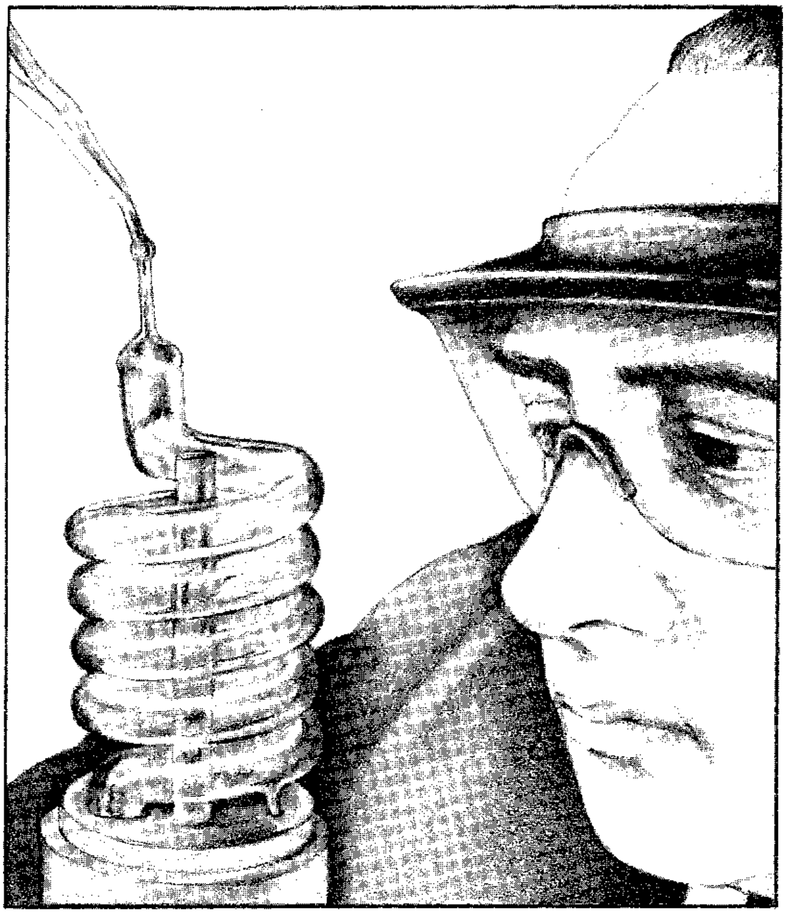
IF YOU CAN prepare masers that produce beams of microwaves of one wavelength or another, then why can't you produce beams of electromagnetic radiation that are not microwaves at all? If you choose your materials carefully, you may get energy levels that are far enough apart to produce unusually energetic radiation. That would be radiation with unusually short wavelengths. Perhaps you could produce a beam of infrared waves, or even of visible light.

Townes was already thinking about that in 1958 and trying to work out what materials might be needed in a maser to produce a beam of light instead of microwaves. A light-producing maser would be an *optical maser.*

That's not what scientists decided to call it, however. A maser is *microwave amplification by stimulated emission of radiation.* If a light beam were produced instead, that would be *light amplification by stimulated emission of radiation.* The initials of that, as you can see, are 1-a-s-e-r, so the device is called a *laser* (LAYZ-er).

You can tell by the first letter. A maser produces a coherent, monochromatic beam of microwaves; a laser produces a coherent, monochromatic beam of light.

The first successful laser was put together in 1960 by an American scientist, Theodore Harold Maiman (MAY-man, b. 1927). He used a rod of synthetic ruby, which consists of a material called aluminum oxide to which a small amount of chromium oxide is added. It is the chromium atoms that give the material a red color and make it a ruby.



Theodore Maiman contemplating the first ruby laser

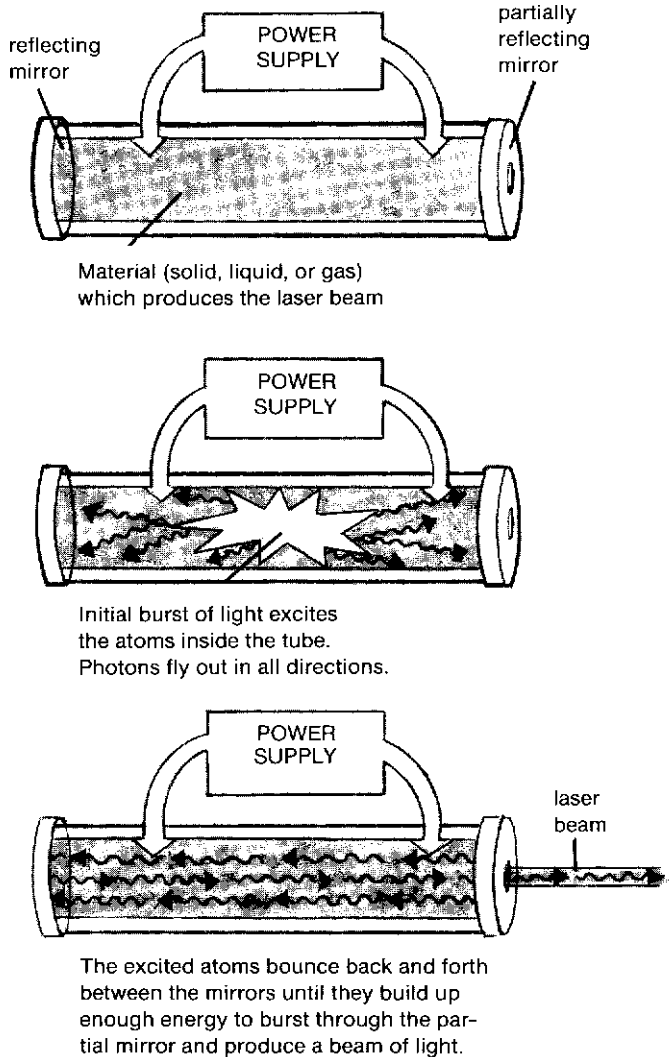
The chromium atoms can be pumped up to an excited state, and, when they fall to a lower level, they produce enough energy to emit photons of a wavelength that is seen as red light. After the rod has been excited, a photon of the correct wavelength is sent into the rod. Then it begins to produce additional photons of that same wavelength. These flash out of the ruby bar to form a deep red beam of coherent, monochromatic light.

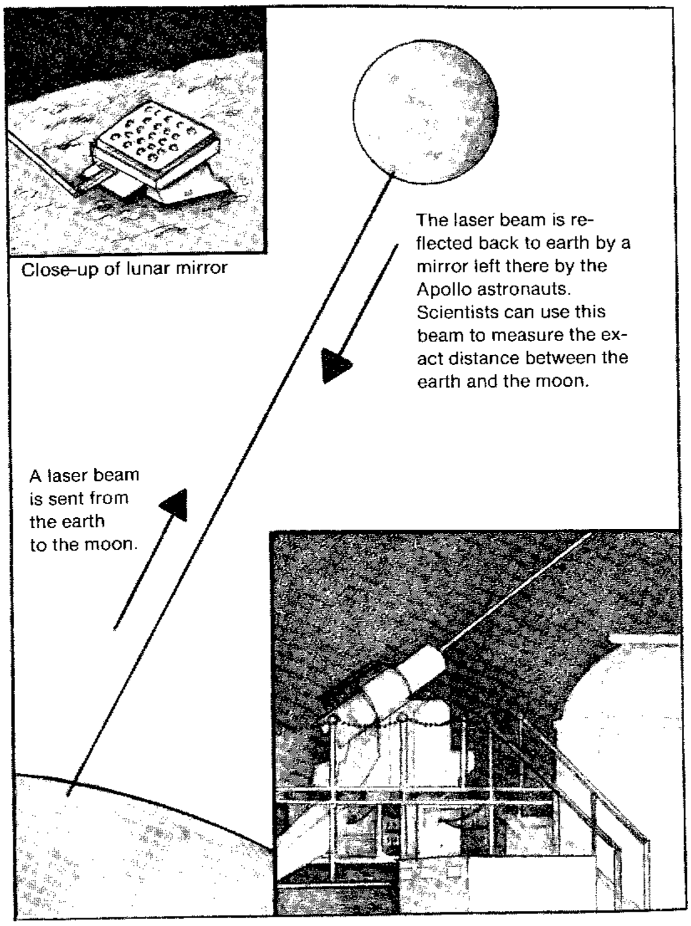
The first laser was intermittent. It produced a flash of light, and it had to be excited again before it could produce another. However, before 1960 was over, an Iranian-born scientist, Ali Javan, used a gas mixture of neon and helium and produced a continuous laser.

Before 1960, scientists had never seen coherent, monochromatic light. All the light that reached them from ordinary Earth sources, from the sun, and from the stars was incoherent and polychromatic.

Since 1960, however, coherent light has been detected From astronomical objects. There are clouds of thin gas in places between the stars, and they are called *interstellar clouds* (IN-ter-STEL-er). The atoms in these gases are, in a few cases, stimulated by light from nearby stars, and they can produce beams of coherent microwaves as a result. Such clouds are called *cosmic masers.*

Something similar happens in the atmospheres of Mars and Venus. The atmosphere on each of these planets is mostly carbon dioxide. The carbon dioxide in the upper heights of those atmospheres is excited by sunlight and produces coherent beams of infrared rays. In fact, carbon dioxide lasers have been designed here on Earth that produce radiation very much like that produced naturally by the upper atmospheres of Mars and of Venus.





Use of the laser beam in astronomy

Cosmic masers and lasers, however, are not nearly as effective as the devices we build on Earth. The coherent beams of radiation produced in space form bundles that go off in different directions. That’s what made them so difficult to detect until scientists knew what they were looking for.

In lasers designed on Earth, the natural tendency for coherent light to move in the same direction is increased by the use of mirrors, which, of course, don’t exist in interstellar clouds or in planetary atmospheres. The two ends of the tube in which the laser beams are formed are accurately polished and made into mirror surfaces. The photons in the beam then bounce back and forth in an exact straight path, gathering more photons and more total energy with each pass.

Any photon that happens to be moving in a direction that is the slightest bit different from the rest reaches one side of the bar in a tiny fraction of a second and is absorbed or leaks out. Any photon that happens to get into the bar from outside and is moving in the wrong direction passes through the bar and out the other side.

Eventually, the laser beam is very tightly focused. One of the mirrors is partly transparent, and when the laser beam grows intense enough (which is almost at once), it blasts through that end of the rod.

A laser beam can be focused so tightly that it can travel a million meters and still hit something as small as a pot and heat the coffee in it. In 1962, a laser beam reached the moon, which is about 383 million meters away, and even at that distance it had only spread out about two miles. We can do better now. In 1969 astronauts left a mirror on the moon and laser beams began bouncing back to earth, allowing scientists to

5. The Uses of Lasers

WHEN MASERS AND lasers were first invented, it seemed they might be suitable for scientists, but many people wondered if they would ever have any uses in the ordinary world around us. It turned out that there are many such uses.

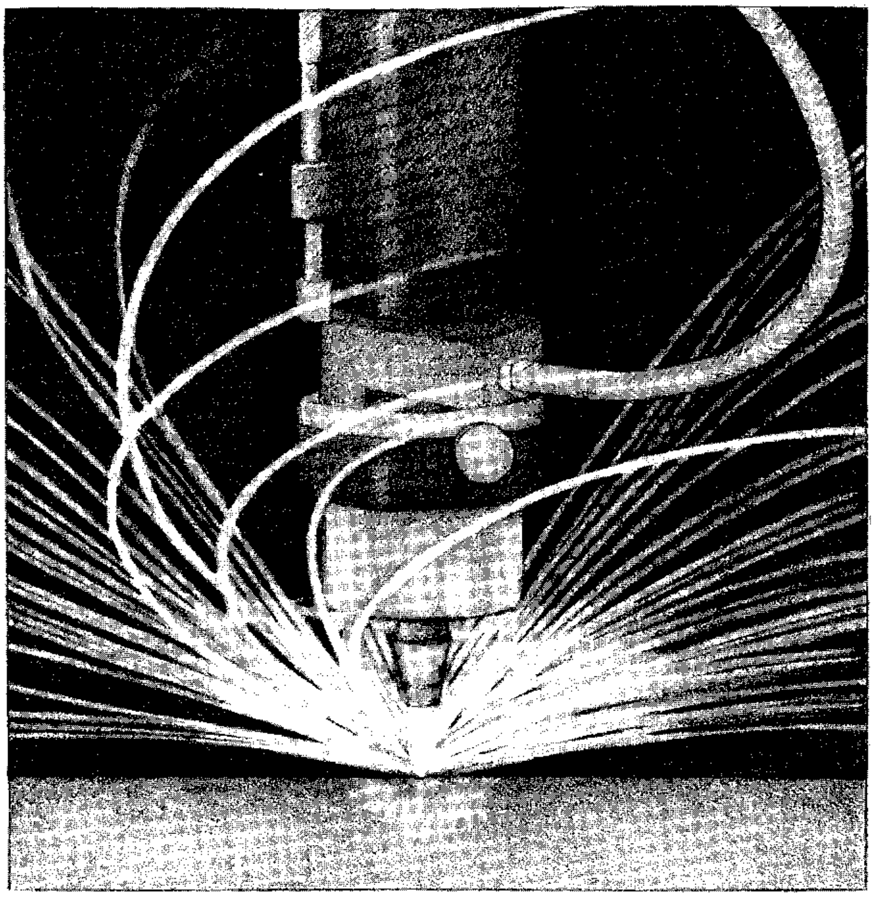
In the first place, lasers can produce coherent light in all sorts of amounts, and they are all useful. Semiconductor chips that produce very tiny laser beams can be used to read the bar codes on the objects you buy in the supermarket so that the price can be recorded. The beam is so feeble that it is not even noticeable. Its power is less than a thousandth of a watt, thousands of times weaker than the smallest night-light.

It is also possible, however, to build a large laser and arrange it so that the energy in it piles up to incredible heights and is then released all at once. In that case, an enormous amount of energy can be produced, but it all gets used up almost at once so that the beam lasts only for a short while.

There are lasers that can produce a flash of coherent light of more than 2 million watts, but it lasts only for a few seconds. There is even one that can flash at 100 million-million watts, which is a hundred thousand times as much energy as a large nuclear reactor can produce. However, such a flash can last only less than a billionth of a second. These giant lasers are only used for scientific work, or for possible weapons. They are not for supermarkets.

Actually, lasers use up a lot more energy than they produce. Of all the energy that goes to excite the molecules, only a part can come out as a flash of laser light—perhaps twenty percent at most. The rest is just turned into heat.

You might wonder what good it is to have a laser beam if you have to waste eighty percent or more of the energy used to produce it. The answer is that the laser beam can be put to use to do things that other forms of energy cannot do. That more than makes up for the energy that is lost.



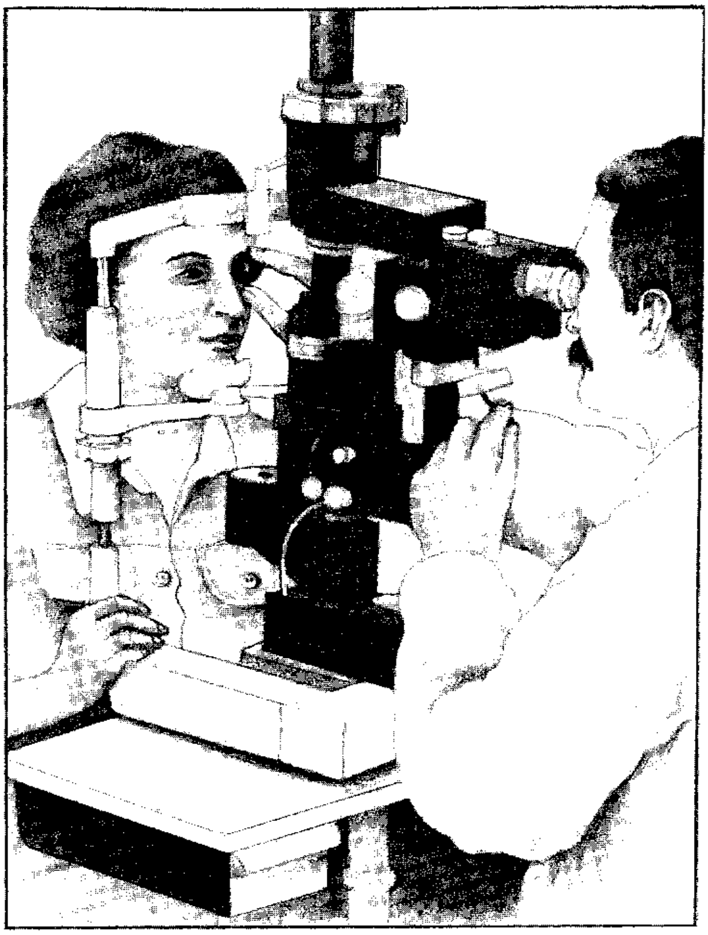
A carbon dioxide laser cutting through metal.
The flashes are incandescent specks of metal

For instance, because the laser beam is coherent, it can be concentrated and made to come to a very fine point. Ordinary light won't do that because its waves go every which way and can't be brought to an exact point. A laser beam can easily be focused into a tiny spot only 1,000 nanometers across, and that is only twice as wide as a light wave. All the energy of the laser beam is concentrated into that tiny spot, and the temperature at that spot goes way up.

If the laser is very weak, it can be used to cut paper and rubber. A stronger laser can be used to cut and drill plastic or wood. If you concentrate the beam very tightly, you can make it hot enough to melt its way through metal.

A concentrated laser beam can cut through metal more quickly and far more neatly than a torch or a saw can. It can also cut metal with the use of less energy altogether, even if eighty percent or more of the energy producing the laser beam is wasted.

The laser can also be used to do very delicate work, if the flash comes and goes in just a tiny fraction of a second. While it is on, the temperature is very high at the exact point where the beam is concentrated, but then the flash goes off again before the heat has time to spread.



The use of laser in eye surgery

For instance, a laser-eraser was invented that produces enough heat to burn off the typewriter ink and does it so quickly that it doesn't have time to scorch the paper. Naturally, it would be silly to use a laser when an ordinary eraser, or a bit of whitener, would do the trick, but the process shows what lasers can do.

Lasers can be used in this way in the human body. For instance, if the retina of the eye should show signs of coming loose, that could lead to blindness. A quick flash of laser light through the pupil can pin the retina tightly to the back of the eye, forming so small a spot that it doesn't interfere with vision. The laser does this so quickly that the heat has no chance to harm anything around the spots. Laser light can also be used to remove warts, freckles, tattoos, corns, wine marks, and even for simple operations.

Lasers can also be used for printing. Early word processors have printers that slam letters against a ribbon onto the paper. That makes considerable noise. In a laser printer, the laser prints the letters on the page, does it very quickly and very silently. All word processors will eventually have laser printers, even mine.

The most common use of lasers right now, though, is in reproducing sound. Until recently, recordings were made on flat disks. A groove is formed by a vibrating needle. The needle vibrates to the complicated sound waves of speech and music. Later, when the record has been hardened, another needle can follow the groove and is made to vibrate in exactly the same way the original needle did. That means the original sound waves are formed again. These are amplified and you can hear speech and music.

In this arrangement, the needle slowly wears out and has to be replaced. There is often a faint scraping sound.

But now there are records in which the sound waves are converted into a pattern of tiny dark spots on a shiny surface. The dots are invisible to the eye. A very weak infrared beam from a tiny semiconductor laser scans the surface and changes the pattern into sound waves.

There is no actual touch of metal against record, so there is no scratching of any kind. The sound reproduction is completely pure and without noise. What's more, more sound can be squeezed onto a record of a given size in the form of tiny dark spots than as a wavering groove. For this reason, since the new laser records are smaller and more compact, they are called *compact disks,* or *CD recordings.* CD recordings are rapidly replacing all others.

Another important use for lasers involves sending messages. For years, people have been using radio waves to communicate. Different radio or television stations can send out programs at the same time, because each one uses a different wavelength. On your radio set or television set, you can adjust the wavelength that is being received by turning a knob. In that way, you get only the station or the channel you want and the rest can be ignored.

Radio and television stations, however, must leave gaps between the wavelengths they use so that there is no overlap and confusion between two nearly alike wavelengths. This means that only a certain number of stations and channels can be found on your sets.

The shorter the wavelength, the more different messages can be squeezed into a given range. For instance, light waves are only about a millionth as long as radio waves, so that you might be able to fit a million times as many stations or channels into a range of light waves as into the same range of radio waves.

There is a catch, though. Radio waves can travel through rain, fog, clouds, trees, walls, and so on. Light can't do that. Radio waves bounce off regions in the upper atmosphere so that they can follow the curve of the Earth and reach long distances. Light travels in a straight line and quickly moves off the curve of the Earth.

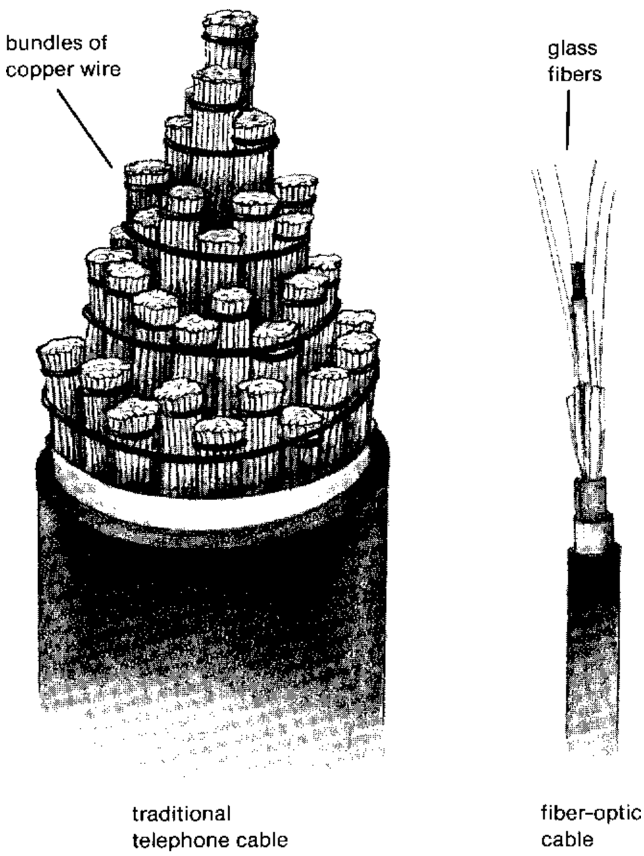
But suppose we're talking about satellites in space. In space, there is no interfering weather, nothing solid to block the light, no curve of the Earth that has to be followed. Someday, when we have many people in space, they will be able to communicate with each other by means of laser beams along millions of different wavelengths.

We can do it on Earth, too, but not for radio and television, where the radiation beams go through the air. What about telephones, though?

We speak on telephones because an electric current races along copper wires. Many different messages can be carried by cable, but suppose we send light beams on long thin glass fibers. If we use a laser beam, we can squeeze hundreds, or even thousands, of different messages into these *optical fibers.*

Glass is much cheaper than copper and coherent light will carry more messages than an electric current will. Right now fiber-optic telephone links run between many cities. Toward the end of 1988, a fiber optic link was laid across the bottom of the Atlantic Ocean.

Fiber optics can guide light to where we want it to go inside the human body.



A comparison of ordinary telephone cable and new fiber-optic cable

In 1989, doctors are experimenting with the use of laser beams to treat some kinds of cancer. First, a patient is given a *photosensitive drug* (FOH-toh-SEN-sih-tev), one that absorbs light. After two or three days, when the drug has gone all through the body, a thin optical fiber is inserted into the body and pushed into the tumor. A laser flash goes through the fiber and into the tumor. The drug absorbs the light and produces energetic atoms and molecules that kill the cells in the immediate neighborhood. In this way, the tumor might be destroyed, while normal cells outside the tumor aren't touched.

Laser beams have also shown their usefulness in photography. In ordinary photography, a beam of ordinary light is reflected from an object and falls on a photographic film. Where a lot of light is reflected, the film is darkened; where little light is reflected, the film isn't darkened. A dark-and-light pattern is produced, and when the film is developed, you have a photograph. The photograph, however, is flat. You don't see anything in three dimensions.

Instead, suppose a beam of light is split in two. One part of the beam strikes the objects being photographed and is reflected, while the second part strikes a mirror and is reflected. The two beams are then allowed to cross each other. They mix and form a jumble because one beam has been scattered by reflecting from an object while the other has not changed.

If you let the jumble where the two beams cross strike a photographic film, you get only a gray fog that doesn't look like anything at all. However, if you then allow light to shine through the foggy film, the light takes on all the wave forms of the two reflected beams and forms an image in the air. It is a three-dimensional image that looks very real, and it is called a *holograph* (HOH-loh-graf).

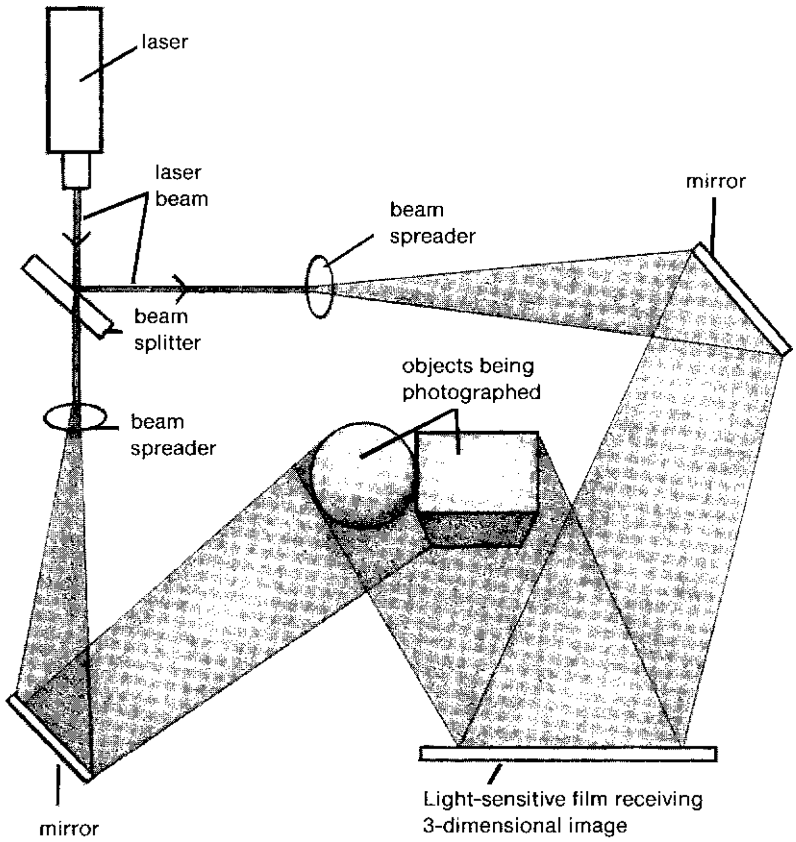


Diagram of the production of a holograph.

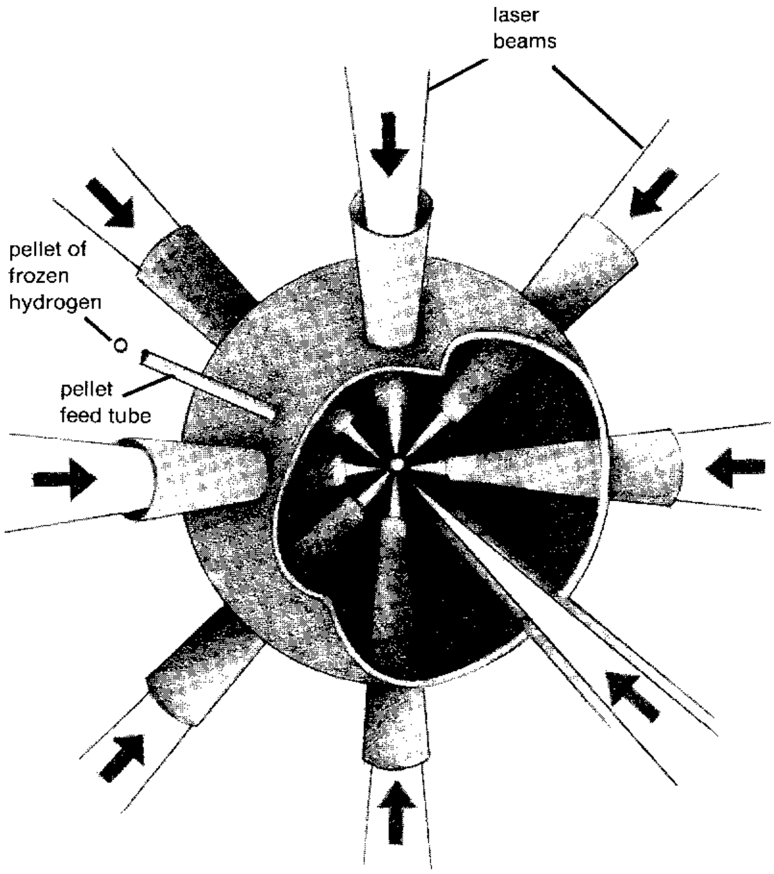
The image of an object is reflected onto photographic film from two different angles.

The theory of this was worked out in 1947 by the Hungarian-born British scientist Dennis Gabor (1900-1979), and in 1971, twenty-four years later, he received a Nobel Prize for the holograph.

The reason it took so long was that at first no holographs could be taken, because ordinary light doesn't give a sufficiently neat jumble. Once lasers were invented, however, holographs could be taken. In 1965, the first holograph was produced by two Americans, Emmet N. Leith and Juris Upatnieks.

Holographs are still not entirely practical, but some say we may be watching three-dimensional television on a table top. You will see football games or listen to orchestras, in miniature, that will look entirely real, except that you will be able to put your hand through them, for they will be only radiation.

Some things are still further off in the future. Scientists are trying to find ways to produce energy by making hydrogen atoms fuse to helium atoms. Such *fusion reactors* (FYOO-zhen) would produce far more energy than ordinary nuclear reactors do. Fusion reactors might also produce very little radioactivity and would be less likely to have dangerous accidents. In addition, the atoms used in fusion are much more common than those used in ordinary nuclear reactors so that the fusion fuel would last us for billions of years.



In an experimental fusion reactor, laser beams are focused on a pellet of frozen hydrogen, heating it to millions of degrees.

The catch is that hydrogen won't undergo fusion unless it is heated up to very high temperatures and kept in one place long enough at those temperatures for the fusion to start. Scientists have been trying to do this for nearly forty years, and so far they haven't succeeded.

One of the possible ways of creating fusion is to start with frozen hydrogen. A tiny pellet of frozen hydrogen would be hit simultaneously from various directions by laser beams. That would raise its temperature to hundreds of millions of degrees. Ordinarily, the hot hydrogen gas that is produced would just expand and escape. The lasers would heat it to that temperature in such a tiny fraction of a second, however, that the hydrogen wouldn't have time to escape. It would undergo fusion instead.

This hasn't been done yet. We need stronger lasers, and scientists are working on the problem.

They are also working on systems whereby lasers in space can shoot down enemy missiles carrying nuclear bombs. This may or may not work, but missiles travel through space so quickly that only a laser beam aimed by a very advanced computer can possibly be quick enough to put a missile out of action.

Isn't it amazing, when you stop to think of it! Look at all the things lasers can do and how many more things they might do in the future. Yet only thirty years ago, lasers had not even been heard of.

End