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WAVES

Pathways of Energy

WAVES

Pathways of Energy

by

WILLIAM BIXBY

ILLUSTRATED WITH PHOTOGRAPHS AND DIAGRAMS

DAVID McKAY AND COMPANY, INC.

NEW YORK

WAVES

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Acknowledgement

The author would like to thank Mr. Irwin S. Boak, Physics Department Chairman, New Haven College, New Haven, Conn., for his careful reading of the manuscript as well as for his many helpful suggestions.

W.B.

Illustrations

Between pages 88 and 89

PLATE 1. The geometry of interference of light waves: Light passes through a narrow slit and spreads out in a circular pattern. It then passes through two further narrow slits, each of which produces a circular pattern of waves beyond the openings. Where the overlapping patterns reinforce each other, bright bands of light result on a screen; where they annul each other there is darkness.

2. Diffraction of light is shown by photographing light which has passed through a single narrow slit. Most of the light falls in the center band directly in front of the slit, but some bends to either side of the opening forming a series of faint bands of light.
When two slits are used as shown in Plate 1, the interference pattern is visible as photographed here.

3. Striking demonstration of circular interference of light produced by reflecting light from a mercury arc lamp on a thin (.002 inches thick) sheet of mica. Front and back surface of the mica reflect light as though they were two nearby sources. Some waves reinforce and others annul, producing the large pattern shown here on the wall of a room. Shadow in the center is caused by the mercury arc lamp.

4. Interference rings are put to practical use by industry. On the left is the interference pattern pro-

duced by reflecting light from a flat surface and the convex surface of a finished ground lens. On the right is the pattern produced by a lens during manufacture. As the lens is ground to a more nearly perfect shape, the pattern becomes more regular until it resembles the one on the left. Irregularities in the pattern direct the grinding operation to the unfinished area of the lens surface.

5. Two patterns of water waves produced simultaneously combine to demonstrate interference. Where crests meet crests or troughs meet troughs there is reinforcement. Where a crest meets a trough, there is annulment and the surface remains undisturbed.
6. Water wave diffraction is demonstrated by letting a train of waves with straight, parallel fronts approach a narrow opening. Wave segments that pass through spread out forming a circular pattern showing that waves "bend" or diffract around the edges of objects.
7. Ocean waves like these travel thousands of miles across the surface of the sea. As they make their final assault on the land, their energy is dissipated. Man has yet to discover a way to make large-scale use of this energy. He must, in fact, spend millions of dollars to protect himself, his buildings and the eroding shores from their awesome power.
8. The earth's thin crust is subjected to great stress caused by interior heat. When the crust cracks, earthquake waves speed along the surface and through the earth to the opposite side. Cities near the quake zone frequently are destroyed. Seismologists have analyzed these waves and deduced the composition of the earth's interior from their findings.

Introduction

As when great shipwrecks mark the tempest's might,
And planks and helms are tossing on the tide
With spars and prows and masts and drifting oars,
And many a hull goes floating by far shores,
A visible sign to mortals who would brave
The guileful ocean's treacherous strength and spite,
Bidding beware, nor evermore confide
In the false whisper of the windless wave.

So WROTE the Roman poet Lucretius nearly two thousand years ago in one of the most impressive and accurate statements ever made on the vast energy to be found in ocean waves.

Men long before this latter-day Epicurean had observed the familiar wave motion on a water surface. From their observations they had induced many worthwhile ideas concerning the behavior of this peculiar disturbance of water. Lucretius not only added beauty to their musings but also attached many acute observations of his own on water waves.

Profound as all their reasoning powers were, however, these ancients lacked the many sense-extending instruments common to modern science. Consequently they could only record what their eyes could see. They had no microscope, telescope, watch, or oscilloscope to assist them. Not that such limitations retarded their speculative thoughts on physical science. Those

natural philosophers constructed many theories to account for what they could not know.

The only waves of which they were conscious were surface water waves and these are, as we know today, mere surface phenomena in more ways than one. Nature abounds in a variety of waves and all waves have characteristics or properties in common. Like the ancients, we are most familiar with surface waves on water and an understanding of them will be a help in understanding other waves.

From ancient times to the present, men have been trying to explain the universe to themselves. In the process they often attempt to find a unifying theme, an essential simplicity that can be explained to and understood by everyone. For some men, the path to philosophy or art offers great attraction. They pursue it vigorously, with all the compulsion of the human ego, and believe all questions will be answered by their efforts. For others, science is a path to understanding, and many of the giants in this field of endeavor have maintained that understanding the universe is possible only through accurate measurement and mathematical expression.

As scientists' knowledge of the physical universe extended, however, they began to suspect that it was infinitely more complex than the most speculative ancient thinker had imagined. Here and there along the path of scientific history an occasional brilliant synthesis of knowledge occurred which took all the divergent facts of many investigations and tied them up in a neat bundle. At those moments scientists heaved sighs of genuine relief. The moment reaffirmed their belief that there *was* an underlying unity—and thank heaven they had just located it. Then slowly or rapidly, the neat bundle began

to fall apart and more and more embarrassing questions were raised. To some men, this failure of science to stay bundled up, to remain simple, seemed discouraging. But imaginative scientists—of which there are few—believed that the destruction of neat bundles and the resulting scientific chaos marked, not retrogression, but another step forward. Yet in the confusion even they hoped for a new synthesis to restore order to their world. New knowledge, when it comes, frequently seems to herald the death of established laws and theories.

In scientific history the middle of the nineteenth century represented a period during which nearly everything appeared to be bundled neatly—packaged forever. The great earlier synthesis of Isaac Newton (1642–1727) and others of his time seemed unshakable. Advances in science from Newton's day tended to affirm all that was known and among shortsighted scientists there grew the feeling that the future of man, or at least his scientific side, could be predicted without fail. A deterministic philosophy became popular.

But then one scientist, Max Planck, burrowing in his researches on radiation, was forced by the evidence of his experiments to contradict one of the strings tying up the neat package of science. While more will be said about his work and discovery later, it is sufficient here simply to state that he upset the accepted applecart of light theory or optics, as it was known.

Swiftly there followed the unraveling process, and the early years of the twentieth century saw what appeared to be chaos returning to the scientific world. The safe, sure walls of determinism came tumbling down and what we today hear spoken of as "modern science" or "atomic science" was born. It was a revolution. Some say the greatest ever to occur in the

history of science. But such comparisons are dangerous since observers of any revolution are confined to their short human life span and cannot directly observe upheavals of the past. Their only knowledge of such occurrences comes secondhand, through the personality-clouded pages of history.

Nonetheless, all scientists agree that the present revolution, the end of which is not in sight, is of major proportions. Amid this upheaval, however, scientists, quite humanly, keep searching for simplicity: an ultimate particle, a great unifying equation, an over-all principle that will begin once more to package the eruption of new information.

So far it has not come. In mathematics alone there is so much new growth that trained mathematicians working in diverse branches do not fully understand one another. Teams of men from different specialties must work on increasingly complex problems.

Much can still be understood by applying general principles of conservation of energy and matter, field theory and other more abstruse scientific principles. And, curiously, one of the most fruitful areas of study for wider understanding of the physical world we are exploring is a realization of the great application of wave theory to many areas of science.

Oceanographers, electrical engineers, cosmic ray experts, acoustical engineers, seismologists—all apply the same principles of waves. For waves seem to be nature's way of carrying energy from one part of the earth or universe to another, the natural transmission belt.

An earthquake sends the energy of its occurrence from one part of the earth to the other—through the earth in waves. A distant shout is heard through waves. Light from the outermost star comes across unchartable space by the same means—waves. And so, of course, do television programs.

CHAPTER I

Waves on the Sea

No ASPECT of the seas surrounding the continents is more evident than the ceaseless pattern of waves on their surface. For the oceans are never at rest. Even without the disturbing force of a local wind, the sea's surface is moved by swells—dying waves—which have journeyed from far places.

From time immemorial, men have viewed these rhythmic sea surges as they spent their energy against rocks and cliffs or by spreading far up on a smooth, gently sloping sandy beach. Observing these periodic disturbances of the ocean's surface, man gave to such motions the name wave, and when he came across similar motions in other portions of his world, he named them waves also. With his insatiable curiosity, man has tried to analyze all waves, and in doing so has created terms and measurements so that he could compare and contrast various waves and their myriad interactions.

Of first interest to even a casual observer is the rhythm of the beat of surf on a beach. Each crescendo of sound that comes to him signals another wave's final assault on the land. And the question may naturally occur to a listener: how many waves strike the beach in a minute? With the aid of a timing device the question can be easily answered. If one day there are twelve thuds per minute and on the next there are fifteen, the observer has one dimension with which he can begin charting his knowl-

edge of waves. To this measurement the scientist gives the name *frequency,* and it is *the number of waves that pass a given point in one second.*

Another useful dimension is arrived at by merely turning the frequency upside down, taking its reciprocal, and thus determining what is called the period of the disturbance. Instead of answering the question of how many waves strike the beach in a minute or second, the observer answers the question: *how many seconds elapse between successive waves? This dimension is called the period of the wave pattern.* In many other physical happenings, the idea of a period has the same meaning although it may be stated a little differently. It merely answers the question: how much time elapses before the same thing occurs again? Thus we can speak of the period of a pendulum, the period of the earth's revolution about the sun or of the moon about the earth. In short, how long does it take for the phenomenon to repeat itself?

The time between successive thuds of waves on a beach determines this and it would be nice to discover that the time between successive waves breaking on a beach for any observed wave pattern is always the same. Such is not the case with water waves. They may appear to form regularly advancing lines of crests but there are periodic variations. Fortunately other wave forms are more regular in their periods. But water waves of a given pattern do have a useful average period, and oceanographers use this measurement to advantage.

Another important dimension of waves is the distance between succeeding waves. Since the waves are in motion, it is a little difficult to measure this property, but it can be done directly either by using optical devices or taking photographs of two or more wave crests and then relating the real distance to

the photographed distance. Indirect measurement of this dimension can be made if the observer knows the speed of the waves. Then, by timing the period and using the speed, he can tell how far apart adjacent crests of the ocean wave pattern may be. This measurement is termed wave length. Although it would occur to an observer first that such a measurement tells the distance between crests of the succeeding waves, it also

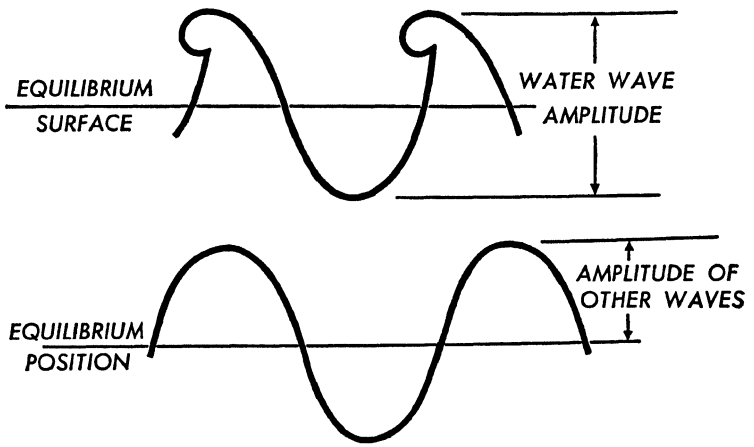


FIG. 1

might occur to him that the same measurement tells the distance between two succeeding low points or troughs. This would be correct also, and the entire idea of wave length can be generalized by saying that *wave length is the distance between two identically located points on successive waves.*

Only one other measurement is needed for us to have the basic wave measurements: wave height or amplitude. *For ocean waves, the measurement of height is taken from the crest, or high point of the wave, to the trough, or low point. For other*

waves, this measurement of amplitude is taken to be half the distance from crest to trough. In the case of water waves, this halfway point between crest and trough is where the water surface would lie if there were no wave disturbance at all—the flat calm, or equilibrium surface, so to speak. Since equilibrium is never a condition of the ocean, however, the maximum and minimum points of the water motion up and down serve for oceanographic study as reference for the measure of an ocean wave's amplitude.

Causes of Ocean Waves

Nearly all waves of the ocean are caused by wind. And if wind itself were as consistent as man wished it were, the problem of how wind causes waves would have been neatly solved and shelved long ago. But wind is rarely constantly blowing at a fixed speed or in a fixed direction. Even when it is reported as being, say, fifteen miles per hour, the meteorologist reading his wind speed indicator or anemometer sees the indicator varying erratically from around ten to twenty miles per hour. The fact is, a truly steady wind is a rarity. We may believe, on a windy day, that the force of the wind in our faces is steady, but precise measurement would show that gusts of long or short duration and without fixed periods is the normal situation.

A sudden breeze springing up over a calm water surface will set up the familiar pattern of wavelets or ripples that can grow into true waves. A true wave is distinguished from these ripples not alone by amplitude. The distinction lies primarily between whether or not the wave form will continue to travel across the surface of the water if the gust dies. For the preliminary wavelets, the ripples, die out almost instantly when the breeze that causes them stops. A true wave will persist for a

considerable time even after such a wind stops. Naturally a wave does not retain its height or its foamy crest without further help from the wind, but it continues to move although it subsides into a rounded form which we then call a swell. As any observer who has stayed long by a seashore knows, when no wind disturbs the surface near shore, there still may be heard the thud of swells breaking. These swells might be thought of as old waves or waves no longer receiving energy from the wind but finally, on the shore, dissipating the energy that was given them hundreds of miles away across the ocean in some stormier area.

That ocean waves possess considerable energy, no one doubts. But man has yet to devise a practical device to get that energy to do work for him on any large scale. To some people it would then seem that all this energy is wasted. And if by waste they mean "not assisting men," they probably are right. To protect themselves from the great energy of these waves, men build breakwaters of reinforced concrete, they narrow the mouths of harbors, or search for naturally formed narrow-entrance harbors, and in times of acute distress at sea, they pour the proverbial oil on troubled waters. Yet, in violent storms, when waves rage against the shores of the continents, few works of man can withstand their onslaught.

True waves at sea can be built by the gusts of wind to astonishing heights. And they would build higher in more violent storms if the wind didn't literally decapitate them. Each growing wave presents a larger and larger surface to the hurrying wind and thus is pushed to yet greater heights. In the troughs of the waves, in even moderate winds, there is an eddy of backward-moving air near the lowest point of the trough, and this air moves in a closed curved path in a plane parallel

to the direction of the wave motion. It is here, in the trough, that the water surface itself is moving counter to the direction of the wave motion.

A brief look at this apparent paradoxical motion will answer some of the most common misconceptions about wave motion of all kinds. For how can the water be moving backward when the wave is moving forward?

The Two Motions of Waves

At first glance, a casual observer viewing surface water waves might comment on "how fast the water is traveling." In stating the motion of the wave that is most readily evident to him, he would be making one of the most common mistakes regarding waves of every kind: that the wave carries with it the water forming it as it progresses.

On momentary reflection, though, a more thoughtful person could overcome the error. For if it were true that the water is carried along by each wave, it follows logically that given a strong onshore wind and an approaching pattern of waves, all the water should pile up on the shore and leave nothing behind it. This does not occur, of course, and so other explanations must be sought.

What in fact does happen is that water particles are momentarily displaced by the passing wave and then return to their original position—or very nearly so. This to-and-fro motion of the particles is easy to analyze and has been analyzed successfully for all types of wave motion involving particles of matter. But this motion is not evident to the unaided and untrained eye. Hence it escapes notice and the eye focuses on the wave itself, traveling rather rapidly across the surface.

This is not to say that the eye is not a good measuring instru-

ment. In many situations it is, but it alone as a receiver of light impressions can be fooled—or more properly, with the human brain behind it, subject as it is to all the various stimuli, can be fooled. Thus the eye may tell the brain that the image seen in a mirror lies behind the mirror. Some people will search desperately for it behind the silvered, reflecting surface when in fact the impression of distance behind the mirror is illusory.

What, then, exactly is this "wave" that the eye becomes fascinated with—if it is not water moving across the ocean's surface? Frankly, it is a bump containing energy.

In the case of water waves, the speed and direction they take are dependent on a number of factors, among the most important of which are: force and duration of the causing wind, wind direction, and wave length of the pattern set up. In relating the speed of water waves to other types of waves a disadvantage is at once raised because the speed of water waves is more variable than the speed of nearly every other wave type. Surface waves on the ocean have a wide range of speeds. If the wave length of one pattern is 20 feet, the velocity will be in the neighborhood of 7 miles per hour. If the wave length is about 1000 feet, the wave speed will be a little more than 48 miles per hour. The fastest surface waves ever observed and reported were calculated to be traveling nearly 105 miles per hour.

Whatever a wave's speed may be, the eye notes this advance of the wave more readily than it does the actual motion of the water particles. These particles, in their to-and-fro motion, might well be likened to an old-time fire bucket brigade. As buckets move from hand to hand, each person in the line swings forward momentarily and passes a bucket to his neighbor, then he swings back to grasp the bucket from the person

behind him. If the buckets are the waves, the people are the water particles. They remain in one location while the "waves" of buckets advance. Actually the motion of water particles on the open sea is circular, in a plane perpendicular to the water surface and parallel to the wave's direction. The center of this circle is nearly stationary, and the particles describe the

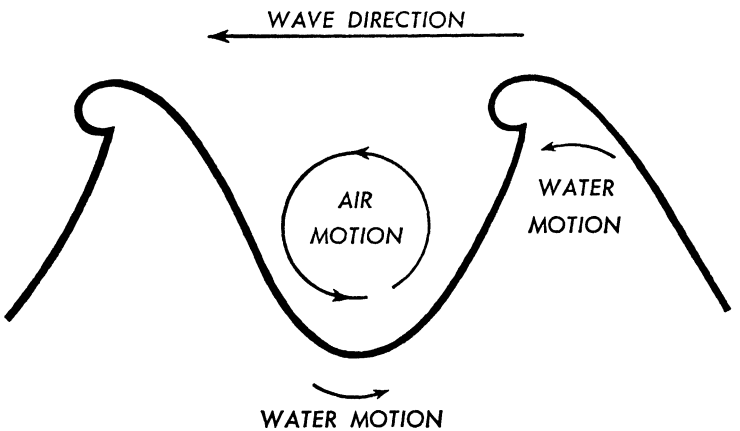


FIG. 2

circle as they move at regular speed around the fixed center.

When the particles are conveying a wave crest, they are moving in the direction of wave motion at the top of the circle. When they form a trough they are moving opposite to the wave direction and are at the bottom of their circles. If you are above the water surface looking down edgewise on these circles, the circles appear to be rather short, straight lines with a particle moving first to one end and then the other in simple to-and-fro motion. When viewed from this position, the motion apparent to the eye is what is termed simple harmonic.

It is characteristic of all particle motions associated with waves. A common example of this type of motion is that approximated by a pendulum. And a moment's thought can convince you of several important facts about simple harmonic motion which is found so frequently in nature. If you think of a swinging pendulum and ask where the speed of the pendulum bob is least, the answer comes instantly: at the extremes

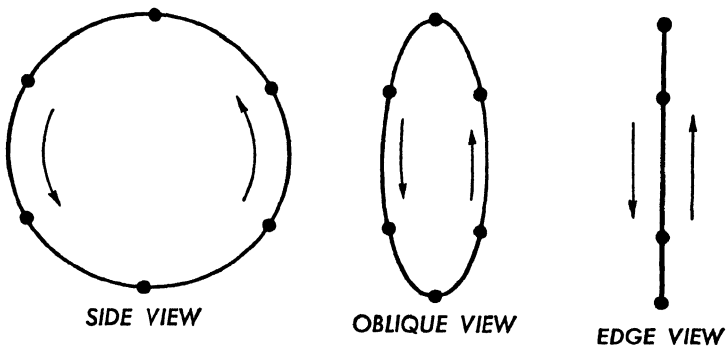


FIG. 3

of its to-and-fro path—where, in short, it stops momentarily before moving in an opposite direction. As to where its speed is greatest, that, too, is easily deduced: at the center of its swing. It has gathered speed (accelerated) from one extreme, down to the midpoint, and the pendulum bob begins to lose speed (decelerate) the instant it passes this midpoint and starts "uphill." Highest velocity at its midpoint and lowest at its ends is one important property of simple harmonic motion.

There are several methods by which this motion can be observed in water waves. Perhaps the easiest is to drop an object that will float in an advancing surface water wave pattern,

say as it moves along the side of a jetty. If there is little wind or the object is weighted so not much of it projects above the water, the to-and-fro movement when viewed from above is quite apparent. Such motion is distorted, however, if the water beneath the waves is shallow. Waves near the breaking point on a beach begin to carry water particles—and floating objects —forward in their final lunge as the crests of the waves spill forward and are transported shoreward. So the outer end of a long jetty or, better, a boat hove to in deep water, would serve best as an observation platform.

Another method which today's underwater swimming enthusiasts can employ demands a face mask and a shoaling bottom where tufts of submarine growth are visible. Lying face down on the water with the body parallel to the line of advancing crests, such a swimmer can see the motion of the tops of the undulating grasses. Those directly beneath him will bend in the direction of wave travel as a crest passes, and reverse their leaning as a trough goes by, bending against the direction of wave travel. Too-shallow water distorts this motion also, so a swimmer should be in as deep water as he can find and still see the bottom.

Experiments have been carried out for many years to determine the depth to which surface waves disturb water, and it has been found that, save for the most violently energetic of storm waves, there is little motion below about a hundred feet. Inertia of the water and the friction of the ocean floor tend to counteract the energy that otherwise would penetrate downward once the wave pattern develops. As the depth to which a wave goes increases, the motion of particles becomes less circular, the circle gradually being squashed, until, when the bottom is reached, the motion noticeable on the sand, mud or

debris is merely back and forth along the sea floor—the circular motion has been squashed flat and become a straight line.

Two Kinds of Waves

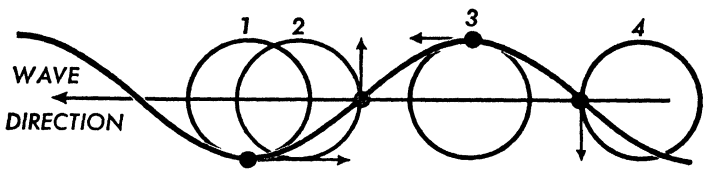
The two wave motions that have been analyzed—the to-and-fro movement of the particles and the forward progress of the waves across the surface—have a relationship that is important. It is a relationship that divides waves of all kinds into one or another category.

If the to-and-fro motion of the particles is at right angles to the direction of wave travel, the waves are termed transverse. A good example of this is the wave that travels along a rope when one end is held fast and the other is given a shake or two. These single or double pulse waves can be seen to move along the rope. If the shaking movement is up and down, then the parts of the rope that are displaced move up and down while the wave itself travels along to the other end. The movements of the rope particles then are at right angles to direction of wave motion, and the wave so produced is a transverse wave. If the rope is hung vertically and shaken in any way, the rope particles still move at right angles to the direction of wave travel. And even if the rope is horizontal and the particle motion is horizontal, they move at right angles to the wave travel—just as a snake moves forward while portions of its body move from side to side.

The other principal relationship between particle motion and wave motion is for the particles to move parallel to the direction of wave travel. There are many examples of this but few are visible to the unaided eye. Sound waves, of which more will be said, are of this nature, as are some forms of seismic or earthquake waves. In fact most matter, whether it be a

solid, liquid or a gas, can be induced to move in this fashion. Such waves are called longitudinal waves.

It will be seen at once that water particles with their circular paths fulfill, at various moments during their cycle, the requirements of both longitudinal and transverse waves. For at the tops and bottoms of their circles, the water particles



PARTICLES 1 & 3 MOVE LONGITUDINALLY AS 2 & 4 MOVE TRANSVERSELY

FIG. 4

are moving parallel to the wave motion itself. When they are moving from the top to the bottom of the circles, the particles are moving at right angles to the wave direction.

Both longitudinal and transverse waves are moved forward by the vibratory motion of material particles. Fortunately, for analysis, both longitudinal wave particles and transverse wave particles follow the rules of simple harmonic motion.

In the case of transverse waves, such as those in a rope, it is easy to see this motion. If the rope is motionless at the outset, all its particles are said to be in their "equilibrium positions." When a disturbance moves them, they alternately move away from, then toward, this equilibrium position, passing through it to complete a cycle by moving to the other side of equilibrium the same distance and returning.

In the case of longitudinal waves, the particles, say air molecules, are shoved forward until they are bunched together, forming an area of compression. They then rebound from this area and go back through their original positions to a position equally distant from their starting points. This back-and-forth motion is identical to the up-and-down motion of rope particles—except in its relationship to the direction of wave travel.

Common forms of transverse waves are those in ropes and strings or metal rods when struck a blow at right angles to the length of the rod. Some earthquake waves are transverse and all waves of an electromagnetic nature are also considered transverse, as we shall see later.

The most common longitudinal wave with which everyone deals is a sound wave.

Yet all have the same measurements in common. The fundamental dimensions remain: wave length, period, frequency, amplitude and speed of travel. In all cases if you wish to analyze the motion of the oscillating particles, you find it to be simple harmonic motion over a short path.

The Energy of Waves

The energy of these waves can be measured too. In doing this, however, scientists have had to overcome certain difficulties. To see what the difficulty is, consider a rock to drop on the smooth surface of a pool and to produce a single wave. Such a wave does not set up a series of advancing waves but only one. While this couldn't actually occur in water because of the nature of water itself, it is more nearly approached in the creation of some electromagnetic waves, such as a discharge of electricity over a very short span of time. But with our ideal

single wave spreading from the point where the rock struck the water, we can see that the thing that started the wave was the energy required to toss the rock, which disturbed the water surface. Some of the energy must overcome the surface tension of water, and more must be used to move the water itself. Yet the wave persists, spreading outward. At first the circle formed by the wave is small and is, let us say, three feet around. An instant later the energy it had when it was three feet around has to be spread around a bigger circle. Obviously there is less energy in one foot of the wave crest when it is six feet around than when it is three feet around. Just by becoming a larger circle, the wave is spreading its energy thinner and thinner across the surface. In addition, more and more of it is being absorbed by the opposing forces, the surface tension and the water's reluctance to be moved, which is called inertia. The energy of waves, then, is not constant, and if the wave were allowed to expand on an infinite sea as far as it wanted, eventually it would die out.

In many cases waves are not sent out across surfaces like that of the pool but are sent from a single point into three-dimensional substances—air, for example. Suppose someone climbed a flagpole, hung a gong up there and struck it. The resulting wave would expand from the point where the energy began to disturb the air medium and it would grow like a balloon. It would encounter the same troublesome energy-absorbing forces in air that it did in water, and while the balloon would continue to expand for a while, the energy contained in any square foot of the balloon's surface would be less and less as it expanded.

Perhaps the easiest way to convince yourself that waves tend to lose some of their energy when they spread out and move

away from the source of the disturbance is to recognize that the farther you are from someone across a field, the louder you must shout to be clearly heard. This loss also accounts for the fact that in radio wave transmission, the distance you wish to send the waves governs the power of the transmitting station. If you wish to be clearly received a thousand miles away, you must put more energy into the waves at the broadcasting station than would be necessary if you wished to transmit your message a distance of only a hundred miles.

CHAPTER 2

Waves in the Earth

COMPARED with air, water and space itself, this earth on which we stand seems solid enough. Yet throughout history earthquakes have periodically shaken men's dwellings and taken their lives. But only those earthquakes that have caused damage or momentarily unbalanced men were recorded or noted. Today we know that the earth is in fact a trembling planet through which waves pass more frequently than had been realized a short time ago. Some, of course, are so slight that they cause no damage whatever to man or his dwellings. But others are severe enough to be recorded in the lengthening history of the comparatively young science dealing with earthquakes: seismology.

Between 600 and 700 earthquakes of noticeable severity occur every year. But the number of minor disturbances sending out waves is incalculable. One scientist has put the number around 50,000 per year which means that more than 135 earthquakes per day shake this solid earth.

From ancient times earthquakes have terrified men, and while many of the historic accounts exaggerate certain aspects of earthquakes, nearly all make mention of the surface of the earth being in motion, a wavelike motion. But only in recent times, as the science of seismology has developed, have scien-

tists measured these waves and used them to analyze an earthquake that may have occurred on the opposite side of the earth from the observing station. From these observations we also have gained our most accurate picture of the earth's interior: its various layers, their depth and their composition.

From current evidence it appears that this earth of ours is, while solid, in a constant state of agitation. Waves of different types crisscross on the surface. Some, traveling more rapidly than others, outdistance them. Others, like wind ripples on the surface of a quiet body of water, are so slight as to be nearly undetectable and die away rapidly. Some go deep into the earth and are reflected from another differently constructed layer of the earth, while still others are bounced back toward the earth's interior when they reach the surface of our restless globe.

Sources of Earth Waves

The source of the waves that shake the earth is the quake itself and it can be caused by several things. Slight quakes, sending periodic tremors to shake the seismographs or earthquake recorders, can be caused by the cooling and contracting of the earth's surface during the night hours and heating and expanding when the sun's energy strikes it during the day. Water itself, in the form of abnormally high tides or excessive downpour on an area, can produce slight shifts or bending of the earth's surface. But these are not truly earthquakes in the popular sense. Those quakes that are of intense interest to seismologists are caused by faults or cracks that lie in the earth's crust. From time to time these faults or lines of weakness within the earth shift due to pressures caused by heat coming from the earth's interior or, as some scientists believe, pressures

developing from above on the surface where great deposits of silt may place such stress on the crust that it is forced to give, adjusting to the added weight.

The lines of weakness or faults in the earth's crust may extend downward many miles, and when movement occurs it may be either horizontal shifting or vertical shifting. Whichever it is, waves containing fantastic amounts of energy are sent out in all directions: up, down, north, east, south and west. Seismologists receive all the information they ever get from these waves and from an analysis of them.

In order to "see" the waves, scientists have developed the seismograph, which records the waves on a specially marked graph paper. The principle of operation of a seismograph is simple, though in actual construction it can be quite complex. The instrument is based on the principle of inertia, one aspect of which is the tendency of an object to remain motionless and oppose any effort to set it in motion. If a weight were hung on a spring and allowed to come to rest, then the other end of the spring were suddenly yanked, the weight at first would remain motionless while the spring stretched. Of course it would begin to move very shortly, but if then the spring could be yanked in the opposite direction, the spring would stretch again since the moving weight tends to go on moving. If we think of the weight hung on a spring in a box, and the box firmly fastened to a concrete pedestal sunk into the lower basement level of a building, we have the idea of a seismograph. The earth wave moves the box but the weight on the spring tries to remain at rest. If a marking pen is fastened to the weight and the graph paper to the inside of the box, a line will be drawn vertically on the paper as the box and earth suddenly move. Put the paper on a continuous, unwinding

roll and as the earth moves up and down a wavy line will be drawn on the unrolling graph paper. This is a picture of the earth wave passing the observation station.

The problem of analyzing the waves drawn in this manner is quite complex because of the continual tremors that are shaking the earth day and night. In some observatories the seismographs are so sensitive they daily record the comings and goings of heavy traffic in the streets above as the workday begins and ends! To separate these tremors from the ones seismologists want to analyze requires a lot of work and calculation.

Unfortunately seismology is a young science and worldwide cooperation among the observatories has been a fact only during the present century. But today analysis of earth waves from major earthquakes comes to special centers from all over the world and gradually the records are being built up.

Kinds of Earth Waves

A fault is a crack or line of structural weakness in the crust of the earth. When pressures develop on or within the earth they eventually cause motion of the earth's crust along the fault line. When a fault slips and an earthquake occurs, several distinct types of earth waves are generated. The point on the earth's surface above the fault slippage is called the epicenter of the quake. The actual point within the earth—which may be miles below the surface—is called the focus of the earthquake. Waves go out, as has been mentioned, in all directions from this focus.

The fastest of these waves is called the primary wave or "P" wave in scientific discussion. It is of the familiar longitudinal type, for it is a wave that compresses the earth particles in the

direction of the wave travel. It is identical in its motion to a sound wave.

The particles of earth are moved forward, pressing on those ahead of them, and then they rebound and finally move back to their original positions. But "P" waves do not produce the sensation of sound on human beings in their path. They have wave lengths much too long for that, and their speed is phenomenal: about five miles per second. They pass directly through the earth, penetrating the mantle and even the liquid core of the earth itself. For such waves as these can pass through both solids and liquids as well as gases. Where such waves reach the surface of the earth, they can transmit some of their energy to the atmosphere and indirectly produce sound. Observers on the scene of violent earthquakes have reported hearing strange sounds at the time of the quake. Some heard what seemed to be the explosions of distant artillery, others heard a ripping or tearing sound, and still others reported a dull booming coming out of the earth underfoot.

The secondary or "S" wave is the other type of wave that passes below the surface of the earth. It also is called a "shake" wave or "shear" wave. It travels more slowly than the primary wave and it moves the earth particles at right angles to the direction of wave travel. The type of stress it sets up is known as shearing stress. Shear can be simply illustrated. Take a broomstick in both hands placed together on the stick. Push with one hand and pull with the other. The stress you have set up where your hands meet on the broomstick is shear stress.

The "S" wave travels at less than five miles per second. It is sent out at the focus of the earthquake simultaneously with the "P" wave but can't keep up with it. Thus it arrives at the seismograph of a distant observatory after the "P" wave has been recorded. Since the speeds of both wave types are known,

the seismologist has a means of telling how far from his station the quake occurred. He then draws the arc of a circle on a map, using a scaled radius equal to the calculated distance. Where the arcs drawn by several stations meet lies the epicenter of the quake.

Unlike "P" waves, "S" waves cannot travel through a liquid or a gas. Shearing stress can be set up only in solid bodies. The molecules of a fluid won't resist a shear stress but will slide easily over one another, and no wave motion dependent on shear stress can continue through such a nonresistant medium. Although "S" waves are sent out in all directions just as "P" waves are, they cannot pass through the liquid core of the earth and reach the other side. On this evidence, we have reasoned that the earth's core must be fluid.

In addition to the waves that pass through all or part of the earth, there are several complex surface waves set up by earthquakes. These spread out like ripples on water and reach observatories much later than either the "P" or "S" waves. Such surface waves on the earth have been reported by eyewitnesses to earthquakes.

Some have reported seeing treetops sway back and forth in motionless air. Others have watched fields of grain undulate as these surface waves passed. Some have actually seen the collisions of such waves running in opposing directions. Just as water waves collide and spew upward momentarily, so these earth waves have sent jets of sand and soil and water from underground streams squirting into the air.

Destructive Energy of Earth Waves

The only use to which man has been able to put waves of the earth is in the analysis of the earth's structure itself and the tracking of earthquakes wherever they occur. Without

question, we will never be able to harness the energy for useful work. One reason is that earthquakes are not predictable in occurrence although in some regions they do occur in cycles. Exactly when one will strike we do not know, and the release of energy is so sudden when they do occur that all men can think of is to survive the catastrophe.

Fortunately many earthquakes occur where there is little human habitation and so, from man's point of view, the destruction is negligible. But when these waves disturb the earth in a densely populated area like Japan, the loss of life and the destruction of buildings is awesome.

Of all inhabited areas of the earth, the islands of Japan are most frequently struck by earthquakes. Analysis of the islands' structure shows that there are so many faults in the earth's crust in that region that the land is somewhat like a dried mud flat, the cracks dividing the surface into irregularly shaped blocks. Periodically these blocks tilt and warp and, when they have reached their limit, settle back or shift to restore a balance. The resulting earthquake often causes great destruction. The population density is high in Japan and few areas can be struck by quakes without bringing death to men. So frequent are minor shocks in the islands that the inhabitants have developed a calm, almost resigned attitude toward earthquakes.

But when a major earthquake does occur, the calmness vanishes and the Japanese react as people do the world over when the waves of the earth come to their city. They panic and try to flee.

At about noon on September 1, 1923, a violent earthquake struck the area of Japan where two great cities stood: Yokohama and Tokyo. The earth, so far as the people were concerned,

seemed to have turned to jelly. The earth waves swept across the area and passengers in a train headed for Yokohama had to cling to their seats to keep from being thrown about. It was, one witness reported, like being in a very small boat on a storm-swept sea. The first great earth wave split a church in half and crumpled it to the ground. The lightly built houses of the Japanese fell like matchboxes. The waves loosened great slabs of earth on hillsides and sent tons of rock and soil down into valleys. In a matter of seconds the two cities were shambles. As the waves shook the earth they broke all the underground water lines in both cities so that when the inevitable fires began there was no way to combat the flames. After the initial quake the waves subsided but there were others of less intensity. These normally follow a major quake and are called aftershocks. When the destruction to man and his works was totaled, it was found that damage amounting to two-and-a-half-billion dollars had occurred, the center of Tokyo was wiped out with all the historical documents and art treasures. Seventy-one per cent of that city was destroyed and 250,000 people lost their lives.

Deep Waves of the Sea

Surface waves on the oceans are caused by the wind. Waves below the surface of the water sometimes occur in the oceans of the world although they are different in nature from surface waves.

If an earthquake occurs in the ocean floor and a section of the sea bottom suddenly shifts, a violent disturbance can displace the water and send a wave outward in all directions. Not all undersea earthquakes produce such waves, however. If the shift of the sea bottom is horizontal, it does not disturb

the water very much. If it is vertical, and of some extent, it can produce what are often inaccurately termed tidal waves.

True tidal waves do exist, of course. But they are caused by the gravitational force exerted on the water by the moon and sun. They have the requirements of waves of period and amplitude. In great expanses of open sea such advancing waves are detectable and, in general, cause the rhythmic rise and fall of normal tides on the shores of the continents.

"Tidal" waves caused by earthquakes are more accurately known as seismic sea waves. That is, waves generated by movements of the earth. Japan has contributed a name to scientific literature for these waves. They are frequently referred to now by the Oriental designation: tsunami (soo-nah-mee).

The vertical shift of the ocean floor or an undersea landslide caused by an earthquake on the slopes of a submerged mountain are the two major sources of tsunami. When these occur, longitudinal waves of compression are set up in the water itself. The molecules of water first are pushed outward, spherically or nearly so in all directions. Their momentary displacement is abnormal; they reverse direction trying to reach their former position of rest, and repeat the motion. So the oscillations are set up and when that part of the sphere reaches the surface, it displaces the water there, causing a bulge and setting up a surface wave.

By the time this has occurred, however, the shock waves of the earthquake itself have already begun speeding toward seismographs around the world. The "P" and "S" waves of a quake travel much faster than the deep waves in the sea, so seismologists have ample time to forewarn people in coastal areas to be on the lookout for tsunami. Where the speed of earth waves is measured in miles per second, the speed of

tsunami is often measured in miles per minute or miles per hour. The speed of these waves varies with the depth of water they happen to be passing through—and since the depth of the ocean floor varies from place to place, the speed of the advancing wave is itself variable. Tsunami have been clocked at speeds up to 500 miles per hour. While this seems rapid enough—and is much more rapid than ordinary wind-produced surface waves—it is such that four hours would elapse before a tsunami would reach a point 2,000 miles from the source. So warning time is given to scientists in this case and they make good use of it.

Land masses surrounding the Pacific Ocean are frequently struck by earthquakes, and so are the submerged portions of the continental shelves. It is in this region that many tsunami occur. The waves, once set in motion, travel to all the shores and all the islands of the Pacific. Whether they will do damage or not to a particular place depends on the direction of wave travel, the distance from the source and the topography of the shore they approach.

Nonetheless, scientists radio warnings to stations on islands and continents advising them that a tsunami may be on its way. These bulletins are now sent with the same regularity of storm bulletins issued by the Weather Bureau. The Hawaiian Islands, lying in the middle of the Pacific, are subject to tsunami that originate from such diverse places as Alaska, Peru and Japan. And the coastal towns of the islands have been struck so frequently by tsunami that in one at least, the city of Hilo, a siren warning system has been established. When warnings are received, the siren wails and the people evacuate the low-lying beaches preparing for the worst even if it does not come.

When they have been generated, tsunami travel in all directions. During a recent series of earthquakes in Chile, the quake zone extended beyond the coastline and great upheavals and landslides occurred below the ocean surface. The seismic sea waves spread across the Pacific.

Twenty-foot waves crashed ashore on the Philippine Islands. A fifteen-foot wave rolled ashore on Montague Island off the coast of Alaska. The entire east coast of Australia was hit by a seismic sea wave. Extreme "tidal surges" were reported in British Columbia. Pitcairn Island, in the middle of the Pacific, reported a forty-foot wave moving at hundreds of miles per hour across the ocean. Three waves struck the town of Hilo in the Hawaiian Islands. Great tsunami struck the northern islands of Japan.

Very little can be done to prevent damage to buildings and wharfs along the shorelines exposed to these waves. As in Hawaii, the only way to save lives is to give adequate warning and hope the people will reach high ground in time to avoid the force of the waves.

This force has been calculated with the aid of instruments. One such wave of average size for a tsunami exerted a force of 800 pounds on each square foot of opposing wall or building that it struck. If such a wave were ten feet high and rolled ashore on just one mile of coastline, it would hit with a force of 42,240,000 pounds. It was also estimated that the force necessary to stop such a wave would be nearly 1,500 pounds per square foot of wave front.

The speed of these waves has already been mentioned. Compared to earth waves they travel slowly, but moving at between 400 and 500 miles per hour they easily overtake ships at sea and pass them. Curiously, many ships are overtaken

by tsunami and no one aboard is aware of what has happened. The reasons are easy to understand when the character of the waves themselves is understood. When the wave is generated below the surface, part of it reaches the "top" of the water and thus a surface wave is set up. But in deep ocean, these waves ordinarily are not of great size or amplitude. The distance between crests—that is, the wave length—may be as much as a hundred or more miles, and a ship encountering one would be raised so gradually by the slope of water on a

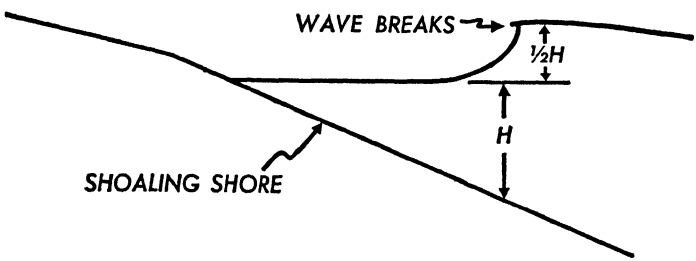


FIG. 5

wave front that no one would be aware of it. Even a 40-foot-high wave could pass unnoticed if it took 100 miles to rise the 40 feet.

The speed and character of these waves change, however, when they approach a shoreline; their speed changes as does their height. Such a wave approaching the mouth of a narrow harbor would push water into the harbor, and as the water became shallower, the wave would literally begin to pile up on itself. When the wave height becomes one-half the distance to the shallow bottom, it breaks. The water on the crest falls forward, down the slope of the wave front, and the effective

speed of the front is increased. This increase of speed raises the pressure that the wave exerts when it does strike the shore, and the resulting destruction is greater also.

Not all tsunami are severe enough to cause great damage and attract the attention of the public. Scientists measuring these waves know now that more exist than they had believed in the past. Only in recent years have there been enough stations and enough co-ordinated effort on the part of scientists throughout the world to detect the small waves that can be traced to undersea earthquakes of small proportions. The principal instrument used for the study of these waves is the simple tide gauge. There are several forms of this instrument but all are designed to do exactly what their name implies: measure the rhythmic rise and fall of tides. The times of high and low tide for each harbor and bay along a continental shoreline have been of extreme importance to sailors from ancient times, and a close watch is kept on the tides as an aid to safe navigation in and out of harbors. Many harbors of the world cannot be entered by vessels of deep draft except at the time of high tide. During the age of sail, of course, ships had to take advantage of incoming and outgoing tides to get in and out of harbors where river currents and opposing winds made the task of close, inshore navigation very treacherous.

Although astronomical calculations can predict the time of high tide for a particular longitude, no theory can account for all the minor deviations of tidal flow due to the configurations of the coastline and the varying slopes of the continental shelf as it approaches the estuaries and inlets where the land emerges above the sea. In short, though tides are periodic and theoretically predictable wave phenomena, they are modified so much by the shores they strike that tide gauges

must be employed all along the shorelines to measure exact times of high and low water.

These gauges will also detect abnormal tides or abnormal times of high tides. When such deviations occur, the logical explanation is that tsunami of minor size have struck the shore. If, for example, high tide at a particular place is expected at noon and the tide gauge shows a high reading at ten in the morning—with the high reading persisting for a long time—the oceanographer might conclude that a tsunami had struck. His reading of the tide gauge and the readings of other gauges along the same coast will tell the story. For such tsunami are unlike the large, destructive ones that catch the headlines. They started from very far away or have been reflected from some distant shore and so have lost much of their energy. In some instances tsunami like this have taken seacoast towns by surprise. The water will rise slowly so that no one is aware of what's happening unless he is watching a tide gauge at the time. The water will rise to the high tidemark, boats moored to short lines will bob about, bow down, in the rising water, and the water will silently continue to rise. It reaches the level of the wharfs and flows into the streets, where it may stay for some time before receding. Such tsunami become noticeable to the casual observer only after they have gone above the local high tidemark. The damage they do is caused by simple flooding, for there is no sudden expenditure of force in these tsunami.

They may, as they enter nearly enclosed harbors, set up a purely local effect known as a seiche. They will put the water of the harbor in motion just as water in a bathtub can be made to surge back and forth, periodically producing alternate high and low marks on the tub side.

Tide gauges measure these seiches as well as the tides, and so the scientist begins to have a picture of the myriad disturbances of the sea, of which tsunami are the most feared by man.

On the islands of Japan, in Hawaii and on other Pacific Islands where the destructive tsunami are more than occasional visitors, custom and direct observation of the sea along the shore can forewarn the people who live by the sea. One of the first indications that a large seismic sea wave is about to strike is the recession of the water from the shore. Where the slope of the shore is shallow, this withdrawal of the water may on occasion continue until land never before seen even at the lowest normal tide lies exposed awaiting the onrush of the wave.

What is happening as this occurs is exactly what happens all the time but in miniature as surface waves approach a shore. Any observer of the sea has watched approaching waves which grow from a swell to a cresting breaker as the wave reaches shallow water. In rising to its full height before curling to crash on the shore, the average surface wave draws water from the shoreline in front of it; that water recedes from the shore and is to all appearances "sucked up" by the wave itself.

Tsunami, far at sea but rapidly approaching a shore, will do the same thing but on a scale so much larger than that of even the largest surface wave that an observer on the shore can only see the water withdrawing.

When this occurs, inhabitants of any coastal point move to high ground inland as rapidly as they can. For they know that only a few minutes are left to them to flee. The withdrawal of the water is the only warning nature gives. Man, of course, has now devised warning methods. Seismologists use radio

over thousands of miles to distant coasts to forewarn of spreading seismic sea waves.

Given this abnormal withdrawal of water from the shores of a shallow bay which opens in the correct direction—the direction of the tsunami's arrival—great destruction can result.

One of the most spectacular tsunami in history struck the coast of the Japanese island of Honshu early one summer evening in 1896. Villagers of the Sanriku section of the coast were on the beach when the ground was shaken by tremors of a distant earthquake. So accustomed are the Japanese to such disturbances that they did not pay much attention to it. Shortly after the earth waves were felt, the ocean began to withdraw from the shore farther than any low tidemark. Still, inexplicably, the Japanese vacationers paid no attention to the ominous signal. Then from a great distance at sea there came a sound which has been described as that of rain falling, a steady gentle sound which grew louder within seconds.

The great tsunami reaching the shoaling part of the ocean bottom began to pile up. It moved toward the land at hundreds of miles per hour and, as it swept in, rose to an estimated height of 100 feet. The great wall of water, packing fantastic energy, destroyed over 10,000 homes—in some cases obliterating 80 or 90 per cent of small villages that lay in its path. Over 27,000 people lost their lives that evening.

To show how such waves can pass at sea unnoticed by sailors, the reports from fishermen working the fishing grounds well off the shores of Sanriku are good evidence. When the tsunami passed them, they noticed nothing. The water had not begun to pile up, and its actual height before reaching the shallow coast may not have been more than a few feet. They reported that their first knowledge of the wave came when they returned

to their moorings later in the evening and saw, as they approached shore, the wreckage of buildings and the bodies of their village friends afloat on the sea.

The 100-foot height of this terribly destructive wave has been surpassed, but fortunately the larger wave struck a shore that was much less densely populated. This was in 1737 and the wave struck the Kamchatka peninsula at Cape Lopatka. That wave rose to a height of more than 200 feet as it crashed on the shore.

CHAPTER 3

Sound

FOR CENTURIES men have made use of sound waves without understanding their mechanism or even asking the fundamental question: How does my voice create sound and how does it move through the atmosphere to the listener's ear? Sound is such a fundamental part of our living that, like many other such phenomena, it has been taken for granted as an axiom of existence.

In developing language, men have utilized their vocal apparatus to create a wide range of complex sound waves which the ear, properly trained in understanding the various noises, interprets as meaningful communication. Other animals also understand their own limited vocabularies, and recent research has discovered that those intelligent aquarians, the dolphins, seem to have a reasonably complicated language. Detected with special submarine radios, the dolphins' language has been taped for further study—with the hope that we may eventually learn to communicate with them.

All such communications, through the air or under water, make use of wave propagation. These sound waves are longitudinal waves that carry the energy of the speaker's voice to the listener's eardrum. They form a natural telephone system.

The human ear, of course, has its limitations and can respond only to sound waves whose frequencies lie between 20

and 20,000 cycles per second. This is called the audible range of sound, but that test is applied only to human ears. We know that other animals can receive higher frequencies, and this is the principle of so-called "silent" whistles used to call trained dogs. Other evidence of different hearing ranges among animals comes from observation of birds and fishes prior to an earthquake. In Japan these creatures have been observed to be in a state of extreme agitation shortly before a quake strikes. The reasonable explanation is that their hearing apparatus picks up sound waves produced by preliminary tremors so slight or of such high frequency that they escape human detection.

To measure the energy contained in sound waves, men have devised another yardstick with the human ear again used as a reference. The slightest audible sound is said to be just over the "threshold of hearing" which is described in decibels. This unit is based on the ear's response to the energy contained in a sound wave. The threshold of hearing is considered to be a decibel level of zero. Ordinary conversation ranges around 75 decibels. A riveter at work produces about 95 decibels.

As the decibel level rises—that is, as the sound energy increases—the human ear is assaulted so vigorously that at the upper end of the decibel scale the engineers have placed the limit of hearing at the so-called "threshold of pain." For the energy in sound can be great enough to cause pain. Jet aircraft engines when run up on the ground can produce painful effects in the personnel who work around them. And the noise at jet airports has drawn many complaints from near-by residents.

Sound Sources

Many materials can be set into vibration so that they produce sound waves in the atmosphere. One of the most common

methods of producing sound for studying it is to stretch a string tightly between two fixed points and pluck the string. It vibrates back and forth and in doing so alternately pushes the air on either side of it first in one direction and then in the other. The sound waves created move outward, and if the frequency of the vibration is within the audible range, the result will be a sound of a certain pitch—the musician's word for frequency of sound received by the ear. Many musical instruments, of course, make use of this method of sound production as it is a most versatile source, producing a richness of quality not found in many others.

A little experimenting will show that the tighter a string is stretched the higher is the resulting frequency. And if the length of the string is changed, the frequency again changes. The sight of a person tuning and then playing a violin is evidence of these two ways to change the frequency of strings. First the violinist tightens or loosens the strings to produce the proper pitch in each one, and then when he plays, he effectively changes the lengths of the strings by pressing his finger on them and holding them tight against the instrument.

Inspection of a violin or guitar will show the different strings seem either to be made of different materials or are at least differently constructed. Some are thicker than others, and an observant person would reach the correct conclusion that four things determine the frequencies of strings when they are set into vibration: length, stretching force, diameter and material of the string.

Another common method of producing sound is by striking a relatively thin metal rod. The rod vibrates back and forth and again sets the air in motion, producing sound waves. Drum diaphragms when struck vibrate in and out and produce their own quality of sound waves.

Wind instruments are more complex but they manage to produce sound by having the air within them set into vibration by the varying vibrations of the performer's lips or, in the case of reeds such as a clarinet, by the vibrations of the reed mouthpiece.

The human voice produces sound waves by the passage of air through the "sound box" or larynx where membranes are stretched by the muscles with either greater or lesser force to change the frequencies emitted—it is a natural "stringed" instrument.

The trouble with many sound sources, however, is that they do not produce sound of a single frequency. Depending on the nature of the source, they may be emitting several different frequencies at once. And while one of these may be strongest—and so give the effect of a single note—the other frequencies are present in enough degree for the ear to notice them. This can be easily proved by hearing a piano note struck, say middle C, and then having an oboe or a clarinet or some other instrument sound the identical note. Although they are supposed to be playing the same frequency—and for the most part are—they each produce various other frequencies or harmonics, as they are called—and the ear easily picks them up, thus being able to distinguish between the instruments at once.

To get a pure tone, one composed as nearly as possible of a single frequency, engineers have developed a limited instrument called a tuning fork. It consists of two tines or prongs connected to a single base. These are often made today of aluminum, and the frequency they emit is dependent primarily on the length of the tines. With a tuning fork, precisely made, the engineer can compare musical instruments with its sound

and know with sufficient certainty that he is listening to a single, unmixed tone.

Speed of Sound

A favorite old saying is that if you see a lightning flash and count slowly until you hear the thunder, you can tell how far away the lightning is. And roughly this is true, for sound travels about a mile every five seconds. More strict measurement shows that it travels 1087 feet in one second when the air temperature is 32°F at ground level. As the temperature of the air rises, the speed of sound increases at the rate of about 1.1 ft/sec for each Fahrenheit degree above 32°F.

Sound travels through other gases, liquids and solids as well as air and its speed through these other substances is quite different from its speed in air. In general, the more dense the substance, the faster sound will travel through it. Sound waves, for example, travel through water at about 4700 ft/sec, through iron at 16,700 ft/sec and through glass at 18,000 ft/sec. It decreases proportionately as the temperature drops.

Another favorite fable that substantiates this is the one about keeping one's ear to the ground. For a sound source many miles away that sends its energy through both air and ground will reach a listener first through the ground because the speed of sound is higher through earth than through air. Many a fictional hero, or villainous Indian, has been depicted putting his ear to a railroad track to receive the first audible hint that the "Iron Horse" was approaching.

An easy way to test the various speeds of sound during summertime is to stand in relatively shallow water and put one ear under water and leave the other in air. Someone striking two rocks together some distance away on the surface will

send sound waves through the water and air simultaneously. The listener will hear two sounds for each blow struck—one arriving through the water and the other through the atmosphere at substantially different times. If you try this, be certain whoever strikes the rocks together is at least 100 yards away. If he is closer, the energy of the sound wave arriving through the water may damage your eardrum.

Our ears, through which we receive most of the useful and meaningful sound waves that come to us, are marvelously adapted to receive and separate the multitude of various sound waves the world produces. We can hear the slight sounds of leaves rustling at a distance on a quiet day and can stand the roar of jet engines for a brief time without suffering permanent damage. We can distinguish between various sounds essentially of the same loudness and frequency, and our ears, coupled with our experience in *seeing* sound produced—such as paper tearing or a shoe scraping—allow us to conjure up pictures of such sounds being produced when the sound alone is present. A familiar voice or footstep will be recognizable and distinguishable from all others by the operation of the complex mechanism that is the human ear.

Scientists working to understand fully the mechanism of hearing do not yet have adequate theories or convincing data to explain everything there is to know about hearing. Once thought to be a relatively simple and straightforward process, hearing now is known to be extremely complex. In a brief and oversimplified way, however, the process of converting the waves of sound striking the ear into meaningful signals to the brain can be sketched.

The ear itself is considered to be in three parts, the outer, middle and inner ear. The outer ear consists of the odd-looking

flap of skin attached to the side of the head and the open tube proceeding inward to the eardrum. The middle ear is an air-filled cavity containing three linked bones which are capable of various movements. The bones are the hammer, anvil and stirrup, and they amplify the vibrations of the eardrum, send-

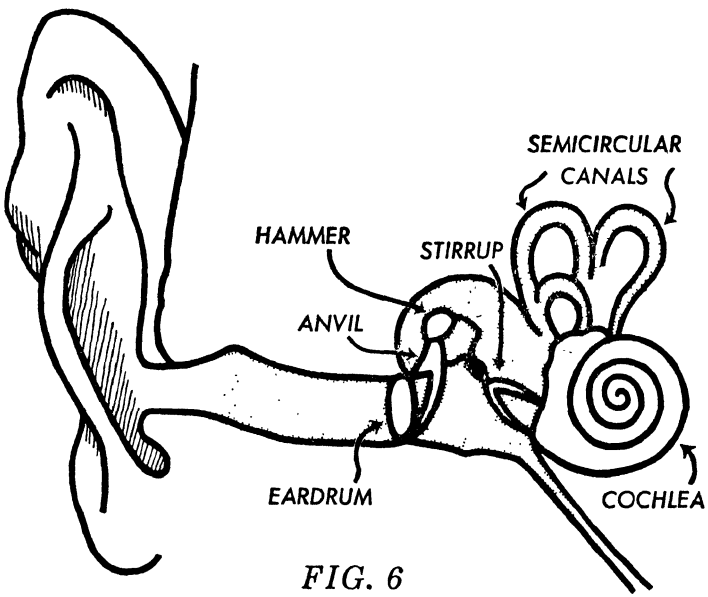


FIG. 6

ing the message along to the inner ear. Within the inner ear lies the cochlea, which looks like a snail shell and is filled with liquid. By means still not known, sound waves excite nerves in the cochlea and the sound then has been converted into a nerve impulse which is sent to the brain. There is evidence to suggest that this process is electrochemical in nature, but the exact order of events and method of operation is not yet fully understood.

The Telephone

A much simpler device to consider than the human ear is the telephone. Probably no children grow up today without at one time or another making a telephone from two tin cans and a length of string. The principles they employ are firmly established, but there are many practical difficulties that cannot be overcome in this simple method of sound transmission. If the string is fastened to the centers of the ends of the tin cans and stretched tightly, a voice speaking in one of the tin cans can be heard by the listener if he places the open end of his tin can to his ear. The string, however, must be stretched tight. If it is limp, no sound will travel along it. Also, if it presses against some obstacle at any point in its length, the sound will be obscured, and should the children try to stretch the string around the corners of buildings, alas, the telephone will not work. But as a simple telephone used under the right circumstances, it can transmit sound energy. The speaker talks into the open end of his tin can and the sound waves strike the somewhat flexible end of the can, setting it into vibration. This in turn sets the string into vibration longitudinally and the receiver's tin can begins to vibrate, more or less faithfully reproducing the chain of waves set up at the other end. With the receiving tin can vibrating, the air within it does also, the re-created sound waves strike the listener's ear and he "hears" his friend's voice.

In the modern telephone the problem of distance and obstacles is solved by the use of an electrical current. The speaker talks into the mouthpiece and again the sound waves set a metallic disk vibrating against a mass of loosely grouped carbon particles. All the while a current is flowing in the wire

connecting speaker to listener. Now carbon particles will carry more or less electricity depending on how many of them are in contact at any given moment. As the vibrating diaphragm compresses the particles, moving inward on them, more of them touch and press against each other. This alters the electrical current. When the diaphragm moves outward, the particles are more loosely grouped and again the electric current is changed. These alterations travel to the receiver and affect a small electromagnet which attracts another metallic diaphragm strongly or weakly as the current demands. As this diaphragm re-creates the initial impulses on the other end of the line, the air in the receiver being held to the listener's ear is set into motion and the sound waves reach his ear, where they are translated into, presumably, intelligent conversation by the brain.

In essence a telephone uses sound waves to alter an electric current, which in turn alters the strength of a magnet. The changing strength of the magnet vibrates a metal disk and the sound waves are faithfully reproduced at the other end of the line. Once the interacting principles of sound and electricity were understood and tested, the telephone became a reality, but for some time not a practical reality. For as wires became longer, the electric signal became weaker, and some way had to be found to overcome this. The answer to the problem lay in supplying boosters for the electrical energy which, when done, permitted transcontinental calls to be made. Today much of transcontinental telephoning is carried on by a system of microwave radio towers that span the continent. But this form of telephony has more to do with radio than with sound. The principle, however, remains the same: sound waves modify an electrical wave and the modified electrical wave produces

sound waves at the other end of the transmission. Yet even microwave radio telephoning has a drawback. It sends its signal in straight lines that have to be picked up by relay towers and redirected around the earth's curving surface. Naturally, wide oceans make this system impractical, for floating towers at sea would be prohibitively expensive. But signals now have been bounced from an artificial satellite circling the earth, and we have both telephone and television transmission by using waves of several kinds: sound, radio and light waves.

How Animals Use Sound Waves

The ear of man is well adapted for its purpose—and so are the ears of many other animals we commonly regard as inferior creatures. Of the five senses, man's sight is most important to him, for it is the most highly developed sense he has. This being the case, our sense of smell, for example, is not employed as frequently and is not so highly developed. A dog, on the other hand, does not rely as heavily on sight as we do but uses his sense of smell to a degree that is impossible for man. In certain animals the sense of hearing is their major sense, the one that protects them, directs their travels and in some cases allows them to locate their next meal.

Proof of man's reliance on sight as his primary sense comes when it is pitch-dark in a room and he tries to find his way about. The instinctive thing man does in this situation is employ not his hearing but his sense of touch. He goes groping about with his hands, trying to locate and avoid obstacles in his path. It would scarcely occur to a person in such a situation to whistle and listen for the echo from the nearest object—basing his judgment of nearness on the time lapse between sending and receiving this sound. But this is what several

"lower" animals do—not only in emergencies but throughout their lifetimes.

Darkness which does not permit even the most sensitive eye to see can be found in the depths of the sea. How do fish at those depths manage to avoid running into obstacles or each other? How do they find their food? Among the lower orders of fishes there is some evidence to suggest that they respond to changes in water pressure as objects loom or other fish or aquatic life swims by. But there is abundant evidence that higher aquatic animals such as whales and porpoises do much better than that. With brains highly developed—and some experts today believe the dolphin or porpoise has a brain as highly developed as man's—these sea mammals not only hear, they produce the sounds that they hear and use them as our eyes use light waves to make things visible.

The mechanism of a porpoise's hearing procedure is not yet fully understood, but research is going on that may disclose the entire process. It is now known with some certainty, however, that a porpoise sends out a sound wave and, by interpreting the echo that comes back when it strikes something, manages to "see" an obstacle or locate a fish. While many of these mammals live in the sea and appear on the surface where there is sufficient light to use their eyes, others spend much time in muddy streams where there certainly is not enough light beneath the water surface to allow them to see. Yet these mammals swim rapidly and without injury to themselves around sunken objects, projections—even threading their way through a tangle of tree roots—all at top speed.

How?

The answer came from recent investigations carried on by a husband-and-wife team, Mr. and Mrs. Schevill, with the aid

of a captured porpoise in a muddy pond. They anchored a small rowboat near one end of the pond and put down an obstacle in the form of a net extending toward the center of the pond perpendicularly from the center of the boat. With the porpoise swimming about trying to locate food, they carefully lowered a small fish into the murky water. Sometimes they lowered it from one end of the boat, sometimes from the other on the opposite side of the net. Yet with remarkable accuracy the porpoise managed to locate that small fish—which was about three inches long—and came in to receive his snack.

The secret of the porpoise's performance lay in the formerly overlooked noises it produced. Underwater listening devices now have established that these intelligent aquatic animals can emit a number of various sounds: grunts, squeals and creaking noises. It is the creaking noises that seem to be the porpoise's "radar signal." With listening devices the researchers discovered that if the porpoise were not creaking he didn't find the fish.

Consider this. An animal emits a short, rather high-frequency sound wave. It travels outward from its source in spherical fashion as described earlier—but now under water. It strikes the bottom and sides of the pool and some of that echo returns to the swimming mammal. Other echoes come from obstacles, from the surface of the water, from plant life, sunken logs and other possible kinds of projections all through the pond. Yet the very small echo that came back to the searching porpoise from a three-inch fish was enough to send him toward it. This organization of the porpoise's hearing apparatus is certainly as complete and complex as our own visual sense. The animal was actually "seeing" with his ears, viewing through them the entire panorama of its submerged world, just as

we might scan a landscape and locate visually the small figure of a sheep grazing on a distant hillside.

In another way the porpoise's hearing is superior to man's. Where an average man can hear sounds with frequencies up to 20,000 cycles per second, it has been established that porpoises can hear sounds as high as 150,000 cycles per second.

This ability of some animals to receive sounds so far above the audible range of the human ear led one early researcher to a frustrating conclusion of a very interesting experiment. In the latter part of the eighteenth century, an Italian scientist, Lazzaro Spallanzani, conducted a series of experiments on bats. These small flying mammals have been known for centuries to be capable of flying easily in total darkness where their eyes, such as they were, did not help them at all. To establish the fact that they were not using their eyes, Spallanzani blindfolded several of them and watched them carefully as they began to fly at dusk. They flew as normally as before. To prove they were not dependent at all on sight, he dissected several of the blindfolded bats after they had flown through the night with their fellows and discovered that they had caught just as many insects as the bats that were not blindfolded. Obviously they had some other means of navigating and locating their dinners during the hours of darkness.

Spallanzani had observed bats sufficiently to know that they could fly swiftly and safely through a maze of small tree branches, that they also could fly between the rungs of a chair in a darkened room. Since sight was not the sense they used, he theorized that the sense of hearing held the secret of their mysterious ability. Accordingly he plugged up the ears of several of his experimental animals. When night came the sleeping bats awoke and those with plugged-up ears started out

to fly with their companions. But they ran into branches, swooped and plunged erratically about and proved in a moment that Spallanzani's theory was correct. But being a careful experimenter, Spallanzani reasoned that this reaction might have been due not to the loss of hearing but to the irritation of the small ear canals caused by the plugs he used. He fitted small metal open-ended tubes in the ear canals of several bats and released them. They flew normally, avoiding obstacles in their habitual way. When they returned to the nest at daylight, Spallanzani closed the ends of the tubes. By doing this he neither increased nor decreased the degree of irritation caused by the tubes but he did cut off the bats' hearing. The bats so treated could not fly the next night, and Spallanzani knew conclusively that hearing was the mechanism employed by the night-flying mammals to get about and search for food.

Spallanzani himself knew that such must be the case, but the next question, What sound do the bats hear? couldn't be answered. The results of his remarkable experiments drew only ridicule from his contemporaries, for he apparently had been led by his observations into a cul-de-sac from which there was no escape. The bats managed to avoid all obstacles in a completely dark room by relying on their sense of hearing—but there was no sound to hear, the room was absolutely quiet so far as Spallanzani could measure it.

Nearly a century and a half passed before the validity of Spallanzani's conclusion could be checked. In 1938 a science student at Harvard, Donald Griffin, became interested in ultrasonic sound and Spallanzani's bat problem. With newly devised equipment that could detect sounds well above the range of the human ear, Griffin tested a group of bats. The equipment revealed that the bats were themselves producing plenty of

sound but most of it was well above the audible range for human beings. Spallanzani was proved correct. The bats flew about, much as the porpoise swims about, emitting brief pulses of sound and then "reading" the echoes that came to them. So quickly can the bat react that his ears serve him as our eyes serve us, quickly—almost automatically—to step over or go around an obstacle.

The portion of the bat's sound that can be heard faintly by people resembles a small ticking or clicking sound. When there are few obstacles in the space through which the bat is flying, the rate of ticks or clicks is slow. But when the animal approaches, say, a tree with many small branches and twigs that could injure him, the rate of clicking rises noticeably until it becomes an almost continuous buzzing noise. Obviously as the hazard increases, more echoes must be picked up—and for more echoes to come to the bat's ears, more signals must be sent out in a short span of time.

This echo-location ability of bats had been suspected a few years earlier by another scientist, and still another group—once the principle of a bat's navigation became known—tried covering the mouths of bats so they could not emit their signals. This worked as effectively as Spallanzani's covering their ears, and the bats were "blinded" by having their source of echo waves cut off.

Men Try Echo-Location

The name now given by men to echo-location beneath the surface of the ocean is sonar and it is familiar to anyone who has read of the submarine-hunting activities of the United States Navy during World War II and the Korean conflict. The principle employed is similar, so far as we know, to the

sound emissions of porpoises and bats. Where bats, however, emit sounds bordering on and above the upper audible limit of the human ear (anywhere above a frequency of 20,000 cycles per second), men have developed even higher frequency emitters for such echo-location in the atmosphere—and called that form of the detection method radar. But sonar serves for underwater detection, and the sounds sent out by submarine hunters are near the human frequency range.

One of the basic wave equations which is very simple yet which tells us much that we want to know about waves of various kinds is that the velocity of a wave type through a particular medium is constant and is equal to the product of the wave length and the frequency. In mathematical form it might read $v = f\lambda$ where v equals the velocity, f the frequency, and λ (lambda) the wave length. In considering sound waves, for example, in air of given density and pressure we might find that its speed is 1100 feet per second. A sound wave traveling at that speed and having a frequency say of 1000 cycles per second would be calculated to have a wave length of 1.1 feet. Another sound wave having the frequency of 2000 cycles per second would have a wave length of just half of the 1000 cycles per second wave, namely 0.55 feet. The comforting thing to keep in mind is that sound waves in a medium such as water travel at the same speed no matter what the frequency or wave length might be.

Now, for sonar to operate efficiently, it has been found that frequencies above 10,000 cycles per second were most efficient and as a matter of fact some as high as 26,000 cycles per second were needed. The trouble obviously was that even if we sent out sound waves efficiently, in short pulses, and listened for the echo, we couldn't hear the echo of a sound wave of 26,000

cycles per second. Something had to be done to make it audible.

Fortunately there is a very simple way to make such sound waves produce an audible wave. It works like this. If, say, a 26,000 cycle-per-second wave were produced and at the same time a 25,000 cycle-per-second wave, the listener could hear neither of these generated waves but he could hear a sound wave of 1000 cycles per second—the difference between the two higher frequency waves. The process by which this comes about will be mentioned later, but it does provide a very easy way to "listen" to waves above the range of the human ear.

Keeping in mind that sonar equipment emits short pulses of high-frequency sound which bounce back from objects and that it also emits sounds a little bit off the probing frequency, we can see—or hear—short pings of reflected sound from an alien object such as a submarine. This signal—a repeated ping, ping, ping—has become familiar to every youngster devoted to war movies or to television programs concerned with submarine hunting by our Navy.

Ordinarily during a scene like this the viewer is shown the screen of an oscilloscope which lights up with every ping, a tense technician, a calm commander and a nervous new lieutenant. The pings crowd closer together and so do the men in the submarine until at last the calm commander says "Fire One." And we all know another enemy ship is doomed. The nervous new lieutenant grins, the tense technician offers him a cigarette and . . .

However this method of echo-location is dramatized, it is presently man's best approximation to that of animals who for centuries have "seen" the world only through sound waves. And our approach to a bat's method of echo-location still

remains rather crude. For the bat, in emitting a short pulse of sound of not more than one or two thousandths of a second, emits not a single frequency but a frequency that changes, in that short space of time, as much as 45,000 cycles per second; other bats can emit sounds of varying and complicated frequency patterns up to 150,000 cycles per second.

To "read" all the echoes that return to the bat requires instinctive skill on the part of the bat. In attempting it, however, we have learned a principle that is useful in interpreting sound waves as well as other kinds of waves. It is called the Doppler effect. All of us have experienced it without perhaps inquiring into it. If you have ever stood near a railroad track and listened to the train whistle as it approaches and passes, you've noticed a change in the pitch of the sound that reaches your ears. Another common way to experience the effect is to listen to the sounding horn of an approaching automobile and note its change of pitch as it passes. This would indicate that you might determine whether an object (submarine, for example) is moving toward or away from you on the basis of the frequency (pitch) of sound received. If both you and the submarine are not moving with relation to each other, the frequency of the received echo will be just that of the wave you emit. If the submarine is moving toward you the pitch will be higher, and if moving away, lower. By careful measurement the actual speed of the moving object can be determined.

Useful Sounds We Cannot Hear

Sound frequencies above the audible range of our ears are termed ultrasonic, and they are being employed directly more and more by science and industry.

Just as sonar uses echo-location under water, industry uses

it to locate flaws in metal castings. Relatively cheap and quick to employ, the oscillator, as it is called, sends ultrasonic waves through metal parts and the echoes are made visible on the screen of an oscilloscope. If the sound waves encounter air bubbles or other flaws in the metal, these are revealed just as sonar reveals a submarine.

By setting liquids into rapid vibration using ultrasonic waves, and then immersing objects to be cleaned in the vibrating liquid, the high-frequency vibrations almost literally shake grease and dirt particles from metal or glass. These waves also are used to produce fine emulsions by breaking colloidal particles into smaller and smaller bits. Very brittle metals can be drilled by directing a beam of such ultrasonic waves on the metal.

To medical scientists ultrasonic sound vibration has proved most useful in treating patients who have pain from arthritis and other similar nerve inflammations. The waves penetrate as much as two inches below the surface of the body, providing some relief for sufferers.

Sonic Boom

In today's jet age, few people have not been startled by what apparently is a nearby explosion on a quiet afternoon as fighter planes break the so-called "sound barrier" and produce a wave of compressed air which strikes the earth with audible and sometimes destructive effects. If any question exists about the energy of sound waves, this peculiarity of the jet age should dismiss it.

What actually happens is that supersonic aircraft set up a bow wave much like that preceding the prow of a boat moving through the water. In the case of aircraft, however, the wave

spreads out in all directions in the atmosphere. When this wave of compression reaches the earth, the energy it contains is made audible as the earth and objects resist the progress of the wave. In a way it is like a water wave breaking on the beach, the crash or boom of surf and the occasional tremors in the ground felt by those near by when the wave encounters the land. The destructive effects of sonic booms have brought numerous complaints from citizens to the Air Force and at least attempts to recover the cost of replacing shattered windows. So far the most prolonged sonic boom on record came from the Air Force bomber that streaked at supersonic speed from the east coast to the west and back again non-stop, leaving a trail of shattered window glass below it that stretched from New York to Los Angeles.

CHAPTER 4

Light Waves

IT IS not surprising that many years ago primitive man worshiped the sun, for it appeared to him to be the giver of all life. He was not far wrong, in a scientific sense. All of the energy that we use today in the form of coal, fuel oil and gasoline, water power and probably even atomic power had its origin in the sun. Without this life-giving energy there could be no plant life as we know it, and without plant life, animal life cannot develop. Coal and petroleum both represent transformations of ancient plant life that once grew and flourished in sunlight.

This continuous and apparently limitless outpouring of energy from the sun reaches the earth across some 93,000,000 miles of space and it, in combination with the earth's position in its orbit about the sun, has defined the major climatic zones in which man can live. These zones in turn have played an important part in shaping the culture of the people living there. In northern latitudes Eskimos, for example, have spent so much time merely staying alive they have been unable to develop the skills or the complex cultures of the temperate latitudes. In tropical zones, where local conditions do not modify the effect of the sun's energy poured too generously on the earth there, men have been forced to live at a more leisurely

pace. In a very real sense the excessive energy of the sun in tropic lands has sapped the mental and physical vigor of the inhabitants. At the ends of the earth, the polar regions, man cannot survive without extreme difficulty, and in the Antarctic continent men live only by bringing all that they need with them, for no edible plant life grows there and no animals inhabit the inland regions.

All this disposition of man across the earth because of the sun! A small not very hot star when compared to other stars in our universe, the sun nonetheless is 864,000 miles in diameter compared to the earth's minuscule 8000 miles. The thermonuclear reactions going on at the surface of the sun produce a temperature there of over 11,000 degrees Fahrenheit and the interior of the sun has been calculated to exist at a temperature of 18 to 36 million degrees Fahrenheit.

From this great reservoir of energy the earth receives its small portion in a great many forms. It is a small portion because the energy dispatched by the sun goes outward in all directions from its essentially spherical surface and only that bit that strikes the earth can be absorbed. Not all of the energy that strikes the earth is retained. Some is reflected or re-radiated into space. Nonetheless it is more than enough for man to exist in the tropics and temperate latitudes.

The most obvious of the forms of energy we receive from the sun is visible light. So obvious a form, in fact, that for centuries men simply took it for granted and did not inquire too deeply into the nature of light. But the question: What is light? has been attacked in recent years with ingenuity, genius and an increasingly complex array of instruments.

For many years men thought of light as small particles, like atoms, that were spewed from the sun and traveled to earth.

Others held that light was simply a wave phenomenon, similar to sound waves or water waves. In fact, as we shall see, there are times when light can be accurately described as a wave phenomenon and at other times must be thought of as particles of energy. At the moment we can imagine particles being emitted by the thermonuclear reactions on the sun, transmitted as waves, and received on this end of the line as particles. A crude analogy might be that of people (particles) boarding a train (wave) at a station. The train wave travels to its destination according to its rules of travel and then the people (particles) disembark on reaching their destination. In short, if we examine light in transit, it answers most of the requirements of waves.

The nature of light, in current theory, is that it is the emission of energy from atoms of matter that have been excited in one way or another. In general there are two ways to get light from atoms of a material: 1) provide energy in a form the atom can transform into light energy, or 2) begin a thermonuclear reaction from which some of the energy released from the nucleus of the atom will be detectable as light—as is happening on the sun.

It would seem then that to investigate light we have to investigate atoms—their structure and behavior. The present idea of what an atom is and how it behaves has come to men only recently, although Greek speculative thinkers long ago conceived a small "indivisible" particle that made up all different kinds of matter.

Great contributors to our present picture of the atom include Neils Bohr, Louis Rutherford, Joseph Priestley, Albert Einstein and Max Planck. In a very simplified way here is what we believe an atom is today.

The principal matter of which an atom is made up is located at its center in a very small, compact mass called the nucleus. Here most of the weight of the atom is concentrated. Circling it, like planets about the sun, are various numbers of electrons. Their number depends on what element it is, for example, carbon or iron or oxygen. An electron weighs very little but it has an electric charge. Like the earth in its orbit around the sun, the electron spins on an axis as it moves about the nucleus. We call the charge of an electron negative, and of its electrical counterpart within the nucleus of the atom positive. The name of this nuclear particle, or nucleon, is a proton. Within the nucleus, too, lie neutrons which have no electrical charge or are, as their name implies, neutral.

Simplest of the atoms are hydrogen atoms which are made up of a single proton in the nucleus and a single electron circling in an orbit relatively far away from the nucleus. Helium is the next most complex atom, and its nucleus contains two protons and two neutrons. Two electrons circle in orbit around it. All other atoms are simply increasingly numerous combinations of neutrons and protons in the nucleus and electrons circling at various distances away in their orbits. These orbits are of increasing diameter and the number of electrons each orbit can contain is limited by the nature of the atom.

For simplicity's sake let's consider trying to get a hydrogen atom to give us some light. If we take a sample of hydrogen gas and heat it or supply electrical energy to it, we can force the electron circling in its assigned orbit to move out to an orbit more distant from the nucleus. If we now cut off the energy supply, the electron, being somewhat out of place and longing to return to its own orbit, falls back to its natural position. In doing so it emits a measurable and visible quantity

of light energy. This energy travels as a wave to a receiving instrument such as your eye. Of course in any given sample of hydrogen gas there are millions of hydrogen atoms all being given energy, or being excited. So instead of just a single pulse or bundle of light energy being transmitted, an apparently continuous stream of energy comes from the gas. Some electrons in hydrogen atoms are dropping back to their natural orbits and emitting light, others are receiving energy and moving out to more distant orbits. If some hydrogen atoms receive more than their share of energy from our source of supply, the electrons may move even farther out. When they fall back they, too, give out light, but of a different wave length. By supplying a great deal of energy, we can get hydrogen to give us many different wave lengths of light energy.

Each time an electron drops to a "lower level," as we call the inner orbits, the energy seems to come out in the form of particles called photons. These, then, are light "particles." Once emitted, however, they form a wave that has frequency, wave length, amplitude and a particular speed.

The other method of producing light energy, by thermonuclear reactions, is more complex but can be thought of in this way. When the nucleus of any atom is invaded and broken up, or when two small nuclei merge to form a larger one, some of the energy that held the nuclei together is sent out in the form of light. Both atomic fission—as in the atomic bomb—and fusion—as in a thermonuclear reaction such as the hydrogen bomb or the sun's activity—produce light energy.

Light—Part of a Wave Family

Light waves from whatever source are now known to be related to many other kinds of waves: radio, television, cosmic, ultraviolet and infrared—to name the main divisions of this

family. Taken all together, these related waves form what we now call the electromagnetic spectrum. While all these waves have different wave lengths and correspondingly different frequencies, they do have the same speed through space—about 186,000 miles per second.

How the Speed of Light Was Measured

For many centuries men believed that the speed of light was infinitely great. No one could detect any time lapse between the lighting of a light and the reception of it by the human eye no matter how distant the observer might be from the source. Among the early scientists who wanted to test this idea was Galileo. He failed to prove that light has a measurable speed, but that didn't convince him he was wrong. He knew he had great difficulty measuring small intervals of time, for in his day there were no stop watches or other precise means of measuring the passage of time. He lived in the day of the hourglass and sundial. Understandably his method failed. It consisted of having two men on distant hilltops expose lanterns alternately as each caught sight of the other's lantern flash. The trouble, of course, lay not only in the matter of a timing device, but also in the reaction time of each man. Upon receiving a signal, some time had to elapse before the eyes and muscles of the men could function to send the signal back.

One of the classic experiments, however, that indicated at least that the speed of light was not infinite was conducted by a Danish astronomer, Olaus Roemer, in 1676. In watching the moons of the planet Jupiter at various times of the year, he found that they apparently remained behind Jupiter, in its shadow and therefore invisible, different lengths of time.

When the earth was moving in its orbit about the sun away from or toward Jupiter, the time for the eclipse of one of the Jupiter moons was about fourteen seconds longer than when the earth was moving so that the distance between earth and Jupiter did not change appreciably, i.e., perpendicular to a line joining earth and Jupiter. His explanation was simply that as the earth moved away from Jupiter, it took a longer time for the light message of the end of the eclipse to reach an earthbound observer. It had to follow then that some time elapsed between the end of the eclipse of Jupiter's moon and the reception of it on earth. Light, then, traveled at a finite speed—though obviously very great. Roemer's measurements were not very precise by today's standards, but he managed to convince some of his fellows that the speed of light is not infinite.

One of the earliest precise experiments in measuring the speed of light was carried out by the scientist Albert Michelson in the early years of the twentieth century. His ingenious method is a sample of the ways men have of overcoming obstacles in measuring extremely large or small quantities. In a way it was not unlike the method Galileo tried to use, but by Michelson's time technology had produced the instruments necessary to do the job accurately.

In California Michelson set up a light source, a beam of light which was focused on one face of an eight-sided revolving mirror. The light striking it was reflected to a mountaintop 22 miles away where it was reflected back to the revolving mirror. On its return trip, however, the beam was arranged to strike another face of the octagonal mirror and be reflected into a viewing telescope. The equipment was carefully arranged so that the viewer through the telescope could not

see any light from the source unless the reflecting mirror faces were in the exact position to reflect the beam from source to mountaintop to telescope. But since the octagonal mirror was revolving at great speed it had to move exactly one-eighth of a revolution during the time the light traveled to the distant mountain and back so a mirror face would be in exactly the right place to reflect it into the viewing telescope. By carefully controlling the speed of revolution of the mirror, Michelson caught the reflected beam and knew that all he had to do was determine the exact speed of revolution of his octagonal mirror. The time for one-eighth of a revolution, then, was the time required for light to travel from the whirling mirror to the distant mountain and back again—a distance of 44 miles.

This and subsequent measurements have produced our present-day value for the speed of light in air: 186,000 miles per second.

We know now that all of that family of related waves included in the electromagnetic spectrum travel at this speed in a vacuum. In other mediums such as water or glass the speed is different, but for a wave of particular wave length or frequency, it is constant for that medium.

Wave Fronts, Rays and the Sine Wave Representation

Water waves, sound waves, and electromagnetic waves such as light are often analyzed by two distinct methods. One method considers wave fronts. This is as though you were hovering over the ocean in a helicopter and gazing down on the pattern of regular ocean waves, seeing the long shadowed lines moving parallel to each other across the surface. The other method is called the ray method and it makes use of a single line drawn at right angles to wave fronts, showing the direction the waves

are traveling. Both are useful but neither can explain certain things about waves. For this dilemma we use what is ordinarily called the sine wave method of representing waves. It can show us not only the wave length, the distance between adjacent crests as the wave front method can do, and the direction of wave motion as the ray method does, it can also tell us what the amplitudes of the waves are. It is a common picture of a wave and often is seen on an oscilloscope.

To produce a sine wave, take a wrist watch without the strap

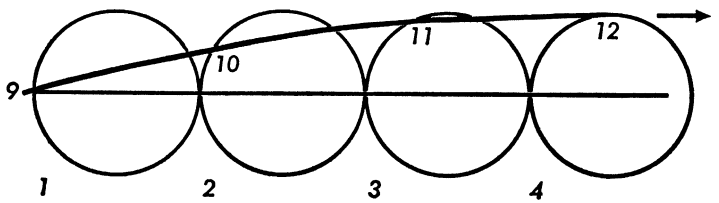


FIG. 7

on it and place it on a piece of paper on which you've drawn a long straight line. Mark the line in segments equal to the diameter of the watch and have the paper long enough to contain twelve such diameters. Hold the watch with its center on the line and the figure nine at the first division mark. Put a mark there and slide (do not turn) the watch to the next division. Put a mark at the ten division on the paper. Slide the watch another interval and mark the eleven o'clock spot. Continue sliding the watch without turning it until you have marked all the way around the watch. Connect the points on the paper that you have placed there with a smooth curved line and you have a sine curve. It is one wave length long (for if

you had continued marking you would have repeated the ten o'clock mark). The amplitude of the wave is the distance from the straight line to the point on the curve farthest from that straight line. You can tell from this curve not only the amplitude but the frequency (one wave per hour, the way you have marked it) and you have a curve that can give you information about the wave at any instant you want. It appears to be a transverse wave, with the portions of it moving up and down while the wave direction is along the straight line. Yet sound waves which are really longitudinal can be represented as such a sine wave. Light waves often are diagrammed as this kind of wave and for a very good reason.

Why "Electromagnetic" Waves?

Sound waves and seismic waves and water waves need a medium to travel through. That is, they depend on disturbing particles of matter in the medium. But elecromagnetic waves such as light can travel through empty space. This mysterious quality of these waves is explainable in terms of electricity and magnetism. The background of these subjects is too broad to include here, but these mysterious electromagnetic waves spring from the interrelationship of electrical and magnetic phenomena.

In examining the world around him, man has been forced to build pictures in his mind that fit the facts of invisible laws of nature. Magnetism itself is invisible. So is electricity. In earlier years scientists like Michael Faraday and James Clerk Maxwell studied magnetism and electricity and found that these two invisible properties of some matter seemed to be related. Through many ingenious experiments, they found a way to express the relationship. Today, in every college physics class,

students accept without question the mathematical statements of the relationship and learn to sketch the "picture" of it that is man's most accurate idea of how electricity and magnetism interact.

Again it is like a wave. We can produce with electrical coils a single electrical discharge between two ends of a wire. This pulse wave, as it is called, is like the single wave imagined when a rock strikes the surface of a still pond. It grows in amplitude, reaches a maximum, and then dies away. And if a simple compass with its magnetized needle is placed near the point of discharge, we will see the needle of the compass turn momentarily and then return to its original position. Obviously while the electric wave existed, grew and then died away, something happened that we call magnetic in its effect. In studying magnetism and electricity Michael Faraday thought up a very useful way of presenting what he discovered. He imagined that a magnetized needle was the source of what he called a magnetic field surrounding it. Today we could call it a "sphere of influence," to steal a phrase from the politicians and diplomats. It is strongest near the needle and becomes less influential as we move away from the source of the "field."

Hans Christian Oersted, a Danish scientist, discovered that if an electrical current flowed through a wire near a compass, the needle was diverted. He could get the same effect by bringing another magnet near the compass, and so he concluded that the electrical current itself created a magnetic field that influenced the field of the compass needle. By more experiment, scientists soon discovered that the magnetic field created by a fluctuating electric current grew as the wave grew and died out as the wave itself died out. Further, it was learned that the direction of the magnetic field and the electrical one

were at right angles to each other. Experimenters soon discovered they could get the same effect backwards. That is, if a magnetic field were created, an electrical current would flow in a nearby circuit. So there must then be some innate relationship between electrical and magnetic properties.

We do not know why the relationship exists, but by many experiments we have proved that it does exist and we have worked out a scheme of showing the relationship. We use two sine waves, one moving up and down as it travels forward and the other moving horizontally as it travels in the same direction. For some as yet unknown, mysterious reason, when a series of electrical waves are sent out from some source, they create magnetic waves—which in turn help move the electrical waves forward. It is by this means that electromagnetic waves can travel through a vacuum, through the millions of miles of space from the sun to the earth and from the most distant stars to the earth.

Some of the electromagnetic waves sent out by the sun's thermonuclear reactions are what we call light waves. They have the correct wave length to excite the nerves of the eye and produce the sensation we call sight. The so-called "visible" part of the electromagnetic spectrum is in reality a very small portion of that spectrum. For investigations in the nineteenth and twentieth centuries revealed that many wave lengths go to make it up. Among them today we include long radio waves, short radio waves, infrared, visible, ultraviolet and X-rays as well as gamma rays. They have a wide range of wave lengths. Only those electromagnetic waves having wave lengths between 0.000015 and 0.0000296 inches can affect the human eye and make things visible to us.

Since human eyes vary in their structure from person to

person, the sensation of sight is subtly different for each of us. Some eyes are stronger than others and can produce clearer images on the brain. Some can see near objects better than distant ones. And nearly all human eyes react differently to colors. Many people are what we call color blind and have difficulty distinguishing among various shades of particular colors.

For a scientist, then, reliance on his eyes alone to measure colors and color differences is uncertain at best. To measure these very short wave lengths of visible light he uses an instrument called a spectroscope and with it he can pick out any wave length of light he wishes. In reality he is picking out a particular color of light. Our eyes react to the various visible wave lengths differently and produce the sensation we ordinarily term color.

For many years scientists argued about the various colors that make up the rainbow or that are plainly visible when sunlight passes through a triangular-shaped piece of glass called a prism. Where did they come from? How did the glass or the rain cloud produce them?

Not until Sir Isaac Newton conducted his famous experiment with a glass prism did men learn the answer and begin to understand the true nature of visible light. Newton showed that sunlight, which the eye sees as white light, was made up of all the visible wave lengths of light. Each of these waves traveled at the same speed in space and very nearly at the same speed through the earth's atmosphere. Thus they arrived at the eye at the same time and all combined to produce the sensation we call white light. But when they passed through some other transparent medium, such as glass or the water in raindrops in a cloud, they traveled at different speeds and they were refracted or bent. The direction of travel of each wave length was

changed by a different amount. Thus they were separated and would strike a reflecting surface held beyond a prism at different points—producing the familiar rainbow-like spectrum.

An examination of this visible spectrum, as it is called, shows many things. It seems to be made up of six common colors: red, orange, yellow, green, blue and violet. Further, there seems to be no distinct boundary line between the colors; they blend into

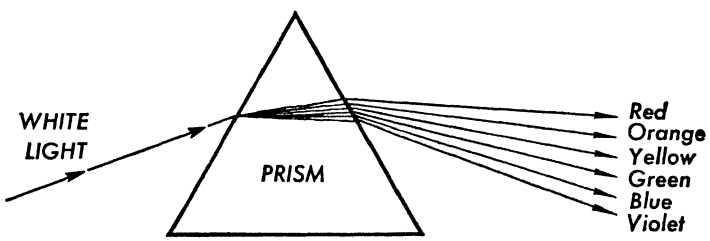


FIG. 8

one another and it is impossible for the eye to tell where, for example, red stops and orange begins. But when we remember that visible light is made up of all wave lengths between 0.000015 and 0.0000296 inches and that each wave length is seen by our eyes as a particular color, it is no wonder that the effect of all those wave lengths when spread out into a spectrum is to show a continuous, uninterrupted change from red at one end to violet at the other.

Yet with his spectroscope a scientist can pick from the entire range of colors, or wave lengths, any precise one he wishes and examine it. In fact, when discussing light he speaks not of colors but of wave lengths. For that is the accurate way to discuss light of a particular color.

Spectroscopy is the special branch of physics that deals with

the analysis of light. Through it modern scientists have learned much about not only the nature of light but also the structure of atoms themselves. For certain atoms will emit light of certain wave lengths, and by examining this light, scientists can get a good idea of the atomic structure that produced the light. Atoms of different elements can be identified by the wave lengths of light they produce when enough energy is supplied in some way to excite them. Thus a sample of neon gas enclosed in a glass tube will emit its characteristic red glow when an electric spark passes through it. With a spectroscope a scientist looking at this red light would not see simply an over-all redness, he would see the particular red wave lengths as lines thrown on a screen in his instrument. With a proper measuring scale, adjusted to a known wave length, he would see these lines on the scale and be able to read the wave lengths they represented. By the same method he could excite atoms of an unknown element or mixture of elements and measure the wave lengths sent out by each element. Since each element emits particular wave lengths under certain excitation the scientist has a means of identifying unknown elements. And while there are other means of identifying unknown elements in the laboratory we use a spectroscope to tell what elements exist on the sun or the stars. The light they send us is one of the best clues to their composition. By light analysis we know what elements make up the surfaces and atmospheres of the stars.

We also have gathered other information about stars by examining the wave lengths of light from them that reach the earth. According to present astronomical theory, the various galaxies that make up our universe are moving away from one another at tremendous speeds; the universe seems to be expand-

ing. The question of how fast this expansion is occurring can be answered by a curious phenomenon called the Doppler effect.

Christian Johann Doppler, an Austrian physicist, discovered the effect and stated that if a star were going away from the earth, the wave lengths of light received in a telescope would be measurably longer than if the star were not moving away from the earth. Also, if the star were coming toward the earth —as some in our own galaxy are doing—the wave lengths received would be shorter.

An everyday example of this effect is that of an observer standing by a railroad track listening to the whistle of an approaching train. As the train comes toward the observer, the sound of the whistle is of a certain pitch. The instant the train passes, however, the pitch drops suddenly to a lower level.

The reason for this is explained by wave motion. As the train approached the observer, the sound waves it sent out were crowded into less and less distance, or to put it another way, more waves reached the observer's ear each second than if the sound source had been stationary. So the observer heard a higher pitched sound than was actually being sent out. When the train passed and was going away from the observer fewer waves reached the observer's ear each second and the sound was of a lower pitch or frequency.

Pitch or frequency of sound waves is determined by wave length, just as color in light is determined by wave length. So, in examining starlight from receding stars, we notice a shift of the wave length toward the longer or red end of the spectrum. For a star in our galaxy that is approaching us we observe a shift of light toward the shorter or violet wave lengths.

Infrared and Ultraviolet Light

If, by the word light, we mean those wave lengths that are visible to the eye, then there is no such thing as ultraviolet light or infrared light. For these wave lengths lie just on either side of the visible range of electromagnetic waves. Yet the energies they possess do affect us and they have, in recent years, been put to certain uses by men.

Long wave lengths in the red end of the visible spectrum become longer still and cannot be interpreted by the nerves of the eye as light. These we call infrared. Yet they are detectable with certain photographic films and transducers. The energy carried by these electromagnetic rays can be converted into heat upon being absorbed by an object placed in their path. Such wave lengths are used in several appliances and there are stoves that make use of infrared radiation to cook food. Infrared lamps are used in relieving muscular soreness and to treat other bone and nerve disorders located below the body's surface. For infrared waves can penetrate surfaces to some degree, and when they have, their energy becomes heat applied where the disorder lies.

The energy contained in short wave lengths in the ultraviolet region of the spectrum can be quite harmful. Perhaps the commonest example of the quantity of energy contained in these wave lengths is sunburn. For the ultraviolet waves actually burn. Fortunately for men, much of the ultraviolet portion of the sun's light is absorbed by gases in the earth's atmosphere and does not reach the surface of the earth. Enough does, however, to cause burning of the skin on prolonged exposure to sunlight.

Light Pressure

Sea waves, dashing against a wall, push on the wall and can, if the wave motion is strong and persistent, destroy the wall. Sound waves also can press on material objects with measurable force. Light waves, though of much shorter wave lengths and amplitudes than either water or sound waves, exert pressure on objects. Their effect on objects on earth is slight, however, and is not noticeable or easily measurable. But in space the effect has been observed. Comets that circle the sun and become visible on earth have long, streaming, illuminated tails. Curiously these streamers of small particles always point away from the sun no matter what the comet's position or path may be. The explanation for this lies in light pressure. Sunlight exerts pressure continuously on this long comet tail and pushes it away from the sun itself. In another space situation light pressure from the sun became evident. When the United States sent up its first large, inflated plastic satellite, which was, as some reports put it, "as tall as a ten-story building," physicists hoped it would remain both large and in orbit for some time. But soon after it was placed in orbit it was found to be slowing down and dropping farther into the earth's atmosphere with each revolution about the earth. Its size was diminishing also. The reason for all these occurrences was the pressure of light from the sun.

CHAPTER 5

Important Properties of Waves

ALL regular waves can be described by their dimensions of wave length, amplitude, frequency and speed of travel. They can be catalogued either as longitudinal or transverse waves. But all this is true only after a scientist is certain he is dealing with a wave. Surface waves on water are visible and are of a size that makes the measurement of them relatively simple. Sound waves are invisible and more difficult to measure. Light waves are of such dimensions as to make their measurement difficult. And while the consideration of light was one of the first areas of scientific study, so little was actually learned of its nature in ancient times that great arguments arose as to whether light was a wave or not.

Claudius Ptolemy of Alexandria, who lived in the second century A.D., experimented with one property of light which is common to all wave forms: its ability to be refracted. This means to have its direction of travel changed when it enters a transparent material. Since refraction is a property of all other wave forms that we know of, the fact that light could also be refracted gave support to those who argued that light was indeed a wave form itself.

The ancient Greeks had figured out by geometry the laws of wave reflection and it was noticed by them that light could

be reflected and that it obeyed the laws of reflection of other waves. This, too, supported the wave idea of light.

But there were two other important properties of wave forms that light seemed to lack. One of these is called interference and the other is termed diffraction.

Interference can be described with familiar water waves. If two waves on the ocean or a lake surface are moving in directions such that they will meet, then they will interfere with each other. If they happen to meet so that their crests join, there will be, for an instant, a greater crest rising to the height of the sum of the individual wave crests. But if the crest of one wave and the trough of another wave meet they will cancel each other. The water surface will neither rise nor fall. Light, for a long time, was believed to lack this property which it should have if it were truly a wave form.

Diffraction also apparently was missing from light. This is a property not many people notice about waves but it is an important one, nonetheless. Again, water waves can serve to demonstrate the property. If ocean waves approach the narrow mouth of a harbor, a small portion of the wave will move into the harbor while the wave front on both sides of the entrance will be reflected by the shore and move out to sea again. The small portion that enters the harbor was traveling in a straight line in the direction of the original wave. But when it goes through the small opening at the harbor entrance, it spreads out and forms a circular wave pattern. In fact, it acts as though the harbor mouth were a point on a smooth lake surface where stones were dropped. The ability to change direction when passing edges of obstacles like the sides of the harbor mouth is called diffraction. It is because of diffraction that you can hear someone talking even though he may be around the cor-

ner of a building from you. The sound waves, on reaching the corner, spread out and around the corner in all directions. But from all the evidence that early scientists could gather, light traveled in straight lines and was not diffracted when it struck edges of objects. Men reasoned that if light were diffracted, it would not cast shadows when striking trees or buildings, but would spread out behind the tree or building and illuminate the ground, destroying the shadow.

There was one other thing that made men doubt that light could be treated as a wave. Waves of every known kind had measurable speed—but the speed of light seemed to be infinite.

Light, it seemed, had some of the properties of waves, but not all of them. Was it a wave? And, if it were not a wave, what was it?

The fact that, so far as men could tell, light traveled in straight lines led many scientists to believe that light was a stream of very small particles sent out by the sun or a candle, which traveled in straight lines and struck the nerves of the eye, causing the sensation of sight. This seemed to be a very plausible explanation and it was popular for a long time. But many other scientists still believed light was a wave form and they set about experimenting to prove it. If they could show that light had all, not just some, of the properties of waves, then they would be able to state that light was actually a true wave. But they had to show that light could be reflected, refracted, diffracted and that it would show the property we call interference.

Reflection

When a water wave strikes a shore "head on" it reflects back on itself. The reflected wave moves from the shore in the di-

rection opposite to the original wave's approach. But if a wave strikes the shore at some angle other than head on, the reflected wave bounces from the shore at what we call the angle of reflection. How does the angle of approach, called the angle of incidence, relate to the angle of reflection? Careful measurement shows they are equal.

While this law of reflection, as it is called, is true of waves, it is also true of particles. A billiard ball approaching the side of a billiard table at a particular angle of incidence will strike the edge and move away with an angle of reflection exactly equal to the angle of incidence. So it has been proved that both waves and particles can behave alike when they are reflected. This property of waves could not, by itself, settle the argument about light.

Refraction

Curiously the most easily observed evidence of wave refraction comes from light itself. But water waves can be made to refract. If a pattern of water waves approaches a shore where the lake or ocean bottom rises gradually, we can witness refraction of water waves. If a wave front approaches such a shore at an angle, the end of the wave reaching shallow water first will be slowed down. The end of the wave still in deep water will continue to move at its original speed. The effect will be to turn the wave from its original direction. It is exactly like the wheels of a car in making a turn. The inside wheel moves more slowly, the outside wheel goes ahead and the car turns.

In the case of light the situation is the same. But to slow light down it must be passed from one medium, such as the air, into another medium, such as glass. The boundary line between the air and the glass is of course a sharply defined line, whereas in

the case of the water wave, the change from deep to shallow water was gradual. So light, if it is truly a wave form, must undergo a change of direction when it strikes such a boundary line. That it does is evident to everyone who has remarked on the bent appearance of an object when part of it is under water

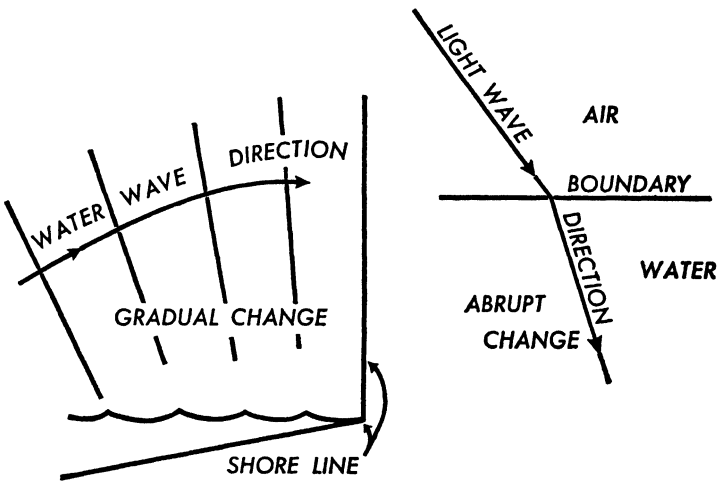


FIG. 9

and part of it is in the air. The oar blade of a rowboat, for example, appears to be bent at the surface of the water and a pencil appears broken when placed in a glass of water with part of it projecting above the water surface.

We know more today about the interior of the earth because of this property of refraction. The three major parts of the earth, crust, mantle and core, have relatively distinct lines of division, and since each part is of a different composition, earth waves travel through them at different speeds. This means that

the earth waves themselves are refracted when they enter or leave a particular division of the earth. By careful measurement of the times of arrival and indicated direction of travel of numerous earth waves, seismologists have gained information about the earth's interior they could not otherwise have received.

From as far back as the second century A.D. when men like Claudius Ptolemy were investigating light, the idea of refraction was known. Ptolemy himself attempted to measure the amount of refraction by passing a narrow beam of light from air into water and glass at various angles. He measured the angle through which the beam was bent and tried to work out some general rule to relate the angle at which the beam struck the surface—the angle of incidence—to the amount of bending that took place—the angle of refraction.

While he failed to solve the general problem, he did discover that the angle of refraction was different for different substances. But it was not until 1621 that a professor of mathematics in Leiden named Willebrord Snell (Snellius, or Snell van Royen,) produced a satisfactory explanation of the relationship between the angles of incidence and the angles of refraction.

As has been mentioned, Isaac Newton used the property of refraction in his experiment to discover the source of color in white light. He was led to this experiment through his interest in fashioning telescopic lenses. He had ground many lenses of various sizes by hand and used them in his telescopes, but in each case he had noted that sunlight, when passed through a lens and observed on a screen, showed white in the center of the light image and, unfortunately, showed a ring of rainbow-like colors near the edges. For distinct observation of stars and other distant objects, this fringe of color, now called chromatic aberration, was a hindrance. No one during Newton's

time knew the cause of it. What actually was happening, of course, was that the various wave lengths of visible light were refracted through the lens at slightly different angles. Thus they came out of the other side of the lens on different paths and struck the screen at different points. He found too that when he tried to focus sunlight at a point, he could not get all the light to come to a distinct point. There seemed to be a blurring effect. The reason was the same. Refraction caused blue light waves to meet at one distance behind the lens, and red, the opposite end of the visible spectrum, at still another.

With these unanswered questions facing him, Newton began a long series of investigations in light which covered many years. Curiously, he himself held to the theory that light was, as he put it, "corpuscular" in nature or was made up of particles. He admitted that it behaved with certain wave characteristics but he held that the light particles in passing through space actually were passing through an as yet undiscovered ether or aether and that the particles disturbed the ether-producing waves.

This idea of an ether was common in Newton's day and it was an idea that explained certain things. Newton's explanation was: "Assuming the rays of light to be small bodies, emitted every way from shining substances, those when they impinge on any refracting or reflecting superficies must as necessarily excite vibrations in the aether as stones do in water when thrown into it."

But what about the property of diffraction? By Newton's time, in the latter part of the seventeenth century, diffraction of light had been noted. Francesco Maria Grimaldi, a professor at the University of Bologna, made many careful investigations into light. In one of them he let sunlight come through a small

opening in the shutter of his window and passed that beam through an even smaller opening made in the screen. Thus only a very small circle of light was admitted. He let that circle of light strike the opposite wall of his room and he measured it. If light traveled in straight lines, the circle of light striking the wall should have been exactly the same size as the opening in his screen. But it wasn't. It was slightly larger. This made Grimaldi suspect that the light passing through the small opening spread out slightly beyond the screen, forming the larger circle on the wall. To test his idea further he placed a small object in the beam of light that came through the small opening which cast a shadow on the wall. Upon measuring the size of the shadow and of the object carefully, he discovered that the shadow was slightly smaller than the object itself. This further strengthened his belief that light was diffracted beyond the edges of objects. Not enough, it was true, to destroy the entire shadow, but enough to be noticed and to support the wave theory of light.

Newton was aware of Grimaldi's experiment and offered another hypothesis to explain the results Grimaldi got. Newton offered the idea that the pervading ether that was supposed to surround all material objects was slightly less thick or dense near the edges of things and that what Grimaldi had noticed was merely refraction of light through layers of ether of varying density.

Newton himself was not one simply to dream up an idea and then try to find facts to support it—in other words to hypothesize idly. But in answer to many arguments against his own work he could offer plausible explanations of things as well as the next man—and emerge with his own concepts intact. In the controversy over the wave versus particle theory of light,

he did not, however, rule out the possibility that light might be well explained by a wave theory. " 'Tis true," he wrote to Sir Robert Hooke, who frequently had criticized his work, "that from my theory I argue the corporeity of light; but I do it without any absolute positiveness. . . ."

In the days of Grimaldi and Newton, there were no measuring instruments fine enough to analyze light and measure its properties. Prisms and lenses were common and all light phenomena associated with these devices could be observed and recorded. Many men did so with painstaking thoroughness. Grimaldi, if not by accident certainly not by design, stumbled on one requirement of any apparatus that is going to show the diffraction of light: he made the opening in his screen very small. As we know now, the property of diffraction can best be observed when the wave pattern passes through a slit or other opening that is about as wide as the wave length of the test wave.

If, for example, a harbor mouth is 100 yards wide, wind ripples on the surface coming through the opening into the harbor will move along almost uninterruptedly. For them the 100-yard-wide opening is too large to be effective. But if ocean waves of a wave length near 100 yards come through the opening, the opening and the edges of the breakwater seriously interrupt the wave form—and diffraction occurs. Light waves, having very small wave lengths, move through window openings with as little disturbance as the wind ripples enter the harbor mouth. But if the opening is reduced until it becomes very small, then the light waves are diffracted and noticeably so.

While studying the diffraction of light, scientists noticed another phenomenon. Around the edges of the image cast on

a wall or a screen was a fringe of color. The fringe appeared to be a series of alternating bands of light that decreased in intensity the farther they were on either side of the image. What caused them? The answer to this question, when it was found, gave great support to the wave theory of light.

Interference

Thomas Young, an English scientist and doctor who lived from 1773 to 1829, became interested in sound and light when he was in medical school. He had made studies of the human eye while still an undergraduate, and for his thesis decided to write on the human voice. This interest led him to do a great deal of research in the physics of sound waves and physical optics, as the study of light was termed. He read all of Newton's published work on light and became convinced that all that was known of light at that time could be explained by using the idea of waves.

In one experiment Young provided the answer to the question of the alternating bands of light around certain light images. He took a single source of light and arranged it so that it would pass through two slits in an opaque screen. The slits were narrow and placed close together. Beyond the two slits he set up a reflecting screen. When he turned on his light and it passed through both slits, the diffraction image was interrupted by a series of dark lines parallel to the image. They looked like black sticks in a picket fence. Young found that if he covered one of the slits, the diffraction image remained but the series of dark lines disappeared.

What was happening was this: With both slits open, the light passing through each one spread out or diffracted. But the light from one slit overlapped the light coming from the other.

An interference pattern was set up which was immediately visible on the screen as a series of dark lines where a wave trough and crest canceled each other upon arriving at the screen.

The importance of Young's experiment was that no particle theory of light could account for the interference pattern he had observed.

Newton himself had studied interference patterns he produced in a novel way. He took a flat piece of glass and one that was curved very slightly like the bottom of a bowl. Upon pressing these two pieces of glass together and passing light through them, he observed concentric circles of alternating lightness and darkness. The explanation comes from light waves reflected from the bottom surface of the bowl and those reflected from the flat piece of glass. The waves reflected from the two surfaces overlap and at some points cancel and at other points reinforce each other. The result is again an interference pattern —though this time a circular one.

Nearly everyone has witnessed interference without realizing it. On viewing a thin layer of oil spread on water or the thin wall of a soap bubble, strange color effects are frequently visible. Sometimes there is a shifting pattern of predominantly red color, at other times a blue and violet color predominates. The answer lies in the light reflected from the inner and outer surfaces of the thin film formed by oil or the soap and water mixture in the bubble. If the film is of a certain thickness, red light waves reflected from the two surfaces of the film cancel each other or undergo destructive interference. This leaves the other end of the spectrum as the predominant wave length of visible light and blue-violet color is seen. If the film is of another thickness, the blue-violet region may be interfered with and destroyed, leaving the red wave lengths available to be seen.

The Measurement of Wave Lengths of Light

One of the problems facing scientists in physical measurement is that of measuring very small objects or distances. Light waves are of such short length, averaging as they do only about 22 millionths of an inch, that their precise measurement presented great difficulty. They could not be measured directly, of course, but by using indirect means the problem was solved. Specifically, the indirect means involved the phenomenon of interference. Young's method of producing interference with two parallel closely placed slits provided the means of measuring the length of light waves. Clearly the dark shadow lines produced occurred only where destructive interference took place. If the reflecting screen on which the dark lines were made visible was moved away from the two parallel slit sources of light, the distance between the dark lines was increased. If the reflecting screen stood at about a yard from the two narrow slits, its distance could easily be measured. The distance between dark lines on the screen could be measured and the distance between the two narrow slit sources was known. These facts, with the aid of simple geometry, allowed the very precise measurement of light wave lengths.

If white light were passed through the slits, the diffraction and interference patterns were of various colors of the spectrum—for interference of different wave lengths occurred at different positions on the screen. But if light of only one wave length—called monochromatic light—was employed, the interference pattern was a simple pattern of dark and light lines. By using monochromatic light scientists have fixed the wave lengths of the various parts of the spectrum.

To produce light of a single wave length, scientists relied on

the fact that the atoms of various elements, when excited, emitted light of particular wave lengths. Some of these were strong emissions and some weak and barely visible. The predominant wave length produced was known to be characteristic of the element being used. Sodium, for example, when excited by heating in a gas flame, produces two wave lengths characteristic of it and the resulting flame is a yellowish orange. Neon, a gas, when enclosed in a tube and excited with electrical energy, produces the familiar red wave lengths seen in many advertising signs.

Diffraction Grating Spectrum

The rainbow colors of the spectrum can be produced by refracting light through a prism. This fact has been known for centuries. But another method of producing a spectrum was developed that makes use of the property of diffraction. If a great number of narrow parallel slits are placed close together, much like openings in a picket fence, white light passed through them will be diffracted in varying degrees according to the wave lengths. That is, blue wave lengths will undergo a certain amount of bending, yellow another amount and red still another. At certain points on a reflecting screen each group of particular wave lengths will combine and reinforce themselves. The result is a spectrum of color that can be studied and the wave lengths of its individual colors measured. To produce a diffraction grating, precise machines are used to mark as many as 15,000 lines per inch on a piece of polished glass.

Polarization

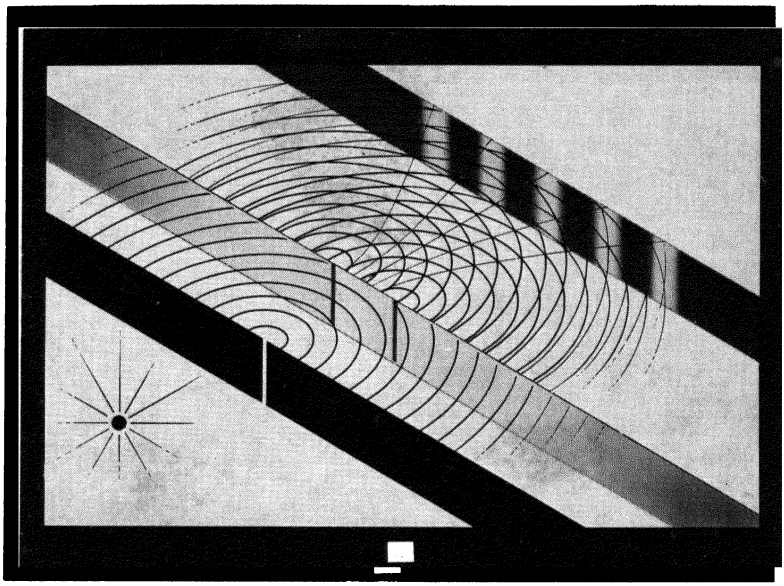
The properties of reflection, refraction, diffraction and interference are common to all wave forms. But of the two wave

types—longitudinal and transverse—only transverse waves are capable of being polarized.

This important characteristic was investigated independently by Thomas Young and another scientist, Augustin Fresnel. A transverse wave is a wave in which the vibration—either electrical, magnetic or particle—is at right angles to the direction of wave travel. Thus a rope which has one end fastened to a wall can be shaken and the particles of the rope move at right angles to the wave formed which travels to the wall. The rope may be twitched in a horizontal plane, a vertical plane or in any other plane and the particles still move at right angles to the direction of wave travel. Suppose we could place our eye at the point where the rope is fastened and watch the wave travel toward us. If the rope were twitched horizontally, we would see the wave as a horizontal section of rope coming toward us. If it were twitched vertically, the section coming toward us would be vertical. And, of course, if it were twitched in any plane, the section coming toward us would appear to be a line lying in that plane.

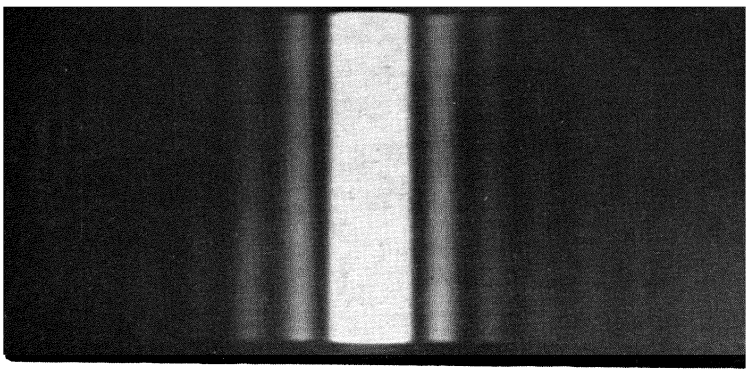
Light waves, like those in a rope, are transverse waves. The electromagnetic vibrations occur at right angles to the direction of wave travel, but the vibrations may occur in any plane, horizontal, vertical or otherwise. In the example given in the chapter on light waves, only one plane of vibration was described to simplify the idea. Light waves, then, can and do vibrate in many planes but the vibrations all take place at right angles to the direction of wave travel.

Now if light waves pass through a thin section of certain materials, the vibrations taking place in one plane may pass through while the vibrations in all other planes are reflected at the surface of the section. This phenomenon can be illus-



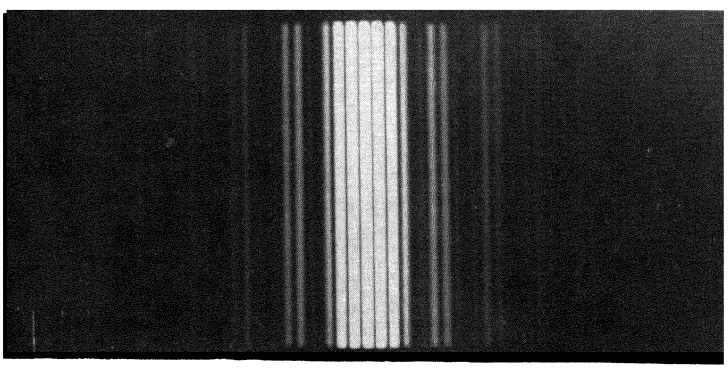
From Gerald Holton and D. H. D. Roller, Foundations of modern physical science, © 1958, Addison-Wesley, Reading, Mass.

The geometry of interference of light waves: Light passes through a narrow slit and spreads out in a circular pattern. It then passes through two further narrow slits, each of which produces a circular pattern of waves beyond the openings. Where the overlapping patterns reinforce each other, bright bands of light result on a screen; where they annul each other there is darkness.



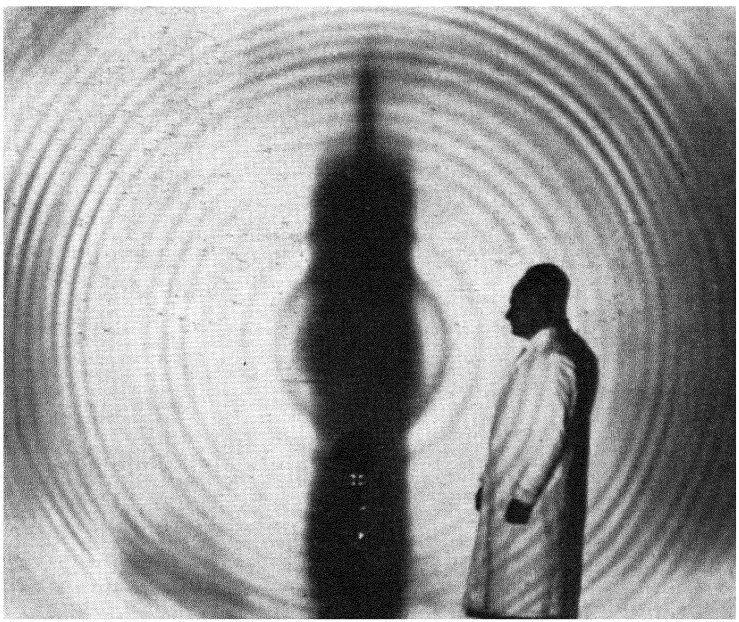
From F. W. Sears and M. W. Zermansky, College physics, © 1960, Addison Wesley, Reading, Mass.

Diffraction of light is shown by photographing light which has passed through a single narrow slit. Most of the light falls in the center band directly in front of the slit, but some bends to either side of the opening forming a series of faint bands of light.



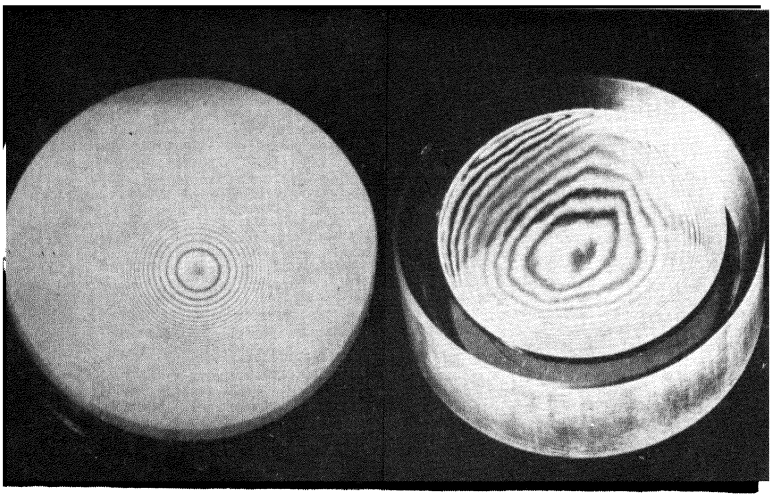
From F. W. Sears and M. W. Zermansky, College physics, © 1960, Addison-Wesley, Reading, Mass.

When two slits are used as shown in Plate 1, the interference pattern is visible as photographed here.



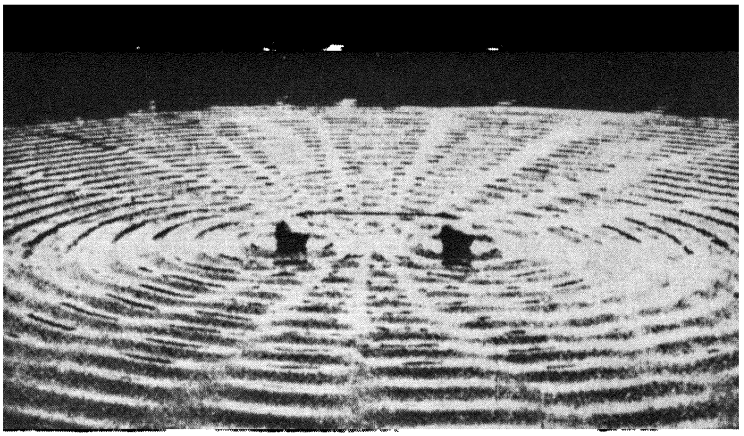
From F. W. Sears and M. W. Zermansky, College physics, © 1960, Addison-Wesley, Reading, Mass.

Striking demonstration of circular interference of light produced by reflecting light from a mercury arc lamp on a thin (.002 inches thick) sheet of mica. Front and back surface of the mica reflect light as though they were two nearby sources. Some waves reinforce and others annul, producing the large pattern shown here on the wall of a room. Shadow in the center is caused by the mercury arc lamp.



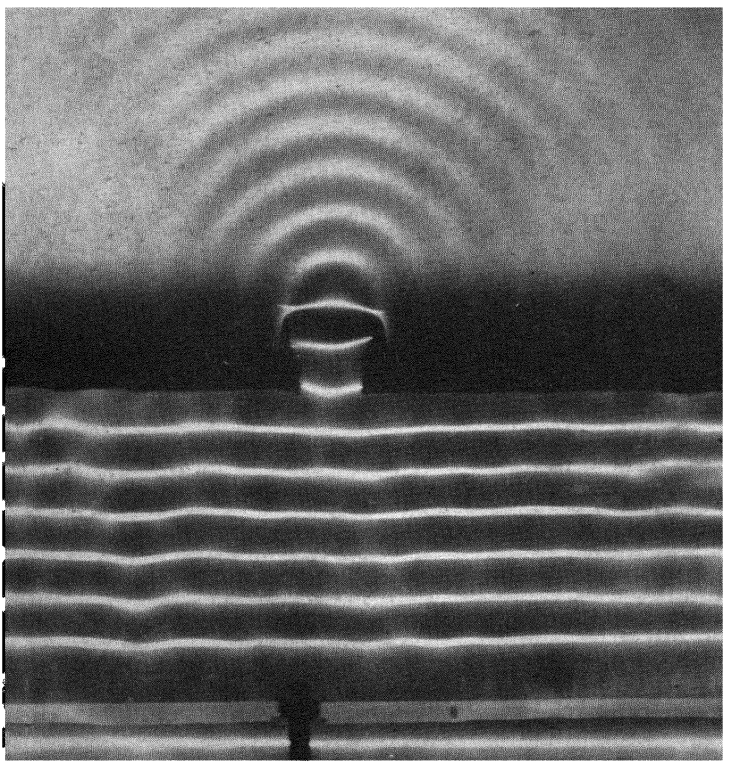
Courtesy of Bausch and Lomb Incorporated, Rochester, New York

Interference rings are put to practical use by industry. On the left is the interference pattern produced by reflecting light from a flat surface and the convex surface of a finished ground lens. On the right is the pattern produced by a lens during manufacture. As the lens is ground to a more nearly perfect shape, the pattern becomes more regular until it resembles the one on the left. Irregularities in the pattern direct the grinding operation to the unfinished area of the lens surface.



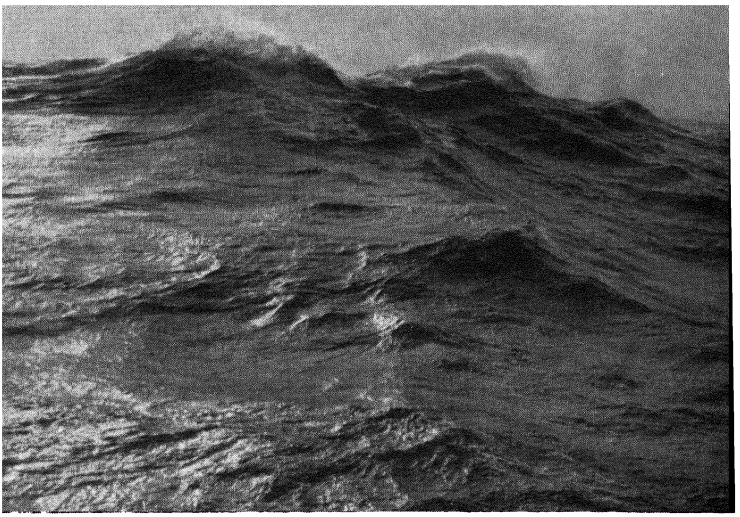
From Gerald Holton and D. H. D. Roller, Foundations of modern physical science, © 1958, Addison-Wesley, Reading, Mass.

Two patterns of water waves produced simultaneously combine to demonstrate interference. Where crests meet crests or troughs meet troughs there is reinforcement. Where a crest meets a trough, there is annulment and the surface remains undisturbed.



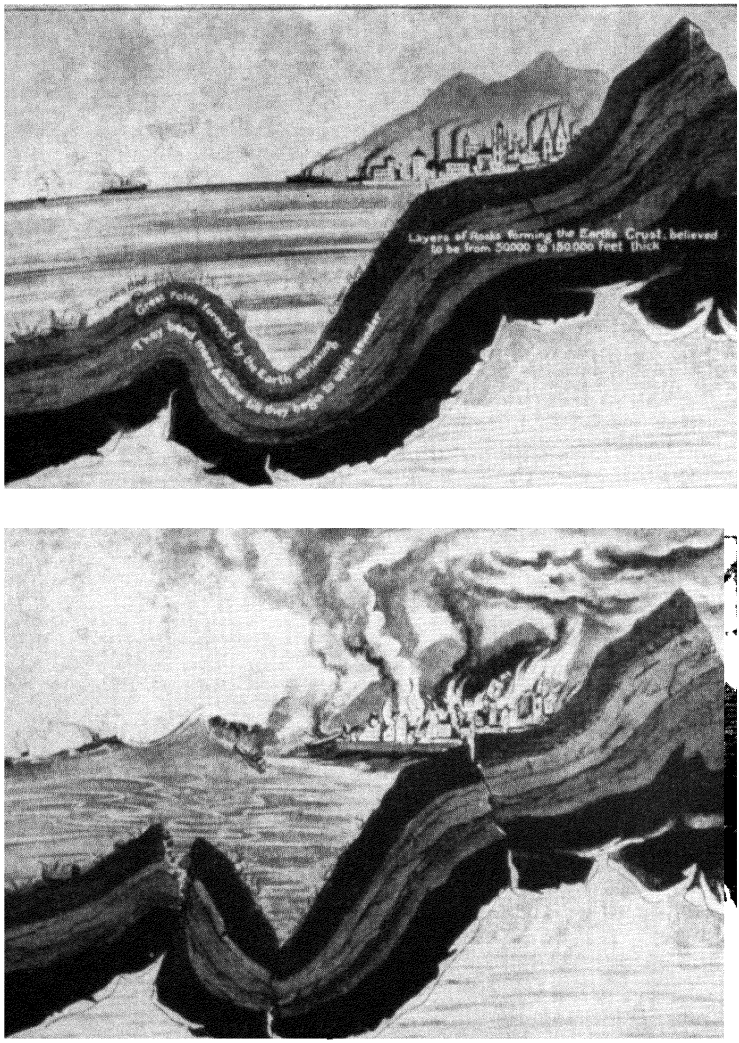
(Copyright 1923, The Century Company) from David Locke Webster, Herman W. Farwell, and Elmer Reginald Drew, General Physics for Colleges, Appleton-Century-Crofts, New York.

Water wave diffraction is demonstrated by letting a train of waves with straight, parallel fronts approach a narrow opening. Wave segments that pass through spread out forming a circular pattern showing that waves "bend" or diffract around the edges of objects.



Courtesy of Underwood and Underwood, New York.

Ocean waves like these travel thousands of miles across the surface of the sea. As they make their final assault on the land, their energy is dissipated. Man has yet to discover a way to make large-scale use of this energy. He must, in fact, spend millions of dollars to protect himself, his buildings and the eroding shores from their awesome power.



Reprinted from the 1911 edition of the Book of Knowledge, by permission of the publishers, Grolier Incorporated, New York.

The earth's thin crust is subjected to great stress caused by interior heat. When the crust cracks, earthquake waves speed along the surface and through the earth to the opposite side. Cities near the quake zone frequently are destroyed. Seismologists have analyzed these waves and deduced the composition of the earth's interior from their findings.

trated with a wave in a rope. Suppose you twitch a rope horizontally but now have the rope passing through a picket fence before reaching the wall where it is fastened. When the wave reaches the vertical pickets and tries to pass through the narrow vertical space between the pickets, the displaced section of the rope strikes the pickets on either side of the opening and either

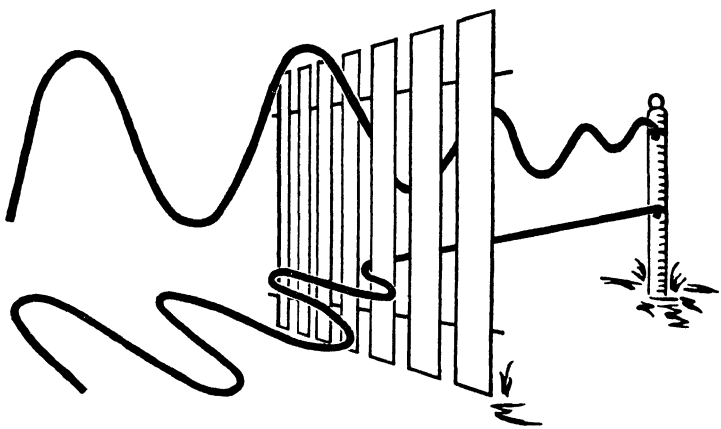


FIG. 10

is reflected or destroyed at the fence. If, however, we twitch the rope vertically, the wave formed which is vibrating vertically can get through the vertical opening between the pickets and so reach the wall. This wave is not interrupted by the picket fence. A twitch in any plane other than vertical will, however, run into the pickets and either be reflected or destroyed.

If a light wave vibrating in all possible planes approaches the "picket fence" of a thin section of, for example, a tourmaline crystal, only the vibration parallel to the crystal lattice or picket fence of the crystal will be transmitted. We say that such light

has been "plane polarized." Two such sections of tourmaline held flat against each other will transmit the polarized waves if their picket fence openings are parallel. But if we rotate one crystal section through 90 degrees, no light is transmitted.

Young and Fresnel's investigation of the polarization of light led to the conclusion that light waves were transverse and not longitudinal. For a longitudinal wave—with particles moving forward and backward parallel to the direction of wave motion —would not be totally stopped in passing through the picket fence of a crystal lattice.

Sunglasses made today with lenses that polarize light cut down on the glare by eliminating part of the sunlight that otherwise would enter the eye. Polarized light also is used to study the composition of crystals and finds extensive use in mineralogy.

Emergence of the Wave Theory of Light

With Young and Fresnel's experiments in interference and polarization, the wave theory of light received more favorable notice. In the nineteenth century, so far as many scientists were concerned, light was an electromagnetic wave, for it had all the known properties of other waves encountered in nature. It became fashionable to point to Newton's "error" in assuming light to be made up of finite particles. But Newton's critics ignored the statement made by him that he did not hold to his particle theory with "any absolute positiveness. . . ."

As has been pointed out, today we consider light a wave phenomenon when it is in transit from a source such as the sun to a receiver such as the material objects on our earth. Its properties and speed have all been measured with considerable accuracy. We place light waves in the electromagnetic spectrum

and on either side of the area occupied by visible wave lengths of light we find many other electromagnetic waves that affect our lives. Some can kill us. Some can restore us to health. And some can give us information and enjoyment through the entertainment mediums of radio and television.

CHAPTER 6

Radio and Television Waves

MICHAEL FARADAY developed the idea of magnetic and electrical fields of force or influence surrounding magnets and electrical devices. And in dealing with the invisible phenomena called magnetism and electricity, his idea has been very useful. It allows us to "picture" an electromagnetic wave and to begin at least to understand how magnetism and electricity interact.

James Clerk Maxwell was the natural follower of Faraday. He was born in the year that Faraday made his statement of the interaction of electric and magnetic fields (1831). Unlike Faraday, Maxwell had an excellent education and was particularly skilled in mathematics. He was struck by Faraday's ingenious explanation of electrical and magnetic occurrences and by his use of fields. He began work to develop mathematical equations that would take Faraday's explanations out of the indefinite realm of word explanation into the definite world of mathematics. To Maxwell's surprise, when he was finished, he had equations of wave motions. Wave equations had been developed for sound, water and other wave phenomena and these depended to some extent on the material properties of the medium that was transmitting the waves. Maxwell's equations for electromagnetic waves depended on Faraday's symbols for all such phenomena: fields of influence and lines of force.

In a very simplified way Maxwell's equations indicated that if a changing electric current could be set up in a wire—and made to change constantly in amount—there should be a radiation of this changing current into the region around the wire. The idea of a constantly changing current brings to mind the obvious question: How can a current grow from zero and go on changing in one direction? That is, get larger and larger without ever stopping? The answer of course is that while it is possible to imagine it, it cannot be done practically. So the idea of an oscillating current was brought forward. Suppose a current grows from zero to a maximum value and then drops back to zero again—and then repeats the process.

We have here the idea of a wave being generated, the idea of a water particle being disturbed by a wave's passing and then returning to its original position. In fact, to generate a train of water waves on the surface of water, something must be in constant motion. A hand plunged into the water will generate an initial wave, but if the hand is then held motionless, no more waves will be produced. If, however, the hand moves from side to side in regular pendulum-like motions, it will be a source of a train of waves that will move outward in a circular pattern over the surface of the water as far as it extends—or until its energy is absorbed by the water. Maxwell's equations showed that the same thing should happen when an oscillating current (analogous to the hand-motion in the water) moves along an electrical conductor. The water surface waiting to be disturbed is the field of influence conceived by Faraday.

Maxwell's equations excited the scientific world and brought more and more attention to electromagnetic fields and their behavior. The trouble was that for some time no one could prove Maxwell's idea by experiment. No one, in short, could

prove that oscillating electric currents would set up a detectable wave train some distance from the source of the disturbance.

Maxwell was what we call today a theoretical physicist. He used mathematics to take an imaginative leap forward in man's understanding of the natural universe. But his theories, carefully proved by mathematics, were so far in advance of experimental science that they could not be tested. Nearly twenty years passed before the important idea that electromagnetic waves could be "broadcast" was proved.

Heinrich Rudolph Hertz was born in Hamburg, Germany, in 1857. He entered an engineering school in Munich but soon discovered that he wanted most to study science rather than apply it in engineering. He transferred to Berlin where he studied under the foremost theoretical scientists of his day and country. At some point during these years, Hertz became interested in Maxwell's theory. When he had graduated from the university and accepted a teaching post, he set about trying to prove the Maxwellian wave equations and to show that the wave predicted by Maxwell could be detected in the region around the current-carrying wire and that furthermore the wave would be similar to a light wave.

Experimenters before Heinrich Hertz hoped to prove that such waves could be produced and that they would be visible light waves. The trouble lay in the fact that no electric current could be produced that oscillated fast enough to produce waves of the frequency of visible light. It was thought at one time that if waves with the frequency of yellow or red light, say, could be generated, then the experimenter could verify them, for they would appear to the eye as visible yellow or red light. All researches had failed, however, to accomplish the task.

Hertz gave up worrying about producing visible light and

contented himself with the best oscillator he could devise. Crude as it was by present-day standards, it served Hertz's purpose. In essence it was a spark coil. This device builds up great electrical pressure or voltage between two small points or metal spheres which are separated by a small air space. When enough electrical "pressure" exists between the two spheres, a spark jumps from one to another. This discharge of electricity through air is similar to a lightning stroke but it happens so fast the human eye cannot detect what is taking place. Actually a series of discharges occurs. The first discharge is the most powerful and the second less so, the third even less so and the series gradually dies away. To the eye it seems to be one "flash" and after it dies away nothing happens until more voltage builds up. The important thing, however, is that during this brief series of discharges, each is opposite in direction to the one preceding it. If the first, say, goes from sphere A to sphere B, the second proceeds from sphere B to sphere A. This spark discharge, in short, is an oscillating current passing through the gap between the two spheres.

While the flash is visible, it is not the oscillating current that is seen because most spark coils do not oscillate with a frequency great enough to become visible. The visibility comes from the energy released which excites the atoms of air between the metal spheres and these produce the visible light.

Hertz's spark coil was a simple piece of apparatus, and the frequency it produced was not higher than 500,000,000 cycles per second. The lowest visible frequency is about 400,000,000,000,000 cycles per second. Hertz knew he was far below that but it did not bother him. He reasoned that if Maxwell's equations were true, then he should be able to detect the frequency he did produce in the region around the spark coil. Today we

would say that during the very brief interval of the spark flash, he was broadcasting a radio signal. The main problem he had to solve was how to detect or receive the signal.

To do this he devised the first antenna. He took a piece of bare wire, bent it in the shape of a circle and fixed two small

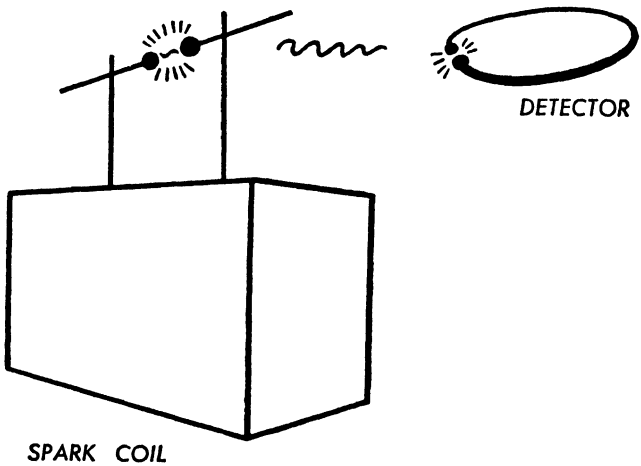


FIG. 11

metal spheres to the ends. He did not let the ends touch, however, but kept them a small distance apart. By bending the length of wire into circles of different diameters, he eventually managed to get the result he had hoped for. When the spark flashed between the spheres on the spark coil, he saw a small spark jump between the spheres of his receiving antenna placed a few feet away.

He moved his "receiver" farther and farther from his spark coil transmitter, and from many yards away he was still able

to detect the spark across his receiving spheres. As elated as Hertz must have been, he did not stop there but went on experimenting. Were there really electromagnetic waves traveling between his transmitter and receiver? Unquestionably something was, but were they waves? And did they travel, as Maxwell predicted, with the speed of light?

To test Maxwell's wave theory, Hertz put up sheets of metal and reflected his transmissions—just as waves would be reflected. He sent them toward a concave metallic reflector and they focused at a point just as light waves would do. He put nonconducting materials between transmitter and receiver and the waves passed through. While they lost some of their energy doing it, they were refracted in going through glass or water.

Next Hertz set about measuring the wave length of his transmissions. When he managed to do that he found they were about 378 inches long or about 9.6 meters. Knowing the frequency of his oscillating spark from electrical calculations, he used the very simple equation that the velocity of a wave is equal to the product of the frequency and the wave length. When he completed his computation he saw that the velocity of his electromagnetic waves equaled the speed of light.

Maxwell's equations, created to explain Faraday's symbol of electric and magnetic fields, were shown by Hertz's experiments to be valid. So each man contributed his part, each built on the work of a predecessor and great success crowned their efforts.

The results of Hertz's experiments were read by his former teacher, the famous scientist Von Helmholtz, before the Physical Society in Berlin.

Scientists all over the world recognized immediately the great contribution Hertz had made to physics. Researchers and

theoretical physicists immediately began work along many different lines of inquiry. Not the least of these was the speculation that light itself might be the result of the oscillation of particles within the light-emitting atoms.

One consequence of Hertz's experiments is radio and television as we know it today. But there still remained a great deal of work to do. For one thing, the Hertz apparatus produced waves detectable only a few feet away. To signal through the atmosphere required a great deal of research and in the year of Hertz's death, 1894, a young Italian named Guglielmo Marconi read for the first time of Hertz and his work. Other men before Marconi had tried to develop a "wireless telegraph," as it was termed, but Marconi by a great deal of ingenious work managed to make the first practical wireless telegraph.

Marconi developed an oscillator that would send more powerful signals. He developed a more sensitive receiver or resonator, as it was called, and he discovered that by attaching a wire or antenna to both transmitter and receiver and another wire to the earth or ground, he could extend the range of his signals. By the time he had developed his wireless set to this extent, Marconi had gone to England to seek support for his dream of communicating through space over great distances. In 1897 the results of his work were noticed by the Royal Scientific Society in England. Marconi had transmitted signals as far as eight miles and there seemed to be no upper limit to the distance that might be spanned.

In 1899 wireless communication was established across the English Channel. But Marconi had bigger dreams. With the help of many English scientists, a large transmitting station was built on the Cornwall coast of England. Marconi himself set out for Newfoundland where he set up a receiving station.

At St. John's, Newfoundland, Marconi rigged his receiver. For his antenna he used a 400-foot length of wire and raised it by means of a kite. During the afternoon of December 12, 1901, he received the first transatlantic wireless signal. It began the era of radio. Thousands of people—many of them youngsters—became fascinated with the idea, and crude amateur sets were soon being built in homes in Europe and America.

With such widespread interest in radio, it was inevitable that improvement in both transmitting and receiving equipment should be rapid and thousands of improvements soon flooded the patent office.

Even before Marconi transmitted the first transatlantic signal, an American inventor, Reginald Fessenden, had managed to send the human voice on waves from a transmitter to a receiver.

Radio Waves

The waves Heinrich Hertz managed to create with his spark coil and detect with his receiving resonator were nearly 10 meters long, almost 400 inches. But the section of the electromagnetic spectrum now designated as radio waves covers wave lengths of from 0.08 centimeters or a little more than 0.03 inches to 30,000 meters—nearly 19 miles.

Their frequency varies too, of course, so that the product of wave length and frequency always equals the speed of light. Day-to-day broadcasting from commercial stations goes on in the 200-meter to 600-meter wave length area. Most radios in home use indicate station locations on a dial marked with frequency, however, so that one may tune, say, to a station at 660 on the dial. This is a frequency of 660 kilocycles per second or 660,000 cycles per second, since the prefix "kilo" means a thousand times the unit used. The speed of light is approximately

186,000 miles per second or 186,000 times 5280 feet per mile, which amounts to 982,080,000 feet per second. Dividing this speed of light by 660,000 cycles per second gives a wave length of 1488 feet.

The government has assigned sections of the radio part of the electromagnetic spectrum for certain types of broadcasting. The broadcast of daily commercial programs occurs in the above-mentioned 200- to 600-meter "band." Short-wave radio sets receive waves from 0.3 meters to 200 meters. These broadcasts include police, marine and airline transmissions and are in the region of the spectrum termed "high frequency."

Until shortly before World War II, these high-frequency waves were the upper limit of oscillators men could devise. But with more research, spurred by the demands of war, oscillators that could generate higher frequencies were developed. These are now termed ultrahigh-frequency waves or microwaves. The ultrahigh frequency is self-explanatory. The term microwaves refers to the lengths of these waves. For as the frequency goes up, the wave length goes down, and in this region we are dealing with waves no longer than three-hundredths of an inch or 800-millionths of a meter. The prefix "micro" means "millionths of," the unit of measure which usually is the meter. Waves shorter than these lie in the infrared region of the electromagnetic spectrum, which in turn borders the region of visible light.

Ultrahigh-frequency waves of very short wave length provide the basis for radar. A signal is sent out by the radar transmitter and upon striking an object in its path, a portion of the wave is reflected directly back to the radar unit where a receiver detects it. Very short wave lengths are required for this since for a wave to be reflected directly back upon itself it must strike some

portion of the object that is exactly at right angles to the direction of wave travel. An airplane being searched for by radar has rounded surfaces and very little of it can be thought of as a flat plane at precisely 90 degrees to the wave's direction of travel. Long waves could not reflect this way from the surface of an airplane. They would merely be interrupted and most of the wave front would travel on beyond the object.

Very long radio waves in the low-frequency end of the electromagnetic spectrum are receiving a great deal more attention from scientists today than in the past. They are being used to examine the magnetic field of the earth itself. Much surprising new knowledge has come from a study of these waves.

According to Faraday's concept of magnetic fields, there are what he termed "lines of force" surrounding any magnet. These lines form a closed path around the magnet itself. If a small straight bar magnet is placed on a piece of cardboard and iron filings are sprinkled on the board, then the board is tapped lightly, the iron filings will line up so they reveal the pattern of Faraday's lines of force. As a matter of fact it was from this demonstration originally made by William Gilbert in the sixteenth century that Faraday took the term "lines of force."

Such lines as revealed by the iron filings start at one pole of the magnet and curve outward into the surrounding region, then return to the other pole of the magnet. And while all you can see on the flat piece of cardboard are the lines in the plane of the cardboard itself, you must remember that the lines fill all the space around the magnet.

The suggestion that the earth itself was a giant magnet and had a magnetic field came early in scientific history. Magnetic compasses make use of the "lining up" of iron filings, since the compass needle acts like one of the filings and aligns itself with

the force lines of the earth's magnetic field. The north-seeking end of the compass needle will point in the direction of the earth's magnetic north pole—which is not at the same place on the earth as the geographic north pole. The south-seeking end of the compass will point toward the south magnetic pole. Scientists have long known that the earth's lines of force curved outward into space and, continuing to curve, eventually returned to earth. But until long-wave radio frequencies were used, there was no way to measure and map this huge magnetic field enveloping us. These long radio waves, when broadcast, follow these lines of force. If a station is at some position, say, in Nova Scotia and it sends out a long-wave signal, the wave travels outward into space, curving along the line of force and returning to some point on the Antarctic continent. By measuring the time between transmitting and receiving such a wave, scientists can actually draw the line of force and determine the exact shape of the earth's magnetic field. Recent investigations show that these lines of force extend as far as 20,000 miles into space—a distance much greater than had been suspected.

Using these same long waves, scientists today can determine the intensity of explosions on the surface of the sun by an indirect method. From the beginning of radio, broadcasters and amateurs have known that periodically their signals were interrupted by some mysterious agency. For some time the thermonuclear explosions on the sun's surface have been blamed for such interruption of communication. The announcement that "sunspot" activity is interfering with the transmission of radio signals has been accepted by average citizens as the explanation. The scientist, of course, wants to know exactly how strong these explosions are and with long-wave radio stations in operation today at many points on the earth he can tell. For when

there is such an explosion on the sun's surface, a torrent of electrified particles and many intense waves of energy come pouring toward the earth. When these sudden abnormal doses of electrical energy strike the earth's magnetic field, they distort the lines of force temporarily. The amount of distortion gives a clue to the intensity of the explosion on the sun that caused it. So today we send long-wave signals along the lines of force, and if the field is distorted, both the time and location of the signal's arrival back on earth are different from what they would be without distortion.

Radio Telescopes

Electromagnetic waves in the visible light region of the spectrum come to us from all the luminous bodies in our galaxy and from many galaxies beyond our own. For hundreds of years men have turned their gaze on the light from these objects and tried to see them more clearly with what are called optical telescopes. Such telescopes make use of lenses to gather and focus light from stars and planets. Binoculars, "spyglasses" and large telescopes, both refracting (lens-type) and reflecting (mirror-type), have given us much information about the stars and planets. But the largest and most expensive of these telescopes, the 200-inch diameter reflecting telescope at Mt. Palomar Observatory in California, has its limits. For light waves entering the earth's atmosphere are refracted and scattered—distorting the image of a star so that no lens or mirror, no matter how perfect, can give us an accurate picture of the object being looked at.

Until recently men have used only this small visible part of the electromagnetic spectrum to gain information about the heavens surrounding the earth. Recently, however, another

method of probing the universe has been developed: radio telescopes. Stars like our sun send not only visible light waves toward us but also waves of other than the visible lengths. Waves in the area of radio wave lengths arrive and penetrate the earth's atmosphere. The means we have used to receive and analyze these radio waves with sensitive receivers are more efficient than lenses and mirrors. Scientists have built radio telescopes to catch the faint but analyzable signals arriving from worlds that are light years away. These telescopes are really great electrical "mirrors" designed to bring radio wave lengths to focus. They have no polished silver surface, however, but are carefully designed concave frames formed by a web of metal conductors. Many of the radio wave lengths that come to the earth have so little energy and are so scattered that a focusing device is necessary to give us enough of the incoming energy to analyze.

Radio Wave Modulation

Today's radio transmitters use electrical principles to produce the frequencies required. A transmitter assigned a frequency of, say, 900 kilocycles produces what is called a carrier wave having that frequency. This wave has energy enough to cover the desired area and is, of course, far above the range of frequency which can be detected by the human ear. How, then, can a human voice operating in its frequency range of 20 to about 20,000 cycles per second be carried on the 900-kilocycle wave?

The answer lies in what is termed wave superposition—which is not as mysterious as it sounds. If two water wave patterns of different frequencies are generated side by side on a pond, the two different waves will tend to combine and form a single though more complex wave pattern. In radio, what is called

amplitude modulation makes use of this wave characteristic. The carrier wave of 900 kilocycles is produced and then the wave pattern of the human voice—translated into an electrical wave—is superimposed on the carrier. The resulting wave varies in amplitude from either of the two original waves. In a sense, the voice wave travels on the back of the carrier wave. Another type of modulation is called frequency modulation. In this kind of transmission the amplitude of the carrier wave remains constant but the voice wave activates an electrical system that varies the frequency of the carrier wave to correspond to the voice wave. The advantage of frequency modulation is that it is freer from outside interference when en route to the receiver than is an amplitude modulated wave. The two types of modulation are often spoken of as AM and FM.

Whichever type of modulation is used on the carrier wave, the electromagnetic vibrations are sent from the transmitter antenna and radiate in all directions. Those portions of the wave that proceed toward or below the horizon are called ground waves and can be received only if the receiving antenna is a short distance from the transmitter, for the ground waves are soon interrupted by the earth itself. How, then, can radio waves travel around the earth and be received thousands of miles from the transmitter? The answer lies in the structure of the atmosphere of the earth. Meteorologists divide the lower atmosphere into three distinct layers on the basis of how the temperature changes with altitude. The lowest two layers are called the troposphere and stratosphere. Together they extend roughly twenty miles above the earth. Above the stratosphere lies a region called the ionosphere. It is named this because it is a region where charged particles called ions exist. Current theory holds that this layer may be several hundreds of miles

thick. The presence of electrically charged particles in this region is believed to be due to the continual bombardment of the atmosphere by the sun. The energy poured out by the sun and striking this outer portion of the atmosphere causes electrons to be knocked out of atoms or gas molecules. These electrons may become linked to other molecules—in which case the result is a negative charge. In a way the ionosphere serves as an electrical blanket for the earth, absorbing some energy from the sun that otherwise would be harmful to us. But the ionosphere also serves as a great reflecting electrical mirror for transmitted radio waves. The waves sent skyward by the transmitting antenna reach some portion of the ionosphere and bounce back toward the earth. In so doing they can reach a point on the earth lying far below the horizon from the point of transmission. These reflected waves may even come back to earth, be reflected there, make another journey skyward and so come once more to the earth's surface where they may be received an even greater distance away.

Receiving Radio Waves

No matter how much energy we put into the transmitted electromagnetic waves, they lose some of it as the distance from the radio transmitter increases. It is exactly like any other wave pattern produced. As the distance from the source of the wave increases, the original amount of energy put into such a wave is spread over a greater and greater wave surface. The result is that any given area of the wave front will contain less energy than the same area taken from the wave front nearer the source.

The problem of receiving waves which possess very little energy, and amplifying or enlarging the message they carry is the important job of a radio receiver. While the electrical

principles involved are not part of the story of waves, a very important wave principle is used. It is called resonance. It is a way of making small amounts of energy produce oscillations of large amplitude.

The easiest way to see this is with a child's swing. To make the swing move higher and higher, we give it small pushes or pulses of energy at precise moments. Those moments during which we supply energy to the swing are instinctively chosen to be at the end of one motion of the swing, that is, when it has momentarily stopped and is about to begin moving in the direction in which we supply the energy. In other words we govern our supplying the energy on the basis of the frequency of the swing itself. Thus small amounts of energy can produce greater and greater amplitude of vibration. The natural frequency of vibration of a swing is determined primarily by its length from the point of support. All objects have a natural frequency of vibration which depends on the structure of the object—its physical dimensions and the material of which it is made.

There are many examples of objects being set into vibration in their natural frequency. A particular dish or pan, for example, begins to rattle when a truck passes a house. The tines of a fork will vibrate if plucked, and a glass will vibrate if a dampened finger is moved slowly about its rim. The power of a human voice sustaining a single note can shatter a glass if the singer produces a tone with a frequency equal or nearly equal to the natural frequency of the glass. As the amplitude of the vibration of the glass increases, it may surpass the elasticity of the glass, and shattering results.

Objects can be made to vibrate whether or not the energy pulses come at exactly the natural frequency of the object, and we call those forced vibrations. But the expenditure of energy

to produce vibration is least if the frequency is exactly the natural frequency of the object being set into vibration. Electric circuits can be "tuned" to produce many different natural frequencies. Thus the antenna of a receiver trying to pick up a 900-kilocycle signal is tuned or altered electrically to have a natural frequency of 900 kilocycles. When the receiver is so tuned, the faint signals coming through the atmosphere set up electrical vibrations which quickly grow in amplitude and become detectable. The signal then is ready for further amplification and analysis in the receiver.

Television

One of the most useful devices ever invented to analyze wave patterns and electrical occurrences in a circuit is the oscilloscope. Essentially it is made up of an evacuated glass tube containing a heated, negatively charged piece of metal called the cathode. This element emits electrons. If a positively charged plate is placed between the cathode and the front of the tube, the electrons will go toward it. Ordinarily they would be absorbed by the positive plate or anode, but if a small hole is drilled in the center of the anode, some electrons will pass through it and proceed beyond to the front of the tube itself. The stream of electrons passing through the center of the anode can be diverted, focused and moved in any desired direction by having the stream move in an electric or magnetic field. When the electrons reach the front of the tube they strike a material that emits light upon receiving the electrons' energy. The material is said to be fluorescent. Now if we move the stream of electrons back and forth across the front of the tube, the viewer outside will see a dot of light proceed from one side of the tube to the other. If the back-and-forth movement of

the electron stream is rapid enough, the dot will appear as a line, for the fluorescent material emits light for a short while after the electron beam has moved on. The human eye also is able to retain an image for a brief time after the image has been removed. This is called persistence of vision. Together these two facts let us "see" the electron dot as a line.

As an analyzer of wave motions, the oscilloscope is unsurpassed. The wave we want to analyze is introduced to the scope by an electrical circuit that periodically alters the electrical or magnetic field through which the stream of electrons passes. The resulting motion of the electron beam reproduces the wave form on the front of the oscilloscope. In this manner we can actually "see" sound waves or other wave motions that otherwise would be invisible.

The motion of the electron beam is determined by the changing fields through which it passes. The intensity of the light produced on the scope's screen is determined by the number of electrons striking the screen in one spot. If we alter this number of electrons, say, reducing it, then the spot is dim. If we increase the number the spot is brighter. It is this principle that is used in the transmission of television programs. The transmitting device is called an iconoscope and it scans the scene to be transmitted. Where the scanning device picks up little light, little current is sent out. Where it picks up a great amount of light, lots of current is transmitted. These alternations of current being transmitted affect the receiving tube, which is similar to that of an oscilloscope. When little current comes in, few electrons strike the screen surface and the spot there is dark; where large amounts of current are received, greater numbers of electrons strike the screen and the spot is bright.

The scanning transmitter "looks" at the scene to be sent out

with a beam that moves very rapidly over a rectangular surface in regularly spaced horizontal lines. If the receiver is synchronized with the transmitter, the fluctuating dark and bright spots reproduce the scene being scanned many miles away and we have a good picture.

In between, of course, the signal is proceeding as an electromagnetic wave, modulated by the scanning device. Television transmissions cannot make use of the ionosphere to "bounce" transmission a great distance around the earth but Telstar, America's artificial satellite, serves now as a transfer station for such communication. Programs are received and rebroadcast by the satellite. This permits an event televised in Europe to be received in the United States and makes world-wide television communication technically possible.

CHAPTER 7

Modern Wave Investigations

DURING the latter part of the nineteenth century the idea that light could be completely understood as a wave motion was firmly implanted in scientific theory. By that time the electromagnetic spectrum of which light is a small part had been fitted into the scheme of things. In short, the long battle between the theories that light was a wave and that it was a stream of particles, which had raged more or less continuously from Newton's day, seemed to have been settled in favor of the wave theory.

Light apparently had all the properties of waves. It could be reflected, refracted, undergo diffraction and exhibit the property of interference which only waves, not particles, could show. The same thing was true of radio waves, or any others in the electromagnetic spectrum.

But toward the end of the nineteenth century, scientists recognized that there were some questions about light emission and absorption that could not be answered by applying wave equations like Maxwell's to the problem. Then, in 1900, Max Planck, a research scientist, published a paper on his work that upset the scientific world. Dr. Planck had been working to answer some questions about the emission of electromagnetic radiations. The method employed was to provide a source of

radiation at a particular temperature and measure the wave lengths of the emitted waves. It had been found by other scientists that different wave lengths in the continuous spectrum produced had varying amounts of energy. And there seemed to be no way to account for assignment of the energy to specific wave lengths. If different temperatures were used, the energy contained in the various wave lengths shifted—for no explainable reason. Another curious fact was that no matter what substance was heated to produce the radiations, they all had nearly the same energy distribution at a given temperature.

This fact in itself suggested that some single law was at work for all substances and that the radiations actually were the result of subatomic oscillators. That is, parts of the atoms themselves were oscillators producing the electromagnetic vibrations or radiations.

Several scientists had tried to produce theories that would explain, mathematically, the answers to these questions, but all failed. One thing that hindered progress was the firm belief that wave equations somehow could provide the solution. The spectra that were produced from the controlled emitters of radiation contained infrared, visible and ultraviolet radiation. At temperatures near those of the surface of the sun, the spectrum produced was continuous—that is, the colors produced and analyzed merged into one another just as the colors of a rainbow do or colors produced with prisms refracting white light. It was also believed that the subatomic oscillators could emit energy in smoothly increasing amounts from zero upward depending on the energy put into the system. Planck discovered that this was not so. The results of his experiments forced him to come to the conclusion that energy from a radiating body is emitted in small but definite amounts. A crude

analogy might be that of a water spigot. By turning the spigot slowly water comes first as a trickle and proceeds smoothly to become a rushing stream. This was the way emitted energy was thought to come from radiating bodies. In fact, as Planck discovered, the energy comes in spurts or quanta. The amount of energy in each quantum depended on the frequency of the electromagnetic wave produced. Planck also found that the quanta emitted by any oscillator could contain a single definite amount of energy or an integral number of those definite amounts. In other words, the quantum could contain one unit of energy, two, three, four or five times that amount, but never one and a half times the basic amount.

Planck himself was alarmed by the results he got from his experiments. He saw that it would upset the theory of light then existing and he tried, without success, to disprove his own work.

From Newton's time onward, the idea that energy of any sort could be gained or lost in a smooth, continuous process had been accepted. For example, a spring set vibrating with a weight on one end of it will move up and down with slowly diminishing amplitude of vibration until finally it stops vibrating altogether and comes to rest. The assumption is that its energy of vibration is slowly but continuously lost or used to overcome friction within the spring. But according to Planck's work, the spring should come to rest in steps or in little jumps as its energy was dissipated.

The implications of Planck's theory were tremendous because it resurrected the particle or corpuscular theory of light. True, the particles Planck believed in were particles of energy, not matter. But they were particles nonetheless.

The scientific world did not accept Planck's hypothesis im-

mediately although it did explain mathematically the answers about radiating bodies. Did his equations actually explain what was happening in the subatomic realm of matter? Or had he merely devised them ingeniously to answer the question? For it is possible with mathematics to devise a formula that will fit or nearly fit a particular problem.

In essence, his statement was that the energy contained in each quantum radiated was related to the frequency of the wave produced. With this premise accepted, he devised a formula to predict the amounts of energy for various wave lengths of radiation emitted at different temperatures. It was radical, new and disbelieved by many. But it worked.

The Photoelectric Effect

Help came to Planck's hypothesis but it was five years in arriving. And it was help of a theoretical nature only. In 1905 Albert Einstein offered an explanation of what was already known as the photoelectric effect.

Curiously, Heinrich Hertz had observed the photoelectric effect, but he merely made a note of it and did not pause to examine what was happening. Hertz found that when he prepared his electrical circuit to produce a spark between the spheres of his oscillator, the spark was better if he first polished the spheres. Just why this was so Hertz did not attempt to answer. In essence, the photoelectric effect is the release of electrons from a metal when light strikes it. The light may be in the ultraviolet or visible region of the spectrum depending on what metal is used. Today we encounter the photoelectric effect most frequently in the so-called "electric eye" doors which open as a person interrupts a light beam.

What puzzled scientists about the photoelectric effect was

this. In experiments, monochromatic light—which is light of a single wave length or color—directed on metals sensitive to the frequency used, released electrons from the surface. According to the theory accepted at that time, if the energy of the light beam were increased, the energy of the electrons released should also rise. In other words, if you put more energy into the system, you should expect to get more energy out of it. But this didn't happen. What did happen as the intensity of the light beam was increased was merely that the number of electrons coming out of the metal increased. The only way that the electrons could be given more energy was by increasing the *frequency* of the light used.

Planck experimented with an electromagnetic radiation emitter and found that certain levels of heat energy produced radiations in a certain frequency range. In the photoelectric effect the energy acquired by the released electrons depended on the frequency of the radiation—visible or ultraviolet—that fell on the metal surface. Apparently absorbers and emitters of electromagnetic radiation took in or let out energy in bundles or quanta, and the size of the bundle depended on the frequency.

Answering these puzzling photoelectric phenomena, Albert Einstein suggested that our usual picture of a wave, when applied to electromagnetic waves, would have to be revised. In a water wave the energy is spread evenly over the front of the wave so that a measurement of any piece of wave front would show as much energy as that contained in any other piece. Einstein postulated that in electromagnetic waves the energy was not evenly distributed but was to be found in bundles or quanta at particular places on the wave front.

When Einstein made this proposal, it seemed that much of

classical or Newtonian physics was being destroyed. For if light, which acted like a wave, was actually a train of energy particles, then all the work done using light as waves would have to be drastically revised.

Einstein's proposal, supported with mathematical proof but as yet not rigorously tested in the laboratory for lack of means, was a large imaginative leap into the future—the future which has produced what we term modern physics today. Was light a wave or not? If all tests made on light in transit from emitter to absorber showed it had wave properties and yet it could be shown *not* to be a wave, then what *were* wave properties and what were all the other phenomena called waves?

X-rays

In the photoelectric effect, electromagnetic radiations striking certain metal surfaces released electrons. The discovery of X-rays, as we call them today, came about through the reverse process. A stream of electrons can be produced by heating a metal filament in a vacuum and directing it toward a positively charged piece of metal. When this was first done, the stream was called a cathode ray because it came from the negative plate or cathode of the apparatus used. We know now the cathode ray is a stream of electrons. These electrons strike the metal plate and the plate emits electromagnetic radiation of very high frequency. When these radiations first were discovered, they were an unknown quantity and hence received the name X-rays, which has been retained. These radiations have wave lengths short enough to penetrate many materials and they also can affect photographic plates. They have thus found wide use in medical work since they can pass through the body in greater or lesser amount depending on the material they pass

through. Thus fewer X-rays penetrate bone tissue than other tissues of the body, and the picture they produce shows the bone structure as dark areas on the photographic negative.

Extensive experiments with X-rays established them as true electromagnetic radiations having wave lengths about four ten-millionths of an inch. It was then thought that if they were waves—or if they had wave properties—they could be diffracted through appropriately narrow slits or openings. The distance of about four ten-millionths of an inch is difficult to produce on a piece of glass by marking lines, or by any other means. But theory already suggested that the spacing between atoms in solid crystals was about this distance and it occurred to one scientist to use a thin section of a crystal as a diffraction grating. That is, by directing X-rays at such a thin section of a crystalline substance, the researcher could tell whether X-rays were capable of being diffracted and so establish the fact that they possessed this wave property. At the same time the resulting pattern of diffracted X-rays would reveal the atomic structure of the crystal itself.

Both experiments were successful and today X-ray diffraction patterns of many materials allow scientists to analyze metals and to determine actual wave lengths of X-rays emitted from different materials.

Light Waves and the Atom

Beginning with Planck's upsetting idea that electromagnetic radiation was emitted in bundles or quanta, through Einstein's theory suggesting that the energy in electromagnetic waves remained in quanta, and later, as experiments brought unexpected and often contradictory results, the modern concept of the atom and its structure was being born. The names of Ernest

Rutherford, A. H. Compton and Neils Bohr figure prominently in our present ideas about the atom, and much of their interest and imagination was awakened by the contradictory results of earlier scientists' work. The question of whether light was a wave or a stream of particles even today is not fully answered. But in searching for an answer, scientists have learned much of value. Not the least they learned was that light may behave like a wave under some circumstances, like a stream or spray of particles under other circumstances. Admittedly light has this dual nature and from that duality there has come one of the most interesting ideas ever proposed in science. In 1924 the French scientist, Louis de Broglie, asked: If waves such as light show properties we ordinarily think belong to particles, do particles have any properties associated with waves? That is, could a particle have wave length and frequency? Could particles be refracted, diffracted?

The de Broglie hypothesis seems startling at first glance—and it startled many scientists when he first put forth the idea. One of the most obvious particles to experiment with was the electron. It had been established that this part of the atom had the characteristics of a particle—that is, it weighed something, even though a small amount. Electrons could be accelerated and their momentum measured. Furthermore, they answered all the requirements scientists could put to them from classical physics. But did they have wave properties as well?

At about the time de Broglie gave a mathematical proof of his hypothesis, two researchers in America were experimenting with the reflection of electrons from metallic surfaces. In our everyday world we know that particles can reflect from a surface. Ping-pong balls, for example, strike a wall and move away from it according to the laws of reflection that hold also for

waves. So ability to be reflected is not proof of something having wave properties.

Refraction is a better clue. But particles can be refracted as can waves. The conditions for refraction of particles are different from those that make waves refract, but the same laws of refraction do apply to particles and waves. So refraction is not definite proof.

But diffraction and interference have been considered positive proof of the wave nature of the phenomenon being studied. The principle of interference of alternate damping out and reinforcement of waves, and the spreading of waves around the edges of obstacles which we call diffraction would be acceptable proof. The two American researchers accomplished the diffraction of an electron beam. They photographed the pattern and de Broglie's theory was vindicated.

Then do all particles behave like waves? According to de Broglie's formula they do theoretically. But as the size and mass of the object becomes larger, the wave length associated with the object becomes smaller. Thus an object the size of a billiard ball would have a wave length so small it could not be detected by our most precise measuring instruments. To put it in another fashion, as the particle character gets smaller, the wave characteristic becomes more noticeable—and measurable. Electrons are small enough for us to notice their wavelike properties; billiard balls are not.

Waves of the Highest Frequency

When X-rays were discovered and measured, they were placed in their proper position in the growing electromagnetic spectrum. Man's knowledge of the universe was extended by their discovery. These electromagnetic radiations were of such short

wave length that they could penetrate many kinds of matter. But with the discovery of radium and other radioactive elements, proof came that X-rays were not the end of the electromagnetic spectrum.

Radioactive materials emit particles and radiation spontaneously. These were found to be of three types in naturally radioactive materials and were named: alpha, beta and gamma rays. One way to distinguish among them was to test their power of penetration and it is on this basis that they are identified. Alpha rays have been found to be relatively heavy particles containing a positive charge and not able to penetrate metal foil very successfully. When emitted by radioactive metals, they travel at less than a tenth of the speed of light. Beta rays have been found to be high-speed electrons ejected from the nucleus of the atom. They travel at anywhere from 0.3 to 0.99 of the speed of light.

The gamma ray is apparently a true electromagnetic radiation traveling at the speed of light. These rays have shorter wave lengths and higher frequencies than X-rays and are the most penetrating of the three rays or radiations. Gamma wave lengths as short as 0.0000000000002 inches have been measured. With such short wave length, it is easy to see how such radiations can penetrate thick sheets of such heavy metals as lead. With their energy they can destroy human tissue, and men exposed to gamma radiation have had a death sentence pronounced.

The Continual Search

Planck, Einstein, Bohr and many other scientists opened the doorway to modern physics. Their quest and the quest of thousands of other scientists was largely spurred by a consideration

of the wave character of light versus its sometime particle behavior.

The hypothesis put forward by de Broglie suggesting the wave character of particles has found wide use in dealing with small particles. And since we have invaded the nucleus of the atom, scientists have had many small particles to experiment with.

During the first half of the twentieth century it seemed to many observers that Newtonian physics was collapsing. The laws he had developed and which had been applied for so long would not, apparently, work on particles of very small size. But soon it developed that with some adaptation and further understanding of the dual nature of matter, its occasional wave and occasional particle behavior, much of what Newton proved still held true.

New ideas, new pictures and models of the universe and its infinitesimally small parts will come forth in the future. But the idea of waves, whether large ocean waves or the smallest imaginable electromagnetic waves, will persist and take its place in the evolving system of science. For to transmit energy, Nature relies on them through earth, through air, through water and through the silent reaches of space.

CHAPTER 8

Wave Experiments

WHEN a person is looking for something—and has an idea what it is—he is more alert, more aware of the sense impressions he receives as he searches. If that person has been trained in the scientific discipline, he may have a "mind prepared to receive" what he observes.

Ordinarily we go about our daily work without truly observing the world around us, and if something occurs of which we do not know the cause and the answer does not spring readily to mind, we shrug it off and the incident passes from our conscious mind. A painter will "see" more of the esthetic nature of the world about him, will ponder over what he sees and then set to work interpreting his vision in a picture. A scientist will observe the myriad phenomena of nature and from his observations will suspect he knows the reasons for a number of happenings. He then tests his suspicions in the laboratory to see if he is correct.

Many years ago the youthful scientist Galileo Galilei provided an almost perfect example of this process. He was attending mass at the Cathedral in Pisa, Italy, when he noticed a monk draw a large chandelier to one side to light its candles. When the chandelier was released, it swung back and forth over the heads of the worshipers. Many people saw the motion of the chandelier, but none save Galileo was "prepared to receive"

the information available in the occurrence. Galileo noticed that at first the chandelier swung in a long arc and then the arc became progressively shorter until the chandelier finally came to rest. He noticed, too, that while the chandelier's arc was long, its speed was great. When the arc was short the speed was less. His supposition or question: Did the chandelier traverse each arc in equal intervals of time? Right there he tested the supposition. Being without a watch, he used his own pulse to time the swings and found that his supposition seemed to be correct. Later he experimented more carefully and produced what we know today as the law of the simple pendulum.

The ability to observe and to draw correct conclusions from observations is the hallmark of a good mind. If that mind is interested in things scientific, the observations and inquiries will be in the realm of the physical universe. The brief and simple experiments included here are designed in most cases merely to direct observation along useful channels. A few of them are quantitative in nature—that is, they should produce a measurable result by simple arithmetic. All can be performed with material that is inexpensive and in many cases is found in the home.

Water Waves

It is difficult to observe water waves closely on a lake or on the ocean. But shallow water in a bathtub can be set in motion and if the resulting waves are observed, several of the important properties of waves can be noticed: reflection, focusing, interference and diffraction.

In recent years a device for studying wave properties through observing water waves has been developed. It is called a ripple tank. Essentially it is a shallow pan of water with a sloping bottom like the bottom of many swimming pools: shallow at

one end, deeper at the other. This gives nearly an ideal situation for the observation of water wave properties since waves produced at the deep end run up on the shallow end and die out without reflecting back into the oncoming wave pattern and distorting what you wish to observe.

But with a little care you can observe most of the properties of waves in a bathtub. Run just enough water into the tub to cover all but the far end of the bottom. For best observation you should have a light shining down into the tub to make the wave pattern more distinct.

Waves produced in such a confined space tend to reflect from the sides of the tub and obscure what you are looking for. If a train of waves is started, the whole surface can become an irregular disturbed surface in which little can be seen and nothing learned. But if a single drop of water is released to disturb the still surface, then the essentially single wave can be watched and its path and direction of travel noted and the wave properties seen.

To produce drops whenever you wish, use an eyedropper or any applicator from such a container as a nosedrop bottle. The other equipment you need will be the light mentioned before, a curved section of tin or several thicknesses of aluminum foil shaped in a semicircle about a foot in diameter, two lengths of wood which can stand upright in the shallow water and together span the width of the tub to within one inch of the sides. To observe interference, you will need a second eyedropper.

Reflection

Place the two lengths of wood end to end forming a single surface against which a wave can strike. Place them at some angle other than 90° to the side of the tub. Fill the dropper with

water and when the surface of the water in the tub has become perfectly still, let one drop fall about a foot from the lengths of wood. The wave is circular and approaches the wood. One portion of the circle strikes the wood first and is immediately reflected. In a very short time the rest of the circular wave front has struck the wood surface and also has been reflected.

Notice that the reflected wave has the same shape as the wave striking the wood. But notice also that the direction of travel of the wave front has been changed. Strict measurement here of the angle of striking and angle of reflecting is not done easily but in the experiment on the reflection of light waves there is a simple way to measure these angles. The angle at which the wave approaches the surface is called the angle of incidence and the angle at which it is reflected is called the angle of reflection.

Continue to allow drops of water to fall until you are certain you have witnessed the reflection of the waves and understand what is meant by the angle of incidence and angle of reflection.

The reflection you have just produced is called plane reflection in which the shape of the reflected wave is exactly like the shape of the incident wave. Sometimes it is desirable to change the shape of a wave upon reflection and this can be done by having the wave strike a curved surface. Take the curved piece of metal or foil and place it in the tub. It must be tall enough, of course, to protrude above the surface of the water at the point you place it. First place the curved metal or foil so that the center part of it is nearest the source of the waves you are going to produce. This position presents what is called a convex surface to the oncoming wave—a surface whose center is struck first and whose outer curved sides are struck some time later as the wave advances.

Produce a wave and watch it strike the curved surface. The reflected wave is still circular in shape but the circle is much larger. Such a convex reflector will spread the wave over a larger area. Now reverse the curved metal or foil so that the center is farther from the source of waves than the ends. Viewed from the source of waves (where you let the drop strike the surface) this shape of the metal surface would be called concave. Again let a drop create a wave. Notice that when it strikes the reflecting surface the reflections at all points seem to converge at a point. With the light shining overhead you should be able to see a small circle of light or dark as the reflected wave converges. This is called convergent focusing and frequently is used to produce a brighter spot of light by reflection than can be obtained otherwise. The mirrors of reflecting telescopes are curved surfaces similar to your piece of metal. The faint light from a distant star is focused at a point and the image gained there is much brighter than it otherwise would have been. It can then be photographed and what would have been an impossibly faint picture of the star becomes a usable and highly informative photograph.

Interference

Waves created by a drop of water falling on the water surface grow, spread out and disappear so rapidly that you must concentrate your glance at the right point to see the desired phenomenon. To witness interference, take two droppers and hold them about an inch apart above the water surface. Squeeze them simultaneously to produce two drops as nearly at the same instant as possible. When the drops strike the surface they will produce two circles of waves which overlap. At some points where the waves cross each other, there will be an increase in

amplitude of the wave pattern, at others there will be a decrease. This pattern of alternately high and minimum amplitudes is called an interference pattern. It will appear briefly on the surface before the waves are reflected from the sides of the tub, distorting the two regular circles of waves. If the light overhead is moved about, a position can be found that will produce maximum light reflection from the high amplitude wave portions and minimum reflection from points of low amplitude. Thus the pattern of light seen will probably be the best visual evidence of the interference phenomenon.

Diffraction

Diffraction of waves is the spreading out of the wave form behind the edges of obstacles. To produce diffraction of water waves, place the two pieces of wood in the bottom of the tub so their ends are about an inch apart. Create a wave form about a foot from the opening between the two pieces of wood and keep your eye fixed on the region just behind the opening. Notice that when the wave strikes the wood a small portion of the wave passes through the opening and the wave pattern behind the wood is itself circular in shape. In other words, the wave spreads out beyond the opening.

Experiment with several different opening widths and note the varying amounts of diffraction. Maximum diffraction occurs when the width of the slit or opening is equal to the wave length of the wave pattern approaching it. Of course you are producing very nearly a single wave, but by squeezing the eye dropper at regular intervals you can produce a wave train which will produce diffraction wavelets on the far side of the opening. The opening, in fact, acts as a source of circular wavelets itself. You can imagine what the situation would be if you had a series

of such openings placed close together and a wave approached all the narrow slits. Circular wavelets would be set up beyond each opening and these circular wavelets would overlap, producing interference patterns. Such a series of narrow slits is called a diffraction grating when light waves are passed through it.

Sound Waves

Sound waves of a frequency between 20 and 20,000 cycles per second are audible or sonic waves. They are produced by many kinds of vibrating objects, and to understand the vibrations of the objects is to see more clearly just what sound waves are. Musical instruments produce sound waves through the vibrations of strings, metal rods and plates, and of enclosed columns of air itself.

A very simple experiment will demonstrate the production of waves through a vibrating piece of metal or wood. Take a yardstick or a hacksaw blade and hold it firmly on a bench or kitchen counter with one end protruding beyond the counter edge by six inches or more. Press down on the rod where it reaches the edge of the counter with your thumb and flick the outer end of the rod with your other hand. The end of the stick or blade will vibrate back and forth and can produce a low-frequency hum. Sounds of such low frequency often are more "felt" than heard. By changing the length of the overhanging section of the rod, the frequency can be changed. Xylophones and glockenspiels make use of vibrating lengths of metal to produce their tones. The metal rods in these instruments are fixed near both ends and the middle of the rod is struck so that both ends and the middle vibrate at the desired frequency. The shorter lengths produce the higher frequencies.

Vibrating strings produce the tones of all stringed instru-

ments. Take a three-foot length of thin wire and stretch it between two nails driven into a board. Pluck the wire and produce a tone. If you tighten the wire the tone produced will be of a higher frequency. If you change its length you will also change the frequency produced. To change the effective length of the wire you have stretched between the nails, force a block of wood between the wire and the board so that the wire passes up and over the edge of the block. The tone now produced by the wire will be different from the original one. Move the wooden wedge to several other locations and discover how shortening the wire affects the frequency produced. Musicians, of course, are familiar with these methods of altering the frequencies or tones produced by their stringed instruments. The bridge of a violin acts as the effective end of the strings even though they continue beyond it. The strings of a violin are tuned by altering the stretching force, and the player alters the effective length while playing the instrument by pressing the strings against the fingerboard. A varying frequency can be produced by setting the string into vibration with the bow and moving a finger along a string while pressing it against the fingerboard.

The vibration of the strings of such instruments as the violin and guitar would not produce sounds of very high intensity by themselves. The wire you have stretched between the nails on the board doesn't make as loud a sound as the wire of a guitar when plucked. The difference is due to the enclosed air in the chest of the violin or guitar. When the string of a violin vibrates, the energy sets the air within the violin chest into vibration also, and the sound heard is greatly amplified.

This is because the vibrations of the strings force the air in the violin chest to vibrate along with it. A simple experiment will show what forced vibrations are. Take a silver fork (pref-

erably not a plated one) and squeeze the outside tines inward with your fingernails. Release the tines and hold the fork near one ear. The tone is distinct but is by no means loud. Now place the handle of the fork in the center of a dinner plate, holding the fork vertically. Again pluck the tines. The sound is much louder. The vibrations of the tines were transmitted through the fork handle and set the plate vibrating too.

Transmission

Air does not transmit sound as rapidly as most solids and liquids. Test this sometime when you are swimming. Have someone stand about a hundred yards from you along the shore in waist-deep water. Tell him to take a piece of wood and slap the water surface hard. If you bend over and turn your head so that one ear is under water and the other in the air, you will hear two distinct sounds for each slap of the piece of wood. The first one is the sound coming to you through the water and the other is the sound arriving later through the air. You may notice also that the sound arriving through the water is louder or more intense than that arriving through the air. Still another way to hear the difference between sound transmitted through air and a solid is to tie two pieces of string, each about two feet long, to the narrowest part of the handle of a tablespoon. First swing the spoon against your kitchen counter and listen to the sound produced. Then press the ends of the strings into your ears with your thumbs and swing the spoon against the counter again. The difference in intensity and quality of sound heard is obvious.

The Speed of Sound

To measure the speed of sound directly requires a whistle or two flat boards, a stop watch and some place where you can re-

ceive good echoes from a measurable distance away. If such a location can be found, sound the whistle, or slap the boards together, and measure the time until the echo is heard. The velocity is the distance to and from the echoing plane or wall divided by the time required for the sound to get to the wall and return. Since sound travels through air at the rate of 1087 feet per second when the temperature is 32°F, the value you get will not be accurate unless you make a temperature correction —or unless the temperature at the time of the experiment is actually 32°F. For each degree of temperature above 32°F that exists when you try this, add 2 feet per second velocity to the 1087 foot per second velocity. Thus if the temperature is 72°F when you experiment, the temperature correction would be $2 \times (72 - 32)$ or 80 feet per second. Add this to 1087 and the actual velocity of sound at your temperature is 1167 feet per second. If the temperature is below 32°F you subtract the temperature correction.

Light Waves

The laws of reflection of waves have been known for a long time and the relationship between what we call the angle of incidence and the angle of reflection is observable though not easily measured when the waves themselves are visible, as in the case of water waves. Light waves, while producing the sensation of sight, are themselves invisible and so to test the laws of wave reflection for light waves we have to make use of images the eye can see.

The equipment needed for this experiment consists of a sheet of white paper (8½ by 11 inches), common pins, a small flat mirror, a clothespin, a pencil, straightedge, and something to measure angles, such as a protractor.

Draw a straight line across the middle of the sheet of un-

lined white paper and place the paper on a flat piece of soft wood. Use the clothespin to hold the mirror upright with its silvered back surface on the line you have drawn. Stick a pin upright in the paper about an inch in front of the mirror near its center. Place your eyes near the top of the board and locate the image of the pin in the mirror. Now move to one side so that you are looking at the mirror image of the pin at some fairly large angle to the mirror surface (about 30° or 40°). While keeping your eye on the mirror image, place two more pins in the board on your line of sight so that the image and these two pins form a single line. The two pins should be stuck into the board about three inches apart along the line of sight.

Move to the opposite end of the mirror and choose another angle. Sight on the image from the new direction and place two more pins along the line of sight as before. Draw light circles around the base of all the pins to mark their positions and then remove them. Remove the mirror. With a straightedge, draw the lines of sight indicated by the pin marks, extending the lines to and behind the line marking the mirror's position on the paper. Draw these lines until they intersect "behind" the mirror line. From the points where the lines of sight meet the mirror line, draw lines to the pinhole where the first pin was set. From the points where the lines of sight meet the mirror line, draw lines that are perpendicular to the mirror line. Label these lines A. Label the lines of sight to the mirror line B. Label the lines from the mirror line to the first pinhole C. Measure the angles between the lines A and B and A and C. The angles formed by lines A and B are called the angles of incidence. Those formed by lines A and C are called angles of reflection. In each set of angles, these two should be equal.

As waves of any kind strike a reflecting surface at some angle

of incidence to the perpendicular drawn to that surface, they reflect at an equal angle called the angle of reflection. To test the idea further you need only choose another line of sight making some other angle with the mirror surface and repeat the drawing as set forth above.

The first two sight lines chosen were extended behind the mirror until they met. It is interesting to notice that the distance the first pin was in front of the mirror is the same as the distance the image (where the sight lines cross behind the mirror) appeared to be behind the mirror.

As you approach a plane mirror, your image appears to approach from behind the mirror and seems to be as far behind the mirror as you are in front of it.

The illusion of images sometimes proves baffling. But a look at your drawing can help explain the illusion. The first pin set into the paper, which we can call the object pin, reflects light in all directions making it visible to the eye. Some of the light reflected by this pin strikes the mirror and is there reflected to your eye. But your eye has no way of knowing that what it is receiving is light reflected from a mirror surface. It "sees" in a straight line and therefore gives you the impression of the image, apparently "behind" the mirror. The image behind the mirror is formed by many reflected light waves coming from the object pin itself.

Refraction

One of the aspects of light that received attention many years ago from scientists was the phenomenon of refraction. It was not, however, until 1621 that Willebrord Snell developed the exact relationship between the angle of incidence of an approaching light wave and the angle of refraction produced at

the boundary surface of another medium through which the light waves were to pass.

All of us have witnessed refraction of light. It is the apparent bending of an object which is half in and half out of water. A pencil placed in a glass of water with the end protruding above the surface will appear, when viewed from the side, to be broken at the surface of the water.

Since we see objects by light they reflect to our eyes, we can start considering light rays from visible objects as they are reflected toward us. If we do this and concern ourselves only with rays reflected from visible objects to our eyes, what follows can easily be understood. Place a penny in the bottom of an empty cup. Then position your line of sight at such an angle that you just cannot see the penny over the rim of the cup. Next, pour or have someone else pour, water slowly into the cup while you keep your eyes fixed on the cup rim. As the cup fills with water, the penny appears to rise above the cup rim and becomes visible to you. Now the light reflected from the penny was refracted by the water and as the rays passed out at the water surface, they were refracted or bent toward you, thus making the penny visible. Refraction of light like this makes the sun visible to an observer before the sun actually has come above the horizon at sunrise. Light from the sun is refracted through the earth's atmosphere and is bent so that you "see" the sun before it has risen—and also, of course, see it a short time after it has set.

To measure the relationship between the angle of incidence and angle of refraction will require a rectangular piece of glass that has smooth edges. Preferably the glass should be a piece of quarter-inch polished plate glass about two or more inches square. Some pocket mirrors have polished edges and can be used. In addition to the glass you need several common pins, a soft piece of wood to stick the pins into, a sheet of white paper,

straightedge and a protractor or other device for measuring angles.

Place the piece of glass flat on the white sheet near one end. With a pencil, outline the glass to fix its position on the paper. Place a pin upright in the paper near one corner of the far side of the glass. Stoop down and look right across the table top through the glass so you can see the pin on the far side. Place another pin against the near edge of the glass. Take a third pin and carefully place it upright in the paper so that all three pins appear to be in a straight line. Mark the pin locations and remove the glass. It is immediately evident that while the pins appeared to be in a straight line, they actually were not. We'll call the first pin A, the second B and the third C. Draw a line between the locations of pin A and B. Draw another line between B and C. Where the line from A to B meets B on the line drawn around the glass, draw another line perpendicular to the edge of the glass extending an inch or two on either side of it. Measure the angle between line AB and the perpendicular. Measure the angle between line BC and the perpendicular.

Replace the glass plate on the paper in exactly the same place. Replace pin A in its original location. Now place pin B in some other location along the near edge of the glass and sight again through it. Put pin C at a point where the three pins appear to line up. Mark all the pin locations again and draw the lines as indicated in your first run of the experiment. Measure the second set of incident and refractive angles.

You now have two sets of angles. If you choose, you may repeat the experiment to obtain several sets, keeping pin A at its original location but placing pin B at different positions along the near edge of the glass before sighting with pin C to line up the three pins.

A comparison of each set of angles does not show any ap-

parent relationship among them. It was at this point that researchers from Claudius Ptolemy onward to Snell were stymied. Snell developed the relationship which makes use of simple trigonometry. If you can get a book containing a table of the sines of angles, you can work out the true relationship that Snell discovered. With each set of angles, divide the sine of the angle of incidence by the sine of the angle of refraction. If you have performed the experiment carefully, you will discover that the ratios of the sines of the angles is the same for each set of angles.

A glance at your paper with the lines marked on it shows several other things of importance. Of course the lines show the refraction that takes place when light rays emerge from glass into the air before reaching your eye. Pin A was visible to you by reflected light. The particular light rays you were interested in came through the glass and emerged into air and then reached your eyes. The angle of incidence was inside the glass. The angle of refraction was in the air between you and the glass. Notice that the line BC bends away from the perpendicular you have drawn. So the angle of refraction in each set of angles is larger than the corresponding incident angle. But if the light rays you measured were proceeding from the air into the glass, the reverse would be true. That is, the angle of incidence would be larger than the angle of refraction. Notice in the trigonometric table that the sines of large angles are greater than the sines of small angles. The ratios of sines of angles you have gotten in your experiment are all less than one. If we had measured light going from air into glass, the ratios of the sines would all be greater than one. This ratio would then be what we call the index of refraction for the particular kind of glass you have used. All you have to do to obtain it is turn the ratio of sines upside down, or take the reciprocal of your developed

ratios. Snell's Law of relationship stated in language is just this simple: "The index of refraction of any transparent medium is the ratio of the sine of the angle of incidence to that of the angle of refraction." So that everyone will know which direction the light is going, i.e., into or out of the "transparent medium," it is customary to consider the incident and refractive angles when light travels from air into the transparent medium.

Interference and Diffraction

The apparatus and light source necessary to show diffraction of light waves is beyond the scope of these simple experiments. Light waves have such short wave lengths that great precision is needed to give visible evidence of interference and diffraction. Yet there is one simple way to witness it. If you turn on a lamp in a room and stand across the room from it, you can produce evidence of interference of light waves. With two fingers, form a very narrow slit through which light can just barely pass. Now squint at the light across the room. A series of dark lines can be seen running the length of the slit you have formed. Most people would think that these lines are due to some defect of vision. What you actually are seeing is a wider band of light than the width of the slit interspersed by lines of destructive interference. The dark lines are lines where the crests and troughs of the light waves meet and destroy the waves. The result, of course, is darkness.

Color

White light, like that from the sun, contains all the visible wave lengths of light. When the eye sees particular wave lengths, it interprets them as what we call color. The fact that white light

is the combination of all visible wave lengths of light was proved beyond doubt by Isaac Newton in one of his first experiments. He used a triangular-shaped glass prism, the sun as a light source, and experimented in a darkened room, admitting only a little sunlight through a narrow opening in the window blind. If you can get two identical prisms, you can repeat one of Newton's most powerful bits of experimental evidence that white light is composed of all colors. He admitted light through the prism. It was refracted according to the laws of refraction. But different wave lengths of light are refracted differently through such a glass and the result is that the red rays emerging are not at the same angle as the blue. If this emerging light is allowed to fall on a white screen, the entire spectrum of colors will be displayed. Such spectra have been produced for many years and the resulting colors studied, but until Newton set to work on the problem, the true source of the colors was not adequately proven. Many people believed the material through which the light passed was the producer of color. Newton studied the spectrum he produced and then, by placing a second prism in correct relation to the first, he found that white light entered the first prism, emerged as a colored spectrum, entered the second and emerged as white light again! He supported his conclusions with many other exhaustive experiments but there was little doubt after he finished that all colors were contained in white light.

Take a prism and into an otherwise darkened room, admit some sunlight through a narrow slit cut in a piece of cardboard. When you produce the spectrum it will show up well on a wall or the ceiling. If you have a large sheet of white paper, use it as a screen on which to catch the spectrum. To enlarge the spectrum for easier viewing, tip the paper at an angle to the

beam of light, spreading the colors out over the sheet. The extremes of the spectrum are red and a blue-violet. Red has a longer wave length than blue-violet.

Take the second prism and arrange it in relation to the first one so that the beam of sunlight coming through a narrow opening passes through both prisms. If you can locate the light beyond the second prism and catch it on a screen, you will see it is white. The second prism must be of the same kind of glass as the first for this experiment to be successful. To help arrange the prisms, you will want some firm clamp on a stand to hold the first one while you manipulate the second one and try to find the correct relationship between the two.

Colored objects appear to have particular colors because they absorb certain wave lengths of light and reflect certain others. A blue object absorbs most wave lengths other than blue and reflects blue. A red object reflects red wave lengths while absorbing others. The ability to absorb specific wave lengths and reflect others is due to the molecular structure of the dye, paint or other color material.

There are a number of simple experiments that illustrate color phenomena. To try them you will need a source of white light such as a flashlight (the filaments of light bulbs produce a fairly white light containing most of the wave lengths that make up the spectrum), several thicknesses of different colored cellophane or colored glass, and colored objects such as book covers or pieces of colored cloth.

When white light tries to pass through a colored transparent material such as red cellophane, most of the wave lengths of the spectrum either are absorbed or reflected by the material and only the red wave lengths are transmitted. Thus a white light shining behind such cellophane appears red to the eye. You will

notice also that the intensity of the light passing through the cellophane is much less than the intensity of the light source itself. This is because of the absorption or reflection mentioned above. Place a blue object in the path of a beam of red light and note that it appears black to the eye. The reason for this is that a blue object reflects blue wave lengths, which is why it appears blue to the eye. Since the red light falling on the blue object has no blue wave lengths in it, the blue surface cannot reflect any. It absorbs the red wave lengths and essentially reflects none of the incident waves.

Place a red object on a white sheet of paper and look at it through several thicknesses of red cellophane. Note that the object seems to disappear or blend into the sheet of paper. The white paper reflects all wave lengths, the red object only red wave lengths. But the red cellophane transmits only red so that the other wave lengths reflected from the paper do not come through, and both paper and object appear red, thus blending into each other.

Remembering the colors of the spectrum and the fact that colored objects reflect the color you see and absorb all others, view different colored objects through variously colored pieces of cellophane. Note the effects produced and try to account for them on the basis of absorption, reflection and transmission of various wave lengths.

Polarized Light

Polarization of light is one of the proofs that light waves are transverse. The most common use of light polarization with which you are familiar is in sunglasses. Take two pairs of such glasses and hold the lens of one against the lens of another. Slowly rotate one of the lenses while looking through them at

some light source. Notice that as you turn one lens with respect to the other there is a gradual lessening of the light being transmitted. At some point there will be minimal transmission of light. This will be the position of the lenses when their polarizing lines are at right angles. Continue turning one lens until the light being transmitted is maximum. This is the position where the polarizing lines are parallel. Note, too, that the intensity of light transmitted through a single lens is considerably less than that of the uninterrupted light source. It is the function of sunglasses to reduce glare, and polarized lenses cut down the intensity of light reaching the eye on bright days.

Electric and Magnetic Fields

While Michael Faraday first proposed the concept of magnetic and electric fields, early researchers long before him knew of the effects of both magnetism and electricity. Lodestones, as natural magnets were called, possessed the power of attracting bits of iron at a distance. A piece of amber rubbed on cats' fur would attract small bits of straw. These mysterious qualities of certain materials were attributed to supernatural powers, for in the ancient world a force acting at a distance was incomprehensible. And while these forces were noted and studied to some extent, they remained unexplained and unusable for many years.

A scientist today can predict, measure and utilize the effects of these forces which act at a distance, but philosophically he may be no nearer a total explanation of them than the Egyptians or Greeks who thought of them as supernatural manifestations. That a scientist can utilize these strange natural forces is due to the work of many men. Hans Christian Oersted, a Danish scientist, discovered in 1820 that a relationship existed between

electricity and magnetism. His researches and those of others following him produced the special study in physics we call electromagnetism. For electricity and magnetism are so closely related that many phenomena depend equally on both magnetism and electricity. Oersted's experiment that first showed this interdependence is very simple to perform. To do it you will need a dry cell, several feet of insulated wire and a small pocket compass.

Place the compass on a table and allow the needle to come to rest. Connect one end of a long piece of insulated wire to the dry cell and arrange the wire so that it passes over the compass needle in the direction in which the needle points when at rest. Touch the other end of the wire to the cell terminal and notice the compass needle. If the connection can be maintained until the needle comes to rest, you will see it pointing at right angles to the wire. This shows the right-angle relationship between electric and magnetic fields in the concept of electromagnetic waves.

An electric current is composed of electrons moving in the wire. When these electrons move, their movement creates a magnetic field around the path they travel. The compass needle, itself a magnet, is affected by the magnetic field produced by the current and it turns to align itself with the "lines of force" of the electrically produced magnetic field.

The magnetic field around the wire is circular in shape. This can be shown with the pocket compass. In normal operation a compass needle takes a position parallel to the earth's magnetic lines of force. Since these come from the north magnetic pole, the needle points toward that pole. If a compass is placed in another magnetic field, the needle will try to align itself parallel to the field's lines of force. Knowing this, we can use

such a compass to examine or explore the shapes of different magnetic fields. To examine the field around the long straight wire, arrange the wire so that a considerable length of it is vertical and is not near other portions of the wire. Connect the wire to the dry cell (prolonged contact will heat the wire since you are short-circuiting the cell) and move the compass slowly around the straight portion of the wire. Notice that the compass needle goes around as you move the compass. It "follows" the lines of force, always trying to take a position parallel to them. Such motion of the needle shows that the field is circular about the wire.

To test the strength of the magnetic field, place the compass at farther and farther distances from the wire and notice the diminishing effect of the electrically created magnetic field on the needle.

The simplified picture of the atom as a small nucleus carrying most of the mass of the atom and containing a positive charge surrounded by electrons which carry negative charges can help explain electric phenomena. Electrons are rather easily removed from certain substances and this is what happens when amber is rubbed on cats' fur, or a glass rod is rubbed with silk. Lacking amber, which the ancient Greeks used, we can use hard rubber such as that found in pipe stems and pocket combs to rub on fur or wool (the sleeve of a wool jacket will do in place of cats' fur). Experiments with static or stationary electricity can be carried out most successfully on cold, dry days.

To test charges and be able to see the effect of electricity acting at a distance, you need a small, light object that can take a charge. Take two small pieces of tissue paper and crumple them into small spheres not more than a quarter of an inch in diameter. Fasten about six inches of light thread to each

sphere and suspend the spheres by the threads from a stick so that they hang about an inch apart.

Rub the comb or pipe stem vigorously on your wool jacket sleeve and touch the spheres with it. Both will acquire a charge and will move apart from each other. The idea of electricity exerting force at a distance is evident, as is another important fact: Like charges repel one another.

The charge that the spheres have acquired is negative. Electrons were rubbed from the wool to the comb and these in turn were placed on the spheres. Remember that only electrons can be removed from atoms by rubbing objects. This being the case, the wool had electrons taken from it and should have a positive charge. Bring the wool sleeve near the charged spheres shortly after you have rubbed it and the spheres will be attracted to the sleeve. The negative charges on the spheres are attracted to unlike or positive charges on the sleeve.

Touch the spheres with your fingers and the charge on them will disappear. Your body acts as a ground for electric charge in this case and the excess electrons on the spheres go from the spheres to you, leaving the spheres neutral.

Again place a charge on the spheres in the same way. Now charge the comb again and bring it near the spheres. They will be repelled by the comb. To discover the strength of the electric field you have surrounding the comb, see how far away from a charged sphere you can place the comb and still detect some motion of the sphere. The sphere of influence of the comb can be determined by this. Faraday visualized the sphere of influence as a field or region and the degree of strength depended on the number of "force lines" passing through any cross section area. Since the lines spread out, the farther you are from the source of the field, the fewer lines there are in any tested area

and eventually you are so far from the field that you cannot detect any influence at all. Then for all practical purposes, the field does not exist beyond the point of minimum detection.

Radio Waves

Heinrich Hertz was the first scientist to detect electromagnetic radiations some distance from the source of them, and with his work proved that Maxwell's wave equations held true. Hertz's problem was not so much to produce the waves, for spark coils were in use at the time for various experimental work. His great contribution was the production of a detector or resonator, as he called it. Today every home radio set is such a detector and a variable one at that, one that can be tuned to receive radio waves of various wave lengths.

When radio waves were first detected, they were named Hertzian waves in honor of their discoverer. We can detect Hertzian waves of our own production using a regular radio receiver.

In addition to the radio receiver, you will need a common dry cell battery and a wire.

Turn on the radio and tune it so that no station is being received. Turn the volume up full. Connect one end of the wire to one terminal of the dry cell and place the cell within two feet of the receiver. Scrape the other end of the wire against the other cell terminal. The "static" produced on the radio is the electromagnetic wave sent out from the spark between the wire and cell terminal. This is a radio wave.

Move the cell and wire gradually farther away from the radio and notice that each time the wire is scraped against the cell terminal the sound produced is fainter. The distance at which you can detect the least signal will depend on the strength of the

dry cell you are using and the sensitivity of the radio receiver you are using.

If you have two dry cells and another small length of wire, connect the two cells with a small length of wire, fastening one end to a positive terminal and the other to a negative terminal (the terminals are marked plus and minus on the sides of the cells). Now fasten one end of the long wire to one of the two remaining terminals. Placing the battery where you first put the single cell, scrape the wire against the other open terminal as you did at first.

Compare the strength of the signal received with one- and two-cell arrangements. Move the two-cell battery farther away and determine if its signal can be received from a more distant point than the one-cell signal. What conclusion could you draw about the distance over which a signal could be sent and the strength of the signal?

Do fluorescent lights ever affect the operation of a radio when being switched on? Do other electrical appliances cause such "static"?

The radio signal you have been creating has a frequency far above the range of the human ear. The radio receiver, designed to interpret such signals, converts the electromagnetic radiation to an audible signal. The sparks created at the battery terminal when you scrape the wire are visible wave lengths of light from excited gas molecules in the air which lay in the path of the electrical discharge between wire and terminal.

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