"Planet Earth"

THE
MYSTERY
WITH
100,000
CLUES

THIS booklet is a very brief introduction to the sciences of the earth and its environment. In a short space, it tries to tell you something of man's ancient curiosity about the physical universe in which he lives, something of what we know about that universe today, and a little about the instruments and experiments that scientists are using to study it.

The text is in the form of a commentary on six posters which treat some of the important study areas in geophysics today. Each poster is reproduced in the booklet and is related to the discussion in the text by a number code. Because the reproductions are greatly reduced in size, you should go to the full-scale posters for detailed reference.

In designing the posters, the artist took some liberties with certain of the proportions and relationships. Sometimes this was necessary because of scale limitations; sometimes it was desirable for effect. You may want to see how many of these liberties you can find and list.

Remember that this booklet gives you only a very short glimpse into the fascinating puzzles of geophysics. The topics which interest you most can be followed up in many absorbing accounts elsewhere. This earth upon which we travel through space — the object of affectionate study through the ages by poets and artists as well as by scientists — becomes far more intriguing as we uncover its puzzles and try to solve them.

CONTENTS

Earth

"OUT of sight, out of mind." In other words, what we *see* is what captures our attention. Thus, much of man's scientific interest has followed his eyes into space – to the moon, the sun, the planets, and the stars. The earth is right under his feet, but his eyes cannot see beneath its surface. Perhaps this is why relatively little attention was given, until recently, to investigating the earth's structure and interior.

Of course, sometimes we are fortunate enough to find a part of the earth's crust exposed, as in the Grand Canyon **(1)**,* and we can study its many layers rather easily. Or we may find exposed rock formations showing the pressures and folding actions that take place in the crust **(2)**. Or, in live volcanoes **(3)**, we may witness the surface evidence of forces deep in the earth's interior.

It would be wonderful indeed if man could lift out a slice of the earth – as we lift out a section of an orange – and examine it in cross section from the crust right through to the core. While man can't do this literally, he has in recent years devised instruments and techniques that permit him to take the earth's measure, check its shape, peer into its interior (figuratively speaking), and analyze its structure.

Where does our modern knowledge of the earth begin?

It is often said that people thought the world was flat until Columbus proved otherwise. Actually, 2,000 years earlier a Greek philosopher, Pythagoras, decided that the world was a sphere. And another Greek, Eratosthenes, computed the diameter of the earth with considerable accuracy. He did this by observing the difference in height of the same star as seen from different locations along the Nile.

USING GRAVITY TO MAP EARTH'S SHAPE AND MASS

The earth is by no means a perfect sphere. In the accompanying illustration, its outline is purposely left indefinite, for we do not know the exact shape of our planet. As early as 1673, man developed the theory that as the earth spins, centrifugal force causes the equator to bulge and the poles to flatten.

*Refer to poster on Page 4.

"Earth! My likeness! Though you look impassive, ample and spheric there
I now suspect that is not all" WHITMAN

Today we can prove this theory. How? By measuring the pull of gravity at the equator and again at the poles. Because the flattened poles are about 13 miles closer to the center of the earth, the pull of gravity is stronger there. In fact, a 200-pound man would weigh about 201 pounds at the poles.

How do we measure gravity? One way is by measuring the time it takes for a pendulum to swing through its arc. Where gravity is greater, the pendulum swings a little faster. But a great number of swings is necessary to compute accurately the minute differences in time that tell the story of gravity differences.

So scientists use a second instrument, the gravimeter **(4)**. This is essentially a very sensitive spring scale. Some gravimeters are so sensitive that they record the change in gravity pull which occurs when they are raised or lowered only one-eighth of an inch.

You can see that if you took gravimeter readings all over the earth you could construct a map showing how near or far you were at each point from the center of the earth. This would give you a picture of the shape of the earth, with all its bulges, hollows, peaks, valleys, and other irregularities.

Actually, however, the matter is not so simple. Gravimeters measure the difference in pull related to your distance from the center of the earth. But gravity varies also with the mass of a body. This means that if you place a gravimeter over lightweight areas in the earth's crust, it will give a lower reading than if placed over very dense areas. So gravimeters are useful both in plotting the earth's shape and charting the distribution of its mass.

Applying this principle, oil companies prospect for oil with gravimeters. Ore deposits may be located in the same way.

Another technique used to give us clues to the earth's shape and the distribution of its mass is based on observations of earth satellites **(5)**.

As the satellites circle the earth, variations in the amount of pull exerted by the earth's gravity at different points on the globe cause irregularities in their elliptical orbits. Since these gravity variations occur with changes in latitude, elevation, and the earth's mass, we may be able to obtain from the satellite orbits a more precise picture of the earth's "figure."

EARTHQUAKES—CLUES TO EARTH'S STRUCTURE

We have said that gravity values vary with the earth's mass, that they are higher where the underlying rock is denser. But how do we penetrate the earth's interior to learn more about its composition and structure?

The answer is found in seismology, the study of earthquakes. Men began the scientific study of earthquakes about 200 years ago. Their interest was stimulated by the great earthquake of 1755 in Lisbon, Portugal, where 60,000 people were killed. From this interest the seismograph was developed. It is


Folds in earth's crust


Live volcano


Gravimeter

an instrument for measuring various kinds of tremors, or waves, in the earth.

The heart of the seismograph is a pendulum **(6).** It uses the principle of inertia to measure seismic waves. When earth tremors jar the instrument's frame, the pendulum bob tends to remain still. The resulting apparent motion between bob and frame is recorded by a pen or light beam. The way the waves travel from the earthquake focus **(7)** to the instrument tells us much about the earth through which they move.

By careful study of seismic wave records, seismologists have decided that the earth's structure consists of three principal layers. At the center, perhaps about 4,400 miles in diameter, is a very dense core **(8).**

The core was discovered when it was noticed that seismic waves passing through the earth left a kind of shadow zone in the opposite hemisphere. Few if any waves were recorded in this zone. Scientists decided there must be a dense core blocking or deflecting the waves. This core must be under such great pressure and heat that it cannot be solid. Yet if it is liquid, it is certainly denser than any liquid we can imagine.

It is estimated that the temperature rises as we penetrate the earth until at the center it is from 2,000 to 6,500 degrees Centigrade, and the pressure there is nearly 4 million times greater than that of the earth's atmosphere.

Similar studies of the direction and time taken by seismic waves in passing from their source to other points on earth showed that around the core was a mantle **(9 and 10),** generally of very solid materials, rising to within 20 or 30 miles of the surface. The thin surface layer is called the crust **(11).**

Notice in the diagram **(12)** the different types of waves and how they are refracted, or bent, by the different materials of the earth's crust, mantle, and core. The solid lines represent primary waves; the dotted lines are secondary waves. From the way certain primary waves come to the surface of the earth, Miss I. Lehmann of Denmark concluded in 1936 that the earth's core is not uniform but consists of two parts. The inner core causes the waves to bend sharply upward.

If earthquake waves tell us so much, scientists reasoned, why wait for earthquakes? Whenever and wherever we want to probe the earth's crust, we will set off our own explosions and analyze the resulting waves. The inset **(13)** shows a seismologist taking a sounding of a man-made explosion in the Antarctic. By timing its echo from the rock below, he can determine the thickness of the icecap and the nature of the underlying topography. In this way, ice near IGY Byrd Station was found to be 14,000 feet thick – the thickest ice layer ever measured.

THE THEORY OF BALANCE IN THE EARTH'S CRUST

From gravity and seismic studies, scientists have developed a theory that the lighter and denser materials in the earth's crust are always seeking a kind of equilibrium with each other. This theory is called "isostasy," or isostatic equilibrium **(14)**.

According to this theory, the great bulk of a mountain tends to "float" in the crustal material that surrounds it – much as an iceberg floats in the sea. This fits in with the fact that mountains generally consist of materials lighter than those surrounding them. But if the theory is correct, there ought to be great roots of light material beneath the mountains, like the nine-tenths of an iceberg that floats under the sea.

To test the theory, seismologists have exploded charges on one side of the Andes and attempted to record the tremors on the other side. Their results seem to indicate that there are great roots of light materials under the Andes, filling thousands of vertical fissures in the heavier rock below, rather than a simple downward bulge of the lighter material. If these indications are borne out, the results would still be consistent with the theory of isostasy.

An interesting aspect of the same theory is that the earth's crust under the dense, depressed ocean bottom should be thinner than under the land areas. Explosion seismology at sea has revealed the thinnest crust ever found – less than three miles thick – near Easter Island in the Pacific.

Of course, various sections of the earth's crust may not have achieved equi-

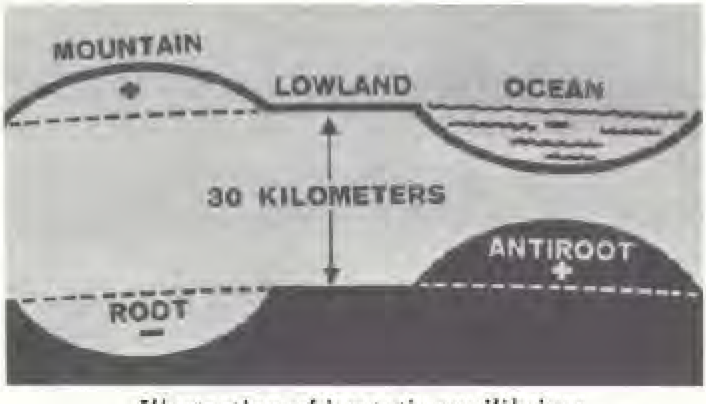


Illustration of isostatic equilibrium


Extensometer

librium. This would contribute to strains which could result in disturbances, slippages, and shocks. To measure the accumulation of strain, a special instrument called the extensometer has been developed. An extensometer has been installed in a tunnel dug into the rock beneath a mountain in the Andes **(15)**. It includes a long rod, securely anchored in the rock at one end, and a recorder, which is at the other end. As minute shifts or strains occur in the rock, the recorder measures them. Perhaps someday scientists will be able to relate the accumulation of such strains to the occurrence of earthquakes. If so, we might eventually be able to predict earthquakes.

Extensometers can measure another amazing feature of our earth. This strange feature was demonstrated first by very sensitive gravimeters. The "solid" earth has daily tides, something like those in the oceans but much less noticeable. Still, the island of Hawaii, for example, rises and falls several inches a day! In some areas, the earth tide may be much greater. (This is another reason why the outline of the earth in the accompanying illustration was made indefinite; it actually changes, although minutely, all the time!)

MAPPING THE EARTH'S SURFACE

In trying to expand our knowledge of the earth and to make our information more exact, we are seeking also to measure distances on the earth more accurately. Our present-day maps are reasonably accurate but not entirely so. During World War II, certain Pacific islands were found to be as much as a mile from their presumed locations, and even today we do not know exactly how far apart the continents are.

In fact, one group of scientists believes that the distance between the continents is changing, that they are drifting over the earth's surface. To resolve this question, we must locate the continents very carefully now, and at some future date locate them again to see what change, if any, has occurred.

One reason for the difficulty in figuring the precise location of any spot on earth is that the earth is *not* a perfect sphere. To find our position, we measure the angles of the sun, moon, or stars in relation to the vertical. But in most places the vertical isn't true because the earth isn't a perfect sphere. This means that a vertical line (the direction in which a weight on a string hangs) doesn't pass through the center of the earth unless we are standing at the poles or the equator. Also, the earth's irregular mass causes a weighted string to be deflected from the vertical. (If you suspend a weight from a string near a mountain, gravitational effects of the mountain will deflect the string away from the true vertical.)

However, with a very precise observing instrument known as the Danjon Impersonal Astrolabe **(16)**, we now can use the stars to determine the positions of two places on earth *relative* to each other with an accuracy of five or ten feet. Invented by A. Danjon of the Paris Observatory, it is called "impersonal" because it uses an automatic recording mechanism to minimize human error by the operator. By taking relative measurements with this instrument now, and repeating them in 50 or 100 years, scientists will be able to determine whether, as some suspect, the continents are drifting.

For finding the *absolute* location of a given place, a new device known as the dual-rate moon position camera **(17)** has been developed by Dr. William Markowitz of the U. S. Naval Observatory, Washington, D. C. The moon camera uses a geometric method. The measured distance between Washington, D. C., and San Diego, California, is considered the base of a triangle. The moon is photographed from both cities. The angles to the moon from each city permit calculation of the sides of the triangle. It then becomes possible to calculate the distance from the center of the earth to the moon.

Then, each time moon photographs are made at the 20 stations where such cameras have been set up, this distance from the center of the earth to the moon is used as one side of a triangle. The moon photographs give us the angles by which we can construct the side from the moon to the point where the photographs are taken. Then we can compute the distance from this point to the center of the earth by treating it as the third side of a triangle. This instrument will help establish the distances from the center of the earth to each of the 20 scattered moon-camera stations. As a result, we can figure more exactly the size and shape of the earth.

Danjon Astrolabe

Moon camera

Moon, star measurement

The moon position camera also will improve our knowledge of the orbit of the moon. It photographs the moon and the stars on the same plate even though they move at different rates. This is done by means of a lens within a lens. The inner lens is driven at the rate of the moon, while the outer is driven at the rate of the stars. This holds the moon's image in a fixed position relative to the stars. Then the distances between the moon and the stars can be measured on the plate **(18)** with great accuracy.

Knowledge of the moon's orbit will improve as lunar probes move from the realm of science fiction into the domain of science at work. At the same time, the farther we venture into outer space, the more exact information we will need about our jumping-off point – Mother Earth.■

O C E A N S

"Icing the pole or in the torrid clime,
Dark — heaving — boundless — endless and sublime" BYRON

The Oceans

WHEN we look at a map of the globe, we can see that the oceans are the chief feature of the earth's surface. In fact, they cover about three-quarters of our planet. But so far as we know, the usual depth of the sea is only two or three miles, and its greatest depth is no more than seven miles. Compare this with the earth's diameter – 8,000 miles – and you can see that our oceans, though extensive, provide the very thinnest of coverings.

Still, this slender coating plays a big part in making it possible for life to exist on earth –

The oceans were the birthplace of life itself.

They supply much of the moisture in our atmosphere.

They are the principal source of life-giving rain.

They help keep our climate on an even keel, for the sea gains and loses the sun's heat more slowly than the land.

The oceans have always been a vast storehouse of food for man, and we have discovered that they may be a source of mineral wealth, too.

Thus, a study of the character of the oceans is very important to an understanding of our physical environment. Are the ocean levels rising or falling? How do the deep bottom waters mix with the surface waters? How long does this circulation take?

Surprising as it may seem, we know relatively little about these and other related problems. But they are the kinds of questions oceanographers are seeking to answer. And more of the sea's mysteries are being revealed as each day passes.

In ancient times, man believed that the sea, like other natural elements, had a superhuman personality. And so he imagined there was a god of the sea. The Greeks called him Poseidon; the Romans, Neptune. Here he is shown as the personification of the oceans. The trident he holds represents the fisherman's spear. Poseidon was known as a capricious god, for the sea itself was changeable, unpredictable. It could be calm and beautiful – or wild and evil.

For many centuries, little was known about the oceans. Seafaring peoples like the Phoenicians, the Polynesians, and the Vikings cruised boldly on the surface of the waters. But they knew almost nothing about the strange world beneath the surface, and fear kept most people close to shore.

Man first learned something of the sea at the water's edge, where he studied the tides. Later, as he sailed over longer distances, he gained some understanding of surface currents. But it wasn't until Benjamin Franklin studied reports on the Gulf Stream by American sea captains that we developed any systematic notion of these currents. Even then, English sea captains refused to accept Franklin's theories. Because they failed to take advantage of the Gulf Stream's currents, their voyages took longer than similar ones made by American mariners.

Man's knowledge of the ocean depths was even slower in coming. For hundreds of years, he merely dropped a line with a lead weight over the side of a ship to gain occasional soundings at comparatively shallow depths. Sometimes he placed a bit of tallow on the bottom of the weight, so that he could bring up a sample of the ocean floor and learn whether it was composed of sand, mud, or gravel. But he developed no systematic method for continuously charting the ocean bottoms to determine whether they were irregular, like the earth's land areas, or vast plains with an occasional mountain rising to become an island.

Today's oceanographic techniques are in sharp contrast with those of only a generation ago. Research vessels of many different types now range all the seas of the world. They carry elaborate equipment, which is used by trained scientists to delve further into the depths of the sea.

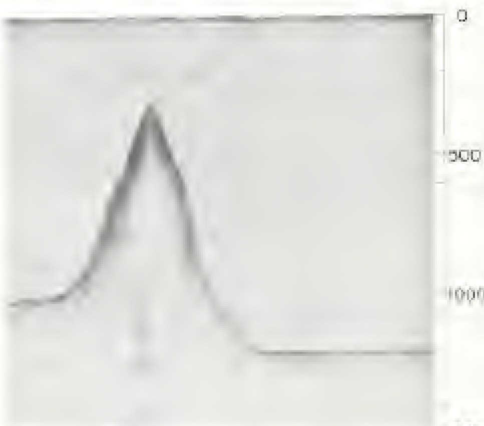
One of the instruments used on research ships is the magnetometer **(1)**.* It measures the earth's magnetic field, which is useful in studying the crustal structure of our planet. This "magnetic fish" is towed far behind the ship in order to eliminate disturbances caused by the engines and other parts that would otherwise distort the reading.

INVESTIGATING THE OCEAN BOTTOM

Electronic instruments similar to the SONAR used by naval vessels in antisubmarine work are also installed in research vessels. They direct impulses of intense sound **(2)** to the ocean bottom. The time it takes these impulses to return from the bottom, which reflects them, is translated to reveal the distance to the bottom. Thus, a continuous profile **(3)** of the bottom of the ocean path traveled by the ship is traced by the instruments. The operator **(4)** can observe interesting or unusual bottom features and note them for further studies of other kinds. In the chart shown here, an underwater mountain, or "sea mount," has been traced. It shows an interesting contrast between a sedimentary plain to the right and an irregular bottom to the left. This difference is caused by the effect of the sea mount on bottom currents.

The ocean bottom is examined more directly by means of deep-coring

Magnetometer

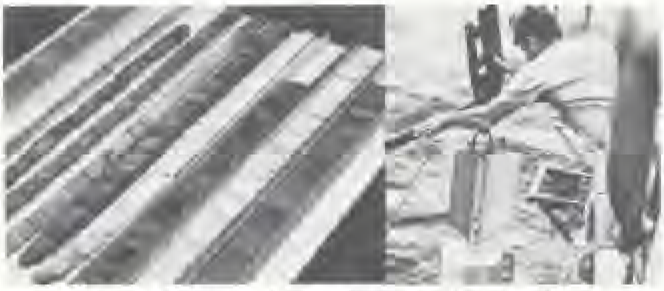


Continuous bottom profile and recording equipment

* Refer to poster on page 10.

devices **(5)**, which are lowered over the side of the ship. Some corers can be driven deep enough into the ocean bed to bring up a core as long as 60 feet. When the core is removed and cut lengthwise **(6)**, it shows successive layers of the ocean bottom as accumulated from debris and sediment over thousands and millions of years. The layers are almost like pages in a history book. Their age can be calculated in different ways, such as the Carbon-14 method (this permits estimates of age based on the known rate of decay of Carbon-14 in all organic matter); their content and character can be analyzed to reveal much of the past climatic conditions, ancient ocean temperatures, types of sea life, and so forth.

Our deepest excursion into the ocean, with the aid of a bathyscaphe, reached only a little more than 13,000 feet. We have never seen the truly great depths like the Tonga Trench and the Mindanao Deep in the Pacific. These are about 36,000 feet deep.



Sample cores from deep-coring device

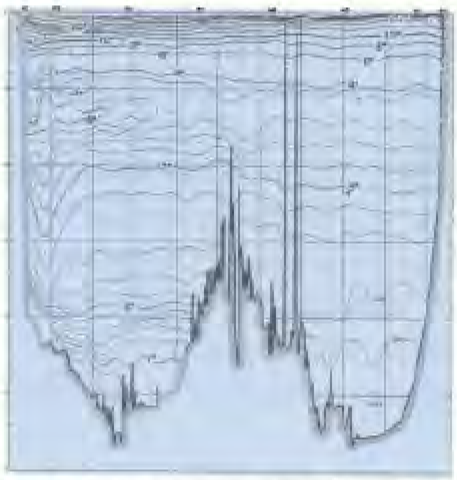
Deep-sea camera scans ocean bottom

But scientists have devised intricate cameras **(7)** to extend their vision to the distant bottoms. Such a camera picks up much more than one might imagine. It illuminates the depths where no light reaches and photographs sea life as it is. The sea animal shown in the underwater photograph **(8)** is never seen in this form on the surface of the water. Constructed to survive the enormous pressures of the great depths, the animal is invariably destroyed by internal pressures when brought to the surface.

The "bottom camera" also reveals patterns in sand and mud that tell us something of the deep currents. During the IGY program, fields of small pebbles were photographed on the sea bottom between the Antarctic continent and South America. Because these pebbles are of the type consumed by penguins to aid their digestion, they may relate to the migratory paths once taken by these birds.

THE CIRCULATION OF THE SEAS

Circulation, of atmosphere or oceans, means an exchange of cold and warm air or water masses. Therefore, measurements of ocean temperature at various depths and at many ship stations can give us a clue to ocean circulation. One instrument used for this purpose is the Nansen bottle **(9)**. Strings of these bottles,with thermometers attached to them, trap water at different depths and



Nansen bottles help plot water temperature layers

Gravity measurement at sea

measure the temperatures, which are then plotted on a chart. (Reversing deep-sea thermometers must be protected from water pressure; an unprotected thermometer is "squeezed" by the pressure and thus the correct reading is changed.) When this is done along a given track traced by the ship, a profile of the temperature layering of waters of different depths can be constructed **(10)**. Many clues to circulation, currents, and turbulence are obtained in this way.

Chemical analysis of the oceans at different depths also tells us much about their circulation. For example, by measuring the amount of Carbon 14, a radioactive form of carbon, in deep water, we can learn the age of the water – the length of time since it has had contact with the surface. Such analyses may reveal something of the circulation patterns of the deep and bottom waters and whether it takes 10 years or 10,000 years for them to complete their cycles.

SEDIMENT AND BOTTOM STRUCTURE

Oceanographers have concluded that the earth's crust under the sea is thinner than it is under the earth's land masses. There are several ways to test this theory and perfect such measurements. One device is the heat-flow probe. An instrument is lowered over the side of the ship and penetrates a short way into the ocean bottom. There it measures the flow of heat from the earth's interior through the crust. By comparing differences in heat flow, oceanographers gain some idea of the relative thickness of the ocean floor.

Instruments to measure gravity reveal differences in the distribution of mass in the earth's crust. This gives us a second way of charting the thickness and nature of sediment on the ocean bottom.

Gravimeters are so sensitive that they record the difference in gravitational pull when they are raised or lowered fractions of an inch. For this reason, they could be used at sea only in submarines submerged in quiet depths **(11)**. This was expensive and slow work, and difficult corrections for distance and position were required.

More recently, the measurement of gravity values at sea has been greatly aided by the invention of the Graf sea gravimeter. The Graf gravimeter is mounted on a stabilized platform. Also, it "dampens" the effects of heaving and tossing on a surface vessel by reflecting changes only over an extended period of time. Therefore, gravity values can be recorded continuously and accurately from the surface.

The seismic technique for examining the bottom gives us information on type, depth, and thickness of sedimentation. Usually, two research vessels work together. One detonates explosive charges in the sea near the surface. The other lays to, often many miles away, with sensitive hydrophones suspended in the water. These pick up the reflections of the sound waves from the bottom layers. Elapsed time is computed and the distance figured. These seismic waves are strong enough to travel through the sedimentary layers to the rock below. This distance is compared with sonic soundings to the mud bottom. The difference gives us a figure for the thickness of the sedimentary layers.

STUDIES OF SEA LIFE

Not all oceanographic research is directed to the physical and chemical characteristics of the oceans and their bottoms. A great deal of attention is given to the fantastic variety of animal and plant life found in the sea. Nets of various designs **(12)** are hauled through the water at different depths to trap sea life characteristic of those depths. Dredges are used to bring up bottom life, and recently a minute animal was brought up alive from a depth of over 16,000 feet.

These investigations have shown that the freezing waters of the Antarctic are by far the richest in sea life, while many of our tropical waters are relatively sparse. There is a good reason for this. In the Antarctic there are vertical currents which bring abundant nutrients from the depths to the surface of the water. Knowledge of the circulation of these rich, cold waters is therefore of great importance for an understanding of our food supply from the sea.

THE LEVEL OF THE SEA

Simple gauges at island and coastal observatories in many areas are used for modern investigations of the tides. These are designed to help us learn not only how the tides vary within the day but how the sea level itself is changing over a period of time **(13).** If the polar caps are melting, as many scientists believe they are, the ocean level may be expected to rise about one foot for every 20 feet of shrinkage in the icecaps. However, the theory at the core of this idea is controversial; it may be that warmer conditions will actually result only in greater precipitation **(14)** in the polar regions. In any event, such changes are very slow and gradual – so slow, in fact, that scientists find it difficult to distinguish actual from apparent trends. They do know, however, that the currents, temperatures, and circulation of the oceans are among the keys to the puzzle. ■

"Vastness! and Age! and Memories of Eld!
Silence! and Desolation! and dim of Night!" POE

The Poles

THE great American geographer Isaiah Bowman once said that the Arctic is a hollow and the Antarctic is a hump. And it is true that the Arctic and Antarctic are more easily understood on the basis of their contrasts than their similarities. The Arctic is a large ocean basin surrounded by land masses; the Antarctic is a land mass surrounded by water.

Of course, both polar areas are cold. But even that is deceiving, for Antarctica is much colder than the Arctic. The Arctic waters store enough heat to keep the area some 20 to 30 degrees Fahrenheit warmer than the Antarctic. And the Arctic has only one-tenth the amount of ice.

To the Greeks, the Arctic meant the land under the Big Dipper, which they called the Bear. A Greek mariner, Pytheas **(1)***, may have been the first man to sail beyond the Arctic Circle. The land of constant cold was the home of Boreas, the god of the north wind. In the accompanying poster, Boreas holds the Antarctic in his icy hands, blowing his coldest winds on it.

Ancient geographers felt there must be a land mass at the "bottom" of the earth in order to "balance" it. In the early 16th century, all the land to the south of the known world was thought to be part of this presumed continent. The voyages of Vasco da Gama and Ferdinand Magellan seemed to show that there was only open sea south of Africa and South America. James Cook **(2)**, the first man to sail beyond the Antarctic Circle, in the 1770's, concluded that any land farther south would be too cold for man.

It is difficult to say exactly who discovered the Antarctic, though it may have been known to sealers by the 1820's. The sealers, however, kept their hunting grounds secret. It is clear that American and British explorers sighted the Antarctic within a short time of each other in 1820 and 1821. While there is some disagreement, an American naval officer, Charles Wilkes, is generally accepted as the man who proved the existence of the continent in 1838-40.

Explorers pushed into the Arctic much earlier, mainly in their search for a northwest passage from Europe to the Orient during the 16th and 17th centuries. But the climate appears to have been more severe then, and the small wooden ships, with only sails for power, could not push through the pack ice. Those who penetrated farthest north found only the endless ice field, 10 to 20 feet thick, floating on a chill sea, grinding ordinary vessels to bits.

At the opposite pole, Antarctica proved to be the coldest of all the continents and,on an average, the highest – its average altitude is more than a mile above sea level. Still caught fast in an ice age, its summer temperatures rarely climb above freezing. Its area is six million square miles – almost twice as large as the United States. Virtually all of this is covered by ice throughout the year. Not one tree grows in this vast expanse, and there is no land mammal. The only living things are birds and seals, which inhabit the very fringes of the sea, where they can obtain food; mosses and lichens; and minute insects.

* Refer to poster on page 16.

SCIENTIFIC INTEREST IN POLAR AREAS

Why is science so interested in these remote, inhospitable areas?

• The earth's magnetic field has its poles in the Arctic and Antarctic. Thus, many of the upper-atmosphere phenomena which are affected by the magnetic field are best studied near the poles. These phenomena include aurora, cosmic rays, disturbances in the magnetic field itself, and chemical and physical properties of the ionosphere (the electrified layers of the atmosphere which affect radio waves). The fact that polar day and night are six months long permits studies to compare the effects of the sun's presence and absence on our upper atmosphere.

• The greatest climate changes in recent earth history occurred with the ice ages. The last ice sheet which came down over the northern part of the United States withdrew perhaps 10,000 years ago. If we want to learn something of such changes, we can study "living" ice sheets in Antarctica and Greenland.

• Our present climate may be significantly affected by the energy and moisture exchanges that occur among the oceans, the world's ice, and the atmosphere. We can study these relationships in the Arctic ice pack or on the Antarctic ice shelves which come down from the land and float out over the sea. The Antarctic holds almost 90 per cent of the world's ice, and may act like an open refrigerator to chill our air and ocean currents.

• To perfect our knowledge of gravity values all over the world and to complete investigations of the earth's crustal structure, we must extend measurements into the great Arctic and Antarctic areas. We may learn much by examining the effects of the great weight of the icecap on the land.

Crevass detectors

Taking seismic measurements

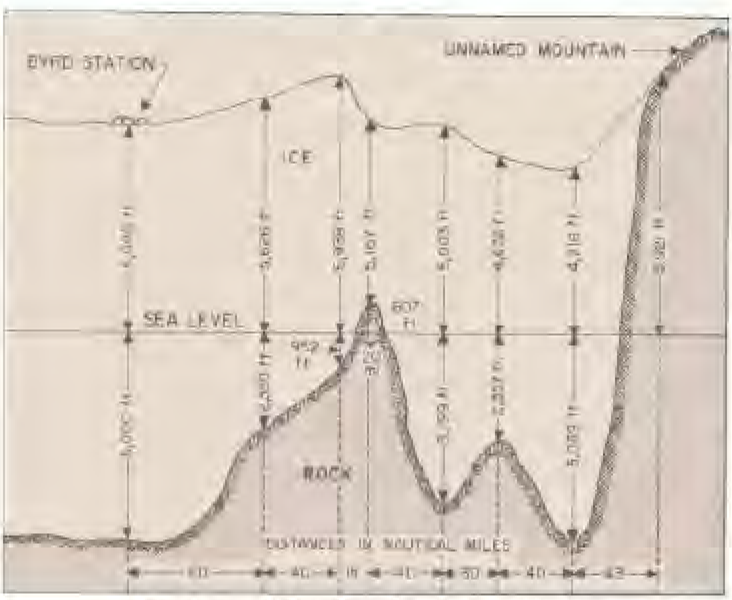
THE ANTARCTIC ICECAP

The first sight to confront a visitor to Antarctica is the long, endless line of ice cliffs that come right down to the sea in most places. How thick is the ice? What is the contour of the land under it? What can we learn from the ice itself?

To study the thickness and other qualities of the great Antarctic icecap, scientists of many nations undertook 16 over-snow traverses during the International Geophysical Year. These treks covered more than 14,000 miles of previously unexplored areas of Antarctica. The most spectacular was the Commonwealth Transantarctic Expedition, which traveled across the frozen continent from one side to the other **(3)**.

United States traverse parties used special tractors, each towing a heavy supply sled. Pan-shaped crevasse detectors **(4)** extended in front of the tractors to warn of areas where light snow bridges covered crevasses – deep cracks in the ice. Some of these cracks could swallow up tractors and all. The traverse parties stopped several times a day to take field seismic measurements **(5)**. By setting off charges and timing the sound waves reflected from the underlying rock, scientists could measure ice thickness all along the various routes. Translated into a graph **(6)**, like the one for the first leg of a traverse out of IGY Byrd Station, the ice-thickness measurements gave us the very first profile of Antarctic land contours under the ice.

Early findings show that there is far more ice in the Antarctic than had been supposed, perhaps 40 per cent more. The Byrd Station **(7)** was found



Contour of land under Antarctic ice


Coring ice for samples

to rest on 10,000 feet of ice extending 5,000 feet below sea level. Elsewhere, the ice thickness varied from 2,000 to 14,000 feet (probably the thickest ice ever measured) over a mountainous rock floor. Most of these mountains are buried deep under the ice. The Ellsworth traverse party **(8)** discovered a deep trench 3,500 feet below sea level, extending from the coast in a south-southwesterly direction. These findings may indicate that a part of Antarctica is cut by deep frozen fjords; or the "continent" may actually consist of a chain of islands formed by the peaks of mountains that jut above sea level and occasionally break through the ice. Perhaps some of the land was depressed below sea level by the weight of the ice.

Deep ice coring reveals weather history

Ice section under microscope

ICE STUDIES

To determine the density of the ice at the surface, a ramsonde **(9)** is used. The ramsonde consists of a metal rod and a sliding weight. The weight is permitted to fall a given distance against a projection on the rod. This drives the rod into the snow. The depth to which it sinks into the snow is used as a measurement of surface density.

Deep pits are also dug in the snow. Samples from various depths are removed by corers **(10)** for later examination. To study the ice at greater depths, a drill rig like those used in drilling for oil is used. At Byrd Station in the Antarctic and on the Greenland icecap in the Arctic, ice cores from more than 1,000 feet below the surface were retrieved. (There is much less snow each year in the Antarctic than in the Arctic. This means that the ice at 1,000 feet below the surface at Byrd Station is roughly twice the age of ice at the same level in Greenland.)

Ice cores can normally be dated by counting the small markings that show where summer melt occurred and later froze again. By counting these annual layers, one can determine the age of the ice just as one reads the rings on a tree to determine the age of the tree. But the identification of annual layers can be very difficult unless there are thin ice crusts or other features to aid in distinguishing summer from winter layers. In Greenland annual layers can be counted fairly easily; but in the Antarctic, where the summers are much colder, there is little melting and little evaporation, and therefore much less precipitation. As a result, the layers are thinner and the summer layers are difficult or impossible to identify. However, chemical analysis can help.

Ice cores serve as a kind of history book. They contain natural substances – such as volcanic ash, meteorites, spores, and bacteria – which fell with the snow and are buried under succeeding layers. The opening of this history book is, however, very difficult. Still, ice cores have been recovered from great depths


Photograph of aurora


Arctic study rocket


Measuring Polar sunlight

(11) to reveal weather patterns and wind circulation hundreds of years ago.

Useful insights into ice formation and structure are gained by cutting thin sections from the ice cores and examining them under the microscope. The ice section in the photograph **(12)** was taken from a depth of 150 meters.

THE "HEAT AND WATER BUDGET"

To study heat and moisture exchanges between sea and ice, ice and air, air and water, and to learn more about the "life" of the pack ice, U. S. and Soviet scientists have occupied two ice stations each in the frozen Arctic Ocean. One of these, called Fletcher's Ice Island **(13)**, is really an iceberg about 200 feet thick, 21 square miles in area. Composed of fresh-water ice, it probably broke off the coast of Ellesmere Island hundreds of years ago and has been drifting in the Arctic Ocean ever since. The other three drifting stations **(14)**, **(15)**, **(16)** were set up on floes directly in the pack ice. They consist of salt-water ice about 7 to 12 feet thick. All four stations drift with the currents of the Arctic Ocean, providing valuable information about ocean circulation patterns. Temperatures in the Arctic rarely get below –50 degrees Fahrenheit, and during the summer months the surface of the pack ice starts to melt. The men must dig channels and holes through the ice **(17)** to permit the water to run off. Strangely enough, more new ice forms at the bottom of the floes during the summer than melts off the top!

BOTTOM TOPOGRAPHY

Gravity and seismic measurements made at Drifting Station Alpha **(14)**, located on a seven-foot-thick ice floe with an area of about four square miles, showed the presence of an unknown underwater mountain range that rises 5,000 feet above the ocean floor.

The height and arrangement of undersea mountains have marked effects on the circulation of the waters. This, in turn, decides whether the cold seas mix with warmer waters and to what extent. It appears now that the Arctic Ocean is divided into two great circulation systems by underwater ranges.

STUDIES OF THE HIGH ATMOSPHERE

Both the Arctic and Antarctic are ideal for upper-atmosphere studies. The atmosphere is virtually free of man-made interference and the sun is absent for six months of the year. So a number of important experiments can be performed. We know, for example, that the sun is the principal cause of electrical charges in the ionosphere. Yet, during the long winter night, when the sun is absent, the polar ionosphere continues to show 24-hour changes and to reflect radio signals – much as in the temperate latitudes.

The long period of darkness also provides an excellent opportunity to study auroras **(18).** These are most intense in the polar regions because the particles from space that cause these glows in our atmosphere are guided there by the earth's magnetic field. (They are spun off in the lower latitudes.)

A rocket-launching facility was set up at the edge of the Arctic Circle **(19),** at Fort Churchill, Canada, because its location was especially favorable for high-atmosphere research. Rockoons (balloon-launched rockets) have been launched aboard ships from the Arctic to the Antarctic to test the relationship between latitude and the frequency of cosmic rays. The frequency of these rays increases in the high latitudes near the magnetic poles.

POLAR WEATHER

Weather observations in the remote Arctic and Antarctic regions are of special and immediate interest. It may be that Southern Hemisphere weather is "made" in the Antarctic. Scientists were therefore eager to set up weather stations in the Antarctic to provide the first weather reports for this enormous area.

The IGY stations of many nations co-operated to combine their weather observations – reports of wind, pressure, and temperature data obtained from radio-equipped balloons **(20)** and at ground levels.

Other meteorological studies are concerned with measuring the heat and light received from the sun and the amount reflected back into the atmosphere by the snow surface **(21).** Special radiation instruments show that the South Pole receives more sunlight than any place on earth during December, its midsummer. But almost all of it is reflected back into the atmosphere. This is why there is very little melting. The air is so dry that a footprint in the snow may remain clear for months.

All these studies in the polar regions – of the earth's crust, the icecaps and ice packs, the weather and upper atmosphere phenomena – are rapidly filling the gaps in our picture of the earth and its environment. The unique conditions in the Arctic and Antarctic make it clear why scientists are so eager to conduct studies there. ■

Weather and Climate

SOMEONE once said that the more history appears to change, the more it remains the same. The opposite might be said of weather and climate. Although the weather appears to repeat itself over and over, actually great changes are constantly but very gradually in the making. Even the patterns of heat and cold, wet and dry, never seem to repeat themselves exactly.

Nevertheless, it is becoming increasingly important to improve our forecasts, and to make reliable projections for longer periods of time. The growth of air transportation alone makes this necessary.

It has been said that we don't lack facts about the weather, we lack theories to account for the facts. If we had adequate theories, all the facts would fall neatly into place. Meanwhile, weather scientists devote themselves to gathering more and more facts, hoping they will yield clues to better theoretical explanations. During the IGY, for example, weather stations in North America alone supplied enough information to the U. S. Data Center to fill 25,000 punched cards a day.

Similar observations are going on at weather stations all over the world. These observations are necessary if a meaningful picture is to be obtained, for weather doesn't respect national boundaries.

To make a simple forecast of tomorrow's weather, meteorologists must gather the broadest information possible. The object is to draw maps and charts, showing how great, three-dimensional masses of air and moisture move across the face of the earth in distinctive patterns.

AIR ON THE MOVE

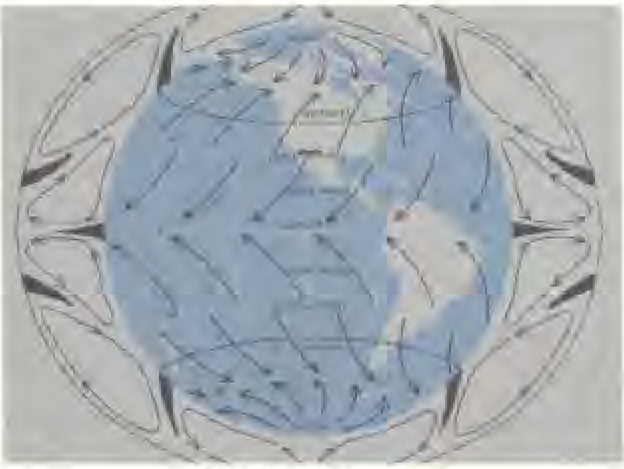
The word "moving" is the key to an understanding of weather. No property of the atmosphere is more important than its motion. Winds distribute heat from the tropics to other areas, carry moisture from the oceans over the continents where it falls as rain, push polluted air out of the cities and bring in clean air to replace it. If our atmosphere stopped moving, the tropics would become intolerably hot and the rest of the planet unbearably cold. The rainless continents would become dust; the cities would suffocate in their own fumes.

Fortunately, the great wind systems of our globe make this impossible. They move the atmosphere with an energy equal to nearly 7,000 A-bombs. Their daily force exceeds all the electric power the United States could produce in 100 years.

This energy, great as it is, could be used up in nine to twelve days through friction between atmosphere and earth. All the world's winds would stop, were their energy not continually renewed by a most powerful generator—the sun. By heating the air and evaporating the water, it keeps our atmosphere moving. Obtaining a complete picture of this motion is a tremendous job.

WEATHER & CLIMATE

"The air moves like a river
and carries the clouds with it." DA VINCI



Global wind pattern

Cross section of the United States

HEAT, SPIN, AND FRICTION

Nevertheless, scientists are putting together a picture of the global patterns of winds **(1)*** and weather. One of the key elements in this picture is heat. The tropics absorb more heat from the sun than they radiate away, while the rest of the world radiates more than it receives. Air warmed in the tropics rises high in the atmosphere and flows toward the poles, where it is cooled. As it becomes denser it falls, then flows back toward the equator. This should give us two loops of air circulation, in the Northern and Southern Hemispheres.

A second element, the effect of the earth's rotation, modifies the pattern. As the earth spins from west to east, a "twist" effect is given to the moving air. One result is that great westerly winds arise in the upper air between 30 and 40 degrees latitude, north and south. (A research rocket launched by the United States in Canada encountered 335-mile-an-hour westerlies at 35 miles altitude.)

These westerlies would reach speeds of thousands of miles per hour, were it not for a third factor in global circulation–friction. Contact between the moving air and the ground slows the wind down. It breaks up the large Northern and Southern Hemisphere patterns into several smaller "cells" or loops in each hemisphere. The uneven topography of the earth's surface causes further complications. Thus, if we take a profile across the United States **(2)**, we see how the Rocky Mountains drain off moisture-bearing clouds from the Pacific, and cause the plains states to be comparatively dry.

These three major elements in the circulation of the earth's atmosphere – the heat of the sun, rotation of the earth, and friction between earth's irregular surface and the air itself – contribute to a very complex circulation system. For the past hundred years or so, the surface circulation has been fairly well known, mainly because of the observations of mariners. But not much has been known of circulation at upper levels.

Today, we are at the very begining of a truly three-dimensional understanding of atmospheric circulation. For example, some helpful insights were obtained when military pilots during World War II observed very high-speed, narrow

*Refer to poster on page 24.

"jet" streams at the new heights planes could then reach. These currents run at two to three hundred miles an hour, 30,000 feet or more above the ground. Special high-altitude balloons and scientific rockets are telling us much more about these fast rivers of air that circulate through our atmosphere.

Other means are also used to investigate atmospheric circulation. Strangely enough, analysis of ice cores taken from the heart of the Arctic and Antarctic icecaps helps. Safely trapped in this snow, fallen long ago, are spores, volcanic ash, and other matter that tells its own stories of air movements. For example, we find volcanic ash in the Greenland icecap at a particular depth. We can tell from the annual snow layers the year in which the ash fell. Historical records tell us there was a great volcanic eruption that year in another part of the world. This gives us new insight into air circulation.

Today we also detect in the atmosphere debris of atomic testing in the form of radioactive particles. These have been found in the Southern Hemisphere, proving that air circulation does move across the equator, and that the north and south atmospheric systems are not completely separate.

Vertical movements in the atmosphere are proved by analysis of gases in the air. Certain gases that are formed at least six miles above the earth are found in air near the ground.

Hand anemometer

Battery of weather instruments

High weather study

KEY ATMOSPHERIC GASES

One of these gases is ozone. Ozone is a type of oxygen formed in the high atmosphere by the absorption of ultraviolet light from the sun. Since an excess of ultraviolet radiation would be harmful to man, ozone is very important as a shield. Strangely enough, scientists in the Antarctic found more ozone there during the long winter night than in the daylight months. Since ozone is formed by solar radiation, we assume that the atmosphere carried it to the Antarctic.

Two gases in our atmosphere play a key role in the earth's weather. They are carbon dioxide and water vapor. These gases are responsible for the so-called "greenhouse" effect. They allow the sun's short-wave heat rays to penetrate to the earth's surface **(3)**, but keep much of the long-wave heat radiated by the earth **(4)** from escaping to outer space. This heats our atmosphere.

Our industrial civilization has been pouring carbon dioxide into the atmosphere at a great rate. By the year 2000 we will have added about 70 per cent more carbon dioxide to the atmosphere. If it remained, it would have a very marked warming effect on the earth's climate, but most of it will probably be absorbed by the oceans. Conceivably, however, it could cause significant melting of the great icecaps and raise sea levels in time.

Water vapor in the atmosphere also contributes to the greenhouse effect. Most of the water vapor in our atmosphere comes from evaporation of sea water **(5)**. The cycle is maintained as the water vapor is precipitated back to the earth's surface in the form of dew, rain, and snow. This cycle is suggested by the figures of the nymphs in the accompanying poster. They fill their pitchers in the sea, raise them above the earth in the form of clouds, then empty them in the form of precipitation **(6)**.

Water vapor in the air condenses to form many types of clouds **(7)** that make up the earth's cloud cover. The clouds reflect much of the long-wave heat radiation back to earth. Over the warm seas, air currents act much like pumps, bringing moisture up from sea level and circulating it upwards to many thousands of feet where clouds may form. The winds may carry the clouds along until colder air permits condensation and rain.

In trying to obtain an over-all picture of cloud function, it would be most helpful to see the earth from out in space so that a measure of its cloud cover could be obtained. The central map of the earth in the poster shows it as it might look from 4,000 miles in space. A somewhat similar but actual picture of cloud cover may be obtained through the use of photocell equipment in earth satellites.

CLIMATE = WEATHER + TIME

By scientific detective work in the 10 per cent of the earth's surface that is covered with ice and snow, and by analysis of now-bare rock formations that once were so covered, we get this general picture of long-range changes in climate: Beginning more than a million years ago, and ending some 10,000 years ago, the earth saw the last of the ice ages. During this time, huge rivers of ice built up in the polar regions as the atmosphere cooled or snowfall increased. They swept down over North America, and left their mark as far south as Kansas and Kentucky. There were at least four such advances. In between, during periods of warming or when precipitation (rain and snow) was reduced, these rivers of ice, known as glaciers, apparently receded.

Similar movements, brought on by climatic changes, seem to be going on today, and scientists are trying to measure them as they take place. At Blue Glacier, in the state of Washington, a team from the University of Washington is making the first direct study of an Arctic alpinetype glacier. Glacier studies are also being made in Alaska **(8)**. Stakes are implanted **(9)** and resurveyed at 15-day intervals to establish the amount and rate of glacier movement. Because of a general warming trend most of the world's glaciers seem to be retreating at present. (Recent temperatures at Little America are 5 degrees Fahrenheit higher than fifty years ago, and in Spitzbergen, 10 degrees warmer.)

TAKING THE WEATHER'S MEASURE

What kind of measurements do weather observers take? Meteorologists range the earth from pole to pole, from surface to stratosphere, using instruments that vary from the most simple to the most complex. A hand anemometer is used at Little America to measure wind velocity **(10)**. On the roof of a Weather Bureau building we see an array of other instruments used in taking observations **(11)**. These include gauges for measuring rain and snowfall, both by depth and by weight, and more sophisticated instruments, such as the psychrometer and ceilometer.

The psychrometer compares wet- and dry-bulb temperatures to indicate relative humidity. In addition to a regular thermometer, used to measure the temperature of the air, the psychrometer has a thermometer with a moistened wick attached to the bulb. As water evaporates from the wick, the cooling effect of evaporation lowers the thermometer reading in proportion to the amount of evaporation that takes place. The difference in reading betwen the two thermometers indicates relative humidity. The smaller the difference, the more saturated the air must be with moisture. Therefore, the higher the relative humidity.

The ceilometer measures the height of the cloud base, that is, the distance from the ground to the bottom of the cloud layer. This figure is particularly important in aviation, where it is used as a standard of safety in permitting take-offs and landings. The ceilometer operates by projecting a powerful beam of light straight up to the cloud base, while a photo-detector 800 to 1,000 feet away on the ground scans the spot of light on the cloud.

Balloons carrying weather instruments **(12)** now reach the stratosphere, traveling 100,000 feet or more above the earth. The instruments measure temperature, relative humidity, and pressure as the balloon ascends, and a radio transmitter sends the information to a ground receiving station where it is automatically recorded. By tracking the balloon with a direction-finding radio, it is also possible to determine direction and speed of the winds aloft. When the balloon reaches its maximum height, it bursts, and the radiosonde, as the box containing instruments and transmitter is called, is parachuted to earth.

In aviation, and in all other phases of our lives during the years to come, weather will continue to be a vital factor. The more knowledge about it we can acquire, the more likely it is that we can use the weather, adapt to it, protect against it, and perhaps even control it in some limited fashion. ■

Sun and Earth

IT TOOK many thousands of years for man to learn the true place of the sun in the scheme of our universe. Only a few hundred years ago he thought the sun revolved around the earth instead of the earth around the sun.

Today we recognize the sun as the hub around which the planets of our solar system wheel. We also know that it is a star — not the smallest star, but still only one-millionth as large as some in the cosmos. Yet it is more than a hundred times greater in diameter than the earth, over 330,000 times greater in mass, and a million times greater in volume.

As our nearest star and a very active one, the sun is the source of a great variety of radiations and particles. These are constantly spewed out into space and have great significance to us on earth. They are thought to be the by-products of processes within the sun, where hydrogen atoms fuse in a series of reactions to release enormous quantities of energy. As this furious process goes on, the sun's loss of weight is estimated at over four million tons a second. Yet it may maintain its temperature for another 35 billion years without noticeable loss.

THE SUN'S SURFACE

With a modern solar telescope **(1)***, we can examine the sun's complex surface, analyzing it and mapping it **(2)**. The sun's surface appears grainy, and the grains, or granules, change their relative brilliance as you watch them. Sometimes there are larger dark areas of the surface called sunspots **(3)**.

Sunspots usually begin to appear in pairs some distance from the sun's equator, but never in the very high latitudes. Then more sunspots appear, closer and closer to the sun's equator. As time goes on, the spots begin to die away. The next cycle begins with a few spots in the higher latitudes again. On the average, the complete cycle takes about eleven and a half years.

Sunspots are not actually dark. They are only less bright than the surrounding areas. Though we do not fully understand them, we do know they are related to periods of increased solar activity that have very marked effects on the earth's

Earth's and sun's axes of rotation

* Refer to poster on page 31.


Solar telescope


Sun surface map


Ionosonde probes upper atmosphere

environment. Solar prominences **(4)** are another aspect of this increased solar activity. The prominences are great clouds of incandescent gas that seem to float far up into the corona, part of the sun's atmosphere, often curving gracefully back into the sun's disk. Often the cloud seems to materialize high in the corona and flow down into the sun. Strong magnetic fields may be involved.

Solar flares, sudden brilliant outbreaks that occur only near sunspots, are also related to the sunspot cycle. From the flares, large surges sometimes shoot out half a million miles from the sun at speeds as much as 300,000 miles an hour.

Such outbreaks may throw great quantities of gases into space, adding to the radiations and particles issuing regularly from the sun. Various effects are felt on earth—some of them almost immediately, while others take over two days to show up in our atmosphere. Flares and prominences follow the sunspots in increased activity.

SOLAR RADIATION

The earth has been called a small target for the sun's radiations. Only about half a billionth part of the total solar radiation strikes the earth. Yet this is enough to keep our planet comfortably above the absolute zero temperatures in space, to power the circulation of our atmosphere and oceans, and to sustain life.

There are two main types of solar radiation: first, the electromagnetic waves, which include the light we see and radio noises; second, particles such as cosmic rays, electrons, and protons.

Only a small portion of the range, or spectrum **(5)**, of solar-wave radiation falls within the frequencies visible to our eyes. One solar scientist says it is as though we could hear less than one octave of a keyboard as wide as ten pianos. Also, many solar phenomena are visible only at chosen wavelengths. But we have been greatly assisted by the invention of such instruments as the spectroheliograph, a device for viewing the sun only in light of a specific frequency—such as hydrogen light.

Most of the energy of the sun received on earth is in the visible part of the spectrum. This includes the color red **(6)** at the lower end of the visible spectrum and the color blue-violet **(7)** at the upper end. Below red there is infrared **(8)**. Still lower are short-wave radiations, including some similar to

SUN & EARTH

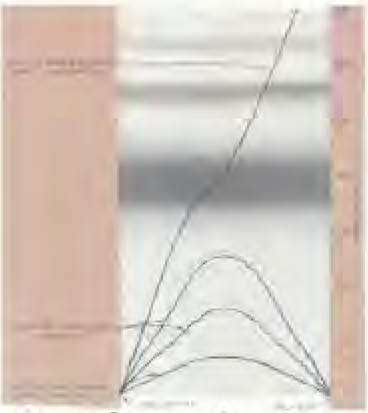
"Knowest thou the ordinances of heaven?
Canst thou set the dominion thereof in the earth?" JOB 38:33

those we use for radar **(9).** Above the violet, at the higher end of the spectrum, comes ultraviolet, which gives us our sun tan, and X rays **(10).**

The very high energy radiations are absorbed in the upper atmosphere and do not penetrate to the earth's surface. The visible and infrared radiations reach the earth; they determine our climate, create our weather, warm the earth's surface, and, through re-radiation, warm its atmosphere. But this portion of the spectrum remains unchanged year after year, varying at most only by fractions of one per cent. The portion we cannot see – the radio waves, X rays, and other high-frequency and particle radiations – *do* change markedly, according to the level of solar activity. By observing these changes, scientists learn much about the sun and the earth and their relationships.

THE IONOSPHERE

Ultraviolet light and X radiation streaming out from the sun are absorbed in the earth's higher atmosphere. In the process, the upper atmosphere becomes


Ionospheric radio effects


Artificial eclipse


Coronagraph


Cosmic ray study

"ionized," or electrified. It then acts to reflect our radio signals back to earth.

By careful observation of the paths, strength, and other reception characteristics of radio signals, scientists can detect changes in the ionosphere related to solar changes. Such changes occur as the sun rises and sets, as it moves north and south with the seasons, and as the sunspots and other solar activities vary.

Using ionospheric sounders **(11),** scientists send pulses of radio energy into the ionosphere and time their return. This permits them to find out how deep into the ionosphere signals of different frequencies penetrate. From such information they can learn how dense the layers are **(12),** how they drift with the winds, and what effect the sun has on them.

In general, the sun increases the depth of the layers during the day. And during some solar flares, disturbances occur in the ionosphere, undoubtedly caused by the intense radiation from the sun. Then radio signals may be distorted or absorbed and we say we have a radio fadeout.

Radio studies have turned up another interesting fact. Certain very low frequency signals, such as those caused by lightning flashes, curve out through our atmosphere to the same relative location in the opposite (north or south) hemisphere **(13).** These signals are called "whistlers" because they make a whistling sound of descending pitch when amplified as sound waves. Theory suggests that these signals follow the lines of the earth's magnetic field.

THE SUN'S CORONA

The influence of the earth's magnetic field extends several earth radii into space **(14).** There must be ionization present for whistlers to be guided on such a path so far out in "empty" space. This and other evidence suggest that there is a thin filler—perhaps the sun's corona—throughout interplanetary space.

The corona **(15)** consists of clouds of electrons, hot electron gas, and interplanetary "dust" that reflect solar light. Its greatest temperatures exceed 3,000,000 degrees Fahrenheit, the hottest observable temperatures in the universe. The corona, as seen during an eclipse, extends millions of miles into space and gives as much light as the half-moon. Yet it could never be seen and studied

Radar tracks cosmic balloon

Airglow photometer

Airglow maps

except during an eclipse. Now, however, scientists use a coronagraph, a telescopic instrument **(16),** which creates an artificial eclipse that can be studied at leisure.

COSMIC RAYS

Among the particles that stream from space to earth are cosmic rays **(17).** It is believed that on certain rare occasions some of these highly energetic, charged particles come from the sun. They were first discovered when sealed electroscopes lost their charges more quickly as they were carried higher into the atmosphere. Highly penetrating charged particles were draining off the electroscopic charge. Original cosmic rays, or primaries, split up in collisions with atoms in our atmosphere and only the resulting secondaries reach the ground.

Like all charged particles, cosmic rays are affected by the earth's magnetic field. All except the most energetic particles approaching earth near the equator are reflected or spun off toward the poles. Those approaching close to the geomagnetic poles of the earth's field are guided toward the earth **(18).**

To measure the intensity of cosmic rays, balloons carrying Geiger counters

(19) are sent high into the air. They are tracked by radar **(20).** Ships, planes, rockets, and satellites have also carried counters to far and high places in the study of cosmic rays. These investigations prove that these rays become more numerous as one moves north or south of the equator toward the poles.

But there is an important difference between the geomagnetic equator and the equator as "seen" by cosmic rays. It has been suggested that this difference may be caused by the effects of the sun's far-reaching corona. For this thin sea of electrified gas may have its own magnetic fields. These may have a warping effect upon the earth's field high in the atmosphere where it influences cosmic rays that arrive from space.

THE AURORA

Other particles from the sun are believed to cause the aurora, the beautiful arcs, rays, bands, and draperies of light that appear high in the night sky, usually in high northern and southern latitudes **(21).** Charged particles of hydrogen atoms from the sun are believed to interact with the earth's atmosphere, causing it to glow – like a neon tube when electrons pass through it.

Like cosmic rays, these particles come under the control of the earth's magnetic field as they approach the atmosphere. They spiral off toward the poles or approach without difficulty at the poles. This is why auroras are most often seen in the Arctic and Antarctic skies. They occur, at heights ranging from 60 to 600 miles, in green, white, and more rarely, red colors. Auroras generally follow disturbances of the sun and may appear in the Northern and Southern Hemispheres at the same times and fairly symmetrically.

AIRGLOW

Somewhat similar to auroras, but not so clearly related to the sun, is the airglow. This light in the night sky is rarely seen with the naked eye. Yet it contributes more light to the night than do the stars. The glow is caused by chemical processes in our atmosphere, probably at heights of 40 to 100 miles. Airglow appears all over the earth, not mainly at high latitudes, but it is patchy and there is quite a bit of movement and change during a night. It is studied with a photometer, a photoelectric device **(22),** and maps of the airglow are made up for different hours during the night to help analyze the changes **(23).**

* * *

Studies of upper atmosphere phenomena, within only 200 or 300 miles of the earth's surface, are here seen to be really studies of the earth's relationships to the sun. For the sun's energy, radiations, and particle emissions are powerful and varied enough to exercise a great "dominion" in earth. The earth's atmosphere and magnetic field, in turn, have strong effects upon these messengers from the sun. Studied alone, cosmic rays, geomagnetism, auroras, the ionosphere, and the sun would each remain a puzzle forever. But studied together, each provides many clues to an understanding of the others.■

Space

BEFORE men could turn their minds to the problems and challenges of space, they had to learn that the earth itself was a space platform. The earliest man to guess the truth may have been the Greek Aristarchus. Three centuries before Christ he said that the earth revolved in space.

Most men had not yet learned enough of the physical laws of the universe to prepare them for this idea. Yet the challenge of space continued to intrigue a few. In the second century A.D., Plutarch wrote that the moon was a small earth. Another Greek, Lucian, followed with a fanciful story about a great storm at sea which lifted a ship and its crew to the moon.

A scientific basis for recognizing the earth as part of the solar system was established by Copernicus in the 16th century. It then became possible to build a more factual understanding of the relationship of earth and its atmosphere to the space around them.

OUR OWN ATMOSPHERE

The notion that our atmosphere had an upper limit seems to have come from man's experience in climbing mountains. He noticed that the air became thinner and reasoned that it must thin out to nothingness at some level. An Arab astronomer, around the year 1000, tried to find the height of the atmosphere by measuring the refraction, or bending, of sunlight in the air.

Today we see the atmosphere in cross section this way: **(1)*** The bottom layer of our atmosphere – the troposphere – is about 10 miles high. The temperature here falls steadily at the rate of one degree Fahrenheit for every 300 feet of ascent until about –80 degrees Fahrenheit is reached. Our weather is mainly confined to this region.

Above the troposphere is the stratosphere, a cold, almost cloudless layer of thin air reaching up to about 35 miles. Temperatures within the stratosphere rise somewhat; above it they drop off sharply.

Beyond the stratosphere is the ionosphere, a region thinly populated by gas molecules. These molecules are ionized (electrically charged), mainly by the sun. The ionosphere has three or more regions of its own and stretches out about 250 miles from the earth.

The extremely sparse area beyond the ionosphere is called the exosphere.

The density of the atmosphere drops very sharply as you rise above the earth. At a height of about 9 miles, 80 per cent of the air mass is below you. At 19 miles, 99 per cent of the air mass is below. And at 60 miles, the air is one-millionth as dense as at sea level.

THE SPACE BEYOND

Where does space begin? We say that space begins, in a physical sense, beyond the ionosphere, perhaps 250 miles from the earth. Yet there is no real dividing

* Refer to poster on page 38.

line, and it now seems that a thin "atmosphere" may fill all of space.

From man's point of view, space may begin much lower. Above 15,000 feet, he cannot breathe for very long without oxygen equipment. At about 60,000 feet, his blood would boil unless he wore a pressure suit. Beyond about 25 miles, the atmosphere is not dense enough to protect him from cosmic radiation. Higher than 30 miles, man is above the ozone belt which absorbs dangerous ultraviolet radiation from the sun. Still higher, above 65 miles, he is in the region meteorites penetrate before being consumed by friction in the atmosphere.

Still, man reached toward space long ago. In 1803 and 1804, French and English balloonists rose nearly 25,000 feet in open gondolas – without oxygen supplies and in temperatures well below zero! Before the end of the century, instrumented balloons reached heights of 50,000 feet and, on rare occasions, even 100,000 feet **(2)**.

The invention of the airplane did not make a great change in man's ability to step into space because the gasoline engine depends upon oxygen much as man does. Also, aircraft wings require relatively dense air in order to gain lift. But from 1920 to 1940, great advances in rocketry were made in the United States by Robert Goddard. Rockets could carry their own oxygen and functioned all the better in thinner air.

ROCKETS

A rocket is a tube containing fuels, a chamber for their combustion, and a nozzle through which the resultant gases are exhausted. It moves ahead in reaction to the discharge of these gases. The fuels can be either liquids or solids.

After World War II, some of the German V-2 rockets were used for research into the upper atmosphere. While extremely powerful, they were too expensive for this purpose. So cheaper, smaller rockets were designed. The Aerobee-Hi can carry 150 pounds of scientific instruments as high as 150 miles. It burns nitric acid and aniline. The Nike-Cajun **(3)** uses a solid propellant to carry 40 pounds of instruments to a height of 100 miles. The Nike is the booster, or first stage, which gives the rocket fast acceleration in the first few seconds. Then it separates and falls away. This fast acceleration helps stabilize the rocket as it

Nike-Cajun rocket

Rockoon = balloon + rocket

Telemetry record

lifts slowly from the ground. It also propels the rocket above the densest portion of the atmosphere, allowing the second stage to reach greater heights.

The balloon and the rocket have been combined in the rockoon **(4)**. A balloon carries a small rocket to about 80,000 feet. There, well above the troposphere, the rocket can be fired by radio – perhaps right at the moment of a solar flare.

A great variety of new facts has already been gathered in the relatively few years since scientific investigation of space by rockets began. Generally, they show that the temperature, pressure, density, and ionization of the upper atmosphere are all strongly influenced by the sun.

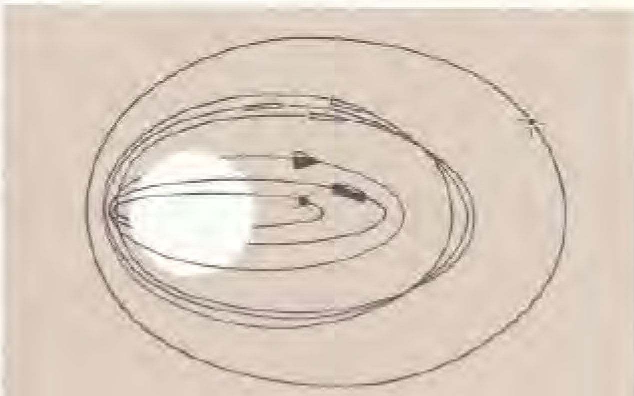
Measures by rocket are very complicated because of the conditions generated by the rocket's own flight – the heat of friction with the air, the air currents, the wobbling and vibration of the rocket itself. But many ingenious techniques have been developed to solve these problems.

How are complex data transmitted to earth? One answer is telemetry – the automatic transmission of data by radio. First the readings are converted into radio signals. The code used is based on such things as variations in the length of signals, the time intervals between them, and the radio frequency of the signals. The results, recorded on the ground on magnetic tape, can then be interpreted at leisure **(5)**. Rocket instrument containers can also be parachuted to earth with their recorded data or even allowed to impact **(6)**.

SATELLITES

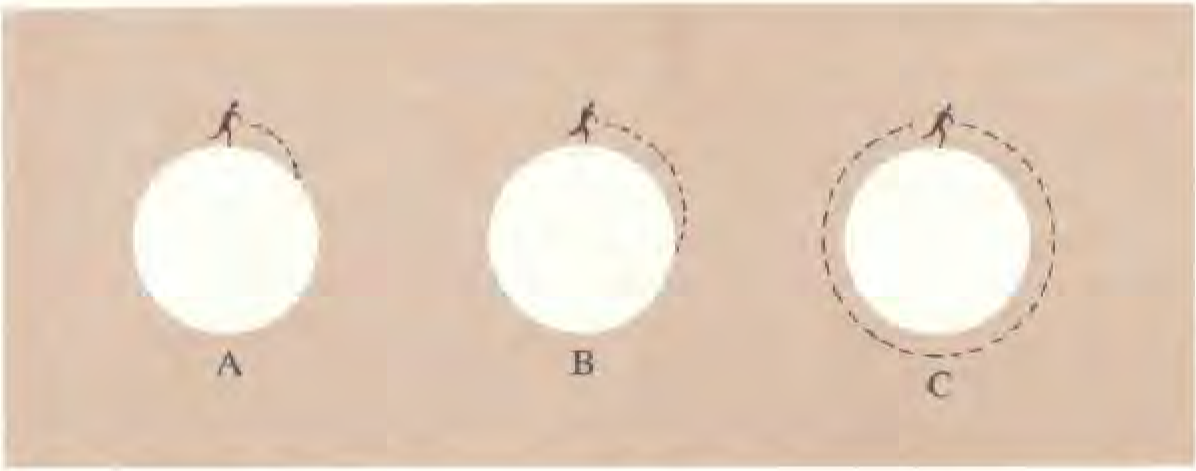
Putting a satellite into orbit is simply an extension of rocketry. For if a rocket reaches a great enough speed at a given height and angle, it will go into orbit. Once in orbit, a satellite offers a number of advantages over the ordinary rocket. It may stay aloft for years instead of only a few minutes, and it covers a wide range of latitudes or longitudes, or both. Within less than an hour it can obtain data on both the day and night sides of the earth and the summer and winter regions. However, rockets are still best for obtaining a very rapid cross section sampling of atmospheric conditions, from the ground to great heights.

Data returns with rocket



Elliptical satellite orbits from perigee to apogee

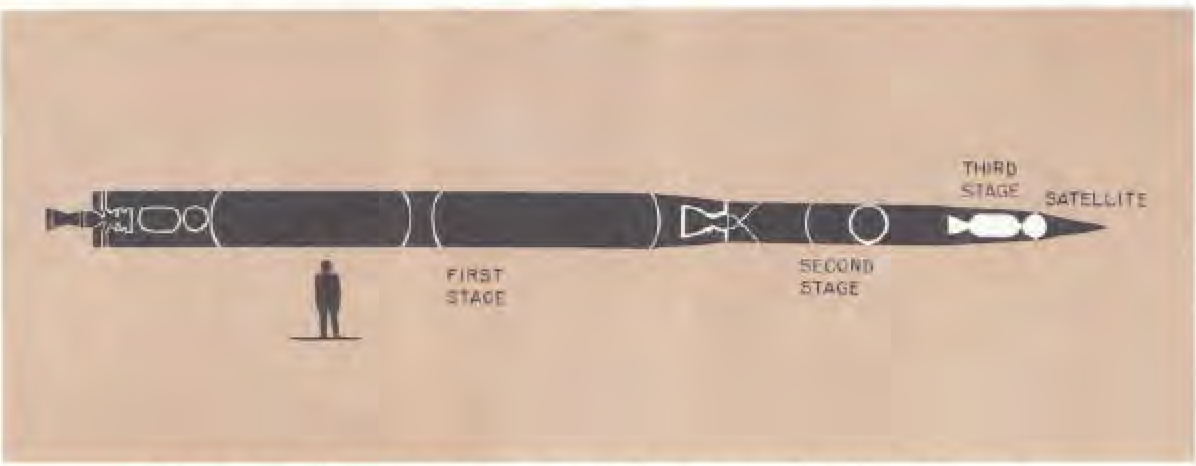
"Ah, but a man's reach should exceed his grasp,
Or what's a heaven for?" BROWNING



Satellite orbits may be understood this way: Think of throwing a stone horizontally. It will fly through the air and fall eventually to the ground (A). If you throw much harder, it will fly farther before the friction of the air slows it down so that gravity can pull it back to earth (B). Now, think of throwing a stone so hard that it keeps going forward just about as far as it falls. It will keep curving downward but it will never reach the earth. Instead, it will make a great circle *around* the earth (C). It will go on this way forever unless there is enough atmosphere drag to absorb its energy.

Actually, it is almost impossible to give just the right amount of push so that a satellite makes a perfect circle. To be sure it orbits, we always try to give some extra push. This sends the satellite out in an elongated path called an ellipse **(7).** At the point closest to the earth, it goes through the densest layers of atmosphere. This absorbs energy; therefore, it doesn't go quite as far out on the next swing away from earth. This process continues until the farthest point, the apogee **(8),** has been reduced to about the same distance from earth as the low point, the perigee **(9).** The satellite finally dives into the dense atmosphere and is burned up by friction.

The main rocket systems used to launch the first U. S. satellites were the Vanguard and the Jupiter-C. The Vanguard used three stages **(10)** to put



Three stage "Vanguard" is one type of rocket used to launch satellites a separate satellite (11) in orbit. The Jupiter-C used four stages, with an instrument package located within the fourth stage. The Vanguard's first two stages were used to gain altitude, and to some extent, horizontal speed, while the third stage accelerated the satellite horizontally to orbital speed – 18,000 miles per hour. In contrast, Jupiter C's first stage alone pushed the rocket system to orbital height. The remaining three stages were all used to gain acceleration so that the fourth, with its instruments, could enter orbit.

The three Vanguard stages were all single rockets. In Jupiter-C, the first stage was a single rocket, the second and third stages consisted of clusters of small rockets nestled in a sort of tub, and the fourth stage was a single rocket.

Because each pound of weight greatly increases the rocket thrust required, instruments must be as small and compact as possible. Great ingenuity has been used for this purpose. For example, Explorer III contained a tape recorder which included a magnetic tape to record cosmic ray counts, a player to run the tape, a mechanism to start the tape playing after receiving a command from the ground, and another device to rewind the tape for further recordings. All this weighed only 8 ounces!

Once a satellite is in orbit (12), it is most important to observe it with precision instruments in order to determine its exact location. We have to know exactly where the satellite is whenever it radios data to us; only then can we tell whether the data apply to day or night, to high or low altitudes and latitudes, etc. Also, we must check very carefully how much the apogee is reduced each day; this tells us the extent of the atmospheric drag in space. In fact, if we could observe the satellite's path closely enough, we could see what perturbations, or departures from a smooth ellipse, it makes on its course; because these are due to gravity variations, they would help us map irregularities in the earth's shape and the distribution of its mass.

How can you locate a very small object from 200 to 2,000 miles off in space? Some amateurs have helped. For very precise tracking, however, a radio system (13) compares the difference in time of reception of the satellite signal's "phase" at two or more points. The satellite can then be

Satellite fitted into rocket

Radio tracking

Photographing satellites

Instruments in rocket cone

Recording satellite messages

Preparing for space

located. The precision optical system uses a huge camera **(14).** This requires fairly good information to begin with, so that the camera can be pointed in the right direction and then track and photograph the satellite against a background of known stars. It times the exposure to 1/1000th of a second.

Satellites have already helped us make more precise measurements of the density of "empty" space. They have encountered a band of intense solar radiation which appears to double every 60 miles above 250 miles to the greatest height yet reached. So far, it appears that the radiation is trapped in this region by the earth's magnetic field. The radiation seems greater than man could safely withstand even for a short time.

Satellites can do much more than this. They may use light-sensitive cells to observe our cloud cover and weather patterns, relay radio and TV signals, aid in navigation and mapping, carry living organisms to great heights for experimental purposes, even carry telescope-like instruments to view the moon **(15),** Mars, Venus, and other celestial bodies without the distortion caused by our atmosphere.

THE FUTURE

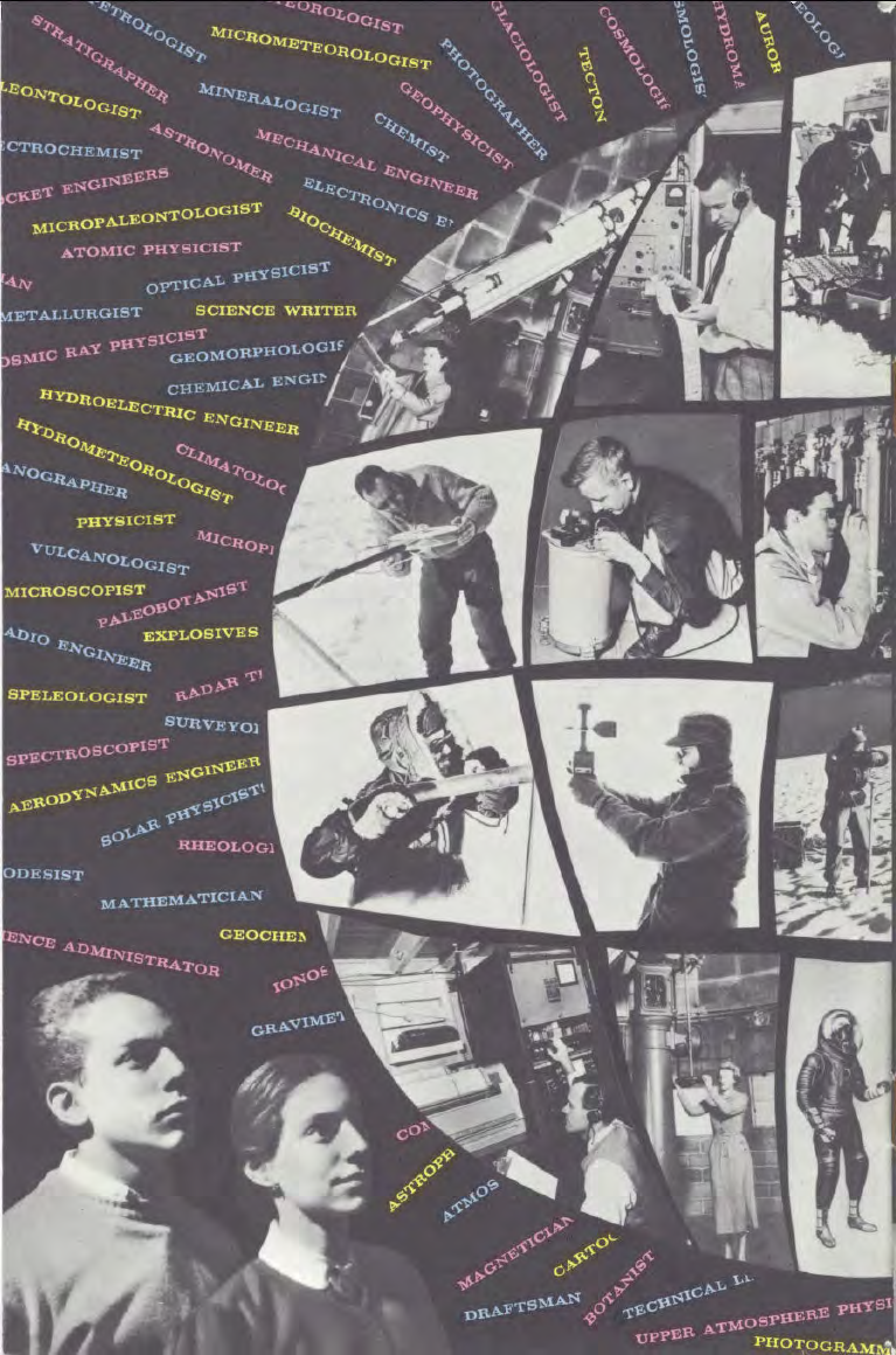
What about man? With the launching of the first satellites we have crossed the threshold of the space age. Yet there are many sobering difficulties. It will take only three days for a rocket to reach the moon. But it could take many, many years just to reach some of the planets in our solar system. And our system – located in an outer spiral of the Milky Way – is only one of many in our galaxy. There are a billion such galaxies within two billion light years of the earth. Light from the nearest star, within the Milky Way, takes over four years to reach us, traveling all the while at 186,000 miles a second. Space travel, if and when it comes, will always be a very small step from our own front door in this great universe. Perhaps it should be devoted principally to learning more about our own space platform – the earth.■

THE FIRST SEVEN SATELLITES

	1957 ALPHA (SPUTNIK I)	1957 BETA (SPUTNIK II)	1958 ALPHA (EXPLORER I)
Weight (lbs.)	184	1120	30.8
Shape	sphere	complex	cylinder
Dimensions	22.8″ in diameter	....	80″ long; 6″ in diameter
Shell Composition	aluminum alloys	aluminum alloys	steel with 8 aluminum oxide stripes
Antennas	4 spring-loaded whip antennas 7′10.5″ to 9′6″	....	1 turnstile antenna with 4 whip elements each 22.5″ long; 1 dipole antenna using the skin of the satellite itself
Payload (lbs.) and Experiments	..........................: internal temperatures; pressures; "and other data"	..........................: cosmic rays; solar ultraviolet and X-radiation; test animal (dog); temperatures; pressures	10.63 lbs.: 1. cosmic rays 2. micrometeor a) microphone b) gauges 3. temperatures a) internal b) rear skin c) front skin d) nose cone
Transmitters	a) 20.005 mc b) 40.002 mc	a) 20.005 mc b) 40.002 mc	a) 108.00 mc at 10 mw [1, 2b, 3c, and 3d, above] b) 108.03 mc at 60 mw [1, 2a, 3a, and 3b above]
Transmitter Lifetime	both a) and b) ceased operating October 27, 1957	both a) and b) ceased operating November 10, 1957	a) ceased operating May 23, 1958; b) ceased February 11, 1958; began again February 24; ceased finally February 28
Power Supply	chemical batteries	chemical batteries	mercury batteries
Lifetime	October 4, 1957 — January 4, 1958	November 3, 1957 — April 13, 1958	January 31, 1958 — (3 to 5 years)
Initial . . .			
perigee (miles)	142	140	224
apogee (miles)	588	1038	1573
period (min.)	96.17	103.75	114.8
inclination to equator	64.3°	65.4°	33.5°
speed (perigee) (mph)	18,000	18,000	18,400
speed (apogee) (mph)	16,200	15,100	13,700

* Explorer II failed to go into orbit

1958 BETA (VANGUARD I)	1958 GAMMA (EXPLORER III)*	1958 DELTA (SPUTNIK III)	1958 EPSILON (EXPLORER IV)
3.25	31.0	2925	37.10
sphere	cylinder	conical	cylinder
6.4″ in diameter	80″ long; 6″ in diameter	11′9″ long; 5′8″ wide at base	80″ long; 6″ in diameter
aluminum	steel with 8 aluminum oxide stripes	aluminum alloys	stainless steel
1 turnstile antenna and 1 dipole antenna with total of six 12″ rod elements	2 dipole antennas using the skin of the satellite itself	folded dipole antennas; trailing rod antennas	2 dipole antennas using the skin of the satellite itself
1.06 lbs.: temperatures	10.83 lbs.: 1. cosmic rays with tape recorder feature 2. micrometeor gauges 3. temperatures a) skin b) internal	2134 lbs.: atmospheric pressure and composition; concentration of positive ions; satellite's electrical charge and tension of earth's electrostatic field; tension of earth's magnetic field; intensity of sun's corpuscular radiation; composition and variations of primary cosmic radiation; distribution of photons and heavy nuclei in cosmic rays; micrometeor and temperature measurements	18.26 lbs.: 2 Geiger-Müller counters and 2 scintillation counters to measure corpuscular radiation at several intensity levels
a) 108.00 mc at 10 mw b) 108.03 mc at 5 mw	a) 108.00 mc at 10 mw [1, 2, 3a, and 3b above] b) 108.03 mc at 60 mw [1 only]	a) 20.005 mc (transmission at 40.01 mc is harmonic of first)	a) 108.00 mc at 10 mw b) 108.03 mc at 60 mw [each transmitter broadcasts all 5 channels of information simultaneously and continuously, although a) was primarily for tracking]
a) ceased operating April 5, 1958; b) will operate indefinitely	a) telemetering and beacon signal stopped May 10, 1958; beacon transmitted again May 15 — June 16; b) first ceased operating May 14, 1958; responded erratically May 22—June 5		a) ceased operating September 8, 1958
a) mercury batteries; b) 6 groups of solar converters	mercury batteries	chemical and solar batteries	mercury batteries
March 17, 1958 — (200 years)	March 26, 1958— June 27-29, 1958	May 15, 1958 —	July 26, 1958—
404	118	130	157
2465	1740	1167	1380
134.29	115.9	106	110
34.25°	33.37°	65°	50.13°
18,400	18,860	18,337	18,406
12,400	13,450	14,637	14,232


STRATIGRAPHER
MICROMETEOROLOGIST
PHOTOGRAPHER
GLACIOLOGIST
COSMOLOGIST
TECTON
AUROR
MINERALOGIST
GEOPHYSICIST
CHEMIST
ASTRONOMER
MECHANICAL ENGINEER
ELECTRONICS E
MICROPALEONTOLOGIST
BIOCHEMIST
ATOMIC PHYSICIST
OPTICAL PHYSICIST
METALLURGIST
SCIENCE WRITER
GEOMORPHOLOGIS
CHEMICAL ENGIN
HYDROELECTRIC ENGINEER
HYDROMETEOROLOGIST
CLIMATOLO
PHYSICIST
MICROP
VULCANOLOGIST
MICROSCOPIST
PALEOBOTANIST
EXPLOSIVES
ADIO ENGINEER
SPELEOLOGIST
RADAR T
SURVEYO
SPECTROSCOPIST
AERODYNAMICS ENGINEER
SOLAR PHYSICIST
RHEOLOG
ODESIST
MATHEMATICIAN
GEOCHEM
ENCE ADMINISTRATOR
IONOS
GRAVIMET
ASTROPH
ATMOS
MAGNETICIAN
CARTO
DRAFTSMAN
BOTANIST
TECHNICAL L
UPPER ATMOSPHERE PHYSI
PHOTOGRAMM