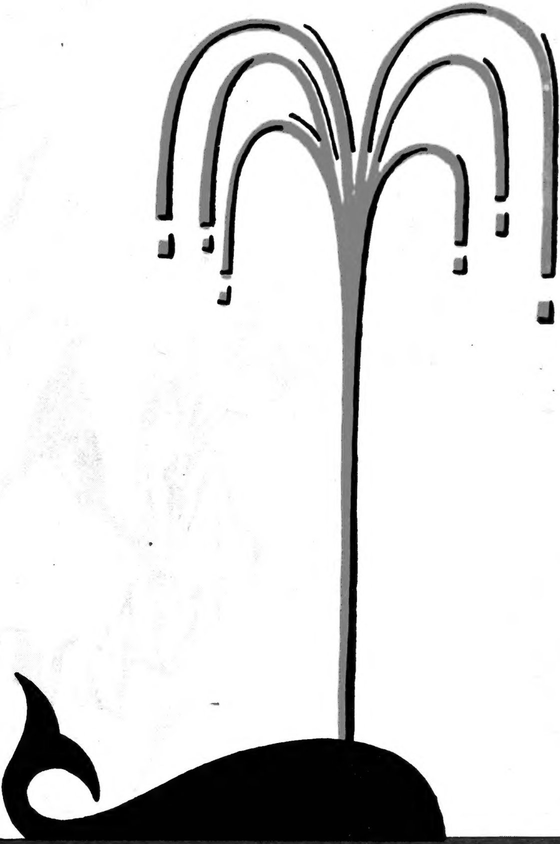

Science of the Seven Seas

by Henry Stommel

Fellow of Pierson College, Yale University

SCIENCE OF THE SEVEN SEAS

Henry Stommel

From John Masefield to Bobby Shaftoe and the three men who shipped out in a tub — the call of the sea has always been strong in all men, from boyhood on. To each it offers a different lure, but the pages of SCIENCE OF THE SEVEN SEAS reflect the sea in all her many moods and explain some of the natural wonders that always capture the imagination.

All — adult and youth alike — who dream of South Sea islands can learn about the formation of coral atolls, home of bright plumaged tropic birds, and strange volcanic islands which periodically sink beneath the ocean's surface, to rise again when some subterranean spasm shakes the earth.

Yachtsmen with a fondness for racing will be interested to know about "dead water" and its effect on ship's speed. Those yachtsmen whose preference is for stretching out on deck to admire cloud formations may learn which clouds are most apt to let go a sudden downpour that will dampen artistic appreciation.

SCIENCE OF THE SEVEN SEAS opens to view the hidden hills and valleys of the ocean floor — flashing with the cold lights of strange fishes that make their own electricity; rich with exotic plants known only to a few scientists; teeming with myriad tiny animals whose skeletons

(Continued on back flap)

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JM

James M. Moulton
VII/8/65

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C-H

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Envelope address:
766 Palmer Ave.
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March 10, 1975

Professor James M. Moulton
Department of Biology
Bowdoin College
Brunswick, Maine 04011

Dear Jim:

Thank you over so much for the kind invitation to give one of the Elliott Lectures at Bowdoin next Fall. I would like to do so, and would impulsively say yes, were it not for the grim fact that later on I would find myself committed, unprepared, and unable to give the kind of lecture that would be fun to give and listen to. I just know that it would work out that way, because of the heavy commitments that I have allowed to encumber me.

Another point worth considering is that there are several younger men whom I think could be more inspiring to your undergraduates - men who are making serious contributions to oceanography, going to sea, setting up and designing experiments - but who are nearer to the undergraduates by a score or so years - and whose ambience, identification with the audience, might make them more attractive speakers. And perhaps actually have a good deal more to say.

I think that you should consider asking Dr. James Luyten or Dr. William Schmitz at Woods Hole Oceanographic Institution.

I am grateful to you for the friendship which you have extended to Elijah. He is a serious student and pleasant person. Next Fall I think he will be spending a year at MIT as a special student before going back to Bowdoin in 1976-77 to finish up.

Hoping that you will accept my reasons......

Yours truly,

Henry

Henry Stommel

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The labor of preparing this little book was very much lightened by the kind cooperation of the staff of Cornell Maritime Press, in particular that of Miss Frances A. Neal.

HENRY STOMMEL

Introduction

The history of mankind is a story of adaptation of nature to man and man to nature. On land men have been remarkably successful in turning nature to their needs: they till the soil, dam up rivers, hew forests, blast mountains and harness many of nature's forces. But, as every mariner knows, this conquest of nature by man halts abruptly at the ocean shores.

In the ocean, nature reigns supreme. Man's ability to cross the oceans lies in his adaptation of himself to nature's whims. On the high seas man does not subjugate nature for, although he is tolerated upon its surface for a while, he is often crushed by its waves and its winds or smashed on its rocks and shoals.

There is a great challenge in the sea—a powerful urge which attracts and enslaves us—and there is happiness and companionship too, but we know that the sea is one domain which we must never dare hope to conquer. There will never be a successful mutiny against the sea.

Except for the small comforts of the ship, a voyage at sea presents a vast unbroken expanse of sea and sky. Poets often speak of the "vast waste of the sea" or "the silent void of the sky." They imply that sea and sky are great empty spaces because they do not see familiar objects in the waters or in the air. Actually, both sea and sky are far from being the dull, plain, uninteresting things that they at first may appear to be.

It is the purpose of this handbook to describe, list and explain some of the natural phenomena which may be observed at sea. Without being technical, we shall discuss many of the things that scientists have discovered about the sea and sky, and we shall touch upon such subjects as oceanography, geophysics, hydrodynamics, astronomy—all immense subjects in themselves.

No one science can claim a monopoly over sea and sky. For example, there are physical phenomena in the form of waves, ocean currents, chemistry of sea water, submarine topography and icebergs. Then there is also a great world of ocean life: myriads of marine animals and plants and sea birds. In ocean meteorology there are such things as cyclones, waterspouts, clouds, winds, St. Elmo's fire and sundogs. Under geophysics we will deal with submarine volcanoes, the tides and terrestrial magnetism. We draw upon astronomy to describe the sun, the moon, the stars and other mysteries of the night sky.

We commend to you, in this handbook, the results of many lifetimes of study and research, material gathered from all corners of the seven seas, and we hope that your interest in the strange antics of sea and sky will help while away many an otherwise empty, dull watch or evening ashore.

HENRY STOMMEL

Contents

Illustrations

The Sea

Waves

The waves of the ocean break on every shore. They pound the rock-bound coasts, grinding rock against rock, building reefs and bars; they toss mighty liners about at sea with ease. Sometimes they are smooth and gentle, sometimes high and rough—they have a thousand moods and tricks. What can science tell us about the waves?

WHAT CAUSES THE WAVES?

It is a matter of common knowledge that when a stone is dropped into a pool of water a circular pattern of little waves (or ripples) is set up which moves away from the center of disturbance. Physics tells us that the falling stone has given up part of its energy of motion to the water, and that it is this energy which causes the ripples to circle out and away from the spot where the stone fell.

Now, fortunately the waves of the ocean are not formed by falling stones. (They would have to be pretty big stones at that!) At sea the waves are produced by other disturbances such as the wind, or perhaps a submarine volcanic explosion or an earthquake on the ocean floor. But whatever the immediate cause, the water suddenly finds itself with an extra amount of energy which it gets rid of by sending out waves—a kind of "share the wealth" scheme. In short, when the water of the sea is disturbed by the wind, a passing ship, or an explosion, it has energy imparted to it. This surplus of energy is distributed over neighboring bodies of water by means of ocean waves, which, moving away from the center of disturbance, gradually are damped out and lose their energy in the form of heat through the friction resistance of one particle of water against another or against the ocean shores.

The experiment with the stone falling into the pond will convince you of another thing about waves; namely, the water does not move along with the waves! A piece of flotsam does not move much in the direction of the waves, neither does your ship. You encounter a large wave; it lifts you up, sets you down again, but does not carry you along with it as it would if the sea water moved along with it. The water stays put; the wave moves through it. A drifting boat progresses because it is pushed by the wind or is carried by a current or by the tide.

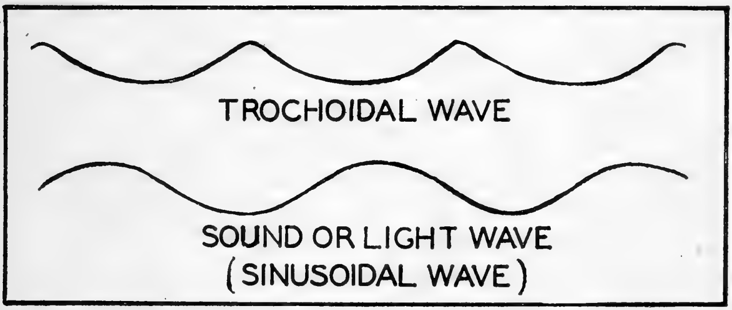
The best way to describe a wave scientifically is to say that it is a traveling disturbance which passes along the surface of the ocean, moving the particles of water around a little, but not actually carrying them along with it. In fact, during the passage of an ocean wave, the particles of water perform a kind of circular motion. As a wave approaches, the particle moves toward it in an upward swooping motion. Gradually it is raised and its direction of motion reversed until it moves along with the wave. Then it sinks and falls back into its original position, and the wave passes on.

A SUBMARINE AS A LABORATORY

In deep water the disturbance of water particles due to a passing ocean wave does not extend very far beneath the surface. Even when there is a considerable amount of wave motion on the surface, water some depth below may be quite calm. This fact is noticed particularly in a submerged submarine. During a heavy swell on the surface a submarine may experience no perceptible motion of the water. In certain scientific investigations at sea, such as the determination of the force of gravity by means of a delicate pendulum experiment, it is important to prevent the apparatus from being jarred. A submarine then provides an excellent place for a laboratory.

THE SHAPE OF A WAVE

The shape of an ocean wave may be approximately described by the curve that the mathematicians call a *trochoid*



(pronounced as in "TROlling for sharKs of cellulOID"). A trochoid is really quite a simple curve despite its peculiar sounding name. Suppose you put a spot upon a wheel and then roll the wheel along a plane in a straight line. The curve that the spot describes in space is a trochoid. Now it has been observed that ocean waves very nearly approximate such a shape.

Extensive studies have been made of the shape of water waves by measuring photographs taken of them at different angles in much the same way that the contours of a countryside are mapped from aerial reconnaissance photographs. The German exploring vessel *Meteor* has been particularly active along these lines, and has published an album of wave pictures, copies of which you may find in a large library. Such photographs show that although actual waves are often approximately the shape of the trochoid, they may often have extremely irregular shapes. We suppose that this irregularity is due to the fact that at sea there are usually many waves of different lengths and sizes, and that when they run together at random, odd shapes inevitably result. A good example of how much a simple wave motion may be modified by such a process of interference, as it is technically called, is to be seen in the "cross seas" where one train of waves crosses another at an angle. This phenomenon of interference that causes the irregularity of ocean swells is well worth reading about in an elementary physics text. It also causes such diverse phenomena as the throbbing of deep organ notes, the iridescent colors of oil on water, and contributes to the twinkling of stars.

Swells are usually started by the action of the wind, and may continue long after the wind that has caused them has died down. Of course, as we might expect, they always go a little slower than the wind which caused them.

HOW FAST DO WAVES TRAVEL?

Ocean waves travel at different speeds. There is a well established relation between their size and their speed. This relation is different for waves in deep water and those in shallow water. In deep water the speed of the waves depends upon their length (that is, the distance measured from the crest of one wave to the crest of the next). No matter how high the wave is, as long as its length remains about the same, its speed will remain constant.

A small table which gives the speed of deep sea waves for different wave lengths might go something like this:

Length in feet	*Velocity in knots*
1	1.1
5	2.4
10	3.8
50	4.5
100	10.8
150	13.3
200	15.3
300	18.7
400	21.6
500	24.2
1000	38.2
2000	48.4

Where the water is shallow in proportion to the length of an ocean wave this simple relation breaks down. As waves move into shallow water their velocity decreases.

Finally, when the water is too shallow, the lower particles of water are retarded by friction, the upper part becomes top-heavy and topples over to form breakers, or a "surf."

This change in the velocity of waves is to be seen on any sandy coast line. Far out at sea the waves follow one another in evenly spaced rows. As they approach the shallower water near the shore they slow down, crowd more closely together and finally break. In this way waves adapt their shapes to fit the shore.

Most of these results and many others can be treated theoretically. Hydrodynamics, that branch of theoretical physics which treats of the motion of fluid particles, is able to follow in almost complete mathematical detail the motions of fluid particles in a water wave simply by starting with such fundamental notions as Newton's laws of motion and the principle of the indestructibility of matter. However, in cases of turbulent motion, such as in a breaking wave or surf, ordinary methods of mathematical analysis are powerless. As a result it is impossible to give tables about breaking waves, or "undertow."

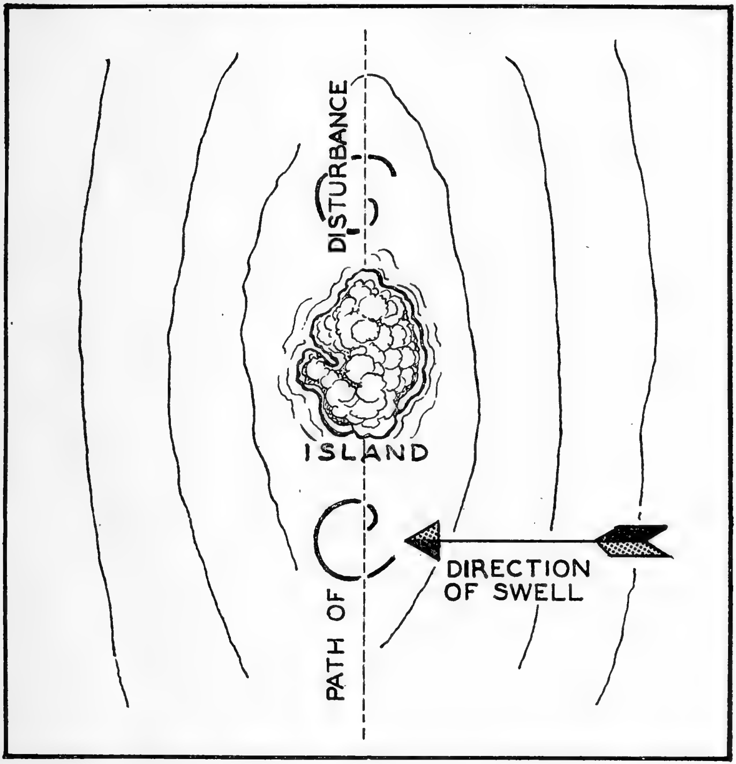
HOW BIG CAN A WAVE GET?

Landlubbers are often paralyzed with fear at the size of ocean waves. Sea stories make a point of describing "mountainous" or "towering" seas. During a severe storm at sea, ocean waves often do seem gigantic, and it is true that they can—and do—inflict terrible damage. However, it is a fact that the heights of waves at sea are often exaggerated. Observed wave heights seldom exceed 40 feet from trough to crest. In a severe hurricane, reports have been made of waves up to 100 feet high. Such exceptional heights are probably due to the sudden piling up, atop one another, of several wave peaks, building up for an instant into one huge mountain of water. Waves of this size, fortunately, are rarely encountered.

A strong wind, blowing for many hours, may build up a considerable sea. It is important to remember that the size of ocean waves depends not only upon the strength of the wind, but also upon the "fetch," that is, the distance to the windward shore.

WAVES AS AIDS TO NAVIGATION

After the wind has died down, the swells generally proceed in long parallel rows in a very orderly fashion. Their shape is altered, however, whenever they meet obstructions and they slow down when reaching shallow water. As everyone knows, one of the outward evidences of a shoal is the change in form and speed of the swells that encounter it.

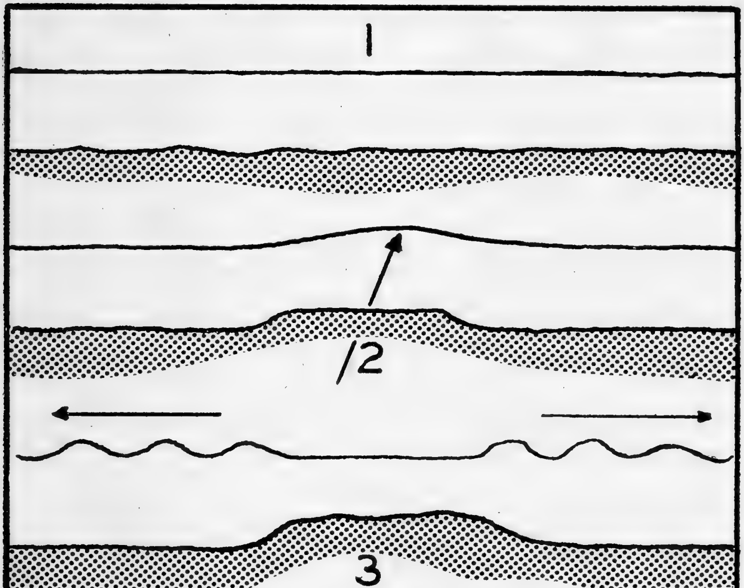


The change in shape of swells is observed in other ways as well. For example, when waves strike a vertical cliff, they are turned back upon themselves. Far offshore an experienced eye will detect these reflected swells riding back over the general swell and will recognize them as signs of danger ahead.

A small island in the sea tends to bend swells as shown in the illustration. This curving of swells is observable sometimes even when the island is beyond the horizon. A long, confused line of turbulent waters extends from the oceanic island at right angles to the direction of the swell. The early Polynesian navigators are said to have made use of this line of confused water. They would simply locate such a line, follow it directly, and would of course be led to the island. At night this line of turbulence is often visible as a broad, phosphorescent lane leading to the island. Similar modifications of wave-forms by land-masses will be met when we discuss the tides.

SUBMARINE EARTHQUAKES

Just as earthquakes occur on the land, they may occur on the ocean floor. Earthquakes are caused by the sudden release of huge stresses built up in the rock layers of the earth's crust. The sudden release of these stresses results in a slipping of the rock layers (called *faulting*) and violently shakes large areas of land or ocean bottom. The shock of the earthquake passes through the water at a speed of about 4500 feet per second. If the earthquake is a particularly violent one, the shock will be felt on shipboard just as though the ship had run aground on submerged rocks. Professor H. V. Sverdrup, an internationally known student of the ocean, has suggested that early navigators thought they had run aground when they felt such shocks. Old charts sometimes show "rocks" at places that we now know are thousands of feet deep. Submarine earthquakes have been known to rupture transoceanic cables. You may find it interesting to look through some older editions of *Coast Pilots* and to compare them with more modern editions. They contain warnings of all sorts of mysterious rocks and shoals which are now known not to exist.



WAVES PRODUCED BY UP-THRUST OF BOTTOM

TIDAL WAVES NOT RELATED TO TIDES

A severe submarine earthquake causes a "doming up" of the surface of the sea for a considerable area, and then huge so-called tidal waves diverge from the area in all directions and may cause great damage on near-by shores, flooding entire towns and drowning the populations. In one such disaster 100,000 lives were lost. A huge wave started near Lisbon in 1755, traveled all the way across the Atlantic and when it reached the West Indies was still almost 20 feet high.

A sudden collapse of a portion of the ocean floor would cause a dimple in the ocean's surface, a phenomenon which geologists suspect has happened at least twice in the China Sea. The dimple would be filled by a shrinking circular wave. Heaven help a ship in the middle!

Tidal waves are usually one hundred to two hundred miles in length—measured from one crest to the next—and several score feet high. On the open sea a ship might pass through a series of these waves without even noticing them because of their great length. Inasmuch as a tidal wave does not have anything to do with the tides, it is better to call it by another name. It is usually called *tsunami,* a Japanese word meaning *storm wave.*

OCEAN VOLCANOES

If you look at a map which shows where the world's volcanoes are located, you will see that most of them lie on the shores of the Pacific Ocean, and a smaller number are situated along a line extending from Java through India, through the Mediterranean up to Iceland. This would suggest that volcanoes are associated with the ocean and that some might lie beneath the surface of the ocean. As a matter of fact it has been established that the ocean floor does have volcanoes of its own and that these sometimes erupt. The molten lava and superheated gases coming into contact with the cold ocean water cause a tremendous explosion. Hot gases and vapor break through the surface of the sea, and would certainly annihilate any ship unfortunate enough to be caught in it. It is possible that some of the mysterious disappearances of ships "lost at sea" can be attributed to such fearful natural phenomena as submarine earthquakes and volcanoes. As it is, we know that fish and other marine animals are destroyed in great numbers.

AN ISLAND EXPLODES

Krakatao is an island in the Sunda Straits between Sumatra and Java. On the 26th and 27th of August, 1883, this island exploded with the loudest noise that has ever been heard in our world. Even a week before the terrible explosion there was considerable volcanic activity. A ship which approached the Straits on the 21st recorded: "Stood south for 12 hours and then came north again, but found things getting worse. Accordingly, stood south once more until the storm settled. All one day it was as dark as the grave and pumice stones and ashes were still coming down. On getting to the straights we came through a bank of ashes and could only force the ship through at one-half knot. When once I got into clear water I was all the remainder of the day sailing through dead bodies of men and women." Another ship got through the Straits to Batavia covered with ashes and claimed that it had passed through areas of sea covered with 7 feet of pumice. Both of these ships were very fortunate, inasmuch as all other abodes of the living near the Straits on the 26th and 27th were utterly destroyed by the explosion . . . lighthouses and all.

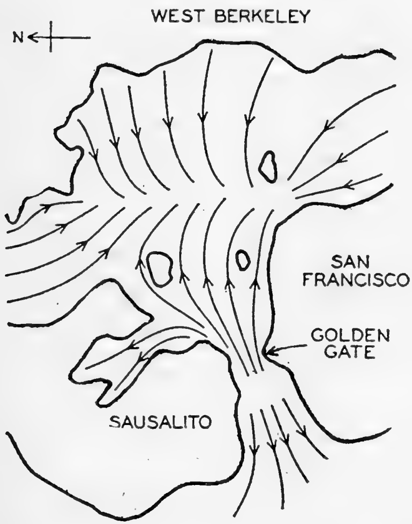
The noise of the explosion of Krakatao was heard 3000 miles away at the Rodrigues. A wave 100 feet in height was set up which swept away 36,000 unhappy souls and traveled all the way around the Cape of Good Hope to the English Channel—a distance of more than 14,000 miles! Before the explosion the island possessed a mountain peak 2600 feet high; after the disaster the island was leveled to the sea; indeed much of the violence of the explosion is supposed to have been due to the flowing of the sea into the incandescent crater of the volcano. For years after the explosion the dust from it remained in the upper air, causing gorgeous red sunsets all around the world.

CALMS AND RIPPLES

There is scarcely a day when the water is so calm that there are not some waves visible. The lightest breath of air gives rise to small waves called ripples. The physical mechanism of the smallest waves is somewhat different from that of the larger ocean waves inasmuch as it is mostly controlled by the surface tension of the topmost layer of water. Their shape is unlike their bigger brothers. They have a so-called sinusoidal shape instead of a trochoidal one. (See illustration on page 5.) Ripples are produced by the wind. They give warning of a squall or gust of wind. The sailor is warned of a squall while it is still a good distance off by the appearance of a confusion of ripples moving rapidly toward him.

WATER VIBRATIONS

Almost all objects may be made to vibrate. When you strike a bell or pluck a stringed instrument you get a particular sound. The pitch and other characteristics of the sound produced depend upon the way the bell or string vibrates when struck. Because different objects have certain preferred ways of vibrating we can obtain definite tones. As a matter of fact all things have certain preferred ways of vibrating. It was this property which was allegedly used by Caruso to break wine glasses with his voice alone. He simply sang the note which the wine glass preferred. The glass trembled and vibrated so violently that it is supposed to have shattered. Bodies of water (lakes and bays) exhibit the same phenomenon. Their water tends to vibrate in certain definite periods,

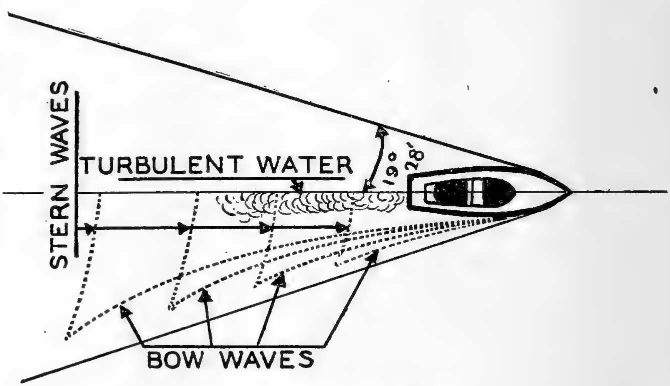


Oscillation with three nodes in San Francisco Bay, according to experiments by Honda, Terada, Yoshida, and Isitani.

the waves being called *seiches* (pronounced "say-shes"). The periods of these waves depend upon the size of the lake or bay just as the tone of a bell depends upon its size. A large bay tends to exhibit long period seiches; a small bay, shorter period vibrations. A good example of this kind of wave motion is to be found in San Francisco Bay, California, where the bay vibrates in three separate parts every 43 minutes.

A SHIP'S WAKE

In many respects a ship is like a floating wedge which, in order to move, must force itself through the water by the work of its screws or the labor of its sails. It takes energy to push a ship through the ocean water. Part of this energy goes into frictional losses where the water layers slip past the hull;



SHIP'S WAKE

more is used up in overcoming the pressure of water that is piled up at the stem by the motion of the ship; a good proportion is also lost in the waves the ship produces, the *wake*.

The waves that make up the wake are of two kinds: (1) bow waves, extending from the bow of the ship aft, slightly concave forward, and (2) stern waves, which are directly behind the ship, slightly convex forward, and which move along with the vessel. The bow waves are always at an angle of about 19½° with the fore and aft line of the ship. This is a surprising fact because it would seem natural to expect the angle to be sharper the faster the ship moved. Yet the theoretical study of ship's waves shows clearly that this angle

Official U.S. Navy Photo

PT traveling in the wake of a sister ship. Stern waves can be seen radiating from wake.

must always remain constant and independent of the vessel's speed.

Directly following the rudder and screw, the water will be observed to be in a very disturbed state, another example of turbulent fluid motion. Under certain circumstances the first stern wave appears so large that it seems almost threatening—as for example when observed from the fantail of a destroyer at full speed. A following or stern wave may be dangerous if it breaks aboard, "poops." Sudden loss of way will cause the wave to run aboard, swamping the vessel.

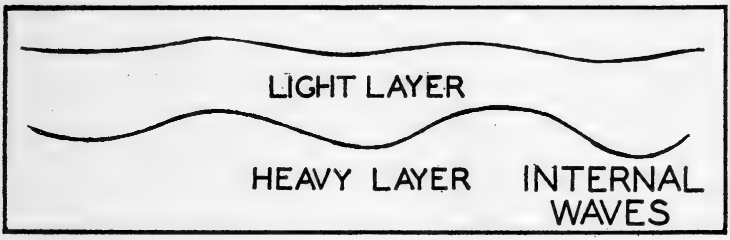
Official U.S. Navy Photo

The wake of a ship. This picture shows the bow waves very well, but does not show the stern waves adequately. The stern waves are largely obscured by the turbulence of the wake.

It is interesting to remember as you stand at the stern rail and watch the snowy rushes of foam extending wide to the distant horizon that all the energy for those waves has been supplied at the expense of fuel consumed in your engines. As far as propelling the ship is concerned, the wake represents lost energy.

"DEAD WATER"—WAVES WITHIN WAVES

A variation on this theme is the phenomenon which arises when the ship happens to be passing through a portion of the ocean where there is a surface layer of water of subnormal density of a thickness about equal to the draft of the ship. The layer of water may simply be fresher water from melting ice, or from the mouth of a near-by river, and should the sea be moderately calm there may be a sharp boundary between the fresher water floating on top and the denser salt water below (much as oil floats on the surface of a body of



water). Should conditions be favorable, *internal* waves may be set up between the two liquid layers, and grow to fairly large size, although they are not visible on the surface at all. Internal waves are waves between the two liquid layers instead of being on the surface between the water and air like ordinary waves. Such waves are a serious drain on the energy of the ship and as a result the ship will make little headway. It will seem to be "stuck" in the water. In the old days of sailing ships, sea captains often experienced this phenomenon—in a stiff breeze their ships barely crept along—and without divining the cause they called it "dead water."

The Ocean Bottom

Professor: "And what would you expect to find on the bottom of the sea?"
Student: "Mud, refuse, sir, and fine sentiments."

We now descend to the bottom of the ocean to explore Davy Jones's locker. It will be well to bring along a light because the lower reaches of the ocean are in perpetual darkness. Below a depth of a hundred fathoms there is virtually no light at all.

The ocean floor is by no means as unexplored and mysterious as one might at first suppose. Doubtless there are many secrets still hidden from us—not only such obvious things as sunken treasure galleons, but also objects of scientific interest as yet unknown to us. There may be hidden natural resources, minerals, petroleum fields, the remains of sunken cities. Imagine the thrill of the first archeologist who drops in a diving bell into the sunken city of Atlantis!

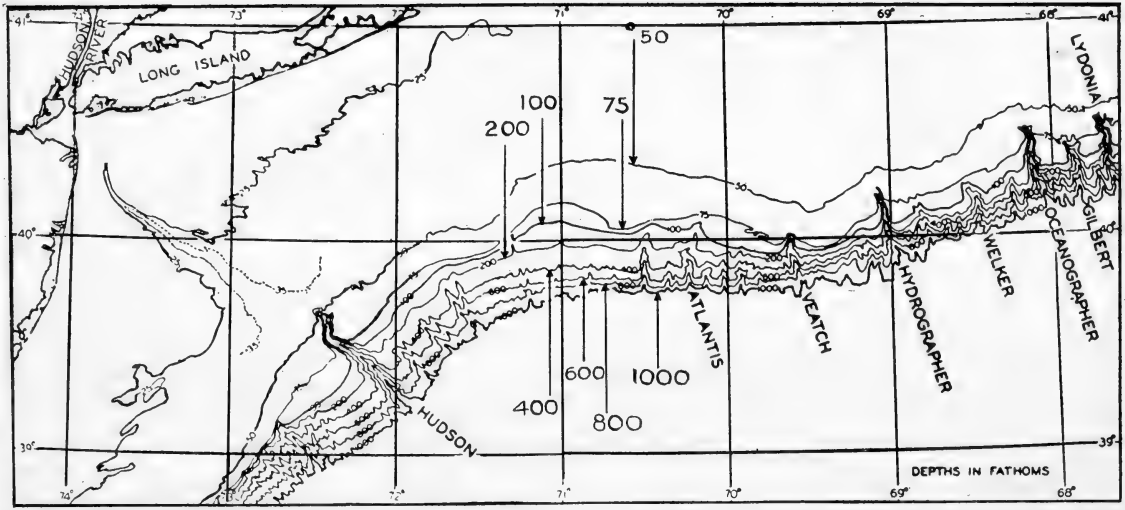
There may be prehistoric animals we think are long extinct still swimming about in the ocean's depths. *Crossopterygia,* a fish supposed to be extinct two hundred million years ago, was caught off the mouth of the Congo a few years ago. Lt. Comdr. R. T. Gould, R.N., has pointed out that the number of sworn statements confirming eye witness observations of "sea serpents" is so large, and the accounts so consistent, that there may well be more to the stories of a monster of the seas than is generally supposed. The general run of landsmen have come to regard seafarers as habitual exaggerators or liars, so that they immediately discount any mention of a sea serpent. This public feeling of skepticism even prevents sailors from speaking about their experiences with unusual happenings at sea.

Who knows but that there may still be species in the ocean deeps that have successfully eluded all our hooks, nets and trawls?

Apart from these speculations about the ocean bottom, there is a definite body of scientific knowledge. It is concerned mainly with the mapping of the ocean bottom and the nature of the material of which it is composed. The scientific study of the form of the ocean floor is called submarine topography.

LAND BENEATH THE SEA

Regions of the ocean floor are classified according to depth. Along the shores of the world's continents there are relatively shallow regions whose depths reach about 100 fathoms. These regions are really extensions of the continental land masses that happen to be submerged by the ocean. They are called continental shelves and in some places extend for long distances beneath the surface of the ocean. Siberia and Alaska are connected by a broad belt of submerged land nowhere deeper than 100 fathoms. This belt conceivably may be the land, then above water, over which some scientists believe men first came to the North American continent—the forefathers of the American Indian. The eastern coasts of North America have extensive continental shelves which provide fine fishing banks. The British Isles are connected with the European mainland by a continental shelf. Such connec-



Topography of the shelf and slope off part of the eastern coast of the United States showing different types of submarine canyons. The Hudson Canyon can be traced far across the shelf; others, such as the Lydonia, Oceanographer, and Hydrographer Canyons, cut into the outer margin of the shelf, while others are restricted to the slope itself. Depth contours in fathoms. (Simplified from chart in Veatch and Smith, 1939.)

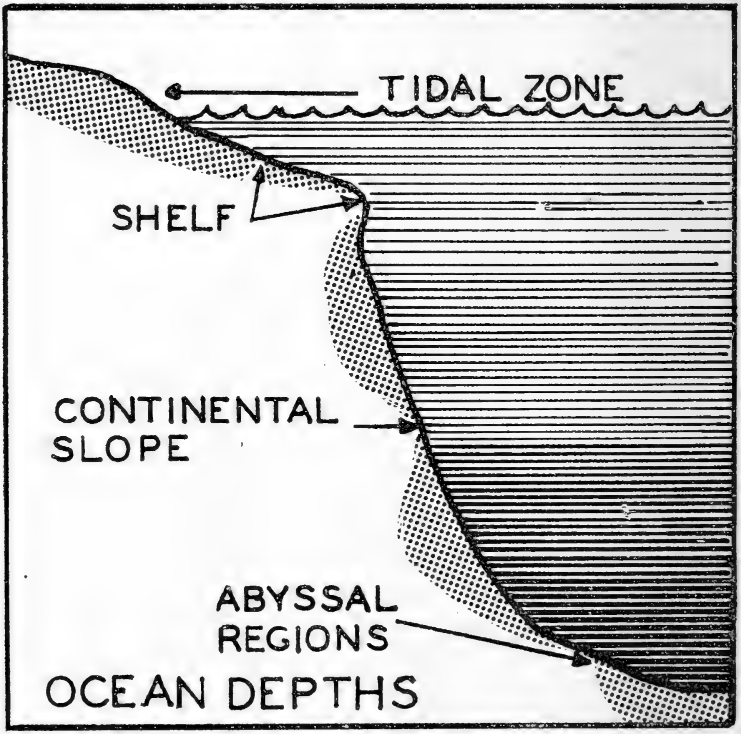
tions also exist between Australia and New Guinea; and between the Malay Peninsula, Sumatra, Java and Borneo. To trace continental shelves and other features of submarine topography a *bathymetric chart of the world oceans* will be found useful. A very small scale chart is provided on page 22. The word "bathymetric" comes from the Greek word "bathos" meaning great depth, and the ending "metric" meaning measure. Bathymetry (pronounced: "Saturday night BATHs In all likelihood preceded a science like geoMETRY") is the study and measuring of great ocean depths.

HOW DEEP IS THE OCEAN?

A favorite question of old time oracles, sphinxes, and riddle-makers was "How deep is the sea?" Now many of the questions asked by those old timers have never been answered. But the one about the depth of the sea has an answer supplied by the science of oceanography. Oceanography (pronounced: "OCEANs are studied in geOGRAPHY"), by the way, is the overall term used to cover all branches of the science of the sea. It includes marine biology, the study of ocean currents, water masses, physics and chemistry of sea water, in much the same way as the words Federal Government cover the President, Congress, and the Supreme Court.

But to return to the riddle: "How deep is the sea?"

At the outer bounds of the continental shelf you will find that the depths fall off rapidly from 100 to 1000 fathoms. This region is called the continental slope. It is the beginning of the true ocean depression. Depths greater than 1000 fathoms are called abyssal regions, and they make up the bulk of the ocean. Regions below 3000 fathoms are called *deeps*. Each deep has a name of its own such as "Jeffreys Deep," "Brooke Deep." The greatest depth that has ever been sounded is off Mindanao in the Philippines, 5736 fathoms. The deepest part



of the Atlantic is north of Puerto Rico, about 5230 fathoms. Ocean deeps are not very numerous and their combined areas are small compared to that of the entire ocean. A glance at a bathymetric chart shows that the greatest part of the ocean is over a thousand fathoms deep, that is about one nautical mile straight down. (One nautical mile is only slightly greater than 1000 fathoms, 1013.7 to be exact.) The chart will also show such interesting features as the Atlantic Ridge which extends down the middle of the Atlantic Ocean; the water here is much shallower than in the surrounding regions. The Azores, St. Paul Rocks, Ascension Island, and Tristan da Cunha are all parts of the ridge which extend above the surface. Another interesting ridge is the Telegraph Plateau, extending from England to Newfoundland, the resting place of several transoceanic telegraph cables.

HOW THE OCEAN BOTTOM LOOKS

It is likely that not many readers have strolled about on the ocean floor, so that they may not be familiar with its appearance. Such first hand experience is neither necessary nor possible at present (at least for the greatest depths) and so we must content ourselves with what we can find out about the bottom by dredging, or employing deep sea snappers. The snappers are shaped like a clam shell with two cup-like halves. Upon touching the bottom a powerful spring snaps the jaws shut and a sample of the bottom is enclosed.

Still another device for sampling the bottom is a coring tube. It is merely a hollow tube which is lowered until it hits the bottom in an upright position. A charge of explosive then drives it into the bottom, forcing a considerable length of the bottom up into the tube. The sample is then hauled aboard. When the tube is opened the bottom is in its actual form, layer by layer. With gadgets such as these the nature of the bottom is studied by oceanographers. For shallow water the tallow on the hand lead may be relied upon to bring up a small sample of the bottom.

Near the shores of the continents, the bottom is disturbed by the incessant movement of the sea water, the lashing of the waves, and currents. The bottom is covered with earth

A portion of the ocean bottom showing ripples presumably formed by subsurface currents.

deposits—mud, sand, gravel, and other materials which were washed down there from the land, and coral muds and sands. An ordinary navigation chart shows what types of deposits are to be found near the land. They are indicated by abbreviations that have come more or less into general use:

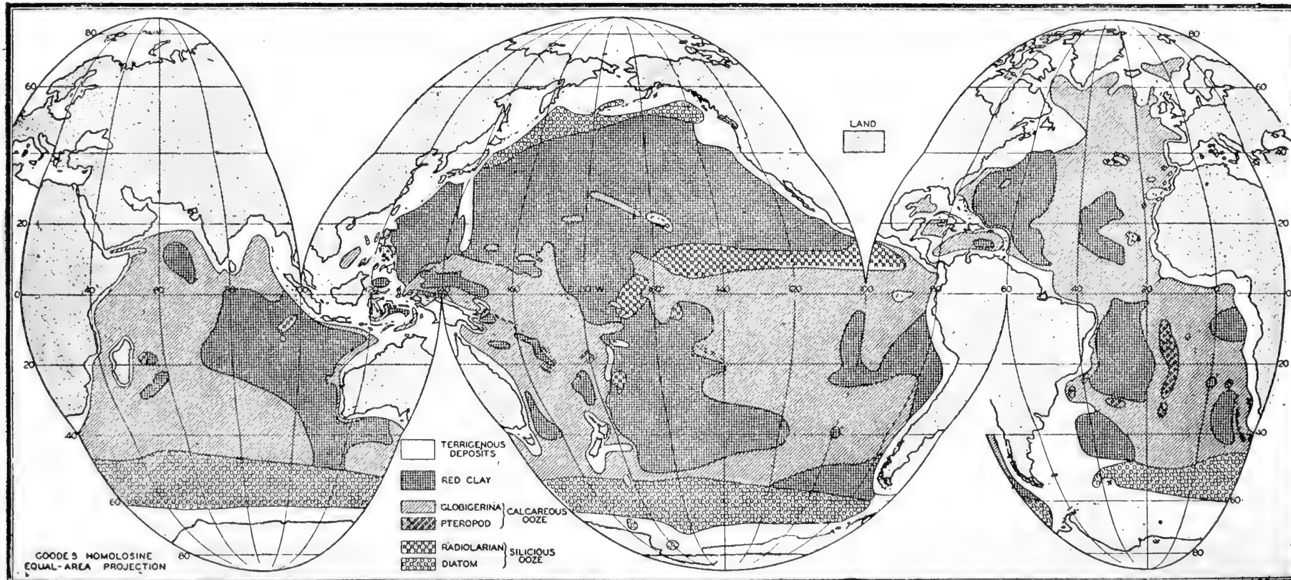
TYPES OF BOTTOM IN SHALLOW WATER

Clay	Cl.	Fine	fne.
Coral	Co.	Coarse	crs.
Gravel	G.	Stiff	stf.
Mud	M.	Soft	sft.
Rocky	rky.	Black	bk.
Sand	S.	Red	rd.
Shells	Sh.	Yellow	yl.
Stones	St.	Gray	gy.
Weed	Wd.		

Beyond the 100 fathom mark, however, is another zone where the action of waves does not penetrate, and where currents are slight. Here the sea bottom remains unchanged for ages. The deeper parts of the ocean are covered with deep sea oozes or red clay. They have been accumulating for long periods of time, periods not measured in centuries, but in hundreds of centuries.

OODLES O' OOZE

The deep sea oozes are the slimy remains of myriads of tiny sea animals and plants whose dead bodies are always raining down from their home at the surface into the darkness of the depths below. These small floating beings are collectively called *plankton* and are by far the most numerous of all forms of ocean life. A fine net dragged through the sea will catch large quantities of them. They provide the basic diet for larger ocean animals, and as a matter of fact are edible for humans as well. Depending upon the kind of ani-



Distribution of the various types of pelagic sediments.

mal or plant which predominates in the surface layers of the ocean, the oozes on the ocean floor will be of different kinds. Ordinarily we recognize four varieties of ooze: Diatom ooze; Globigerina ooze, Pteropod ooze and Radiolarian ooze. It is unfortunate that such little creatures should have such big names. It seems to be the way of the biological world—but even though they are Greek to most ordinary mortals, such terms are quite descriptive to the biologist. They are pronounced as follows:

Diatom: "DIet is A cruelty to the sTOMach."

Globigerina: "GLOBal strategy Is to keep GERmany IN An unarmed state."

Pteropod: "TEAR Old peas from the PODs."

Radiolarian: "RADIO, tooL of the totalitARIAN!"

These, then, are the creatures who, when alive, frolic and swim through all the seven seas, and who, when overtaken by old age and death, fall to the ocean bottom to become part of the eternal ooze.

Diatoms are microscopic plants abounding in the polar seas. They develop delicate cases of silica—the same substance of which sand and quartz are made. When the tiny diatoms die the plant tissue soon decays, but the silica cases are made of tougher stuff and fall slowly to the bottom to form diatom ooze. Diatom ooze is predominant on the floor of the Antarctic Ocean and also is found in a narrow belt south of the Aleutians extending from Canada to Northern Japan.

Radiolarians are minute animals with very intricate skeletons of silica; their accumulated skeletons make up the radiolarian ooze which predominates in the tropical regions of the eastern portions of the Pacific and Indian Oceans.

Both diatom and radiolarian oozes are made of silica. Animals with calcareous (chalky) shells form globigerina and pteropod oozes. Globigerina have spherical shells and thousands of tiny hairlike appendages which make them appear like Christmas tree decorations. The ooze they form is the principal constituent of the floor of the Atlantic Ocean and covers large areas in other oceans as well. Globigerina ooze covers as large an area of the ocean floor as the area of all the dry land of the world.

Pteropods are little swimming snails commonly called "sea butterflies." Pteropod ooze is less abundant than other varieties of ooze, is found in shallower water than globigerina and is generally located near the Equator.

The deepest parts of the ocean are not covered with ooze because in passing through such great extents of ocean water all the tiny skeletons and shells are completely dissolved. One substance that can survive the long trip down is volcanic dust, shot up into the atmosphere by a volcanic eruption, and later settling into the sea. Wind-blown dust from the world's great deserts also finds its way to the ocean floor. It collects in the abyssal regions to form a red clay. Thus the deeper parts of the ocean—particularly in the Pacific Ocean—are floored with a true red clay. The rate at which the sediments under the open sea form is extremely slow—less than one-half inch in a thousand years.

GLOBAL JUNKYARD

The depths of the ocean act as a kind of junk heap for other things as well. The oceanographer is not much surprised to find side by side in one haul the tooth of a prehistoric shark, cinders dropped from a steamer long ago, a piece of meteoric iron from outer space, perhaps stones and rocks from a distant continent carried there on a melting iceberg, and sand dust from the Sahara.

The pressure in the ocean deeps is over 10,000 pounds per square inch. Although pressures of this amount are tremendous, physicists at Harvard have produced far greater pressures in their laboratories.

The great pressure at these depths compresses the sea water somewhat, increasing its density. However, the increase is not significant and cannot prevent heavy objects from sinking all the way to the bottom. Sailors are fond of arguing about how far things will sink, whether it concerns a sinking wreck or a burial at sea. Let it be said, therefore, once and for all, that if an object is heavy enough to sink beneath the surface, it is heavy enough to sink all the way down. There is no reason to suppose that the derelicts of bygone days, and the corpses of shipwrecked sailors are floating about in some eerie intermediate zone of the ocean between top and bottom.

Large objects of similar density tend to sink faster than small ones! This is because they offer less resistance *in proportion to their weight,* than do small ones. A grain of coarse sand would fall a foot through water in about one second, whereas fine clay particles would take half a year to settle the same distance. At this rate it must have taken the fine clay particles from the deepest ocean deposits 15,000 years to sink from the surface to the bottom, yet even these particles reach the bottom.

The Nature of Sea Water

There is always a punster on board every ship . . . the kind who pulls sadistic practical jokes, gives people the "hot foot," or asks stupid riddles. I remember one who once asked us at mess: ". . . and what is the chief constituent of blue ink?"

"Tannin?" asked the skipper.

"Nope."

"Ferric ferrocyanide?" queried a more learned shipmate.

"Nope."

"Red dye, I suppose."

"No, give up?" There was a grumbled assent.

"Water!" he cried, and fell back in gales of solitary laughter.

The chemical constitution of sea water is very complex, containing most of the known chemical elements to greater or less degree. But, of course, the chief constituent is just ordinary water. There are so many different elements and complex ions present that it is impossible to manufacture perfect artificial sea water in the laboratory. Good formulas have been developed but artificial water can always be distinguished from the real stuff.

CHEMISTRY OF SEA WATER

When sea water evaporates it leaves a whitish residue. This is the obvious evidence that there are dissolved substances in it. The chemical elements present in the sea are pretty well known. The accompanying table gives the percentage of different chemical elements present in a typical sample of sea water. We do not include the hydrogen and oxygen that make up the water itself. As you will see, sodium and chlorine make up the largest portion of the impurities in sea water. Together they form sodium chloride—ordinary salt—but there are smaller quantities of other elements which are combined to form many complex substances and ions.

TABLE OF ELEMENTS IN SEA WATER

(dissolved gases excluded)

Chlorine	1.898%	Strontium	0.0013	Phosphorus	0.00001 max.
Sodium	1.056	Boron	0.00046	Barium	0.000005
Magnesium	0.127	Silicon	0.00040 max.	Iodine	0.000005
Sulphur	0.088	Fluorine	0.00014	Arsenic	0.000002 max.
Calcium	0.040	Nitrogen	0.00007 max.	Iron	0.000002 max.
Potassium	0.038	Aluminum	0.00005	Manganese	0.000001 max.
Bromine	0.0065	Rubidium	0.00002	Copper	0.000001 max.
Carbon	0.0028	Lithium	0.00001		

plus the following:

0.0000005% to 0.00000005% zinc, lead, selenium, cesium, uranium, molybdenum.

0.00000004% to 0.000000003% thorium, cerium, silver, vanadium, lanthanum, yttrium, nickel, scandium, mercury.

0.0000000006% gold.

0.000000000000003% radium.

plus tiny traces of cadmium, chromium, cobalt and tin.

In practical oceanography many analyses are made of ocean water, but few are made in such a detailed form as given above. Instead, a crude kind of determination is usually made by mixing a sample of sea water with standard silver nitrate solution, using potassium chromate as an indicator. The silver solution is poured into a sample of sea water by means of a burette (measuring tube). When the solution first becomes red the burette is turned off and the percentage of salinity is read directly from its scale. Special apparatus and standard solutions for this purpose are available through most chemical supply houses. Also available are hydrometers for salinity determination. Another instrument used is an electrical conductivity apparatus which determines the amount of salt in a sample of sea water by measuring the amount of current which can pass through the solution. This latter type of apparatus is somewhat more expensive than the hydrometers or chemical solutions.

CHANGES IN COMPOSITION OF THE SEA

One of the remarkable aspects of ocean water chemistry is the fact that although the major constituents of sea water may be present in greater or lesser quantities (that is, the water may be more or less salty), the ratio of the constituents among themselves is almost always the same. Another way of putting it is to say that although the absolute proportions of the dissolved substances in sea water vary considerably, the relative proportions are remarkably constant.

There are some important exceptions to this rule, such as the proportions of such elements as silica, phosphorus, and combined nitrogen, which vary considerably depending upon locality and season. The reason for these exceptions to the rule is that they are necessary elements for the life processes of living plankton (the tiny floating animals of the sea) and are absorbed in large quantities from one time to another and at other times are redeposited. The balance of such substances is of the utmost importance in controlling the cycles of life that occur in the sea, and plays a significant role as a primary factor in the biological environment. Much study and work has been done by oceanographers in the correlation of the chemical properties of sea water and the abundance of certain forms of sea life, both as functions of locality and time of year. Such studies have a commercial importance (for fishermen and oyster farmers), as well as a purely scientific interest.

LIVING CHEMICAL FACTORIES

Among the fascinating processes of nature is the way that living organisms are able to concentrate certain chemical elements within their bodies. An example is the way that the human organism concentrates iron in the blood hemoglobin. Marine organisms are very versatile in this respect, some concentrating iron, calcium, silica, copper, boron, iodine, strontium, even arsenic! Some marine plants have a mysterious way of collecting iodine from the sea—as a matter of fact, seaweeds gathered on the shores and chemically treated are the commercial source of iodine. If the seaweeds did not perform the preliminary task of separating the iodine from the sea water, we would have a very difficult task obtaining it ourselves.

Similarly, calcium is concentrated by shellfish; phosphorus by brachiopods; silica by diatoms; strontium by some animals who seem to prefer it for their bones in place of calcium. Copper is apparently essential for the oyster; potassium for certain algae. Radioactive elements including radium—as rare as they are in sea water—are concentrated by sea animals about 100 times.

The table of elements present in sea water which was given above does not contain reference to dissolved gases which may be present in it; but they may be present in considerable amounts, particularly nitrogen, carbon dioxide, and oxygen. In the depths of the Black Sea there is hydrogen sulphide, a poisonous gas which suppresses life except in the uppermost layers of that body of water. No animals or plants can exist in the lower reaches of the Black Sea.

The fluids of our bodies are very similar in composition to sea water. In fact, salt water is sometimes used for transfusions when blood of the correct type is not available. The similarity is part of the evidence that all living beings, humans included, are descended from marine animals of a remote epoch. Sea water is not a good beverage, however, because prolonged drinking of it tends to concentrate too much salt in the body. Too much salt (by a process called osmosis) tends to shrink the cells of the body tissues, resulting in severe illness or death.

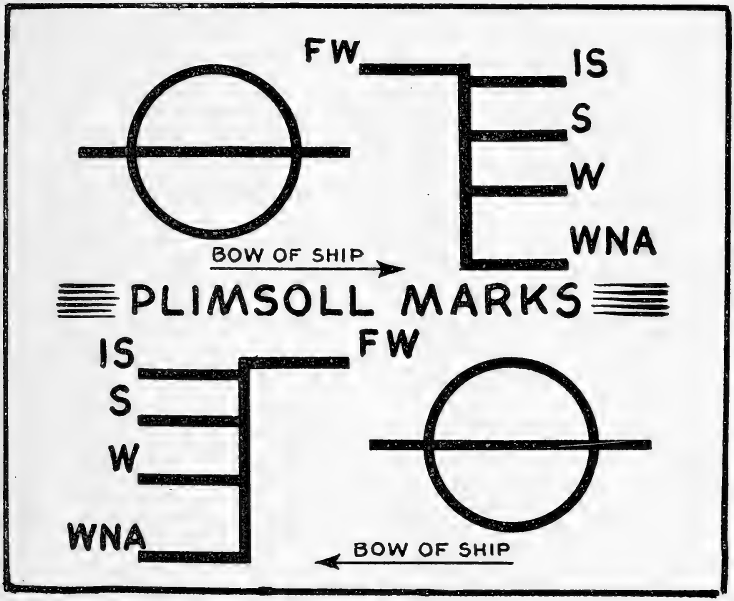
WHERE DID THE SALT COME FROM?

All the salt in the sea is supposed to have originated in rocks and minerals from which it has been leached by countless rains for millions of years. In addition, quantities of chlorides and fluorides may have been supplied by volcanic vents. The story of the little salt mill that could not be stopped is in scientific disrepute. Nevertheless, the total amount of salt in the sea is very great—so much that if it were dried out, it would cover all the present dry land to a uniform depth of 500 feet. It is difficult to imagine so much salt as that being washed out of the earth even after millions of years.

DOES SALT IN WATER HELP THINGS TO FLOAT?

It is common knowledge that objects float more easily in salt water than in fresh water. Swimmers frequently experience greater ease in swimming in salt water than in fresh water.

Ocean liners are buoyed up differently (that is, have a different water line) in different bodies of water. By international agreement (International Load Line Convention, 1930) vessels of 150 gross tons or over must have load lines painted on their hulls. This line represents the maximum safe draft of the vessel. There are usually different lines for different bodies of water because of their different densities.



Plimsoll marks appear on each side of hull. Abbreviations mean

FW	*Fresh water*	*S*	*Summer*
IS	*Indian Ocean, summer*	*W*	*Winter*
WNA	*Winter North Atlantic*		

The physical law of floating is that the buoyant force exerted upon a ship is equal to the weight of the water displaced. Salt water, being denser than fresh water, weighs more for a given volume and hence exerts a greater buoyant force. The law is said to have been first discovered by the ancient Greek mathematician, Archimedes (287-212 B.C.). He discovered the law while in the bath, and in his delight ran home naked shouting "Eureka! Eureka!" Besides having accomplished his fundamental theoretical work in hydraulics, Archimedes was quite a hand at practical matters. He invented machines to use against the Romans in the siege of Syracuse. He built long range catapults (early "flame throwers") for throwing fiery brands into enemy ships, machines for discharging volleys of arrows through openings in the walls, long movable poles that projected out over the water and dropped heavy weights on the enemy's vessels. One machine could grapple a vessel with an iron hook, lift it up partly out of the water, and then drop it again.

The enemy leader, Marcellus, chided his own engineers with the following remarks:

"Shall we not make an end of fighting against this geometrical Briareus, who uses our ships as cups to ladle water from the sea, drives off our sambuca ignominiously with cudgel-blows and, by the multitude of missiles that he hurls at us all at once, outdoes the hundred-handed giants of mythology?"

Archimedes met his death on the seashore while making a geometrical diagram in the sand. A conquering Roman soldier approached him, Archimedes told him to stand aside out of the sunlight, at which the soldier became so incensed that he drew his sword and slew the old mathematician.

THE COLOR OF SEA WATER

Sea water exhibits a deep blue color in deep regions, a lighter greenish blue in shallow regions of the ocean. The blue color is supposed to be caused by tiny particles scattering the light of the sun, and since they are very small they scatter the blue light more than the other visible colors. In shallow regions the bottom itself reflects up some light and this plus the blue gives a greenish hue. At other times the ocean is colored a deep brown or even a vermilion red by colloidally suspended mud or by the presence of dinoflagellates as in the Red Sea and the Gulf of California. Dinoflagellates are simple little one-celled creatures possessing intricate cellulose cases, and two little hairs (called flagella) by which they move.

On a dark night aboard ship you may note that the bow spray of your ship shines brightly. The phenomenon is generally spoken of as "phosphorescence of the sea" though it really has nothing to do with the tiny amount of phosphorus present in sea water. It is better to call it "bioluminescence" inasmuch as it is light produced by myriads of tiny sea organisms. The glow is due mainly to the presence of the tiny dinoflagellates (Ceratium and Noctiluca, et al.). Since they are particularly abundant in warm water, sea luminescence is found most often in the tropics.

FISH WITH "FLASHLIGHTS"

Some animals produce a luminescent slime which they secrete over their bodies giving them a brilliant glowing appearance. One variety of squid is capable of squirting out a bright fiery cloud. He lives in the dark nether regions of the ocean where the inky cloud that most squids eject would be of little use to him. Still other animals are provided with specially developed light organs—almost like little headlights—complete to reflectors, lenses and all!

The process by which this light is produced appears to be the slow burning of a chemical substance called luciferin. The reaction is peculiar because light is given off rather than heat, as is the case in most chemical reactions.

An experiment that you may perform, which duplicates to a certain extent the natural process of bioluminescence, is included here. Get two jars. Fill one jar half full of water, add a tiny pinch of sodium hydroxide; then stir in carefully a very small trace (about as much as will cover the end of a matchstick) of Luminol (not to be confused with the sleeping medicine luminal) which you can obtain from any chemical supply house. In the second jar place some crystals of potassium ferricyanide, and fill the jar half full with hydrogen peroxide (the 3% kind that platinum blondes use). Let the solutions stand for about one minute. Then, in a darkened room, empty the contents of the first jar into the second. There will be a bright flash of "cold" light, and the liquid will remain luminescent for many minutes. A very weird effect is produced as you pour the bright liquid from one container to another in the dark.

Just why sea animals light themselves up in such a spectacular way is not completely understood; however it is evident that some are able to attract food into their mouths by use of the light, whereas other fish actually use the light to help them see around in the darkness of the ocean depths, just as divers use an electric torch.

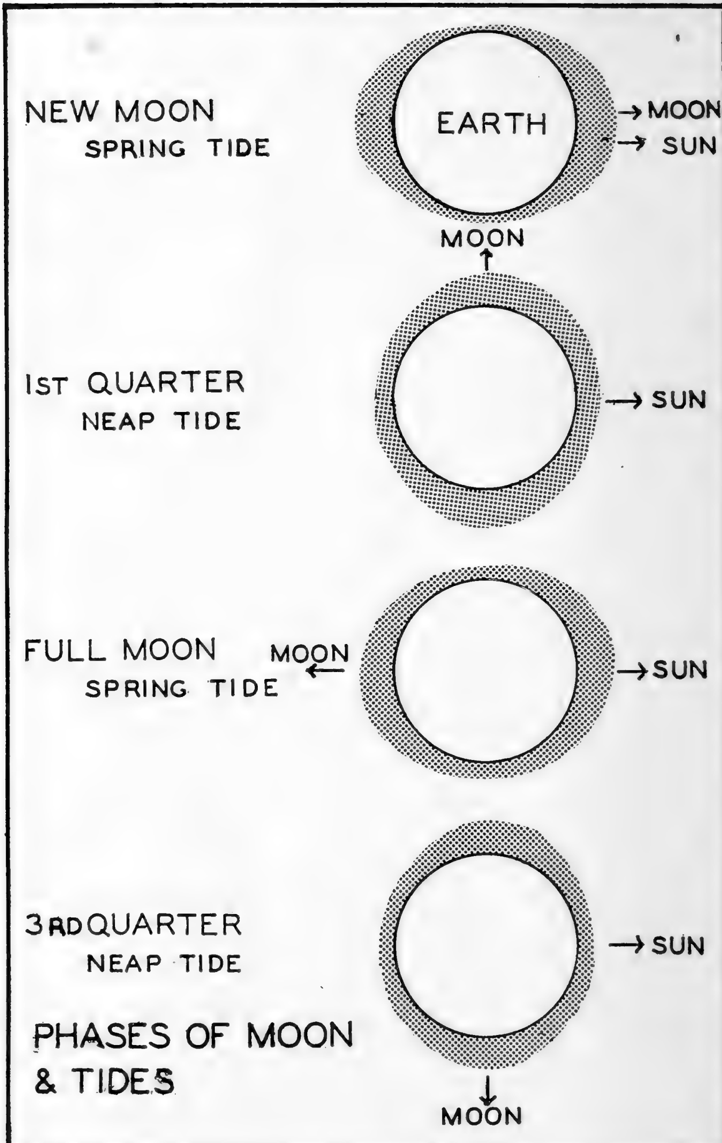
Tides

From time immemorial men have observed the tides and wondered about them. Some of the ancient scholars recognized the relation between the moon and the time of tide, but knowing nothing about gravitation were unable to account for the connection.

Crude theories about the tides were prevalent until relatively recent times. Gilbert of Colchester (1544-1623) thought the tides were the result of the earth's breathing! And he was not an unscientific man for his time. He was the author of *De Magnete,* a historic treatise on the magnetism of the earth which for the first time laid down the principles that later were to be used in the theory of the marine compass. John Kepler (1571-1630), the father of modern astronomy, held the same view. Kepler was an astute man of science; he computed the first accurate orbits of the planets of the solar system, but he, too, thought the periodic rise and fall of the ocean level was due to the earth's being alive and breathing. It was not until Newton (1642-1727) propounded the principle of universal gravitation, and the theory of tides was developed from work of many scientists including Count Lagrange (1736-1813) and the Marquis de Laplace (1749-1827), that the nature of the tides was fully appreciated.

WHAT CAUSES THE TIDES?

The waters of the oceans are held to the surface of the earth by the gravitational force that the earth exerts upon



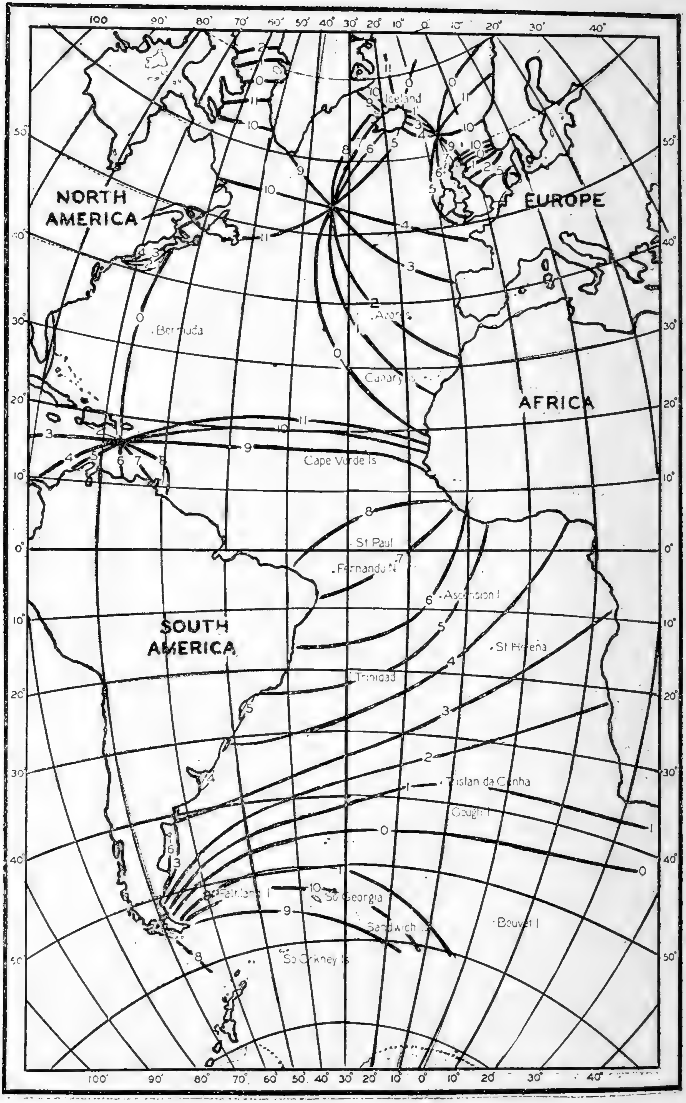
PHASES OF MOON & TIDES

each particle of water. If the earth were isolated by itself in space, its unvarying gravitational force would produce a smooth globular surface, and there would be no such things as tides. But the universe in which we live is inhabited by other celestial bodies besides the earth, and these other celestial bodies, the moon and sun in particular, also exert gravitational forces upon the ocean waters. However, since they are so much further away from the ocean than the earth itself is, their influence is far less than that of earthly gravity. Their attractions are sufficient, however, to cause a heaping up of water toward them and also on the side of the earth opposite them. It is this heaping up of water due to the attractions of the sun and moon that is called the tides. It is worth while to note that the moon or sun produces a high tide not only directly beneath it on the earth, but also at the antipodes of that point (on the other side of the world).

Both the moon and sun produce tides of their own, and since the sun and moon move around the earth at different speeds, their two tides do not always coincide. At new and full moon however, the earth, sun, and moon are all in a line and hence both tides coincide, and as a result we have extra large tides called spring tides. At first and last quarter phases of the moon, the sun and moon act against one another and cause rather small tides called neap tides. Spring tides are about 2.8 times the size of neap tides.

HOW ARE TIDES PREDICTED?

Experience shows us that high tides do not follow the motions of the celestial bodies as faithfully as the above idealized picture would suggest. The contradiction between the simple theory outlined, and the actual facts is largely due to the obstacles in the ocean, the continental land masses, which



Cotidal lines of the semidiurnal tide in the Atlantic Ocean (Sterneck).

prevent the tides from moving freely. Such obstacles modify the motion of the tide waves to such a great extent that the theory derived from the positions of the sun and moon gives only very rough approximations of what actually happens. The rotation of the earth, temperature, climate, barometric pressure, etc., also help to modify the tides. As a result of all these disturbances in the tides, the only way to predict them accurately is to observe them carefully for long periods of time and analyze the tabulated observations mathematically by a process called Harmonic Analysis. The results of the mathematical examination are then compounded in a tide predicting machine which automatically computes and prints tables of tides years in advance. Such machines are owned and operated by the United States, British, and German governments.

Charts are drawn showing the relative heights of the tides for large ocean areas. A line upon the chart may indicate all places where the tide is of the same height at the same time. This line is called a *cotidal line.* There are also points in the ocean where there are no tides at all, known as *amphodromic points.* For example, in the North Atlantic there are three such amphodromic points. One is in the neighborhood of the Faeroes; another in the middle of the ocean at about latitude 54° N.; the third southwest of Puerto Rico.

EXCEPTIONAL TIDES

In a few harbors there are exceptionally great tides, which are in the main due to peculiarly shaped land masses which tend to collect the energy of a tide wave and to channel it up a narrow funnel-shaped bay. The Bay of Fundy exhibits tides of fifty feet. Other bays show the same effect to a lesser extent. Long Island Sound is a good example. The Tide Tables (issued by the U.S. Coast and Geodetic Survey, Washington, D.C.) indicate larger tides the further one penetrates into the Sound. To illustrate the point we have selected several points along the shore of the Sound, and listed the height of morning high water on January 1st, 1944.

New London, Conn.	+2.4 ft.
Madison, Conn.	+4.9 ft.
Bridgeport, Conn.	+6.8 ft.
Willets Pt., N.Y.	+7.4 ft.

It will be noticed that the further from the mouth of the Sound, the greater the high water.

HOW YOU MAY PREDICT THE TIDES

An approximate way to estimate the time of high water at any particular port will now be described.

Evidently, from what has already been said, the time of high water depends upon the time when the moon is in upper transit (that is, when it is highest in the sky). It is not necessary to watch the moon to see when it is highest in the sky. Its phase gives a good hint as to when that will occur.

From the phase of the moon obtain the time of transit (take an intermediate value for in-between phases). Now add to this time the *establishment of the port* and the sum is the time of next high water. Another high water follows about 12 hours and 25 minutes later. The establishment of the port is a fixed quantity different for every port. It may be found in old editions of Nathaniel Bowditch's *American Practical Navigator* (Hydrographic Office) or in the Tide Tables.

TABLE OF APPROXIMATE TIME OF TRANSIT OF THE MOON ACCORDING TO ITS PHASE

	Phase	Time of Transit* (Standard Time)
	New Moon	1200
Waxing	Crescent	1500
	Half Moon	1800
	Gibbous	2100
	Full Moon	0000
	Gibbous	0300
Waning	Half Moon	0600
	Crescent	0900
	New Moon	1200

* In the so-called French system now in use by the armed forces of the United States, each day begins at midnight, and time is counted in four figures, without the use of a.m. and p.m. Thus 1:00 a.m. is 0100, 8:35 a.m. is 0835, noon is 1200, 5:40 p.m. is 1740 and so on up to 2400, which is midnight.

Example No. 1.

December 18, 1944, at Pier 9 North, Philadelphia, Pa. The moon appears as crescent moon. It is waxing (that is growing larger every night). The table gives time of transit of crescent moon as 1500.

The Tide Tables give the establishment of Pier 9 North, Philadelphia, Pa., as 0128.

Add the two numbers:

$$\begin{array}{r} 1500 \\ +0128 \\ \hline 1628 \end{array}$$

The time of high water is about 1628 standard time. The

Table also states that the average height of high water at that locality is 5.4 ft. above mean low water.

Example No. 2.

April 17, 1944. Moon is slightly smaller than half moon. It is waning (growing smaller night after night). From the table we estimate that such a moon will be in transit about 0700. Supposing we are in Hamburg, we look up the establishment in the Tide Tables (or an old Bowditch) and find 0440. Add these two figures:

$$\begin{array}{r} 0700 \\ +0440 \\ \hline 1140 \end{array}$$

That is, the next high tide will be at about 1140 standard time. The tables tell us it will be about 7 feet high.

Having found the time of one high water it is easy enough to find the time of a few preceding and succeeding ones. High waters are separated by intervals of about 12 hours and 25 minutes.

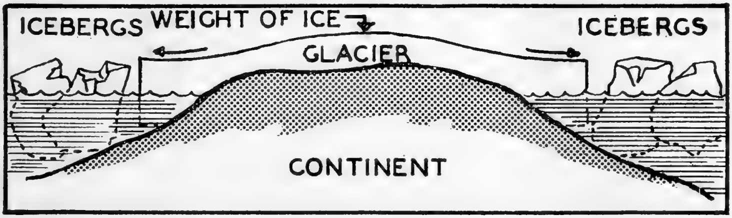
Ice

Ice at sea has always constituted a real terror to the seaman. Icebergs drifting down from the Arctic into the North Atlantic shipping lanes have stove in many a hapless ship and sent her and her crew to the bottom. The most widely known case was the loss of the SS *Titanic*, with her 1517 souls aboard. In still higher latitudes, ships are occasionally caught between moving masses of pack ice and crushed like eggshells under the tremendous pressures they exert. An example of such an event was the fateful expedition of the *Jeannette* in 1879 to the Arctic Sea in an attempt to reach the North Pole. The expedition, under Lieutenant Commander George Washington De Long, U.S.N., an Annapolis graduate, seemed to be under an evil spell from the start. In hopes of finding a clear passage through and above the Bering Straits (because of their mistaken notion that the warm Kuroshio Current flowed up through them), they found themselves caught in the pack ice early in September 1879, and were forced to spend the winter in the Polar regions. Even during the ensuing summer they were unable to free the ship and had to endure another winter in the terrible cold of the far north. During this time their food supply dwindled and deteriorated. Occasionally their ship would be momentarily freed in a narrow crack in the ice, down which huge blocks and chunks of ice came hurtling, any one of which could have completely smashed their tiny craft. In June 1881, the *Jeannette* was finally crushed and sunk, and the sick and weary crew hauled three boats and what little supplies they had left over the ice southward. Finally, upon reaching clear water, a storm arose, one of the boats broached to, and all its crew were lost. The remaining two boats were separated in the same storm and finally landed at different points in the wilderness of the Lena River Delta. One crew reached safety, but De Long and those who were in his boat died of starvation before they could find aid. Sea ice has sent many another ship and crew to the bottom. It is no wonder, then, that the presence of ice is adequate cause for concern.

WHERE ALL THE ICE COMES FROM

The ice that one encounters at sea has been studied in some detail, and a suitable classification of its different forms has been devised by Maurstad, a Norwegian oceanographer. For the purpose of primary classification we consider the origin of the ice; whether it is formed on land or in the sea. In certain localities like Greenland and the Antarctic Continent snow is the main form of precipitation; and as a result the land is covered by a thick layer of compacted snow. As the years pass more and more snow is accumulated, forming extensive glaciers. Such glaciers differ from ordinary mountain glaciers chiefly in size because they may cover an entire continent as in Antarctica. They may be several thousands of feet thick and cover everything except the highest mountain peaks.

To relieve the pressures generated by so large an accumulation of ice, a general movement of the ice toward its outer edges arises. The glacier tends to move toward the shores of the continent, and its ice may extend for many miles out to sea, floating along the surface. Eventually, because of wave and tidal action, large blocks of ice are broken from the parent body and float away. This process, called *calving*, is accompanied by loud reports and roars as the ice cracks.



Charles Darwin, the father of the Theory of Evolution, gathered his evidence for the theory on a scientific expedition in the British ship *Beagle*. Once, upon sighting a glacier, he put off in a small boat to examine it more closely and almost met an untimely end when suddenly a large piece split off nearby with a loud crash and dangerous waves.

Ice fragments broken from glaciers are called *glacier ice*, and many ordinary icebergs fall under this general heading. Because glacier ice is composed of compacted snow it is essentially free from salt and when melted supplies fresh water. Thirsty sailors of bygone days filled empty water casks with water obtained on icebergs.

Ice formed in rivers may be swept into the ocean, and is called *river ice*. This kind of ice is not very dangerous or very important. Besides glacier ice and river ice, we have another kind of ice, formed in the sea itself. Thus we distinguish three kinds of ice according to origin: glacier ice, river ice, and *sea ice*.

SEA ICE

Ice whose origin is the sea is called sea ice. When the temperature of the sea reaches two or three degrees below freezing, the sea water itself begins to freeze. As sea water freezes, it separates from the dissolved salts and as a result

Official U.S. Navy Photo

Sludge ice in the Northern Pacific.

sea ice may be fresh, although it often contains small amounts of occluded salt and bubbles of salt water within it.

Let us examine the formation of sea ice. When the temperature of sea water falls to about —1.8° C., ice crystals form in the shape of thin plates an inch or so long. If they are sufficiently thick on the surface they form *slush,* the sea takes on a dull leaden color and all wind ripples disappear. Snow falling into freezing water forms *snow slush.* It may be distinguished from ordinary slush by the crystal shapes. If the water is calm *ice rind* will form, a thin sheet less than two inches in thickness. A ship makes no noise passing through slush, but makes a distinctive sound passing through rind.

MORE KINDS OF SEA ICE

If there are winds and waves an ice rind cannot form, but the slush may be compacted into lumps called *sludge ice.* Sometimes these lumps take on a circular disklike shape with raised edges, and then are known as *pancake ice.* If sludge ice is compressed further into a thick layer it is called *slob ice* and is an effective barrier against small vessels. Newly frozen stretches of ice from two to eight inches thick are known as *young ice,* a strong resilient layer, not easily broken by swells, greenish in color, and moist on top. As the young ice grows it reaches a thickness of one to three feet, and then is known as *level ice.* Level ice often remains a whole winter intact when in sheltered places, but is soon broken to pieces in the open sea. As it is jammed together it builds up piles of broken pieces, heaped one atop another in a haphazard manner, forming long ridges and grotesque mounds known as *hummocky ice.* All of this ice is broken up in the course of time. The fragments are classified as follows:

Large tabular masses 1/10 to 1/2 mile across: floes
Tabular masses 10 yds. to 1/10 mile across: small floes, cake ice
Smaller fragments: cake ice
Irregular masses, 3 to 7 ft. above water: growlers
Less than two feet above water: bits, or in large numbers sometimes called *brash ice.*

If ice is only one year old it is called *winter ice;* if it is many years old it is called *polar ice.* Polar ice predominates in the polar sea as the name suggests. The thickness of this ice is on the average about 9 to 10 feet in the winter, although in certain mounds and ridges it reaches depths of 15 to 20 feet.

STRIPS AND BELTS

Floating ice fragments may arrange themselves into long *strips* or *belts* extending in parallel lines from horizon to horizon. By strips we mean narrow, thin lines of ice; by belts we mean lines many miles across. Strips are ordinarily formed at right angles to the direction of the wind; belts, parallel to the direction of the wind.

ICEBERGS

The real giants of the ocean ice are icebergs. They have different shapes. They may be flat-topped, with steep sides. Such ones are termed *blocky.* If they are triangular shaped, or dome shaped, pinnacled or with deep valleys, winged, horny, or twinned, they are classed as *pyramidy.* Icebergs usually appear a snowy white, but sometimes they are colored by bands of mud, pigmented marine life, or clear ice. Glacier born bergs often carry large quantities of rock debris, boulders, gravel, etc., thousands of miles out to sea and drop them into the ocean as they melt.

Icebergs in the Antarctic Ocean attain enormous sizes, some being 20 miles wide, 70 miles long and with a vertical thickness of 2500 feet, 270 feet of which may be above water. Bergs of this size have been mistaken for islands—and no wonder!

From a list compiled by Captain Lecky—that veritable old sea dog, author of *Wrinkles,* and master mariner—we may take a few examples of real giants:

Date	*Latitude*	*Longitude*	*Height*	*Length*	*Ship Reporting*
February, 1891	53°S	141°W	1000 ft.	10 mi.	*Marianna*
May, 1892	44°S	30°W	1000 ft.	40 mi.	*Strathdon*
January, 1893	50°S	45°W	1500 ft.	3 mi.	*Loch Torridon*
August, 1908	49°S	42°W	1300 ft.	10 mi.	*Cognati*

ICE FROM THE SKY

Ice not only advances upon the mariner by sea, but also falls on him from the sky. Hail, sleet, glaze, rime, and frost are all forms of ice precipitated from the atmosphere. Hail consists of irregular lumps of ice, usually in alternate concentric layers of clear and opaque material. Hailstones sometimes are as big as walnuts and they have been reported as large as oranges. Such giant hailstones would weigh about one pound apiece. Humphreys of the U.S. Weather Bureau tells us that cattle have been killed at Annapolis, Maryland, by such hailstones. Hail occurs only during thunderstorms. Photographs of unusual hailstones are worth taking, or plasticine casts can be made of them before they melt. Do not mistake sleet for hail.

Instead of having a complicated concentric layer structure like hail, sleet is composed simply of frozen raindrops. When sleet covers a deck it freezes into a hard grainy surface that can give a man a nasty fall if he is not pretty sure on his feet.

Rain, falling upon a cold exposed surface freezes to form a clear icy coating, glaze. During an ice storm the rigging of a ship may become so coated with glaze that its weight is increased anywhere from ten to a hundredfold. Needless to say, such an increase in load may damage small lines and wires, or may stiffen lines upon a sailing vessel to such a degree that it becomes very difficult to work with them.

Official U.S. Navy Photo

Glaze ice coating on U.S. destroyer in the North Atlantic.

Rime and frost are light, feathery deposits formed by moisture-laden air as it strikes cold surfaces. Delicate crystalline growths may develop on windward surfaces in the form of beautiful clusters of intricate ice needles.

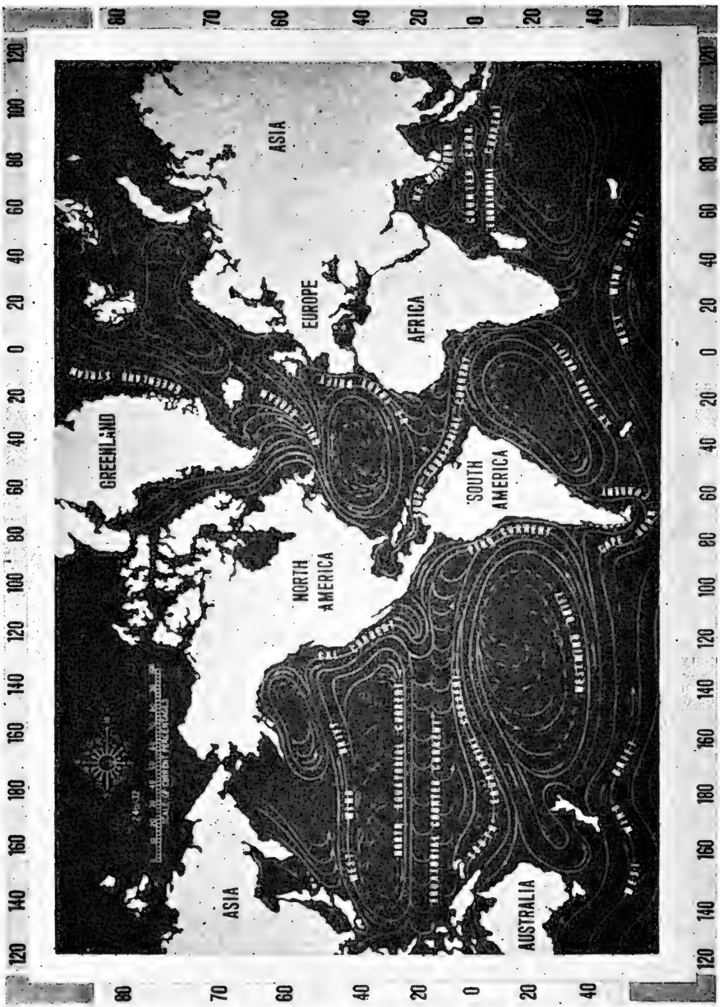
Currents

The great transportation system of the ocean is its vast network of currents. Some of these currents extend for thousands of miles through the entire length of an ocean. Still others are of a more local nature, being confined to a single harbor or inlet. The large and small scale currents may be studied conveniently if separated. But this separation is more than a mere matter of convenience, because there is a real difference between the causes of large and small scale currents. Therefore we distinguish between:

1. Ocean currents: large scale currents; caused chiefly by differences of density or by prevailing winds.
2. Tidal currents: small scale currents; caused by the differences of level of tides in small harbors and inlets.

OCEAN CURRENTS

There is a general world wide system of ocean currents which remains more or less the same throughout the years. It includes such great ocean rivers as the Gulf Stream, the Kuroshio Current, and the Equatorial Currents. These currents are related to differences in density of the water in different parts of the ocean. The differences in density are due either to temperature (warm water is in general less dense than cold water) or to the salt content (the density is greater the more salt the water contains). The salt content, in turn, depends upon the rate of evaporation of sea water at the



USMS Training Aids Unit Chart

Ocean currents.

surface, or the amount of rainfall, melting ice, or the inflow of large rivers.

The prevailing winds of certain latitudes also help to build up ocean currents.

DEFLECTION OF CURRENTS BY EARTH'S ROTATION

A glance at the Chart of Ocean Currents shows that instead of moving in straight lines the ocean currents are deflected clockwise in the Northern Hemisphere, and counterclockwise in the Southern Hemisphere. This deflection is due to the rotation of the earth. How does it arise?

The earth rotates to the East, imparting to every particle of matter of land and sea a fixed angular momentum. A law of dynamics (the physics of moving bodies) states that the angular momentum of a particle must always be a constant amount.

Inasmuch as angular momentum is made up of both the angular velocity and the distance of the particle from the axis of rotation, a change in one of these two quantities necessitates a corresponding change, but in the opposite direction, of the other. As a body of water moves North from the Equator, as in the Gulf Stream, its distance from the earth's axis of rotation is decreased. As a result its angular velocity must increase. This amounts to a movement East as well as North, which is the observed fact for the Gulf Stream. By a similar analysis the deflections of all the other ocean currents may be accounted for.

HOW ARE CURRENTS MEASURED?

An obvious way of measuring currents is to set sealed bottles containing a message afloat in the ocean, and to hope that they will be picked up eventually and returned. From a knowledge of the time and place at which they were released, and at which they were recovered, a rough estimate of the speed and direction of the current may be obtained.

Other studies can be made from the drifts of derelicts and wreckage, which may travel enormous distances and stay afloat for years before finally being destroyed or sunk.

Modern methods for measuring currents include measurements at all depths with an Ekman current meter. The instrument is lowered to any depth, left there for a definite length of time. It is then hauled in and the number of revolutions of its little propeller read from a dial. The direction of the current is obtained by a self-registering compass attachment.

Another means of determining currents at sea is by comparison of a large number of measurements of salinity and temperature at different depths. From their data the currents may be computed from hydrodynamic theory. The interested reader may refer to such a study made by C. O'D. Iselin of the Woods Hole Oceanographic Institution. (A Study of the Circulation of the Western North Atlantic, Contribution No. 108, Price $1.00, obtainable by writing the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.)

Ocean currents arise between bodies of lighter (less dense) and heavier water. A simple rule for obtaining the direction of such a current is:

In Northern Hemisphere: Stand so that the lighter body of water lies on your right, the heavier on your left. You are then looking in the direction of the current. The Gulf Stream, which skirts the warm Sargasso Sea, is a good example.

In the Southern Hemisphere: Reverse the words "right" and "left."

The Sargasso Sea mentioned above is a large area of water bounded by the Gulf Stream on the North and West, the North Equatorial Current on the South. It derives its name from the fact that large quantities of sargassum weed are usually found floating there. The region was once regarded by seamen with superstitious dread.

TIDAL CURRENTS

On a much smaller scale than their gigantic brothers are the tidal currents. Their motion is derived from the inequalities of the heights of tides at different places. At the inlet to a bay there are likely to be four reversals of current each day: flood, ebb, flood, ebb. A flood current follows low water; an ebb current, high water. The periods between alternate floods and ebbs are called slack water.

The tidal currents for many harbors can be obtained from Current Tables published by the U.S. Coast and Geodetic Survey.

Offshore tidal currents are likely to be of a more complex nature. The current may take on a kind of rotary motion, completing the circle each half day. Such a current is completely defined by two quantities: set (direction of flow), and drift (velocity of current in knots). It is important to remember that the direction of currents is the direction toward which the current flows. This is different from wind directions, which are measured by the direction from which the wind blows. A northwest wind might easily whip up a southeast current!

BORES

In a river with a broad mouth the current of the river tends to prevent the tide from rising. After a struggle the tide overwhelms the river current and there is a great surge of water up the river in the form of a single large wave, behind which the water is several feet higher. Such a solitary wave is called a *bore*. Some bores are as high as 8 to 12 feet and are accompanied by a rushing noise which can be heard many miles away.

WHIRLPOOLS

The danger of whirlpools has been much exaggerated, particularly that of the Maelstrom, between the islands of Moskenaes and Mosken in the Lofoten Islands off the west coast of Norway. Although dangerous for small boats, whirlpools are not the terrors usually painted by imaginative writers. An example of such overstatement is found in Edgar Allan Poe's *Descent into the Maelstrom:*

"Never shall I forget the sensation of awe, horror, and admiration with which I gazed about me. The boat appeared to be hanging, as if by magic, midway down, upon the interior surface of a funnel vast in circumference, prodigious in depth, and whose perfectly smooth sides might have been mistaken for ebony, but for the bewildering rapidity with which they spun around, and for the gleaming ghostly radiance they shot forth, as the rays of the full moon streamed in a flood of golden glory along the black walls, and far away down into the inmost recesses of the abyss."

Similarly the terrors of the Straits of Messina, the Charybdis and Scylla, the frightful whirlpools of Homer and Virgil, are hardly even noticed by the captains of today.

Shores and Islands

The shores of the ocean represent fairly complex geological processes. Before we treat the shores themselves it will be wise to mention the different kinds of rocks which are likely to occur on them. Rocks are classified under three chief headings: igneous, sedimentary, and metamorphic rocks.

Igneous rocks were formed by the cooling of hot lavas from beneath the surface of the earth. Most uniform crystalline rocks are igneous rocks, the size of the crystals being a good indication of whether the rocks cooled quickly or slowly. Large crystals indicate slow cooling; small crystals indicate quick cooling. Igneous rocks may also be classified according to chemical composition; acidic rocks being called granitic; basic rocks, basaltic.

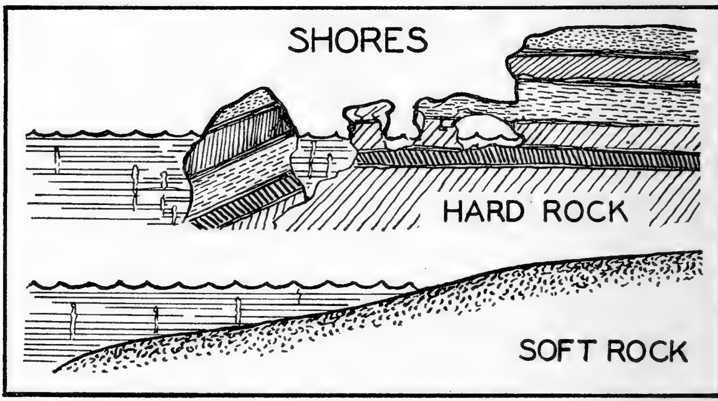
Other rocks give indications of having been formed by gradual deposition of material in layers over countless years. Under great pressures and slow chemical action the loose material of the layers has been cemented together. Such rocks are called *sedimentary rocks.* They contain various sized particles of old igneous rocks, sand, pebbles, muds, and the fossils of ancient forms of life, terrestrial and marine. It is in sedimentary rocks that fossil remains are most likely to be found.

Finally there are the *metamorphic rocks,* masses of rock which were originally either igneous or sedimentary but which have undergone such complete transformations under the influence of geological processes of pressure, chemical action, folding, etc., that they are classified in a special class all by themselves.

The ocean shores are made up of different rocks the world over, and exhibit a wide variety of forms; from the broad sandy beaches of Florida to the iron-bound rocks and cliffs of Norway.

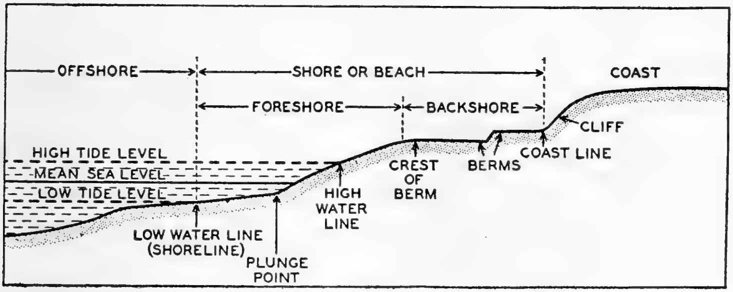
HOW A SHORE IS MADE

In studying a coast line one should not regard what he observes as a static state of being. He should attempt to inter-



pret what he sees as one step in a geologic process which is continually going on even though slowly as man measures time. The main processes which occur on coast lines are (1) marine denudation; (2) marine deposition, and (3) earth movements. The nature of a coast line has much more meaning if one seeks to understand which of these processes is operating.

Marine denudation is the process by which the sea erodes a shore line, breaks up the rocks and soil composing it, so that gradually the sea encroaches upon the land. The greatest destruction of shore lines occurs during storms when waves batter against rocks, tear heavy blocks of stone from cliffs, etc. The enormous destructive power of an ocean storm can be appreciated from the havoc wrought upon sea walls, from the washing away of lighthouses, from the easy way in which waves can move huge blocks of stone weighing many tons.

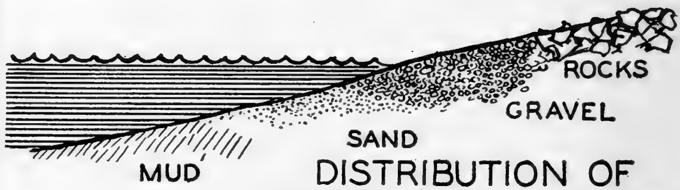


Terms applied to beach profile. Berms *are small impermanent terraces formed by deposition in calm weather and by erosion in storms.* Plunge point *is where waves break, depending on height of waves and tide.*

Coasts that are composed of hard rock exhibit a very irregular shore line: cliffs, pinnacles, natural arches, and rocky little islands jutting out into the ocean. Not uncommon is a region of shallow water or a level rock platform near the shore.

Coasts composed of soft rock have a much more even and smooth appearance: broad sandy beaches, a gradual slope into the sea, and smaller size particles in the deposits.

An even coast line may change into an uneven one, or vice versa, by a change in the level of the land. Coast lines tend to become straight with advancing age. Subterranean forces in many portions of the world are constantly changing the level of the land so that what may previously have been below water level may become today's shore line; or valleys high above the sea may be lowered until filled by the sea to form long inlets and estuaries. Studies of the topography of the ocean bottom reveal in some places great canyons where



DISTRIBUTION OF PARTICLES ON BEACH

rivers once flowed, submerged mountains, and inundated forests. In other regions of the world the remains of marine animals are found on mountain tops thousands of feet above sea level. All this is evidence of the constant changing of the level of the land.

Of particular interest are the fiords of Norway. Evidence points that they were originally valleys carved out of a mountainous land surface by glaciers, later submerged by a general lowering of the land level to form long rock-bound inlets.

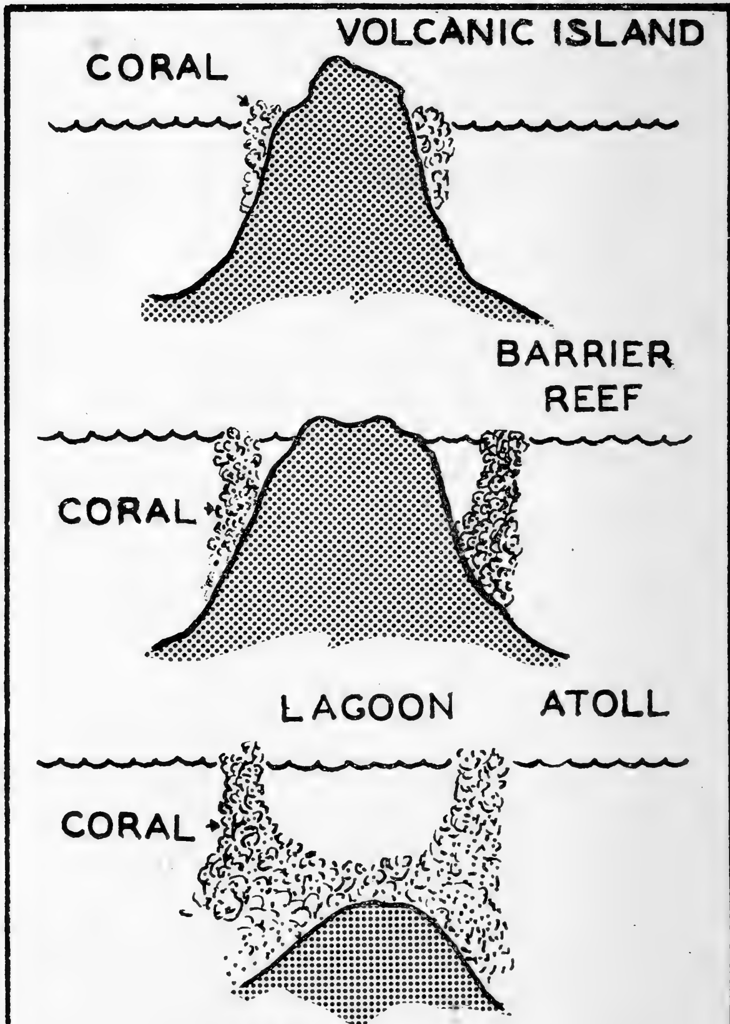
Acting against the process of marine denudation is the process of marine deposition which is constantly building up the coast lines of the world. Loose materials carried from the land by rivers, and the remains of marine animals and plants are deposited by wave action on certain shores with the result that instead of wearing away they are growing larger. There is often a gradation of size in the particles forming such a beach from coarse particles above the waterline to very fine sand and mud below it. Examples of deposition are the coastal plain of Texas and the shallow reef-bordered sounds of North Carolina. Another beach building process is the rising of the land.

OCEAN ISLANDS

Two kinds of ocean islands should be distinguished: the island which rests upon a continental shelf, which is merely a projecting part of the continent, and the true oceanic island. The true oceanic island reaches to the surface from the depths of the ocean, and may be either volcanic or coral in nature. Charles Darwin, at the age of 25 years, conceived of the following explanation for coral islands. The original island is supposed to have been volcanic in nature. In the course of many years it began to sink back into the ocean, but a ring of coral growing on its shores gradually built up into a ring around it until finally when the volcanic part of the island had completely sunk from view the coral ring was all that was left, forming an atoll with enclosed lagoon.

CONTINENTS MOVING?

While we are on the subject of shores it may be interesting to say a few words about Wegener's theory of continental drift. According to Wegener, grand "old man" of geophysics, all the land of the world was once gathered together in one huge continent called the *world island*. Due to some rather mysterious forces the island broke up into the con-



CORAL ATOLL
FORMED BY
SINKING VOLCANIC ISLAND

tinents as we now know them and began to shift apart gradually. A rather convincing part of this argument is the way that the coasts of the Americas and Europe and Africa fit together. Especially convincing is the fit of South America with Africa.

UNKNOWN ISLANDS

One hears it said so often these days that "the days of exploration of new territory are over," that he is likely to get a wrong impression concerning the completeness of our geographical knowledge. Let it be known, then, that there are probably entire islands as yet undiscovered, and others whose positions are marked on navigation charts with an "existence doubtful." As late as 1915 a group of islands was rediscovered in Hudson Bay, the Belcher Islands. For three centuries previous the Bay had been traversed by trading vessels and the islands remained uncharted. Nor is the size, three million acres, insignificant.

A little more understandable, but still surprising is the late rediscovery of Bouvet Island, a thousand miles southwest of the Cape of Good Hope. The island was discovered by the Frenchman Bouvet on January 1, 1739. Years later attempts were made to rediscover the island by Furneaux (1774), and by Captain Cook (1775). An American whaler, Lindsay, (1808) reported having seen the island, but no one accepted his evidence against that of the famous Captain Cook. Captain George Norris took possession of the island in the name of the English king in 1825. Then came further blows to the credibility of the island's existence. The famous antarctic explorer, James Ross, searched for, but could not find, Bouvet Island (1843). It was similarly invisible to Lieut. T. Moore

(1845). More reports of having seen the island came in 1878, 1882, and 1893, so that the island's existence again seemed more likely. In 1898 the oceanographic vessel *Valdivia* finally established its position, 54° 26′ S, 3° 24′ E.

THE AURORAS

The Auroras were islands supposed to exist somewhere east of the Falkland Islands, but since then have been proved nonexistent. According to a report of the Royal Hydrographical Society in Madrid (1809) the Auroras were first discovered by the ship of the same name in 1762, sighted next by the ship *Princess* in 1790, and were finally surveyed and definitely established by the hydrographic corvette *Atrevida* (1794). Despite the scientific calculations and descriptions of the report, it seems to have been either falsified or grossly mistaken. Captain James Weddell made an attempt to find the Auroras in 1820, but a most diligent search of the area failed. Repeated present day sailings through this area confirm the nonexistence of the islands.

The interested reader may find a full account of the Auroras and other doubtful islands in *Oddities, A Book of Unexplained Facts* by Lieutenant Commander Rupert T. Gould, R.N. (Philip Alan Co., London, 1928). Lieutenant Commander Gould is also the author of a masterly history of the marine chronometer.

ATLANTIS—BURIED CIVILIZATION

Atlantis, the once flourishing continent, the flower of ancient civilization which suddenly sank beneath the sea, is one of our most persistent myths. The legends of many cultures refer to a highly developed civilization in prehistory which met a sudden end, and was destroyed without leaving a single trace. Plato first mentioned the name Atlantis in his dialogues *Timaeus* and *Critias.* From that time on the name has been used by dreamy romanticists, philosophers, impatient social reformers and the like, almost as a synonym for Utopia. When Henry Schliemann, the great German archeologist, actually discovered the sites of Troy and Mycenae, which had long been considered legendary, interest was revived in the stories about Atlantis, the lost continent. Numerous Atlantean societies were formed, and still exist. Most of them are content to lie back in mystic adoration of the pictures of Atlantis their imaginations create, or perhaps they labor over some new addition to the extensive Atlantean literature which already numbers about 2,000 separate books and articles. Such semireligious groups resent scientific investigation in the subject, this resentment even taking the form of violence. As recently as fifteen years ago, the proceedings of a scholarly meeting at the Sorbonne were disrupted by Atlantean visionaries who hurled two bombs into the room.

Geologists tell us that there was a portion of land in the Atlantic (along the mid-Atlantic ridge) which sank into the ocean sometime during the Pleistocene (1,000,000 B.C. to present). However, it is generally supposed that its sinking occurred at such a remote date that no human civilization would have been possible. Whether or not there really is, somewhere on the ocean floor, a city of weed covered towers and walls, is a question which exploration on the ocean bottom must ultimately decide.

HOW OLD IS THE OCEAN?

The age of the ocean is evidently dependent upon the age of the earth, because in the natural sequence of events there had to be an earth before an ocean could form upon it. It will be prudent to remark at the very beginning that very little is known about the age of the earth or its origin. What we have to say in the following paragraphs, therefore, must be regarded as hypothetical, possible, but certainly not positive.

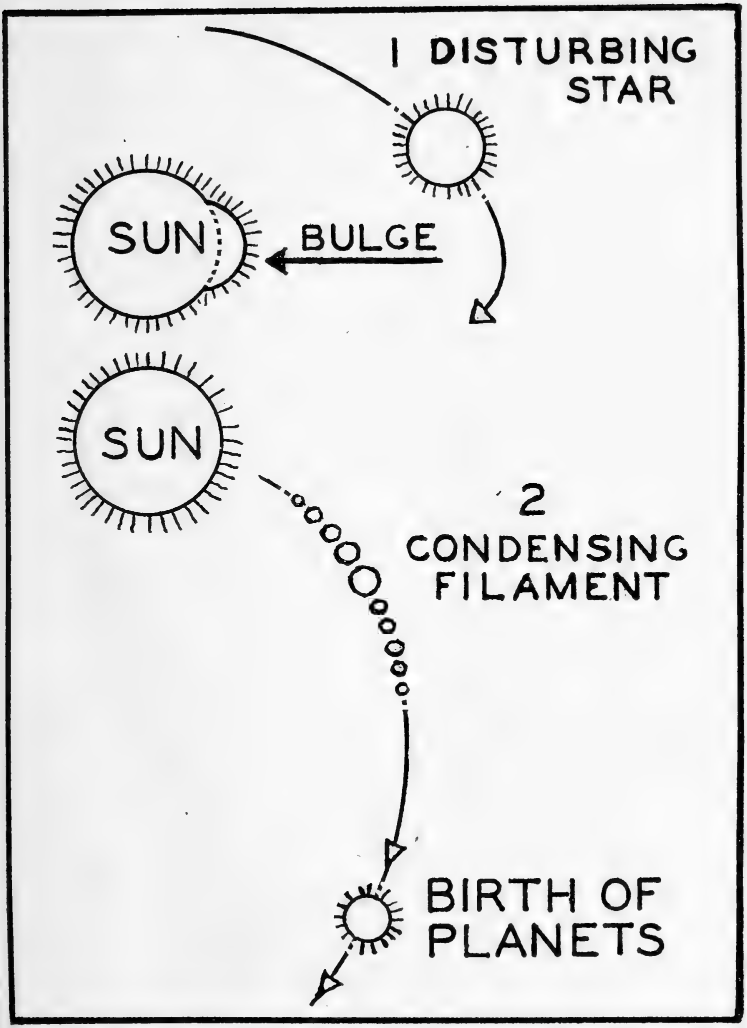
THE EARTH IS BORN

Once upon a time there were no planets revolving about the sun. The sun was a little brighter than it is now, but it had no Earth, no Mercury, no Venus, or any other planets to shine upon. It remained in this lonesome state for periods of time which are unmeasurable by human standards.

Finally one day (this was at a time before there were such things as days and nights) another star approached our sun, closely grazed it and then flew off again into the oblivion of outer space. In the encounter a filament of the sun's surface was torn off by virtue of the other star's gravitational influence and given a higher angular velocity so that it could not fall back into the sun.

This filament was exceedingly hot, bright, vaporous, and flaming like the sun itself. But in time it condensed into droplets of vapor and liquid, each drop forming one of the planets as we know them today. Our earth was one of these drops.

(At present this theory of the birth of the earth is in disrepute. Professor Lyman Spitzer, Jr., a well known astrophysicist, has shown that a filament so formed would probably dissipate into space rather than condense into drops. But, since no better explanation of the earth's formation has been proposed, we can tentatively hold to this theory rather than do with no explanation at all.)


I DISTURBING
STAR
SUN
BULGE
SUN
2
CONDENSING
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BIRTH OF
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THE EARTH COOLS OFF

Whether or not the earth was born from the sun, it is evident that its early history was a hot one. At one time (three to four billion years ago) it was in a molten state. Harold Jeffreys, British mathematical physicist, estimates that it took about 15,000 years before the molten mass began to solidify. The heavier portions settled toward the center of the earth, and the lighter parts remained floating upon the surface to form our present day crust.

Most of the light gases that were present in the outer portions of the earth while still in the molten state were probably lost to outer space. That means that our present day atmosphere and ocean may not be the same as the primitive gas and water vapor that covered the young earth. Much of the original water vapor of the earth must have gone into the formation of igneous rocks. Silica and water are supposed to be miscible at high temperatures, according to Dr. Harold Jeffreys. This amazing fact means that, when heated hot enough, rock and water will mix in all proportions.

The present day ocean and atmosphere are supposed to have been formed by the excessive volcanic action of these early times. Water vapor and carbon dioxide are plentiful in volcanic gases. The water vapor condensed to form the oceans and the atmosphere was largely carbon dioxide. The oldest Pre-Cambrian granites are supposed to be about one and one half billion years old, the age being determined by the extent of decay of certain radioactive elements present in the rocks. The earliest forms of life appeared about one billion years ago. Eventually the plants converted most of the carbon dioxide of the atmosphere to oxygen, and the world began to look more like the earth as we know it today.

Attempts have been made to measure the age of the ocean by computing how much salt is borne into it by rivers each year, and dividing that number into the total amount of salt in the ocean today. This method gives the ocean an age of ninety to six hundred million years, but is unreliable because it assumes (1) that the rate of salt additions to the sea water has always been the same as it is today, (2) that the original sea water was fresh, (3) that all the salt deposited in the ocean remains there forever. Each of these three assumptions is highly doubtful.

At a point in the earth's history some one billion years ago the science of geology takes over and brings us to the present. It derives most of its knowledge from a minute study of layers of rock all over the world. Though not an exact science, it is much more precise and reliable than the fancies outlined above.

THE GEOLOGICAL TIME SCALE

The following timetable shows the progression of geological time from the earliest known rocks down to the present (starting about one and one half billion years ago).

Archeozoic Era

This is the very earliest era. During it the oldest known rocks were formed. It was during this remote time that life probably first appeared in the form of tiny single-celled animals and plants. No fossils are known from this era. The rocks are highly metamorphosed, made up of all kinds of igneous and sedimentary types, but mostly the former.

Proterozoic Era
(began about 700 million years ago)

This era is almost devoid of life except for various low forms; various kinds of algae, etc. Extreme north and south regions of the earth were apparently in glacial climates.

Lower Paleozoic Era
(began about 450 million years ago)

During this era the first marine faunas appear, the most abundant being trilobites, fossils of which are found in vast quantities. This is the time when hard shelled animals thrived. As the era progressed armored fishes, corals, nautiloids appeared.

Middle Paleozoic Era
(began about 315 million years ago)

The first terrestrial air breathers (scorpions, lung fishes) made their appearance, and also the first land plants, and fresh water fishes.

Upper Paleozoic Era
(began about 240 million years ago)

The formation of coal beds from rich jungle foliage, the death and extinction of earlier animal species; rise of insects and spiders, primitive snakes and other reptiles, and the ancient sharks, whose teeth we still dredge from the ocean bottom.

Mesozoic Era
(began about 150 million years ago)

This is the era of flowering plants, of birds and winged reptiles, the age of dinosaurs. Toward the end of this era certain archaic mammals made their appearance; the era ends with a period of world-wide mountain building.

Cenozoic Era
(began about 40 million years ago)

Now the archaic mammals began to disappear. Dinosaurs were extinct. The higher mammals began to appear about twenty million years ago. The Pleistocene Epoch began about one million years ago, an epoch of successive glaciations and interglacial intervals. The elephant and mastodon, the saber tooth tiger, the giant ground sloth, the horse make their appearance; some die out. The progenitors of man put in their bid in the struggle for existence. The last epoch, the Recent, began fifteen to twenty-five thousand years ago. It may be merely an interglacial epoch.

THE FUTURE

It may not be out of place at this point to say a few words about the future. Barring some catastrophic occurrence like an explosion of the sun, which would certainly spell doom for all the earth's inhabitants, there is no reason to suspect that our planet might not endure another thousand million years, with constantly changing climatic conditions, but still capable of supporting life. But the prospects for man, the species, may not be so bright. None of the species of higher animals has survived for an indefinite length of time. The early higher animals are now all extinct. Each species, in its time, has fallen victim to overspecialization, a fate which may equally well overwhelm the human races.

Examples of overspecialization are the division of labor in modern industry and the accompanying mass unemployment that occasionally shakes our civilization's economic structure; and the increasing severity of modern wars in the wake of technological progress. Man, the individual, differs from his brother animals in his awareness of his own finiteness, of his inevitable end in death. But mankind as a species, like all the rest of the animal kingdom, is unconcerned with its own distant future and eventual extinction.

On the other hand, overspecialization of the brain may be a special kind of creation which by its own inherent powers, versatility, and ingenuity may overcome the inevitable changes which destroyed other less resourceful animals, and it may solve the peculiar difficulties which its own precocity and civilization have posed. In that case man might survive many millions of years more through whole cycles of geological change. Mountains will be leveled, ocean beds raised, now populous areas submerged, glacial periods come and go, the very orbit of the Earth changed, and through this all man may emerge in a future Golden Age.

The Sky

Atmospheric Optical Illusions

Hundreds of townsfolk in the east of England, just above the Strait of Dover, testify that, late one afternoon just before an air raid during World War II, they saw a vision in the sky, of Christ on the Cross. Eyewitness reports ran as follows:

A housewife: "I went into the garden. Something strange in the sky attracted my attention and rooted me to the spot. I looked up and saw a cross clearly!"

An engineer: "I saw the sign of the cross actually start to form. There was no mistake in either the shape of the crucifix or in the figure nailed to it."

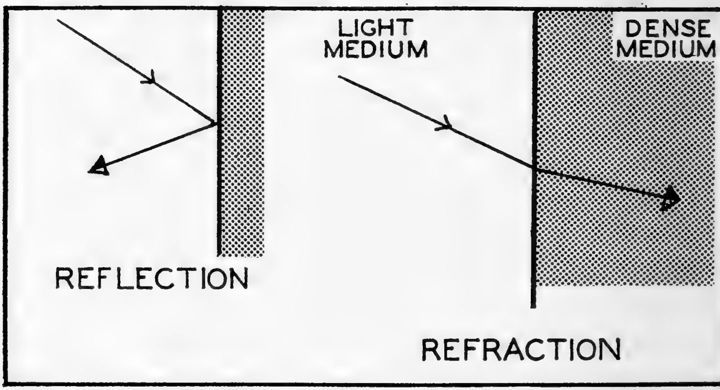
Now, as to whether there actually was a *real cross* with Christ on it in the sky, we may be relatively assured that such a miracle did not occur. But undoubtedly there was the *image* of a cross in the sky; perhaps clouds and the devout imagination of the observers supplied the figure.

Such optical illusions are by no means uncommon; history tells us of many crosses in the sky that have been seen from time to time. The Emperor Constantine (311 A.D.) was said to have embraced Christianity as a result of having seen such a vision. Modern scholars are tempted to think he did so for more practical political reasons. But who can venture to interpret with assurance the motives or statements of the leaders of nations?

Crosses in the sky, as a matter of fact, are much overrated as optical illusions because of their religious significance. There are many other equally fascinating and more frequent effects.

THE MECHANICS OF AN ILLUSION

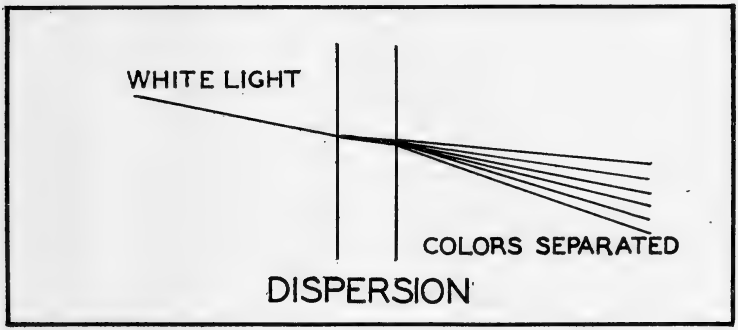
We shall discuss here the strange optical effects that are observable in the earth's atmosphere such as rainbows, sundogs, halos, mirages, twilight glow, etc. Most of these illusions have at one time or another been the subject of rigorous scientific study and you will find mathematical theories of them in books on Meteorological Optics. They are due



to a variety of causes—the many tricks that the air of our atmosphere can play upon a light beam before it reaches our eyes. At the risk of being tedious, we should begin by listing the principal means by which the atmosphere interferes with the simple straight line course that a light beam invariably follows when undisturbed.

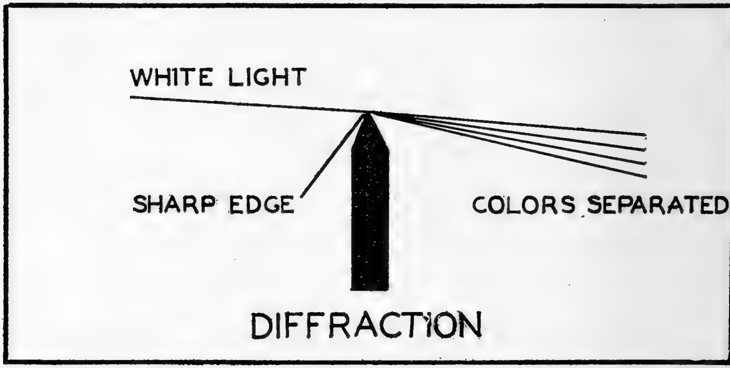
Reflection occurs when a ray of light strikes a mirror. The light is bent back abruptly in its path just as a rubber ball bounces back upon hitting a wall. In the air, droplets of water or crystals of ice may act as little mirrors.

Refraction is observed when light travels from one medium into another. A ray of light changes its course when it goes from the air into water or into a denser mass of air. Nonuniformity in the distribution of air, or the presence of water droplets or ice crystals suspended in the air may give rise to refractive phenomena.

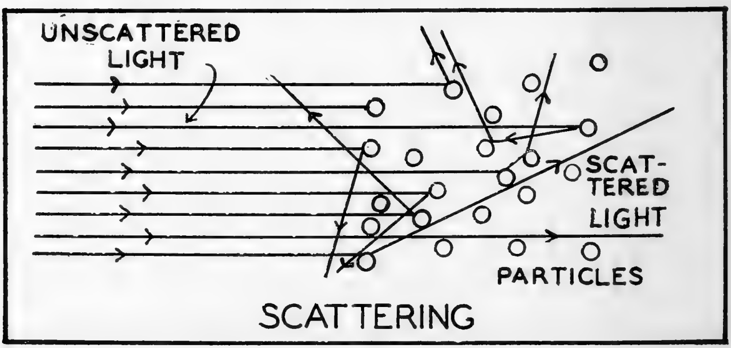


Dispersion occurs because different wave lengths, or colors, of light are refracted different amounts by the same refracting substance. White light, as almost everyone knows, is made up of many different colors. Dispersion tends to break white light up into its component parts, to form a spectrum or "rainbow." Violet light is bent most, red light least.

Diffraction is an interference phenomenon which causes light to bend slightly around corners, so that no shadows ever have a completely sharp edge. As in the case of dispersion, diffraction also results in a separation of the colors but in this case the order of the separation of colors is reversed, red being bent most, violet least. The spectrum due to diffraction is the reverse of that due to dispersion.

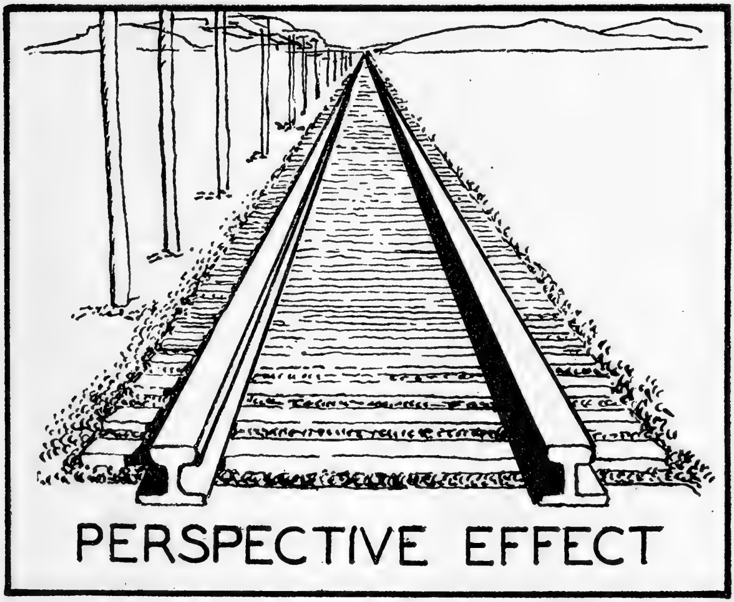


Scattering of light occurs when a ray of light falls upon many small particles (such as dust particles in the air). After



the impact of light upon the particles, it is reflected back in all different directions in much the same way as water splashes all over when you turn on the faucet over a sink full of dishes.

Perspective should also be listed as an important contributor to optical illusions. You are familiar with the way railroad tracks appear to meet in the distance even though you

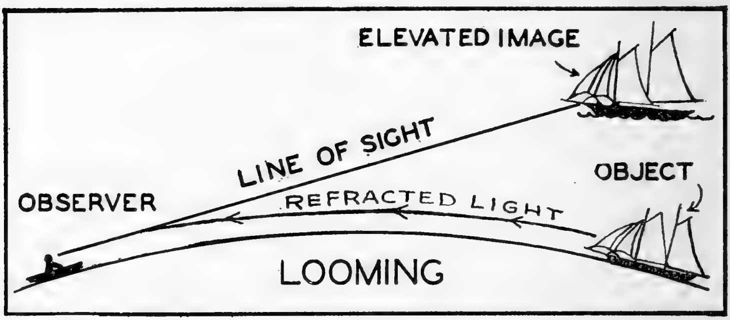


know for a fact that they are really parallel all the way. Similar effects of perspective are responsible for some of the strange things observed at sea.

Once you have familiarized yourself with the above terms, you will find the following accounts of optical illusions readily understandable.

MIRAGES

The air itself is not uniform over all regions of the sea. In some places it may be particularly heated and expanded; in others it may be saturated with water vapor; in others cold, dry, and dense. In general, the atmosphere is a rather heterogeneous, nonuniform substance. As a result certain portions of the air have different optical densities from neighboring ones. When a ray of light passes through such regions of the atmosphere it is refracted, that is, has its path slightly changed when leaving one air mass and entering another. This bending of light due to refraction may bring a ship normally beyond the horizon into view, or it may raise the image of distant coasts so high that they appear quite near. Sometimes there is a kind of multiple refraction which makes several images appear one above the other, or it may appear to turn a distant ship upside down. Such illusions are called mirages and are usually due to abrupt changes in the density of air at different horizontal levels. A discontinuity in the vertical plane, which may change the apparent bearings of distant objects by several degrees, is more rarely met with.



Coast lines often appear very much distorted because of this kind of refraction. In the Straits of Messina an otherwise ordinary coast line is distorted into huge towers, magnified palaces, and marvelous castle-like structures of the most

COAST MIRAGE

fantastic shapes and sizes. Italian fishermen call this mirage the *Fata Morgana.* Such mirages and the looming and sinking of objects above and below the horizon are frequently observed at sea.

APPARENT CHANGE OF POSITION

The apparent positions of the sun, moon, and stars are also affected by atmospheric refraction as every navigator knows. A star is not precisely in the location in which it seems to be: its actual position is somewhat lower in the sky than it appears to the beholder. Because of refraction the sun and moon become visible about three minutes before they actually rise, and they still remain visible for the same period after they have, in reality, already set.

REFRACTION VARIATIONS

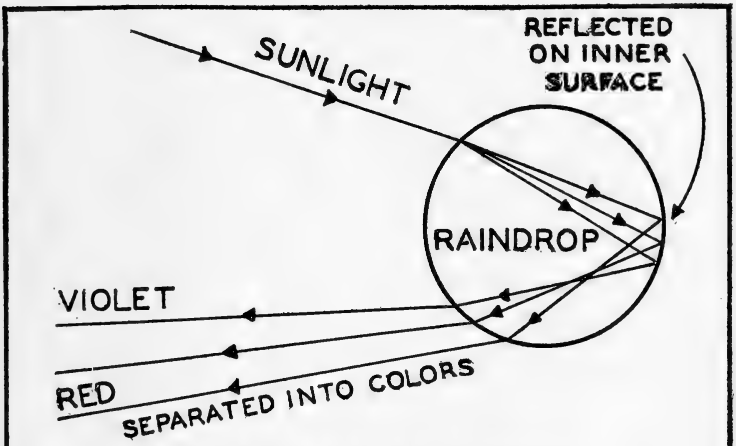
Refraction is not always a constant amount—it changes continually with the condition of the air. As the air masses move about and flow across one another there are slight changes in refraction every few tenths of a second. These little changes are the cause of the twinkling of the stars.

They also contribute to the indistinctness of distant views usually referred to as *optical haze* and the shimmering observed near the surface of the water or on deck on hot days. One of the most spectacular of refractive phenomena is the so-called *green flash.* If you observe the sun as it is setting, on an evening when the horizon is exceptionally clear, just as the last portion of the sun's disk disappears below the horizon you will see a bright yellow flash, a green one, and then possibly a blue and a violet one. This occurs because in dispersion the blue and green light are bent more than the red and yellow. As a result they are the last to disappear. In the morning at sunrise the same thing may be observed but in reverse order: blue appearing first, then green, yellow, and finally the red disk of the sun itself. The green flash is not a very easy thing to observe, but it is worth repeated trials because of its beauty and the fact that very few people have ever seen it. So much for phenomena due to refraction of the air itself. We now turn to optical effects due to refraction by particles suspended in the air: raindrops, ice crystals, and snowflakes.

RAINDROPS CAUSE ILLUSIONS TOO: RAINBOWS

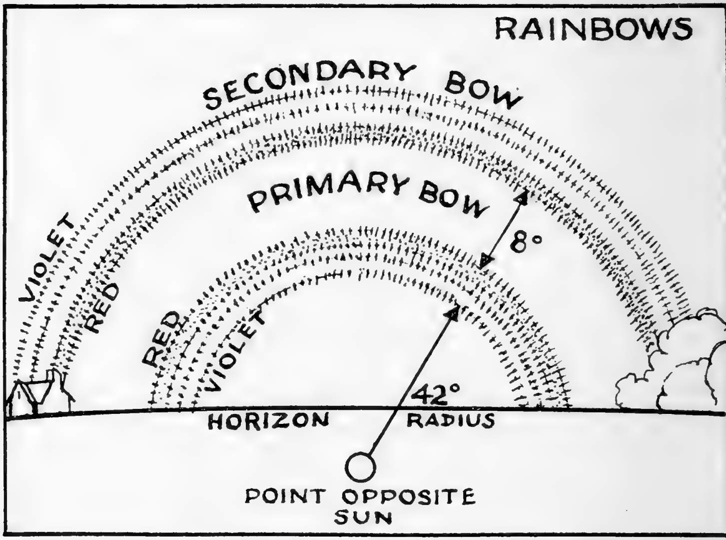
The rainbow is not as simple a thing as it may first seem. Sometimes a single rainbow stretches from horizon to horizon. Often you will see a number of concentric rainbows, some with their colors running in an opposite direction to that of their neighbors. All of the different rainbows may be accounted for by means of rigorous mathematical theory; however we will describe here how they are formed in a qualitative way.

Rainbows occur wherever there are a sufficient number of water droplets exposed to sunlight at the correct angles. The fine spray of a hose, or the drops of a distant thundershower show the rainbow alike. The distance of the drops from the observer makes no difference in the appearance of the rainbow, whether the distance is only a few feet or many miles. When sunlight strikes a raindrop it enters into it, is refracted and reflected around inside the drop several times



OPTICS OF RAINDROP

and finally is permitted to pass out of the drop again. However, the light which escapes from the raindrop has been dispersed, that is, has been broken up into its spectral colors, and its direction is also different from the direction of the original sunlight ray. What is more, since most of the light of a particular color is reflected at some specific angle to the direction of the incident sunlight, it is concentrated. So if you are in one position with respect to the sun and a particular raindrop, blue light may predominate and the drop will appear a deep blue; or, if you move the drop to a different position, the drop may appear yellow, green, orange, or red. Hence in a cloud of raindrops, all those making a particular angle between the direction of the sun's rays and the direction to the observer will appear in one color, and all those at



a different angle will appear a different color. The figure shows how this produces the circular shape of the rainbow, and the spectral sequence of colors.

KINDS OF RAINBOWS

There are many rainbows theoretically possible, but usually only three are visible: the primary, secondary, and tertiary. The primary bow is by far the brightest. It is opposite the sun and has a radius of about 42°. Its outer border is reddish, the inner border is a deep blue or violet. The secondary bow is next brightest and appears surrounding the primary bow with a radius about 8° greater than that of the primary. The order of colors of the secondary bow is reversed.

Sometimes there is visible a much fainter bow, the tertiary, which in all respects resembles the primary except that it is much fainter and is in the opposite part of the sky surrounding the sun. You will probably never see the tertiary bow.

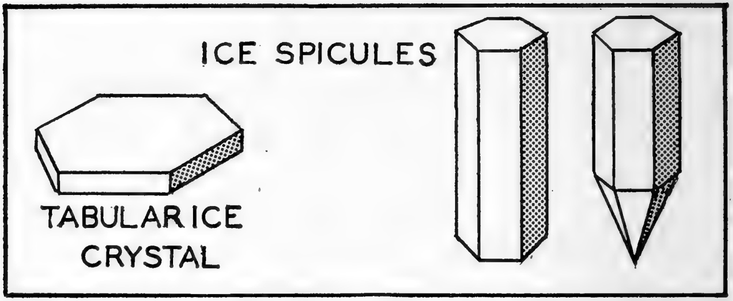
Rainbows differ considerably in appearance, probably due to the size of the drops involved. Sometimes the colors will be very brilliant, and at other times the bow will have but a dull whitish color—the *fog bow.* Rainbows are visible at night under a bright moon, or a bright electric light can produce similar effects. They are not seen when the sun is directly overhead except from airplanes and high points because the primary bow is always formed opposite the sun, which in this case would be straight down.

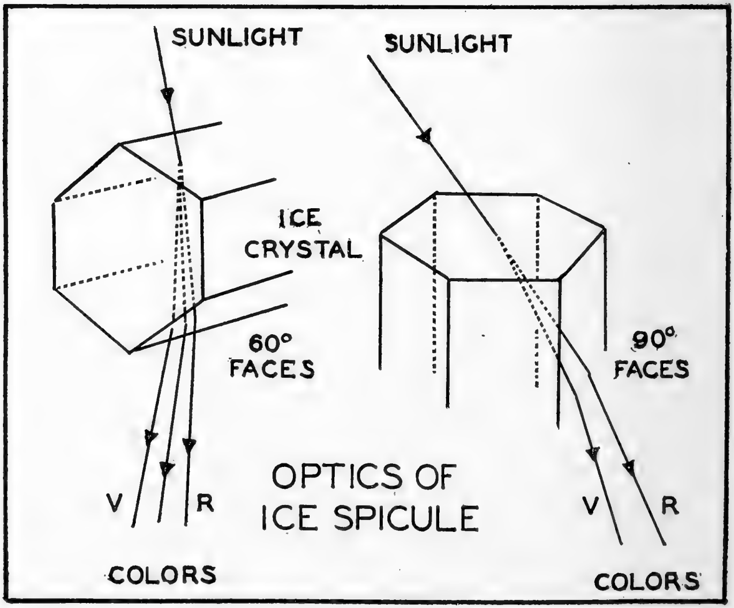
Sometimes extra rainbows appear as a result of the reflection of sunlight on the surface of the ocean. In still other cases the surface may be slightly oily and very light raindrops may rest on the surface for a while without mixing with the ocean water. Under such circumstances one may observe a horizontal rainbow.

Rainbows are certainly beautiful and marvelous. But all the world's scientists have never found a pot of gold at the end of one of them.

ICE CRYSTALS IN THE SKY

When water freezes into crystals it tends to do so in a hexagonal pattern. The crystals may be flat flakes, or in long


ICE SPICULES
TABULAR ICE
CRYSTAL


SUNLIGHT
SUNLIGHT
ICE
CRYSTAL
60°
FACES
90°
FACES
V
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OPTICS OF
ICE SPICULE
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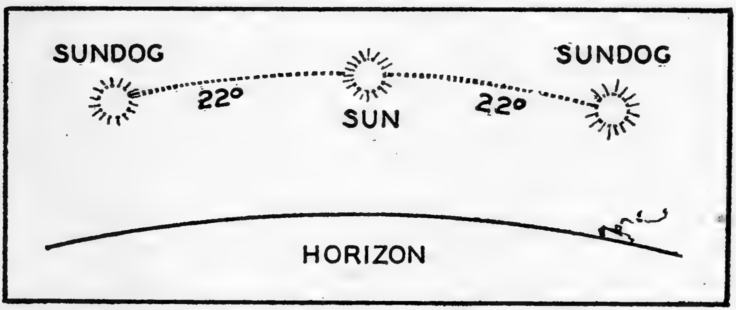
COLORS

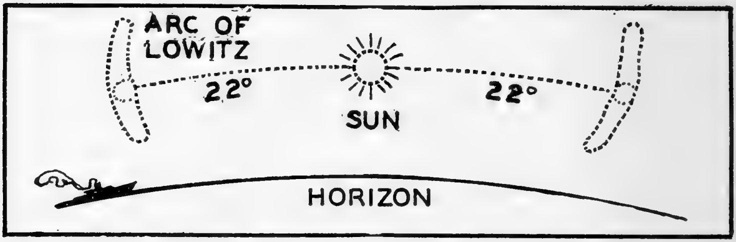
needle-like prisms. The flat flakes, snowflakes, are extremely complicated and occur in beautiful patterns, no two ever being exactly alike. With a low power microscope and considerable care you may be able to collect some snowflakes and get a look at them before they melt—but you will have to be nimble and resourceful for they have a way of melting very quickly. A good suggestion for you, should you ever try this, is to cool both the microscope and slides to freezing temperature.

In high clouds water crystallizes into long thin six-sided needles either with flat ends or, more rarely, with sharp pyramidal points.



GHOST SUNS, ARCS OF LOWITZ

When the light of the sun falls upon ice crystals suspended in the air it produces striking effects. The crystals act as tiny prisms. Since they are falling uniformly through the air they tend to get lined up in one direction with their sides vertical. The sides are inclined to one another at 60°, but the ends are inclined to the sides at 90°. Hence the crystals may act in a variety of ways, either as 60° or 90° prisms, as combinations, or as simple mirrors. When the needle crystals are aligned vertically they produce two bright spots about 22° on each side of the sun at the same altitude. The resulting apparition is that of two ghost suns accompanying the real sun, one 22° to the left, the other 22° to the right. Ghost suns are more

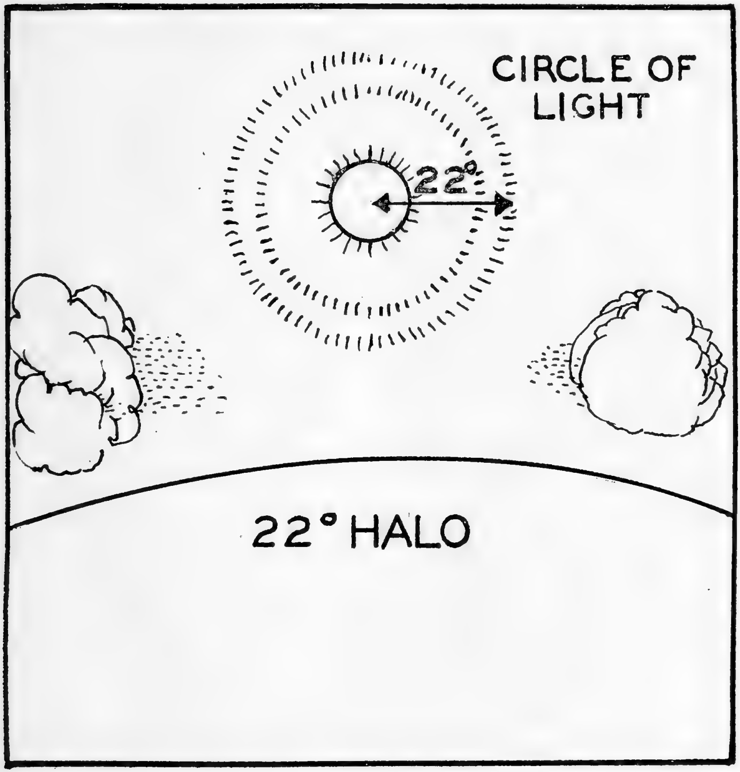


properly called parhelia or *sundogs*. If the crystals are vibrating slightly in their vertical position, curved arcs will appear to pass vertically through the sundogs, the so-called arcs of Lowitz.

HALOS WITHOUT SAINTS

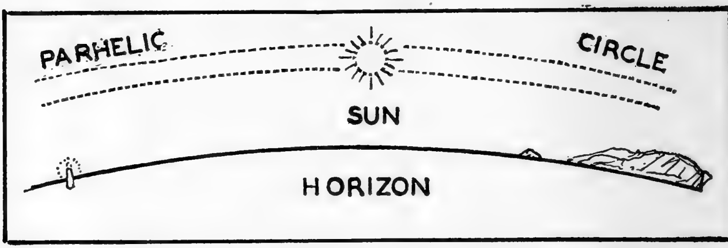
In high cirrus clouds the crystals are very much agitated by the winds and are oriented more or less at random. Under these circumstances the sundogs disappear and in their place a circular halo of 22° radius appears to surround the sun. This halo is especially noticeable around the moon on a cold night when it shines through high thin clouds.

All of the above phenomena are due to the refraction of light through the 60° angles of ice crystals. If light shines through the 90° angles instead, similar effects are observed, but all are at an angle of 46° from the sun instead of 22°. Hence halos of 46°, sundogs 46° distant etc., are sometimes visible. Under exceptional conditions halos are observed at other angles than 22° and 46° as a result of complicated multiple internal reflections in the crystals.

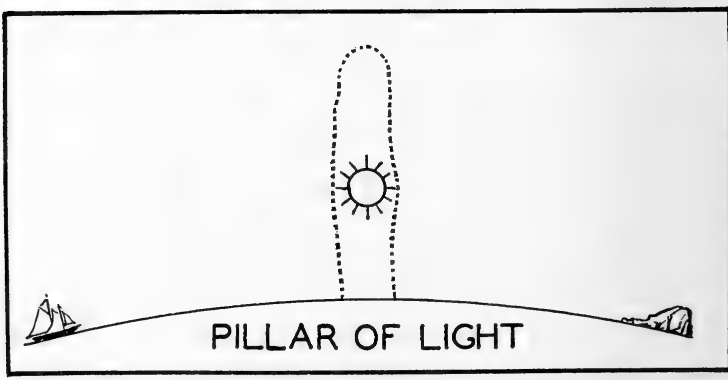


REFLECTION ILLUSIONS; TINY MIRRORS IN THE SKY; CROSSES

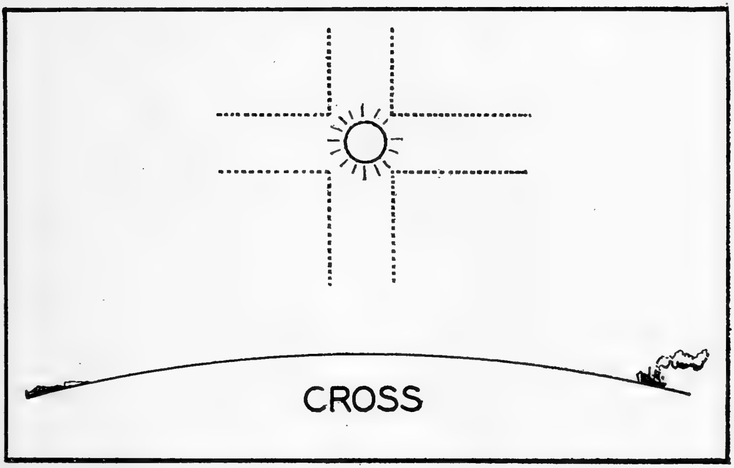
The above phenomena are due to the refraction of light in ice crystals as has been explained. In the production of optical apparitions reflection may also play a part. All of the previous effects were accompanied by coloration because refraction always exhibits some degree of dispersion. In re-



flection, however, white light is not broken up into its component colors, the result being that all halos and rings caused by reflection are pure white. One such reflection effect is the



parhelic circle, a horizontal circle passing through the sun and extending all the way around the sky. Sundogs due to reflection may occur at many different positions in the sky, but are always the same height above the horizon as the real sun. Sundogs produced by reflection of sunlight from suspended ice spicules are pure white; those produced by refraction are somewhat colored. Other reflection phenomena include huge pillars passing vertically through the sun, or very rarely bright white crosses with center at the sun or moon. These crosses are supposed to be the natural explanation of the ones seen during such manifestations as those



mentioned at the beginning of this chapter. One more cross story: British troops at the battle of the Somme in World War I swore that they saw a cross in the heavens. It is supposed to have happened at night after hours of an overcast cloudy sky. Suddenly the moonlight broke through the clouds in the form of a perfect cross—a perfect setup for a reflection illusion by little ice mirrors too.

CORONAS, WEATHER PROPHETS

Diffraction phenomena of the atmosphere are caused by small particles in the air, and exhibit a variety of colors. They are frequently observable as a small circle of light directly surrounding the sun or moon. The size of the circle of light permits us to compute the average size of the particles producing it. The circle of light is spoken of as the *corona.* If the corona decreases in size it signifies the fact that the particles (in this case raindrops) are growing in size and that we may expect rain. If the corona grows in size it signifies that the drops are evaporating and that fair weather is at hand.

SPECTERS OF THE BROCKEN

A variation of diffraction is the *Specter of the Brocken* which may be observed when your shadow is cast upon a bank of fog or mist. Bright colors and pearly white light rings surround the dark center of the shadow. They derive their name from a German mountain of the same name, from whose summit they are frequently visible. Naturally enough, they were a source of great amusement, and supernatural speculation for the inhabitants of the region. It must be admitted that they have a frightening aspect.

NAVIGATIONAL USES

Early navigators made considerable use of reflection of colors from land or sea surface upon the bottoms of clouds overlying them, or in the sky itself. The lighter greenish color of the water in the lagoon of an atoll is reflected by clouds overhead. Whalers scan the sky for *iceblink,* a whitish discoloration of the sky due to the presence of ice on the surface below. In this way they are warned of the approach of dangerous icebergs and fields. On the other hand, should they be icebound, a dark streak in the sky, *water sky,* may reveal a clear passage or open water.

FURTHER CONSIDERATIONS

The fact that the sky appears blue in color, and that at sunset the sun is a deep red and illuminates clouds with a gorgeous red and yellow glow, is due to scattering of light by tiny particles in the atmosphere—microscopic dust particles and presumably even the air molecules themselves. Because the particles are small they are able to scatter effectively only the shorter wave lengths of light—the violet and the blue. The shorter wave lengths of light are scattered in all directions so that the sky has a bluish color no matter in which way the observer looks. This leaves only yellow and red light coming directly from the sun, so that the sun appears golden. At sunrise or sunset the light of the sun passes through more air than when overhead, and then only the red light comes directly from the sun, all else being scattered, so that near the horizon the sun appears a deep red.

In conclusion we might mention some effects which are purely psychological in nature, or due to perspective. If two parallel bands of clouds pass across the sky, they will appear to meet at either horizon, although being parallel they actually do not meet. The same illusion is observed when distant ships send up parallel searchlight beams, extending from horizon to horizon. The beams arch across the sky, are furthest separated directly overhead and appear to meet at both ends.

The sun and moon appear to be much larger at the horizon than when overhead; however, when measured by a sextant, or photographed, the difference in size is seen to be purely psychological. The apparent flattening of the disks is real enough, being due to differential atmospheric refraction.

The Upper Air

Men have always wondered what it is like in the upper air. Even before the invention of the airplane, however, this knowledge was growing rapidly through information and data gathered on balloon ascents.

The first practical balloon was constructed in 1782 by the brothers Montgolfier, Joseph and Etienne, who succeeded in sending up bags filled with smoke and hot air at the small French town of Annonay. In 1783 the physicist J. A. C. Charles constructed a balloon which was filled with hydrogen gas. It was not long before both types of balloons were built in larger sizes, and the first human being ascended in one. The first free hydrogen balloon ascension was made at Paris in 1783 by P. de Rozier and the Marquis d'Arlandes in a Montgolfier balloon. Perhaps the largest hot air balloon ever built was made in 1784 at Lyons. It was said to be over 100 feet in diameter, filled with hot air supplied by a little furnace that used chopped straw as fuel.

Soon after, Blanchard and Jeffries crossed the English Channel in a balloon. Several times during the voyage they found themselves descending and had to cut away all cords, anchors, instruments, even discard their clothes and shoes. It was only a matter of time which saved them from being forced to the last measure: that of cutting away the car itself. In 1793 Blanchard made the first balloon trip in the

United States, making the ascension in Philadelphia in the presence of George Washington, and landing at Woodbury, New Jersey.

Many balloon ascents were made for the purpose of obtaining meteorological data about the upper air. Even today the airplane has not completely replaced the balloon for meteorological work. Accounts of early balloonists are worth reading. One American aeronaut, a John Wise, was about to make a rash attempt to cross the Atlantic Ocean in a free balloon, but fortunately for him, his balloon burst while being filled. Another tale, with a more tragic ending, occurred in 1897 when Salomon Andree, with two companions, ascended at Spitsbergen in hope of reaching the North Pole. As might be expected, nothing more was heard from them except for a few messages picked up in sealed bottles found floating in the sea. In 1930 Andree's remains plus a few photographs were found on White Island by a whaler.

Modern attempts to reach the highest altitude record have been more scientifically prepared. Nevertheless they have often ended with the unexpected, in a sudden plunge through space.

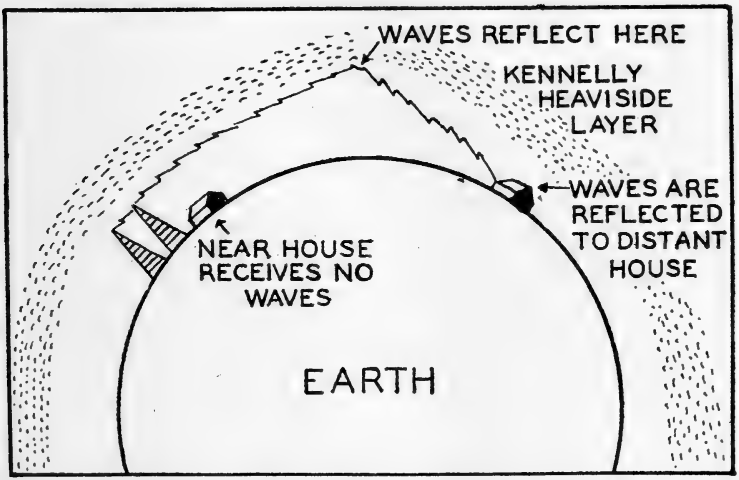
THE TWO BIG DIVISIONS OF THE AIR

We live at the bottom of a great ocean of air. The air is usually divided into two layers: (1) the troposphere, the air in which we live, up to a height of about 6 miles, and (2) the stratosphere, the very thin cold air layer that is above the troposphere and extends up to about 300 miles. Since the troposphere is only 6 miles thick and the stratosphere is 300 miles thick it is evident that the volume of the former is considerably less than that of the latter. However the total amount of air in the troposphere is really much greater than that in the stratosphere because with higher altitudes the air thins out rapidly until at the upper limit of the stratosphere there is almost none at all—just the emptiness, the vacuum of outer space.

We will reserve the discussion of the lower regions of the atmosphere for those sections in which we discuss the winds, clouds, storms, etc., and will confine ourselves to a discussion here of those remote high regions of the upper air far beyond the reaches of weather changes. From ascents in airplanes and balloons, it is known that for the first 6 miles the temperature of the air falls off rapidly until it reaches a temperature of —67° (Fahrenheit). At this point we enter the stratosphere and discover with further ascent that the temperature remains constant many more miles at approximately this same low temperature of 67° below zero. As far as men and their instruments have been able to penetrate, the temperature remains constant. At very great altitudes it is supposed that the temperature of the air increases until at 50 to 100 miles it reaches about 85° above zero (Fahrenheit).

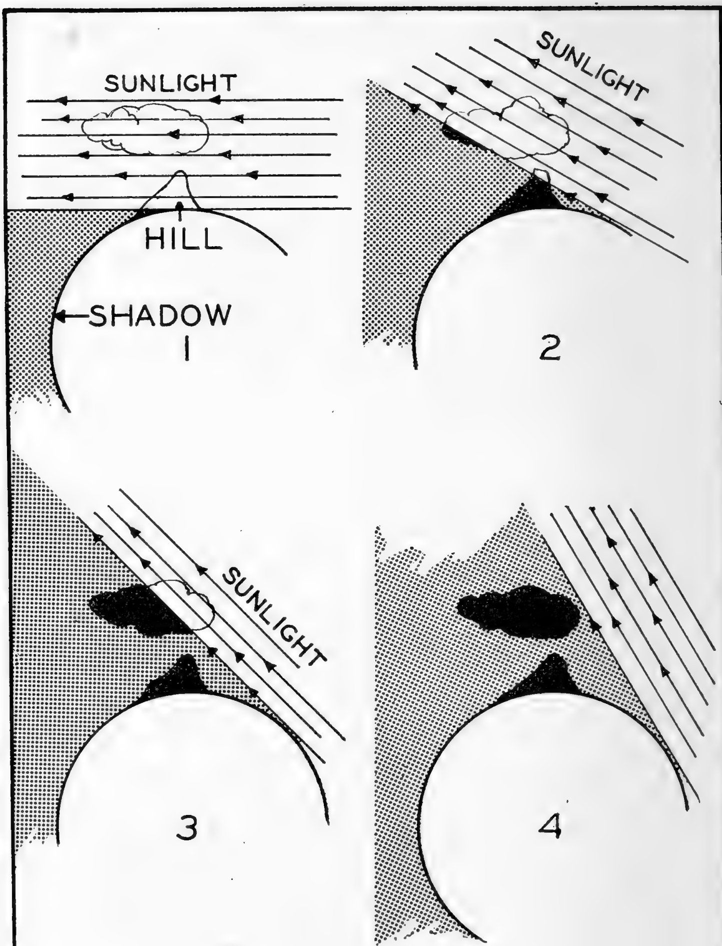
HOW HIGH IS UP?

There are no clouds in the upper air, and so the only way that we know about its real extent is by observing auroral displays, duration of twilight, and meteors. One other evidence of the height of the atmosphere is the Kennelly-Heaviside layer, the effects of which have long been understood and carefully examined by radio engineers. The Kennelly-Heaviside layer is about 35 miles up in the daytime, about 55 miles at night. It is completely invisible to your eye or to a telescope; the only way that we know that it is there at all is that it reflects radio waves. This property of reflecting radio waves is very important for long distance radio communication because it acts as an invisible barrier preventing radio waves from escaping from the earth to outer space. It is presumably composed of charged particles of air, ions. The particles of air become charged by the strong solar radiation at great altitudes. A layer of electrically charged particles acts upon radio waves in much the same way as a mirror does upon light waves. The existence of an ionized layer at such



altitudes is sufficient proof that the atmosphere extends at least to altitudes of 50–60 miles even though it is very thin up there.

The duration of twilight is another piece of evidence which indicates the height of the atmosphere. After the sun sets below the horizon, certain high objects like mountain peaks are still illuminated for a few moments by sunlight. Gradually they disappear into darkness until only the highest



SUN ILLUMINATING
HIGHER OBJECTS AS IT SETS

clouds are still illuminated by the sun; finally even the highest clouds are shut off from sunlight as the sun continues to sink lower and lower—but twilight continues for some time even after that. The duration of twilight is explained by the fact that the sunlight is still striking air particles high above the highest clouds and that some of that light is being reflected back to earth. Eventually even this residual light disappears as the sun proceeds further on its way; but the duration of twilight shows that the atmosphere extends for a considerable distance above the highest clouds.

NORTHERN LIGHTS

Probably the most striking of all phenomena that take place in the upper atmosphere is a display of "aurora borealis" called "Northern Lights," when observed near the North Pole and "aurora australis" when observed near the South Pole. Auroral displays occur as great glowing shifting pulsating streaks of light in the night sky, in a wide variety of shapes—arcs, rays, curtains, draperies, bands, coronas and diffuse general glow. When faint, they may be of the order of the brightness of the Milky Way and are usually a whitish color. But when they are intense, they may be as bright as the full moon and exhibit many colors—yellow, red, green—colors which change rapidly from one to another. Usually the lower edges of the displays are well defined and bright, whereas the upper edges gradually fade away into invisibility. The rapid movements and changes and endless combinations defy description. In the regions near to the poles a corona is sometimes observed as a ring or crown of light directly overhead in the sky with rays emanating from it on all sides like spokes of a wheel, growing and fading in strength, moving back and forth like great celestial searchlights. Photographs of such sights are always welcomed by the scientists who study them. From photographs taken simultaneously in several different places several miles apart, it is possible to estimate the height of the displays. They have been placed at heights from 50 to 500 miles. Their nature is not completely understood, but it is supposed that they are caused by the impact upon the upper air of charged electric particles shot out by sunspots on the sun. That they are electric disturbances originating in the sun cannot be doubted because they follow the sunspot cycles of the sun very closely, and are in general accompanied by disturbances in the earth's magnetic field and heavy earth currents. Radio and cable communication are severely disturbed during the more brilliant auroras.

There is always a faint aurora in the sky, but it is not necessarily visible to our eyes. The spectroscope is able to discern its presence however. Only when it becomes sufficiently strong does it appear to us as the most magnificent of the manifestations of the upper air—an auroral display.

SHOOTING STARS

> *"When beggars die there are no comets seen,*
> *The heavens themselves blaze forth the death of princes."*

The ignorant have always attached a supernatural meaning to the appearance of meteors. A particularly brilliant shooting star was supposed to foreshadow certain war or pestilence. As late as 1833, during a spectacular meteor shower, there were reports of people retiring in terror to their cellars, or if caught upon the road climbing under their wagons—convinced that the world was coming to an end.

The true, material nature of meteors was first satisfactorily proved by the German physicist, Chladni (1756-1827), who demonstrated that they are chunks of rock or iron that are flying around in the unfathomable void of outer space. When they approach the earth they are attracted to it with velocities up to 42 miles per second. Upon striking the upper air they are heated to incandescence by the friction of the air. If they are iron their outer surface is melted and becomes white hot.

Most meteors are only the size of grains of sand, and soon burn up when they strike the upper air. Others are bigger, large enough to reach the surface of the earth or ocean before being burned up. They have been found in all sizes up to many tons on the surface of the dry land, and small ones are continually being found in the clays and ooze dredged from the deep ocean floor. When meteors flash into our atmosphere they give off momentarily a bright light, like stars that suddenly dart across the sky and disappear. They are often spoken of as "shooting stars" although of course they are not stars at all.

The brighter ones are called *fireballs* or *bolides*. Sometimes they fade out quietly, at other times they explode violently like a rocket and the report may follow many seconds later. Occasionally they are bright enough to light up the entire sea for miles around. Some are visible even in full daylight. Other meteors leave luminous trails in the sky that are visible long after the meteor itself has disappeared.

Meteors usually occur in sporadic bursts—several at a time. This is because in their lonely wandering through space for millions of years they tend to pick up companions by their mutual gravitational fields. Meteors that reach the surface of the land or sea are spoken of as *meteorites.*

A GIANT METEORITE CRATER

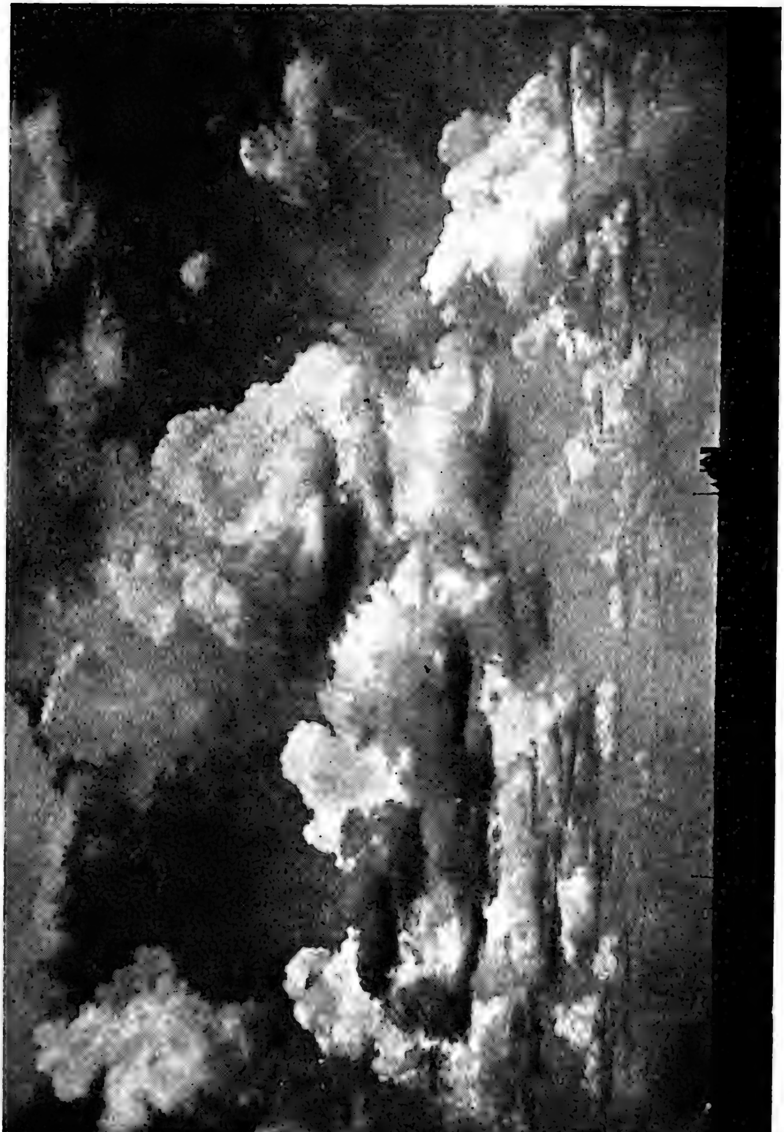
In Arizona there is a crater 4000 feet in diameter, 600 feet deep, which was caused by the impact of a meteorite several thousand years ago. More recently, on June 30, 1908, a great swarm of meteorites fell in the forests of Siberia. The heat was felt fifty miles away, trees were leveled, houses damaged. The latitude of the fall was the same as that of St. Petersburg. If the fall had occurred a few hours later it might easily have demolished that famous city completely.

Of course the meteorites that fall at sea do not leave permanent markings for us to investigate at our leisure, but there is no reason to suspect that they would prefer dry land to the oceans. One Sunday, a few years ago, a yachtsman was enjoying a peaceful afternoon in his power boat on the Long Island Sound. The blissful quiet was unexpectedly shattered by an explosion and large splash. Fearful that he had come within range of some coast artillery practice he hastily departed from the region, only to find out later that there had been no artillery practice that day. It has been suggested that the inexplicable noise and splash were caused by a falling meteorite.

METEOR TIMETABLE

The most conspicuous meteor showers are likely to be observed within a few nights of the following days each year: January 2, April 20, May 6, July 8, August 12, October 20, November 24 and December 10. Each of these groups has its own peculiar characteristics, some are slow and yellow colored; others are swift in their flight across the sky and of a soft bluish green; and most of them will appear to come from a particular preferred point of the sky, different for each group, known as the *radiant* point.

This, then, is the realm of the upper air, a frigid region far above our heads, to which, though remote, we owe much. It shades us from the harmful short-wave radiation of the sun; and it shields us from the direct impact of meteorites. But besides acting as a protector, it also provides awesome art exhibitions: it paints the northern lights in all their gaudy hues and the restful shadows of twilight.



Cumulus.

Fogs and Clouds

One of the jobs of science is to take any of the many phases of nature—no matter how beautiful and varied, how great or small, how simple or complex—and to break it down, analyze it, classify it, and if possible synthesize it. For some people this approach tends to ruin nature, it devitalizes the natural event, neutralizes its beauty and romance. As you gaze at the daytime sky, you may become enthralled by the magnificence of the great white fair-weather clouds, you may be awestruck by the violence of a thunderstorm—the huge dark rolling clouds above, and the tattered fragments of cloud scudding along below them. But you need not lose any of the aesthetic values of such a scene (or for that matter, any natural phenomenon) just because you are able to classify the events, to name this cloud *cumulus*, and the other *nimbus*.

It is well to keep these two aspects—the event as seen and felt by you, and the event as interpreted by science—distinct and separate in your mind. The event as experienced is perhaps the nearest to reality that you can come. The scientific interpretation, on the other hand, helps you to understand, but should not be confused with the reality of the event. The scientist is forced to build up an ideal model of the physical world, or to establish arbitrary categories which help him to describe and classify events. But when you observe nature you will often find events which are not

Cirrus, tufted form.

Cirrostratus and altostratus.

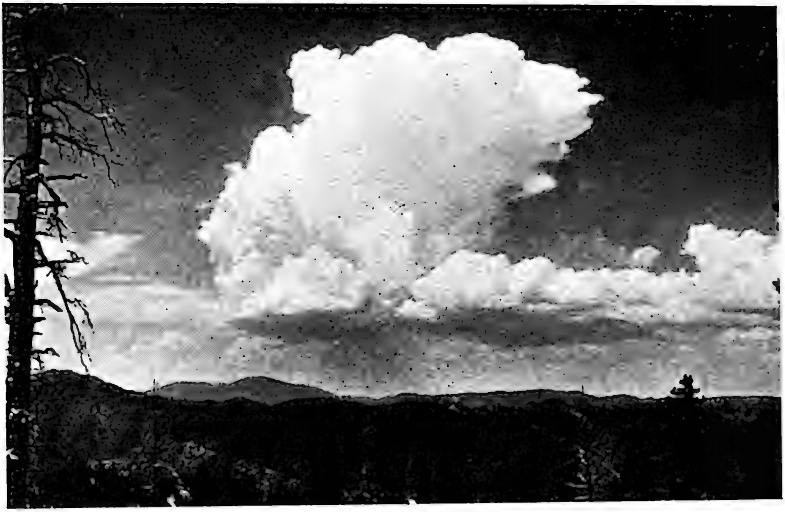
readily classifiable; for instance, you may not be able to decide to what category a certain cloud belongs.

This is not to be regarded as a lack of ability on your part, or as a failure of science. It is merely a borderline case—one of the constant reminders that there is a difference between the world as theory and the world as fact. One of the

Stratocumulus.

healthiest signs of modern day science is the recognition that the predictions of science do not *invariably* occur. The really amazing thing is how *often* present day science is right.

What we have to say about fogs and clouds here is to list their scientific explanation and classification. For a knowledge of fogs and clouds as fact, observe them yourself.

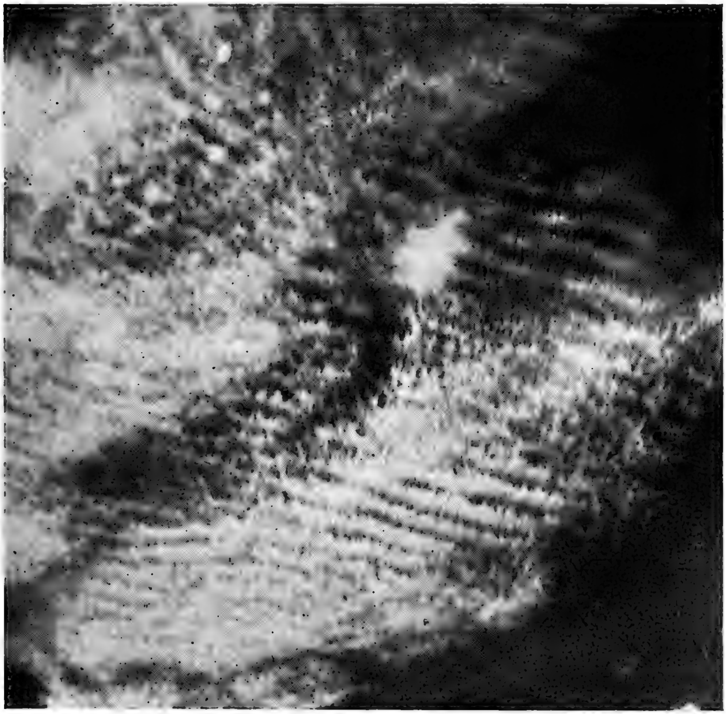


Cumulonimbus with anvil head forming (thunderstorm).

Cumulus and altocumulus.

WHAT IS A CLOUD?

Fogs and clouds are portions of the atmosphere containing large numbers of fine water droplets or tiny ice spicules. Fundamentally there is no difference between fogs and clouds



Cirrocumulus.

except for the fact that a fog rests upon the earth, whereas a cloud floats above the earth. They result from the fact that the ability of the air to hold moisture is very strongly de-

Thin altostratus and scud.

Thick stratocumulus.

pendent upon the temperature of the air involved. At high temperatures the air is capable of holding large quantities of water in the vaporized state; but at low temperatures it holds much less. The amount of water that warm air over a tropical sea can evaporate may be 30 or 40 times that which cold air over a polar sea can contain.

If a warm moisture-laden body of air is suddenly cooled, its water-holding ability is reduced and some of the water will be condensed to the liquid state as tiny water droplets, or to the solid state as ice spicules. Because of their small size the tiny particles of water or ice float in the air. The result is a cloud.

HOW A CLOUD FORMS

The necessary cooling may occur in one of two ways: (1) by radiation, which simply means that the heat energy radiates away or (2) by advection, that is, a sudden change in the volume of the air. Expansion of a mass of gas cools it; compression warms it. Fogs are caused both by radiation and advection; clouds are usually formed by advection alone. A mass of moisture-laden air ordinarily forms clouds when it moves into lower pressure areas. If you observe clouds on a fine day you can see them growing or dissolving away. The best way to decide whether clouds are growing, staying pretty much the same, or dissolving away is to choose a small wisp of cloud and look at it at thirty-second intervals. You will be able to judge very quickly the state of the clouds.

CLASSIFICATION OF CLOUDS

Clouds occur in so many different forms that it is necessary to classify them according to some definite plan, as shown in the accompanying table.

CLOUD CHARACTERISTICS

Type Cloud & Abbreviation	Range of Base (feet)	Range of Top (feet)	Appearance	Composition	Accompanying Precipitation	Icing Above Freezing Level	Turbulence in Cloud
Cirrus Ci	10,000 to 30,000	10,000 to 30,000	white, soft, fibrous & shadowless	ice crystals	none	none	none
Cirrocumulus Cc	10,000 to 30,000	10,000 to 30,000	globular & flaky without shadows	ice crystals	none	none	may be mild
Cirrostratus Cs	10,000 to 30,000	10,000 to 30,000	whitish thin veil without shadows	ice crystals	none	none	none
Altocumulus Ac	6000 to 20,000	6000 to 20,000	laminated & globular masses in one or more layers, often with shadows	usually water droplets	occasional shower	light to moderate	mild or moderate
Altostratus As	6000 to 20,000	6000 to 20,000	dull, heavy veil with shadows; inconspicuous	usually water droplets	steady rain or snow	light to moderate	usually none
Cumulonimbus Cb	1000 to 20,000	12,000 to 35,000	heavy towering mass with icy top	water droplets except at top	showery, rain & hail	moderate to heavy	moderate to severe

CLOUD CHARACTERISTICS (Continued)

Type Cloud & Abbreviation	Range of Base (feet)	Range of Top (feet)	Appearance	Composition	Accompanying Precipitation	Icing Above Freezing Level	Turbulence in Cloud
Towering cumulus Cu	1000 to 20,000	5000 to 30,000	dome or finger-shaped with great vertical depth	water droplets	occasional shower	moderate or heavy	usually moderate
Flat cumulus Cu	1000 to 20,000	2000 to 20,000	isolated tufts with rounded tops	water droplets	none	light to moderate	mild
Stratocumulus Sc	1000 to 6000	1000 to 6000	globular & laminated; soft gray with shadows	water droplets	drizzle or snow flurries	light to moderate	mild
Stratus St	1000 to 6000	1000 to 6000	dull flat & grayish with few shadows	usually water droplets	drizzle or snow flurries	light	mild or none
Scud or Nimbostratus Ns	100 to 6000	100 to 6000	detached & torn appearing fragments	usually water droplets	none	light	mild
Fog	ocean or land surface	100 to 2000	uniform & gray	usually water droplets	none	light	none

Lightning

Everybody knows that lightning is electricity—and lots of it. As a matter of fact, one cannot get through grade school without hearing several times about Benjamin Franklin and the time he flew a kite during a thunderstorm, and how he drew a spark from a key attached to the kite string. Flying kites during thunderstorms is not a practice to be recommended, however, and it was lucky for old Benjamin Franklin that the spark he drew from the key was as small as it was. After accounts of the experiment of Franklin were published, the experiment was repeated in several countries. In St. Petersburg a certain hapless professor, while flying a kite, was struck dead on the spot by a flash of lightning which entered his forehead and left him in such an advanced state of decomposition that he had to be buried in great haste.

LIGHTNING STRIKES

The effects of being struck by lightning are often very ghastly—perhaps leaving the victim covered with terrible burns, or with no outward mark at all. In other cases the skin may be turned black, but otherwise remain quite intact, whereas the whole interior of the body is reduced to ashes or liquefied and the bones splintered as though the very marrow in them had exploded. These grim details should discourage experiments with kites.

LIGHTNING HITS SHIPS

Maritime history is filled with tales of ships lost with all hands due to their being struck by lightning. In wooden ships lightning could splinter a mast all the way down to the step and then blast a hole through the bottom. Many years ago the ship *West Point* was struck seven times in as many minutes, and as a result of these seven celestial broadsides lost part of her crew—a convincing proof that lightning can strike several times in the same place if it has a mind to. During a five-year period in the early nineteenth century, the British Royal Navy lost seventy ships to lightning bolts, a calamity joyfully credited to God by the French. Modern ships are protected against lightning, however, so the outcome of present day naval contests is less in the hands of God, more dependent upon armament—a kind of evolution from bolt to bomb.

Even in iron hull ships, a lightning stroke has some effect. For example, it can reverse the magnetism of a ship completely and throw off the compasses drastically. After a ship has been struck by lightning, it is imperative to redetermine the deviation table (or curve), or perhaps even to have the compass recompensated. Compasses are compensated for deviation (error produced by the magnetic influence of steel and iron in a ship) by proper placing of various magnets both inside and outside of the binnacle. The actual procedure, which is a tricky and involved process requiring much study and experience, is usually handled by professional compensators. (The subject is too technical for discussion here, but a good reference, for those who are interested, is *A Treatise on Compass Compensation* by L. V. Kielhorn, D. Van Nostrand Company, New York, 1942.)

HOW IS LIGHTNING PRODUCED?

From their attempts to explain the wide variety of electrical phenomena, both those that occur naturally and those that can be produced in the laboratory, physicists have come to believe that electricity is made up of small particles called electrons. Electrons which are bound in systems with other kinds of elementary particles make up atoms of matter; but when free to roam for themselves they produce electric currents. When we speak of *positive* electricity, they say, we really mean the absence of electrons. *Negative* electricity is the presence of electrons. Electrons are subject to a compelling tendency to get to places where they are scarce. In the swirling clouds of a thunderstorm, electrons may be separated systematically from certain parts of clouds and accumulated in other portions. When these accumulations of electrons build up too high, there is a sudden discharge between the clouds or between a cloud and the earth as the electrons make a dash to restore a more equitable distribution of themselves. Such a discharge is a stroke of lightning.

One frequently experiences a sudden shower of rain directly following a lightning stroke. Contrary to a popular misconception, it is not the lightning that produces the extra rain, but the rain that produces the lightning. In falling, raindrops accumulate electric charges from the surrounding air in much the same way a cat's fur accumulates charges when brushed. The raindrops carry these charges to the ground and in this way transport electricity from one place to another, building up inequalities in the distribution of electricity which are evened out by lightning bolts or slower brush discharge. The apparent reversal of cause and effect in time occurs because the rain takes so much longer to fall on us than the time necessary for the flash and report of the lightning stroke.

LIGHTNING SNAPSHOTS

By means of special revolving and wide-view cameras it is possible to photograph lightning strokes. It is discovered that what appears to be a single stroke is often a series of distinct strokes following one another so quickly that they give the appearance of a single stroke. One station for getting shots of lightning was situated near the Empire State Building. Whenever a promising thunderstorm was in the neighborhood the scientists were rushed out of bed, or away from their other tasks, to their skyscraper laboratory in hopes of getting a picture, no matter what the time of day or night. What price science! Lightning can be photographed, however, with an ordinary box camera; special cameras are necessary only for scientific purposes.

DANGER! HIGH VOLTAGE

The voltages developed in lightning strokes are very great when compared to those which we use in ordinary electrical appliances. It requires about 50,000 volts to produce a spark one inch in length. Imagine, then, what a voltage is required for a bolt about a half mile long! In color lightning is either a brilliant white or a rose pink. Both of these varieties have distinct spectra which have been studied with the spectroscope. The cause of the light of lightning is not fully understood. Air has been heated to very high temperatures in the laboratory, but it has never been made so hot that it gives off light of its own as in an electrical discharge. It is generally supposed that the light is a result of disturbances within the atoms themselves caused by the passing electrons of the discharge.

When the discharge has ceased to flow, the atoms of air return to their normal states and no more light is generated.

Thunder is caused by the violent expansion of air near the stroke and the resultant compressional wave which spreads out from the disturbance. A small electric spark produces a simple snapping sound; the sounds from the different parts of a long lightning stroke arrive at our ears at different times, causing a prolonged rumbling sound. Despite the violence of lightning itself, thunder is seldom heard more than fifteen miles away. Large cannon have been heard much farther.

The lapse of time between a lightning flash and the ensuing thunder is a good index of the distance of the lightning stroke. The number of seconds elapsed between lightning and thunder divided by five gives the distance roughly in miles.

KINDS OF LIGHTNING

There are several distinct kinds of lightning observed: streak lightning, bead lightning, rocket lightning, ball lightning, and sheet lightning.

Streak lightning is the ordinary kind of lightning that we have already discussed. It is a discharge along an erratic, broken, zigzag path, often branching off in different directions. The cause of its erratic paths is the lack of homogeneity of the atmosphere. Certain portions of the air are more resistant to the current's passage than others and force the discharge to follow a crooked path.

Occasionally a streak of lightning is observed to break up into a string of bright "beads"—hence it is known as bead lightning.

Sometimes a progressive growth in the length of a lightning bolt is observed. The bolt seems to shoot up in the manner of a rocket and so it is known as "rocket" lightning.

GREAT BALLS OF FIRE!

Ball lightning is one of the strangest of natural phenomena. Some experts question its existence or claim that it is illusory, but so many well documented observations are on record that its existence may be considered to be well established. It is usually described as a brilliantly luminous globe anywhere from the size of a lemon to that of a basketball. The literature abounds in accounts of balls of this kind of lightning floating down chimneys and into windows, chasing frightened women, and exploding with considerable violence and even causing loss of life. An aeronautical engineer of the author's acquaintance describes one he saw in Freeport, Long Island, during a short summer thundershower. He says it floated gently down the street about three feet from the ground until it collided with a fire hydrant and with a loud clap disappeared. Another friend, a naval officer, tells of one which he saw as a child, a brilliant golden sphere which floated in his nursery window, frightened the nurse, and then entered the bathroom where it exploded, causing some damage to the plumbing there. Such balls have been observed plummeting from the clouds, bouncing upon the ground like rubber balls, and then rebounding up into the clouds again. Sometimes they simply grow dim and disappear quietly. Scientists have not yet discovered an explanation of the mechanism of this phenomenon.

SHEETS OF FLAME

Sheet lightning appears as broad diffuse patches of sudden light behind large cloud masses. It is supposed to be merely the reflection of other kinds of lightning upon surrounding clouds. Lightning of this type is commonly observed during the frequent brief thundershowers of summer and when the actual storm has already passed or not yet begun, the flashes are often called "heat" lightning.

ST. ELMO'S FIRE

During an electric storm other less dramatic phenomena may occur on shipboard. A familiar form is St. Elmo's Fire—a bright continuous glow emanating from mast tops, sharp corners, and rigging. Streaks of bluish flame are visible from all high points. The strength of these discharges varies according to the strength of the storm. As the storm increases in fury, the St. Elmo's fire grows brighter and larger; and as the storm wanes, the mysterious lights flicker and die. If one climbs to such a point of discharge and extends his hand out toward the sky, the flames will leap off his finger tips, the electric discharge passing through his body, and yet there will be almost no perceptible shock. However, such electric currents may have some temporary minor physiological effect. Sailors who have been exposed to St. Elmo's fire in the rigging of old ships have been known to complain of slight disturbances of vision, dizziness, etc. It is not certain whether the effect is imaginary, or whether it is due to the ozone given off by the electric discharge or some more subtle effect.

Many strange tales about freak tricks played by lightning are told, some of doubtful truth, such as the story about the sailor who was struck by a bolt of lightning which left the name of his ship branded upon his chest, or the one about the ship's officer who had all his gold braid burned off without suffering any other ill effects.

The Winds

Winds are produced by the balancing of the earth's heat budget. This is a delicate process which works somewhat as follows:

The earth continually receives heat from the sun; it also radiates heat away from its surface. Just as much heat must be radiated away into space as is received from the sun, otherwise the temperature on the earth would be continually rising or falling. But here is the catch: most of the sun's heat falls on the earth in the tropics, but the heat is radiated away more or less equally all over the earth. Therefore there must be a transfer of heat from the tropics to the polar regions. This actually takes place. The outward manifestation is the world-wide system of winds (and ocean currents).

In general it can be said that the winds of the world are distributed geographically according to latitude as shown in the chart and accompanying table. Although local conditions often change wind directions completely, there are certain prevailing winds at different latitudes.

LOCAL WINDS

A more accurate knowledge of the winds at any locality may be obtained from a study of the wind roses on a pilot chart.

Along the coasts other local winds arise, owing their existence to local inequalities in the heating of land and sea during the day, or of cooling during the night. During the day

USMS Training Aids Unit Chart

Wind belts.

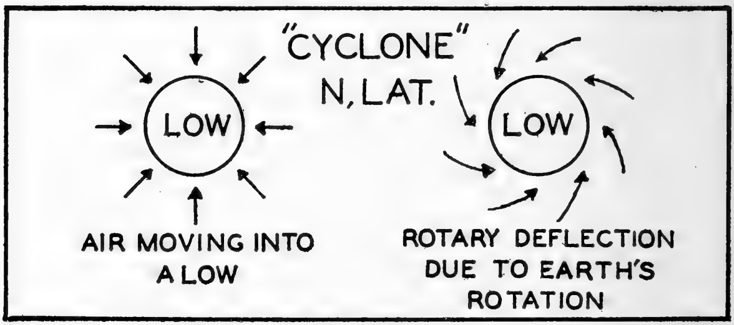
WORLD WIDE SCHEME OF THE WINDS

North Pole–80°N	Arctic easterlies, high pressure, cold
70°N–60°N	Frontal zone, variable winds
50°N–40°N	Prevailing westerlies
30°N	Horse Latitudes, fair, calm, high pressure
20°N	Northeast Trades
10°N–10°S	Doldrums, light variable winds, frequent showers, low pressure, cloudiness
20°S	Southeast Trades
30°S	Horse Latitudes, fair, calm, high pressure
40°S	"Roaring Forties"
50°S	"Howling Fifties," prevailing westerlies
60°S	"Screeching Sixties"
70°S	Frontal zone, variable winds
80°S–South Pole	Antarctic easterlies, high pressure, cold

the sun heats land surfaces much more rapidly than the water surface, so that there is a tendency for air to move toward the land giving rise to a "sea breeze." With the coming of night the land cools more rapidly than does the water so that winds arise in the opposite direction, the "land breeze."

AIR MASSES

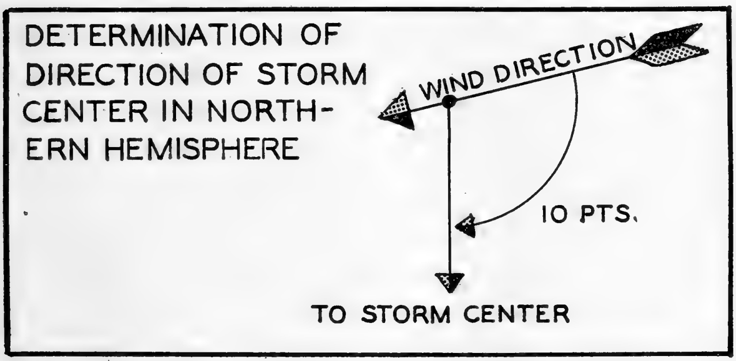
A very important concept in weather analysis is the idea of an air mass. Certain continents, bodies of water, etc., act as source regions for quantities of air with particular characteristics. A land mass in the high north, for example Canada, produces cold, dry air masses; a body of water like the Gulf of Mexico produces warm, wet air. Weather forecasters keep careful track of the movements of these air masses from day to day and find the study of great aid in forecasting weather conditions. A warm air mass displacing a cold one is spoken of as a warm front; a cold air mass moving in to displace a warm one is called a cold front. Meteorological disturbances (windstorms, cyclones, thundershowers, etc.) are likely to be concentrated along a front. Warm and cold fronts each have characteristic kinds of storms. An approaching warm front will be heralded by the appearance of cirrus clouds in the sky. Gradually the clouds appear to get heavier; cirrus changes to cirrostratus, to altostratus, and finally to nimbostratus, with accompanying rainfall and temperature



rise. A cold front brings much more violent storms and hence is of more concern at sea than a warm front is. No stratus clouds form, the first signs being altocumulus clouds which change to large thunderclouds, rain, and a temperature drop. Often there is a complete line of thunderstorms all along a cold front—a "line squall."

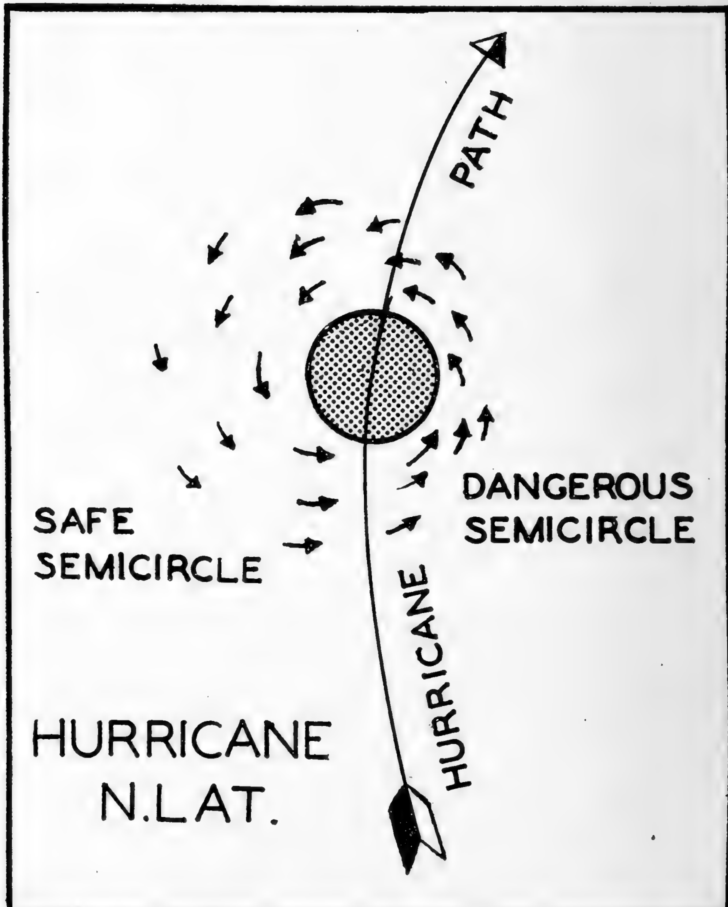
HURRICANES

Air flows inward toward a center of low pressure. As it does so its course is deflected because of the earth's rotation; as a result it actually moves in a spiral path toward the low pressure point. This spiral motion is counterclockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere. Winds exhibiting such spiral motion are called cyclones, may extend in a large vortex several thousand miles in diameter. Naturally at different points in the cyclone the winds will be met in different directions. By observing the direction of the wind it is possible to determine the direction of the storm center, the so-called eye of the storm. For example, in the Northern Hemisphere the storm center will



bear about ten points (measured clockwise) from the direction from which the wind is blowing. In the Southern Hemisphere, measure the ten points counterclockwise. Having obtained the bearing of the storm center one may then estimate its distance by the barometer's rate of falling. Combining bearing and distance gives a fair approximation of the position of the storm center. Successive determinations may be made and the path of the storm plotted. The usual speed of a storm center will be found to be about 15–20 knots.

In the tropics, analogous, smaller, but much more violent cyclones occur, often called "hurricanes." The strong winds that compose the tropical cyclone whip up a very rough sea.



In the eye of the storm there is a calm, but the seas are so mountainous that a small boat has almost no chance to survive, and even large vessels may suffer damage. A navigator finding himself in a position directly in the path of the center of the storm steers a course with the wind. This maneuver brings him into the "safe" semicircle. Steering into the wind would mean slower progress and also would bring the ship into the "dangerous" semicircle, the more tempestuous half of a cyclone.

Official U.S. Navy Photo

Waterspout extending down from clouds to reach water surface.

WATERSPOUTS

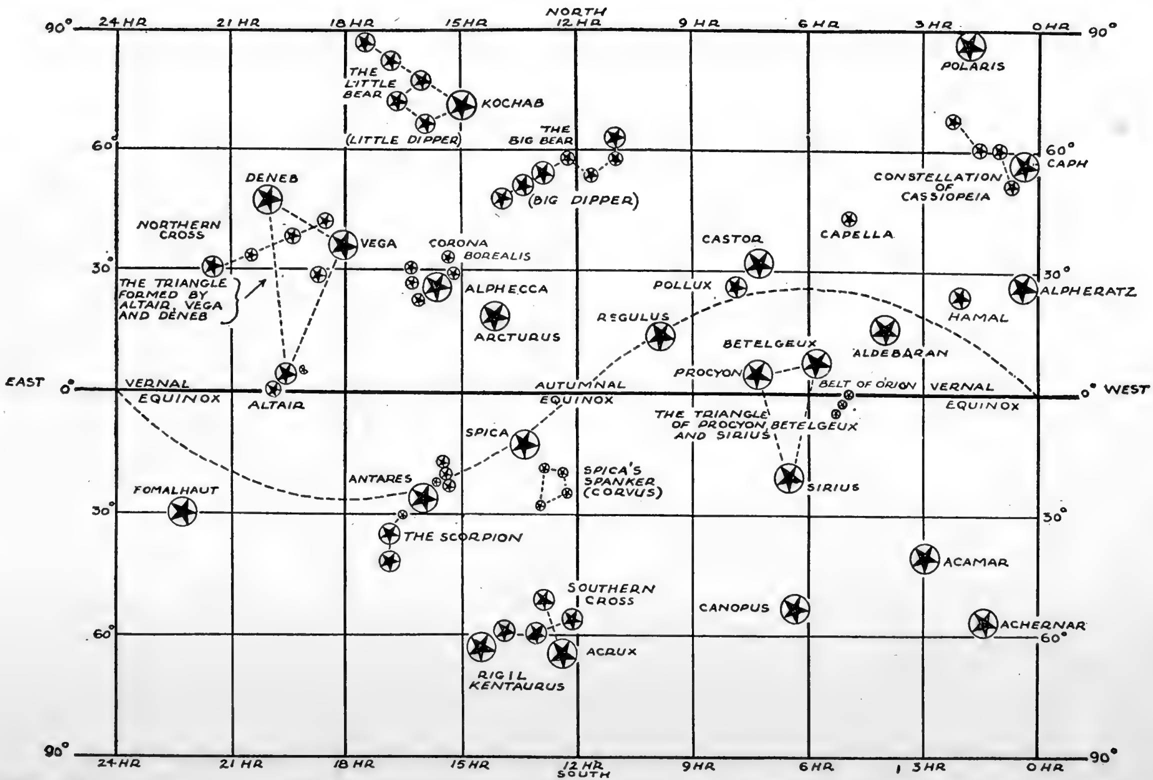
At high levels in the air there are usually winds blowing in a direction opposite to that of the trades, called the countertrades. Should these countertrades be at about cloud level, and should an upward convection current be present at the same time, the entire vertical column of air may be drawn into a violent whirlwind. As the inner core of the whirlwind is expanded by centrifugal force it is cooled somewhat, and a funnel shaped cloud spout may form within the vortex. Eventually the spout may reach down to the spray whipped up from the surface of the sea by the wind. The waterspout makes a deafening roar and though it appears to draw water up from the sea, actually the water it contains is fresh water condensed from the atmosphere. The average speed of a waterspout is about 25 miles an hour, but the winds of which it is composed reach the highest wind velocities known, up to 500 miles per hour. A good sized waterspout is a real enough danger, capable of tearing to pieces anything which might come into its path.

Celestial Bodies

The celestial bodies: moon, sun, planets, and stars, are all old friends of the mariner. Like old friends they have many things to tell us, tales of magnitudes and measures transcending our ability to understand and appreciate, and other stories, too, which give us perspective, or at least some inkling of our place in the universe.

THEIR MOTIONS

The astronomical bodies which we see execute a regular motion across the sky during the course of a single night, and a similar though longer period motion over the course of the year. These two principal motions of the celestial bodies, the daily and the yearly, are to be considered as apparent rather than real because they are produced by the daily rotation of the earth about its axis and its yearly revolution about the sun in its orbit. Superimposed upon these two chief motions are the peculiar motions of the celestial bodies themselves, the most outstanding of which is that of the moon which moves among the stars a distance equal to its own diameter each hour. The planets also have motions of their own superimposed upon the overall daily and yearly apparent motions previously mentioned. Although they are fairly complicated motions they are all capable of being calculated mathematically and the positions of the planets will be found tabulated for each day of the year in *The American Ephemeris and Nautical Almanac* or the British *Nautical Almanac.* All of these tables are the result of long and tedious computations



Star chart for navigation. The earth's path through the heavens (ecliptic) is shown by the dotted line.

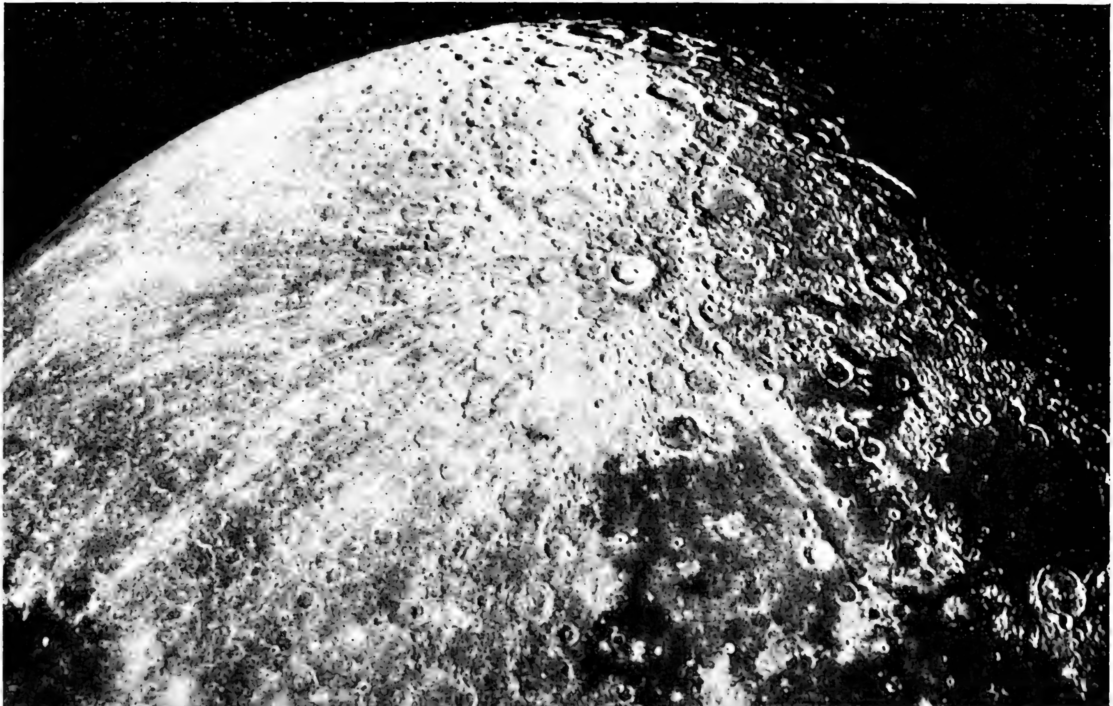
which take into account not only the planets' motion about the sun, but also their mutual attractions and perturbations according to the Law of Universal Gravitation and Newton's Laws of Motion. Positions of celestial bodies are listed by two quantities: right ascension and declination on the celestial sphere, just as geographical positions are given by longitude and latitude on the earth. Right ascension is measured from a standard meridian in the sky, the vernal equinoctial colure, as longitude on the earth is measured from the Greenwich meridian. Declination is measured north and south of the celestial equator, as latitude on earth is measured north and south of the equator.

THE ZODIAC

Furthermore the sun, moon, and planets all follow, more or less closely, a definite path in the sky called the ecliptic. Along the ecliptic are a series of twelve constellations, groups or configurations of stars, called the Signs of the Zodiac. A rough way of locating the sun, moon or the planets is to designate the particular Sign of the Zodiac in which the body is at the time. The apparent positions of the celestial bodies are essential to celestial navigation. By means of a comparison between the right ascension and declination of celestial bodies as given in an almanac, and the observed height above the horizon (altitude) and bearing (azimuth) of the same bodies, the navigator is able to determine with sufficient accuracy the position of his ship at sea (i.e., its latitude and longitude).

THE STARS

Besides the sun, moon and planets, the other visible astronomical objects are several thousand points of light of vari-



Moon's surface, showing craters and long streaks called "rays," also some dark areas called "seas" although it is evident from the picture that they do not contain any liquid.

ous brightness which we call collectively the fixed stars. Because of their great remoteness whatever motions they have individually appear so inconsiderable to us over the course of a few centuries that they remain "fixed" in the sky, partaking only of the general daily and yearly motions. Consequently the constellations which they form remain very much the same year after year. In the course of many centuries, however, even the constellations change their familiar shapes.

THE MOON

The Moon is the nearest of all our celestial neighbors, at a distance from the earth of about a quarter of a million miles. It is a globe only 2000 miles in diameter with mountains, plains, cliffs, deserts, a very rugged landscape indeed, but decidedly distasteful to a sailor because there is no ocean there at all! Not a river, lake, or pond for that matter. And it never rains there either, because there is no water and no atmosphere. It is a hard doctrine to teach and believe, but all the evidence points to the fact that the beautiful silvery moon, sublime and serene as it appears, is only a barren desert, utterly devoid of any life as we know it, suffering from great extremes of temperature and exposed to a constant barrage of meteorites and debris which easily reaches the surface without hindrance because there is no atmosphere to slow it down or consume it in friction-generated fire.

CELESTIAL DESOLATION

A pair of powerful field glasses brings the dismal scene of the moon's surface into view. The most striking of the lunar features is the large number of pits or craters that are observable in all portions of the disk. Some of these craters are, by direct measurement, over one hundred miles in diameter. Besides the giant craters there are numerous smaller ones of all different sizes and in all different states of decay. On the whole, the larger craters seem much older and present a more tumbledown appearance than do the smaller ones, presumably indicating that the smaller craters were formed at a later date. Of course there is at present no erosion of the moon's surface due to water or winds because of the absence of those elements, but there are very extreme changes in temperature at least twice a month on the moon's surface so that surface rocks might easily be cracked and spalled off by this agency alone. Add to this the incessant hail of meteorites upon the moon, and the possibility of other agencies in the past, and it will be agreed that, whereas the moon's features are more permanent than geological formations of the earth, they are not exactly eternal.

SEAS WITHOUT WATER

Other features of the moon's surface are the extensive "seas" or *maria*—great expanses of dark, even material. Geologists regard the moon's maria as the remains of past outflowing of molten rock from beneath the moon's surface that have now cooled off and hardened into solid rock. These maria are responsible for those dark portions of the moon, visible to the naked eye, whose irregular shapes have suggested such popular fancies as the "man in the moon" or the "hunter and his dog."

LUNAR THEORY

The precise prediction of the moon's pathway through the sky has been a classic problem for the astronomers of many ages. Before the introduction of the marine chronometer, observations of the moon (so-called "lunars") were necessary for a determination of longitude. In addition to the observations, precise tables of the moon's position were also required. Many of the best scientific minds—Newton, Laplace, Delaunay—spent their time trying to unravel the mysteries of the moon's motion. Modern lunar theories call for extensive use of the most advanced dynamical theories. They require long series computations which involve hundreds of separate periodic terms depending on such different things as the distribution of density of materials in the earth, the earth's oblateness, all of the planets in the solar system, the retardation of the tides, the ellipticity of the earth's orbit. Separating these various effects and determining their magnitude empirically and theoretically is a painstaking and difficult task. Only recently has the theory of the moon's motion been satisfactorily completed by the late Professor Ernest Brown of Yale who spent the major portion of his life on this task. He would awaken about two o'clock in the morning, do his calculations propped up in bed until breakfast time when he would get up and get ready to teach his classes. Lunar sights are no longer necessary however for determination of time at sea in a world which enjoys the benefits of radio time signals and accurate chronometers.

THE PLANETS

The planets, of which the Earth is one, all revolve around the sun. They are the principal members of the solar system. Some are accompanied in their travels by smaller satellites. The Earth has one satellite, the Moon. Other planets have a number of satellites, some of these moons being the merest chunks of rock a few miles in diameter, others being almost the size of the Earth.

The order of the planets, from the nearest to the sun outward into space, is:

Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto

LITTLE MERCURY

Mercury, the planet nearest the sun, has the shortest period of rotation of all the planets and is the smallest. It keeps one face toward the sun, the other turned away from the sun invariably. As a result one hemisphere must be very much hotter than the other. Because Mercury always appears very close to the sun in the sky and is therefore always more or less in its glare, little is known about the telescopic appearance of its surface. In other respects Mercury is a very fascinating planet because in its motion it exhibits some anomalous motion (precession of the perihelion) which cannot be accounted for according to classical mechanical theories. An attempt to rectify this deplorable situation was made by Leverrier, the famous theoretical astronomer of the Paris Observatory. He postulated the existence of another planet even nearer the sun than Mercury. Immediately he received news that such a planet had been observed in transit across the sun's disk (a planet in crossing the surface of the sun appears as a dark spot—transits are quite rare) by a French amateur astronomer, and a name was proposed for the new planet, Vulcan. The "discoverer" even received the decoration of the Legion of Honor from the French Government. However, subsequent observations of Vulcan have never been made, or have been disproved, so that today we no longer accept Vulcan into the solar family. But the anomalous motion of Mercury still persists, and in fact this deviation from classical theory has become one of the strong arguments for the Theory of Relativity as developed by Einstein, a theory which has an explanation for Mercury's erratic behavior.

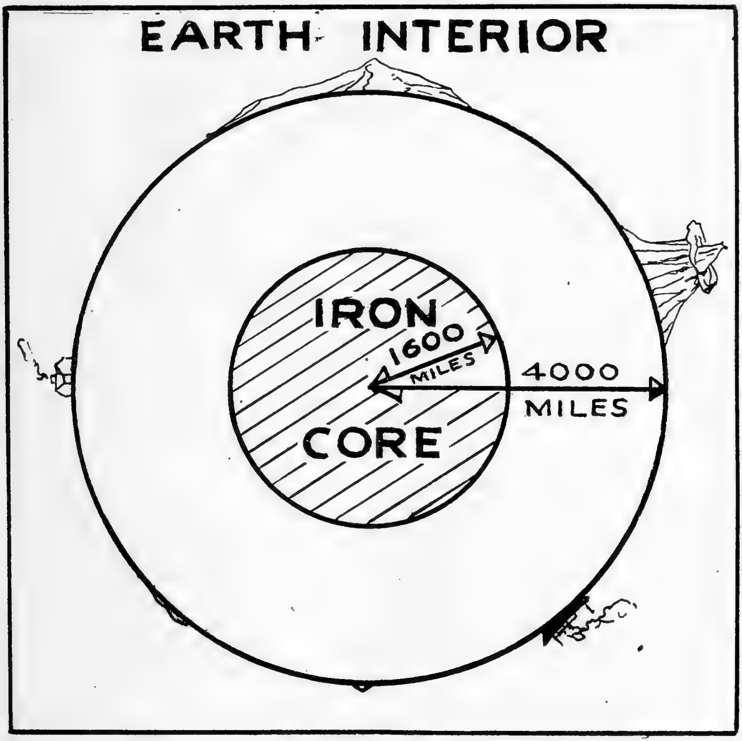
VENUS, THE VEILED GODDESS

The planet Venus, named after the Roman goddess of beauty and love, is about the size of the earth, but so enshrouded with mists and veiled in clouds that no one has ever seen her surface. Scientists, in their rude attempts to probe her mysteries, have applied the spectroscope to her, but have learned little about her except some notion about the chemical constitution of her outer atmosphere. As Venus takes different positions with respect to the earth in space, she sends us different amounts of light. At her brightest she is visible to the naked eye in full daylight, if you know where to look for her.

Twice, in little over a century, Venus crosses the disk of the sun. The event is called a Transit of Venus. It is so rare that Captain Cook, the old navigator and discoverer of Pacific islands, brought an expedition all the way from England to a cape on Tahiti to observe one. The point of land is still called Venus Point.

THE EARTH

When you see a ship disappear below the horizon you accept this as evidence that the earth is round as geography books tell us. A few facts may not be out of place. The earth is a sphere 7,927 miles in diameter, with the poles somewhat flattened so that points at the poles are about 13 miles nearer to the center than points on the equator. The total area of the earth is 196,950,000 square miles, only 57,510,000 square miles of which is land; the rest, 139,440,000 square miles being covered by the oceans. The irregularities of sea and land topography are not sufficient to make the earth a very rough sphere. In fact, in proportion, the earth is smoother than a billiard ball. In other respects it is more like a golf ball—with a tough outer skin and a liquid center. The liquid center, known to geophysicists as the Dahm core, is supposed to be composed of molten iron. We are certain that the center of the earth is liquid because of the way earthquake waves that travel through it behave. There are two kinds of earthquake waves: compressional and transverse waves. At the source of an earthquake both kinds are produced, and both may be received at near-by seismological observatories. However, at great distances, where the waves have to penetrate deep layers of the earth, seismological stations are able to pick up only the compressional waves. Now it is known from laboratory experiments as well as from theory that transverse waves are unable to pass through a liquid, so that their absence is interpreted as being evidence of the liquid state of the earth's interior. Further astronomical evidence indicates that the density of the center must be about that of iron, so the probability that the center is composed of iron is increased, especially inasmuch as iron is the most cosmically abundant heavy metal. Finally, we know that the earth's



temperature rises with depth, from experience with deep mines. All of these things together point to the conclusion that the center of the earth is composed of molten iron.

Studies of earthquake waves give further information of the structure of the earth hundreds of miles down where we have never been able to gain access. Present theories indicate that the central iron core is enclosed with a series of further layers of different compositions, the outermost layer being of course our familiar land and sea as we know them.

DEPTH CHARGES

By exploding quantities of TNT on the ocean floor, and recording the reflections and echoes of the waves with submerged instruments, some information has been obtained about the rocks which lie beneath the bottom of the ocean, but little is really known about the structure of the ocean bottom. Most studies, such as our knowledge of the oozes, extend only to the first few inches. Dr. Maurice Ewing of the Woods Hole Oceanographic Institution was about to obtain data on the depth of ocean sediments and the rocks that lie underneath them. The war has interrupted these investigations temporarily.

THE EARTH IN SPACE

As it goes through space the earth executes a rather complicated motion. First of all it rotates upon its North-South axis once every day. The rotation causes the sequence of night and day, the rising of the sun and moon, of the stars, their procession across the sky, and their setting. Once around in a day at first may seem slow, but if measured as linear velocity at a point near the equator it means over 1000 miles per hour—a speed that has been maintained for millions of years. As a matter of fact, the earth is slowing down a little because of the action of the friction of the tides in shallow seas such as the Bering Sea. In the year 2000, a day will be 1/1000 of a second longer than it was in 1900. Over the course of a century such lengthening of each day adds up to quite a bit. Since Julius Caesar's time the earth has lost over an hour's time.

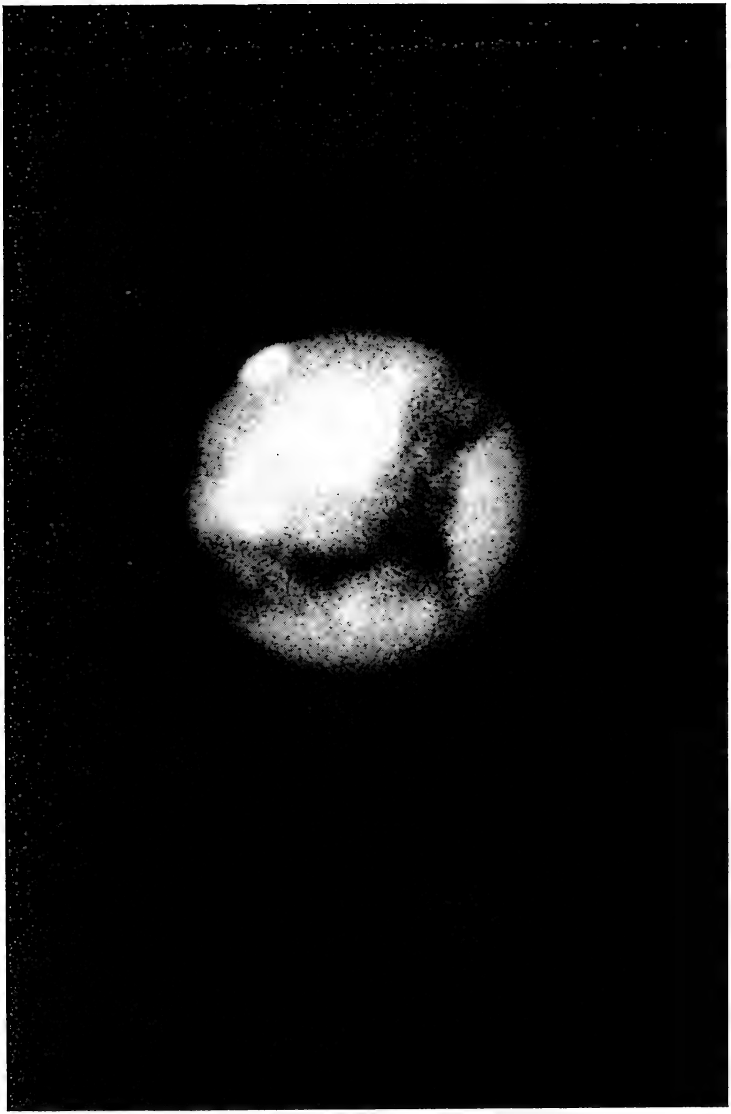
WHAT DO YOU WEIGH?

The spinning of the earth on its axis causes a centrifugal force acting at the equator which lessens the apparent weight of objects. A man who weighs 200 pounds at the North Pole would weigh about 198.94 pounds at the equator.

Besides spinning upon its axis, the earth also moves around the sun in an elliptical orbit, completing one revolution every year. The average distance of the earth from the sun is about 92,900,000 miles; the distance changes slightly during the year, being smallest in December, and largest in June. The size of the elliptical orbit, its orientation in space, and its shape may be described quantitatively by certain geometric quantities called the "elements" of the earth's orbit.

ICE AGES

These elements do not remain invariable for long periods of time because there are other planets in the solar system which tend to disturb the motion of the earth by their gravitational influences. Such slight perturbations of the earth's orbit over the course of many hundreds of thousands of years cause certain portions of the earth to receive more or less sunlight and result in corresponding changes in temperature and climatic conditions. There is some evidence that such long period perturbations of the earth's orbit are among the primary causes of those great periods of cold in past history —the Ice Ages—which have occurred at intervals during the



Mars. The dark middle regions wax and wane with the seasons and are supposed to be vegetation. The white spot is the polar icecap.

past and will certainly recur in the future. Mankind has already weathered several ice ages, and will probably see some more.

IS THERE LIFE ON MARS?

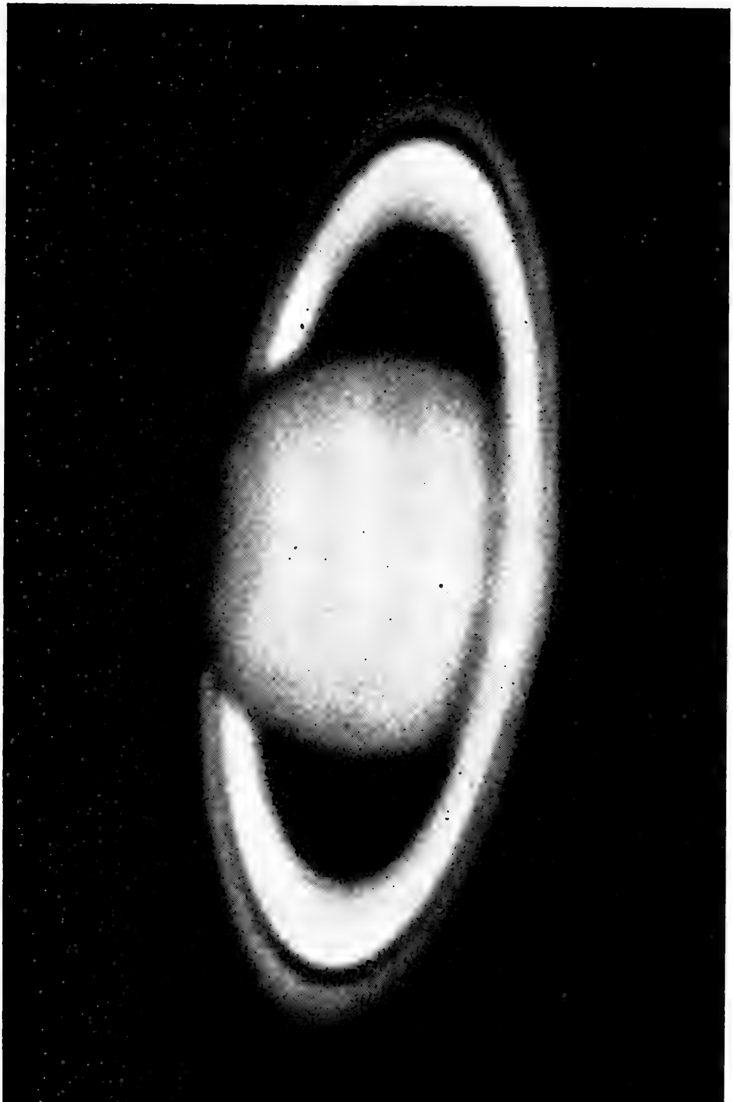
Next in line after the Earth is the planet Mars, somewhat smaller than the Earth but large enough to show some rather definite surface features under satisfactory conditions. A good though not large telescope is necessary to view the features of Mars. Most striking of all the features is the polar ice cap, a white spot on the planet's visible pole which changes its size and shape with the Martian seasons, becoming large in the winter and small in the summer. Besides the polar ice cap there are large areas of dusky dark green color which also vary in size, shape and intensity as the seasons change. Some astronomers are inclined to attribute these spots to large forests or growths of some kind of vegetation, while others, who refuse to admit any kind of life is possible on Mars, postulate hygroscopic (moisture-absorbing) minerals of one sort or another. Thirdly, we should mention the "canals" of Mars, the most fascinating and most debatable feature of the planet. Many astronomers of good repute have insisted that they have seen long, dark lines on the surface of Mars which have been given the name canals, although this term was never meant to signify that they were actual water-filled canals. Other equally good astronomers, with eyes just as keen, have tried to see the same canals through the same telescope during the same night and have positively been unable to see any such markings. Photography is unable to settle the issue. Most photographs have shown no canals, but some show faint blurred markings which suggest markings of just such a kind. Moreover, astronomical photographs of the planets are notoriously disappointing as compared to the view obtained with eye and telescope. Most astronomers are willing to admit the possibility of life on Mars, even the possibility of a regular system of canals, but as yet will not commit themselves because the observations are not sufficiently definite one way or the other. As the famous American astronomer, Percival Lowell, has pointed out, if there does exist a huge and intricate network of actual canals on Mars, it must be the work of intelligent beings. Moreover, from the magnitude of the project they must have achieved a civilization inclusive of their entire planet—which is more than we, unfortunately, have been able to do on ours.

THE WRECK OF A PLANET

Outside of the orbit of Mars is a great gap in which there is no planet, but in which there are a large number of smaller bodies called asteroids. These smaller bodies are considered to be the fragments of a large planet which once had an orbit in the gap outside of Mars. The number of asteroids is constantly being added to as new ones are discovered. They are so numerous that keeping track of them is becoming a serious problem. It is probable that a Home for Lost Asteroids will have to be provided to take care of the majority of them with the exception of large or peculiar asteroids of particular interest whose special properties make them worth studying.

JUPITER

Beyond the asteroids is the giant planet, Jupiter, ten times the diameter of the earth, accompanied by a host of moons



Saturn and its rings. A third faint inner ring is not visible in the photograph.

(four of which are visible through a small telescope). Jupiter's surface is fluid, the fluid being composed for the most part of various gases liquefied because of the low temperature (about —270° F). Great colored streaks covering the surface parallel to the equator are by far the most conspicuous feature of a telescopic view of the planet.

SATURN, THE RINGED ONE

Next in order of distance from the sun is Saturn, slightly smaller in size than Jupiter, but chiefly remarkable because of its three rings, two of which are very bright and easily visible through a small telescope. The third ring, the innermost "crepe" ring, is much more difficult to observe. No number of drawings or models or photographs of Saturn can convey the feeling of awe and wonder that comes over the observer as he takes his first telescopic look at Saturn's rings. Even though he knows what to expect, you will hear him mutter to himself something like: "Well, I'll be damned!"

THE OUTERMOST PLANETS

Uranus, Neptune and Pluto are the outermost planets of the solar system. Before the last two had been actually observed, their existence was deduced from variations in the orbits of some of the planets which could only be produced by the influence of other planets.

Beyond Saturn, and slightly less than half its size, is Uranus with its four satellites. As seen in a telescope, Uranus is sea-green in color. It is so remote in space that it is barely visible to the naked eye. Uranus rotates on its axis in 10.7 hours and takes about 84 of our years to complete its revolution around the sun.

Although Neptune is the third largest of the planets, it is

Halley's Comet, June 6, 1910. The tail, over 100 million miles in length, has broken off from the main body of the comet and is beginning to drift away.

invisible to the naked eye. Seen through a telescope, it has a greenish appearance. The discovery of the planet in 1846, as the result of computations by Leverrier, is considered one of the great triumphs of mathematical astronomy. Neptune, which is known to have one satellite, has a period of revolution around the sun equal to 164 earth years.

Pluto which is the most remote known planet of our solar system was an object of search for many years. Dr. Percival Lowell, founder and director of the Lowell Observatory in Flagstaff, Arizona, predicted its orbit and the research which he originated in 1905 led to the location of the planet in 1930 by C. W. Tombaugh of the Lowell Observatory. Pluto is invisible to the naked eye and as seen in the telescope is of yellowish color. It completes its revolution about the sun in 248 years and is about half the size of the earth.

FIERY TAILS

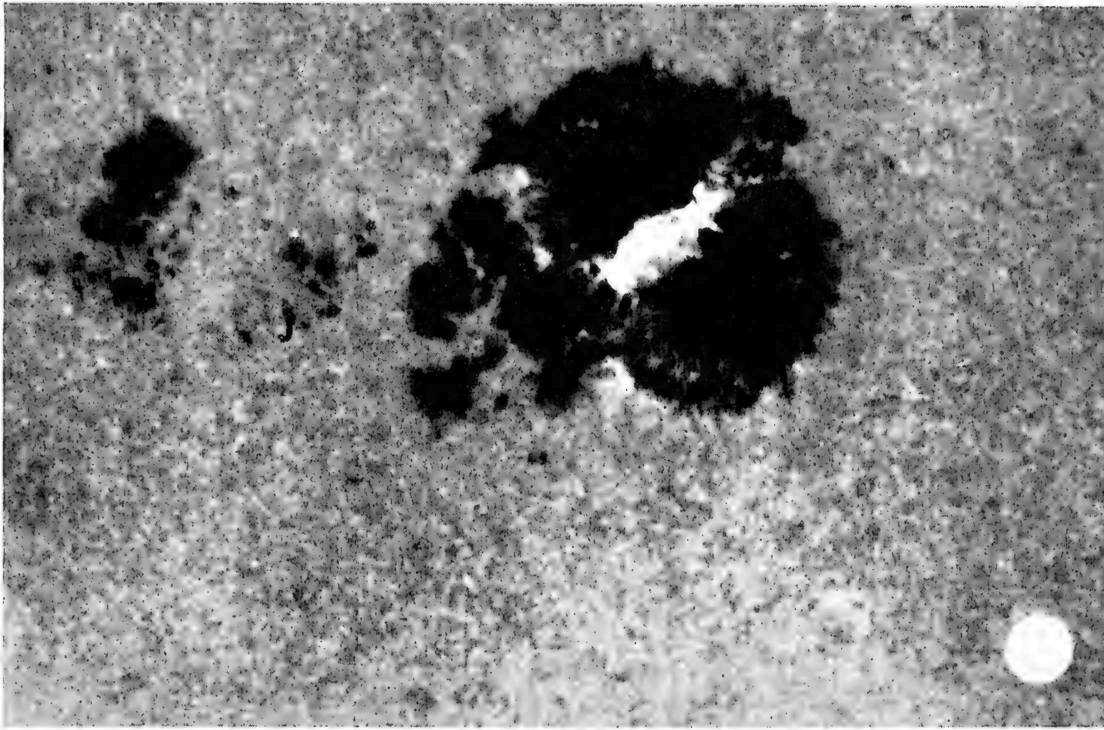
Comets occasionally appear in the sky as brilliant starlike bodies from which long tails of luminous material extend. The tails are composed of very thin and tenuous gases which are driven away from the main body of the comet (head of comet) by the pressure of the sun's radiation and are hence always pointed away from the sun. Moreover, the tails, and therefore the visibility of comets, are present only when the comet is near to the sun. At all other points of the comets' orbits around the sun they are invisible. Once their orbits have been determined, the return of comets may be confidently predicted, although some comets have broken up and been destroyed (Biela's Comet) and others presumably approach the sun only once and then are forever lost again in the remoteness of interstellar space.

THE SUN

The Sun is the central body of the solar system about which all of the previously mentioned bodies revolve. It is a fiery ball 800,000 miles in diameter—one hundred times the diameter of the earth, one million times the earth's volume. The material which composes the sun is different from matter as we know it on earth because of the high temperatures and pressures which prevail.

THE PHYSICIST SAYS

Atomic physics teaches us that matter is made up of atoms, each of which is a complex system of electrons and protons (elementary negative and positive electric charges) revolving about one another in well defined orbits. Under high temperatures and pressures such as those on the sun, these atomic systems are partially disrupted or disturbed, electrons are torn from the outer orbits, or the orbits themselves are changed from their normal unexcited state. The atoms of matter on the sun are continually disrupted, excited, and then reform themselves again, a process which results in the tremendous pouring out of light and heat from the sun. What the ultimate source of all the sun's energy is, is as yet not completely understood, although recent investigations in so-called nuclear chain reactions have been suggestive of possible processes sufficiently powerful and long-lived. The entire heat radiation of the sun is five hundred and eight sextillion horsepower. To give an idea of the staggering size of this number, and the immense power it signifies, we may state that this power is enough so that with it every man, woman, and child on the earth could operate continuously one hundred billion medium sized steamships of 2500 horse-



Great sunspot of 1905. The grainy appearance of the background is not a fault of the photograph, it is the actual appearance of the surface of the sun. The white spot the size of the earth shows how large the sunspots really are in comparison.

power each, providing of course there were a large enough ocean somewhere.

STORMS ON THE SUN

The bright glare of the sun masks its surface features from view. With a smoked glass or special optical instrument (spectroheliosope, coronavisor) or during a total eclipse, certain features are visible which otherwise are impossible to see directly. For example, there are the great solar storms or "prominences"; clouds of exploding gas rising to a height of hundreds of thousands of miles above the sun's surface and then subsiding and falling back into the sun. Sunspots are another apparition on the sun, visible as dark, black dots on the sun's disk. They are whirlpools of cooler material on the sun. Since sunspots whirl around large quantities of magnetically charged particles, magnetic fields are set up. Sunspots act very much like large horseshoe magnets, the similarity is enhanced by the fact that they usually occur in pairs whirling in opposite directions and connected to one another below the surface. During a solar eclipse, when the bright disk of the sun is covered by the moon, long streamers of light are seen extending from the sun in all directions for distances of several solar diameters—a phenomenon named the *corona.*

AND THE REST

The sun is just one of the many myriads of stars in the universe. The reason why it appears so much brighter than other stars is that it is so much nearer to us. As a matter of fact, the sun is just a medium kind of star—not one so intensely hot as the white-blue stars, nor one of the cooler giant red stars. With a little patience (and best with the aid of a good pair of binoculars) you will soon be able to recognize

The Great Nebula of Andromeda, the nearest galaxy to our own Milky Way Galaxy. These are just two out of millions of similar systems of stars which make up universes within the Universe. Each is composed of millions of stars at least as big as our sun. The near-by stars scattered more or less evenly over the plate are in reality much nearer than the Andromeda Galaxy. They belong to our own system.

colors in the stars. Observe a blue star like Vega, or a red star like Antares, and you will come to realize what remarkable differences in color the stars do exhibit, even though at first glance they appear colorless.

WHY IS A STAR?

Stars are the fundamental building blocks of the universe. Planets like our earth are mere fragments of matter without much cosmic significance, but a star is sufficiently large to rank as a distinct member of the universe. Curiously, there is not a very great range in the amount of matter making up different stars. There are big ones and small ones to be sure, but only rarely is a big one more than ten times larger than the average size, or a small one more than ten times smaller. We may well inquire, why this tendency of cosmic matter to form stars all more or less of a standard size? In way of explanation, Sir Arthur Eddington has pointed out that there are two conflicting forces at work in the universe: (1) gravitation and (2) radiation pressure. Gravitation is the mysterious force which attracts every particle of matter in the universe to every other particle. Radiation pressure is the pressure due to intense heat and light radiation. Stars, he says, occur in sizes just large enough to bring about an equilibrium between these two conflicting forces of gravitation and radiation pressure. If they were much smaller they would collapse under gravitational stress; if they were much larger they would explode because of excess radiation pressure.

THE HOSTS OF HEAVEN

Stars occur singly in space, or in systems of two, three, or more as you may readily verify by observation. Many

A view of the Milky Way looking toward the center of our galaxy.

multiple systems of stars are visible in the sky with only a small glass. As many as 50,000 stars may be grouped together in a single system of stars—such as the Great Globular Cluster in Hercules.

Not all stars maintain the same brightness. Some (Mira) vary their brightness in regular intervals, and are known as variables. Other stars have been known to explode with a blinding flash that increases their brightness many thousandfold, and then in a few days they fade from sight. Explosive stars are called *novae;* their explosions cannot be predicted. Someday even our sun might explode, a catastrophe which no earthly life could survive.

Great clouds of luminous gas, the *nebulae,* abound in space. They take on many strange shapes and forms such as the North American Nebula (shaped like the geographic outline of North America), the Ring Nebula of Lyra (a celestial smoke ring), or the Horse-head Nebula of Orion.

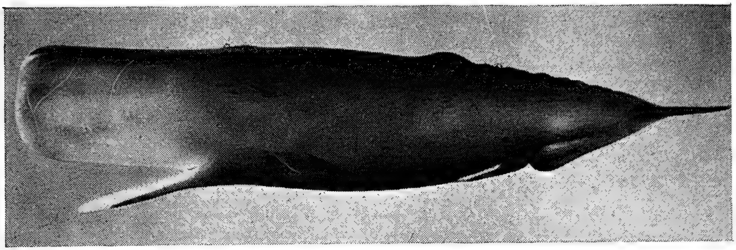
UNIVERSES WITHIN UNIVERSES

The stars, nebulae, clusters, etc., are all gathered together in great super-systems known as galaxies. A galaxy may contain several billions of stars. The solar system, all the visible stars, and many millions of stars invisible to the naked eye are in the Milky Way Galaxy, to which we belong. By means of the largest telescopes we can see millions of other galaxies beyond our own. Because they all appear to be moving away from us, it is supposed that our universe is rapidly expanding. Just as atoms are the smallest particles of matter in the universe, galaxies are the largest aggregates of matter known.

Ocean Life

Ocean Life

The life of the ocean is so abundant that many volumes would be necessary to portray it adequately. Naturally, no attempt at completeness has been made in a little volume like the present one. The author is not a biologist; his chief efforts have been in the physical sciences. Therefore, this section should be regarded as an album of pictures with notes, illustrating some of the life of the sea that the reader may someday encounter. For purposes of classification of animals seen, the reader must refer to authoritative treatises.



Model of sperm whale.

Whales are the biggest animals that exist on earth today. Although they live in the sea, they are not regarded as fishes inasmuch as they are warm-blooded, give birth to live off-spring, and must breathe air. Even though they can reach great depths they must come to the surface in order to get a fresh supply of life-sustaining oxygen. When they expel the

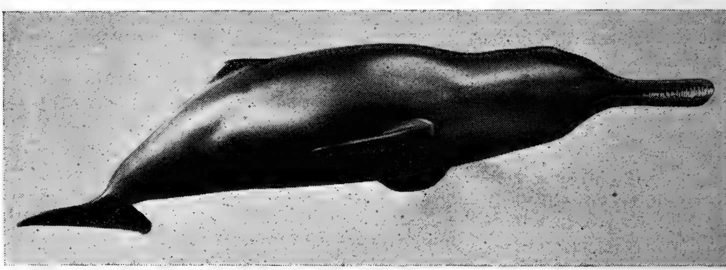
Model of humpbacked whale.

consumed air from their lungs, they do so in a blast of vapor, the spout; the whale is then said to be "blowing."

Whales once occurred in far greater numbers than they do today, but they have been killed off by whalers until now some species are quite rare.

Porpoises, like whales, are warm-blooded mammals. There are many species of them, the largest being the blackfish variety.

They are extremely fast in the water, often playing around the bow of a fast-moving vessel. At night they can be seen



Porpoise.

by virtue of their phosphorescent wakes, or one may detect their presence by their baby-like cries or coughing noises.

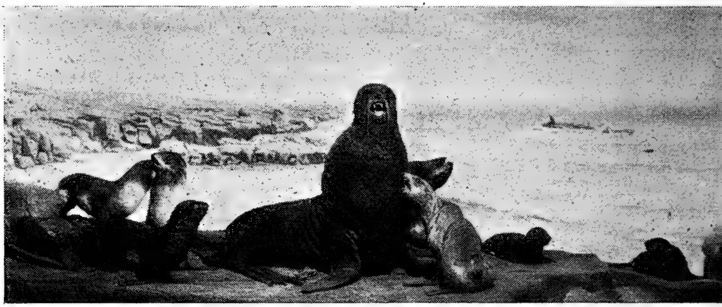
Sailors regard them as friends and claim that it is bad luck to molest them.

Seals mostly inhabit seacoasts and ice floes in colder parts of the earth, but some do occur in warmer regions. They feed on fish and marine animals. True seals do not have external ears and their hind limbs are of little use except for swimming. Eared seals, which include sea lions and fur seals, have small but well developed ears and move about on land with more ease than the true seals because their hind limbs have greater independence and mobility.

Sea lion rookery on St. George Island (habitat group).

The largest sea lions inhabit the North Pacific and reach a length of about twelve feet. Those native to the Pacific coast of South America are smaller and have a slight mane formed by lengthened hair on the neck. Still smaller are the California sea lions.

Fur seals were hunted for their valuable fur until they were nearly exterminated. Their breeding places, called rookeries, are now protected to some extent under inter-

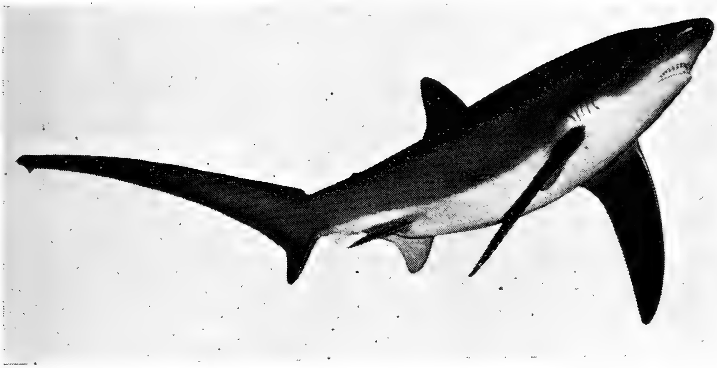


Alaska fur seal group.

national agreement. The Alaskan fur seals breed on the American owned Pribilof Islands in the Bering Sea.

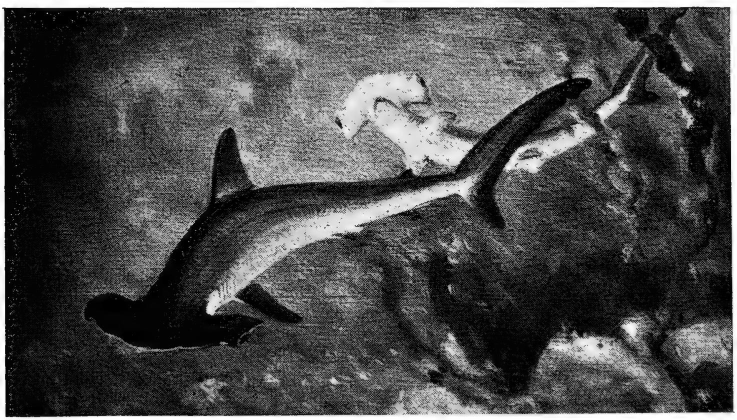
Although related to the seal, the walrus is a separate family. They were much hunted and are now rare except in the far north. The males often weigh over a ton and have thick, heavy neck and shoulders. Their upper canine teeth (in humans called "eyeteeth") form long protruding tusks of fine ivory. The females have smaller, slenderer tusks.

Section of walrus group.



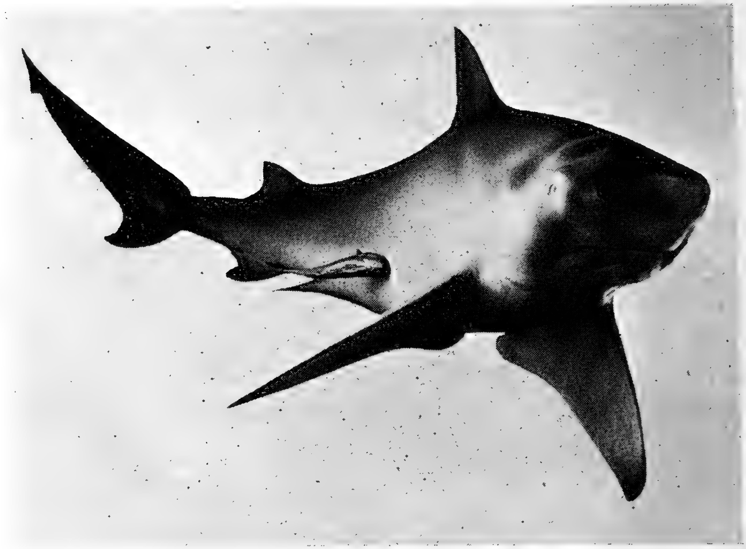
Thresher shark.

Not all sharks are man-eaters, but there are enough kinds which like the taste of human flesh to keep up their notorious reputation. Partly digested remains of human parts are occasionally found in the digestive tracts of captured sharks.



Hammerhead shark (painting by C. R. Knight).

The tenacity of life that sharks exhibit is most amazing. After having been out of water for hours, after having their bodies slit and gutted, they still swim away when dropped into the water, and will even eat their own entrails. Many people have lost hands or arms when trying to remove hooks



Ground shark with pilot or sucker fish.

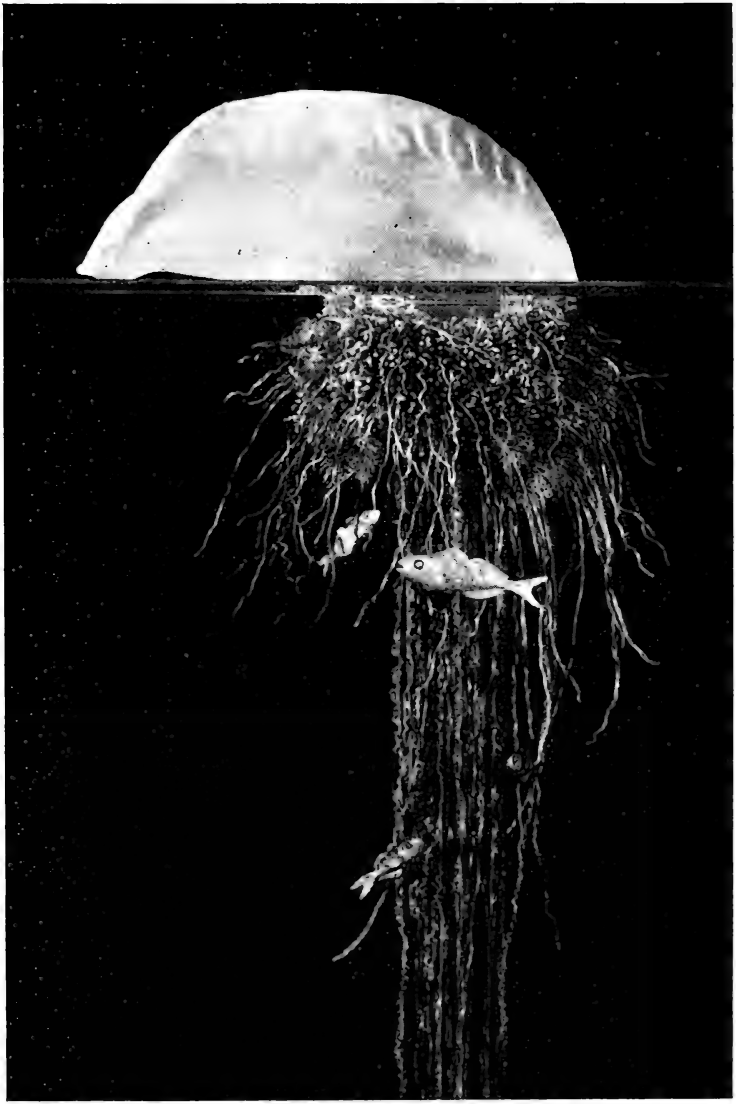
from the powerful jaws of what they thought were dead sharks.

The sucker fish, or remora, is often associated with the shark. It has a suction disk on the top of its head by means of which it fastens itself to its host. A remora when captured can be made to fasten itself on a wet deck or other surface.

Basking shark.

Shovel-nosed sturgeon.

Alligator gar.

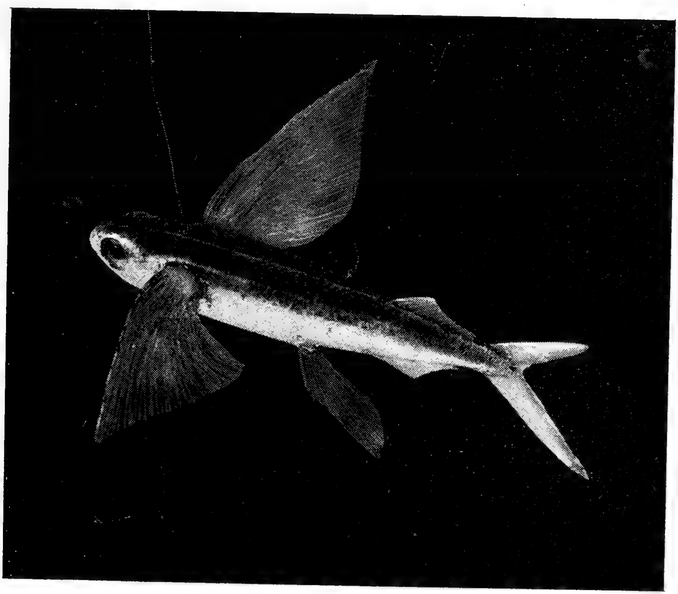


Natural size glass model of Portuguese man-of-war with Portuguese man-of-war fishes.

The Portuguese man-of-war is a colony of small jelly-like animals who sail the sea by means of a float about six inches long with a little sail on top. They are able to raise and lower the sail at will, and do not sail directly with the wind, but tack across it at 45° according to Dr. Woodcock of the Woods Hole Oceanographic Institution.

Suspended from the floating bladder are numerous filaments extending down to 25 or 30 feet beneath the surface. These long threads can sting severely, and are used to paralyze small fishes.

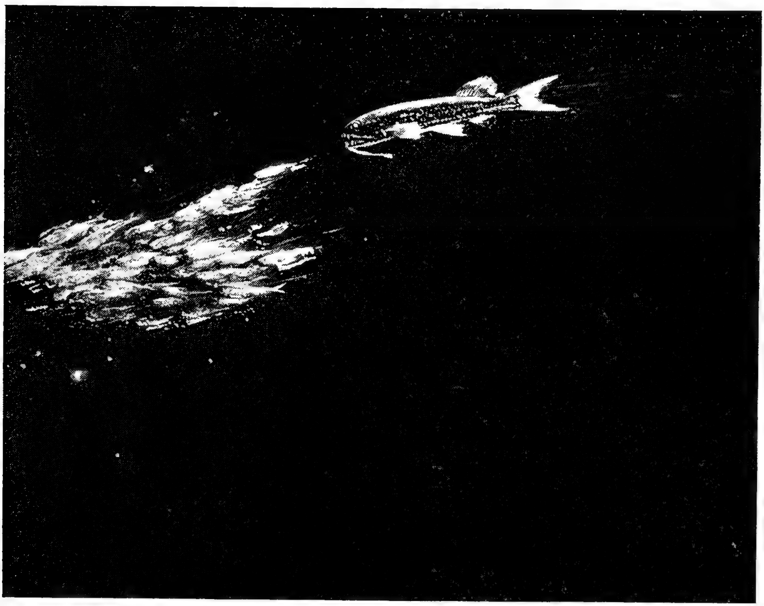
One kind of fish, the so-called Portuguese man-of-war fish, is not affected by the poison. It finds the filaments a safe refuge, and usually stays safely inside of them.



Flying fish.

Australian sea horse.

Amberjack.



Astronesthes niger chasing Myctophids (lantern fishes).

Deep sea scallops at 384 feet. At the center is a delicate sea anemone. Dr. Ewing has taken all his pictures by means of a specially developed underwater camera.

Bed of mussels at 15 feet.

An accumulation of starfish on the bottom in 240 feet of water, Block Island Sound.

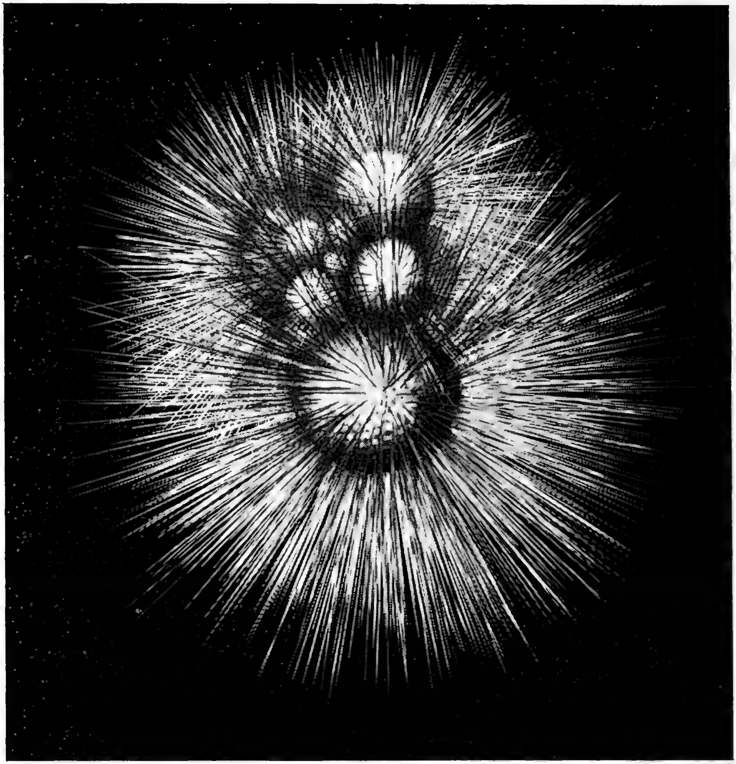
Starfish at 240 feet, Georges Bank.

Sand dollars at 220 feet, Georges Bank.

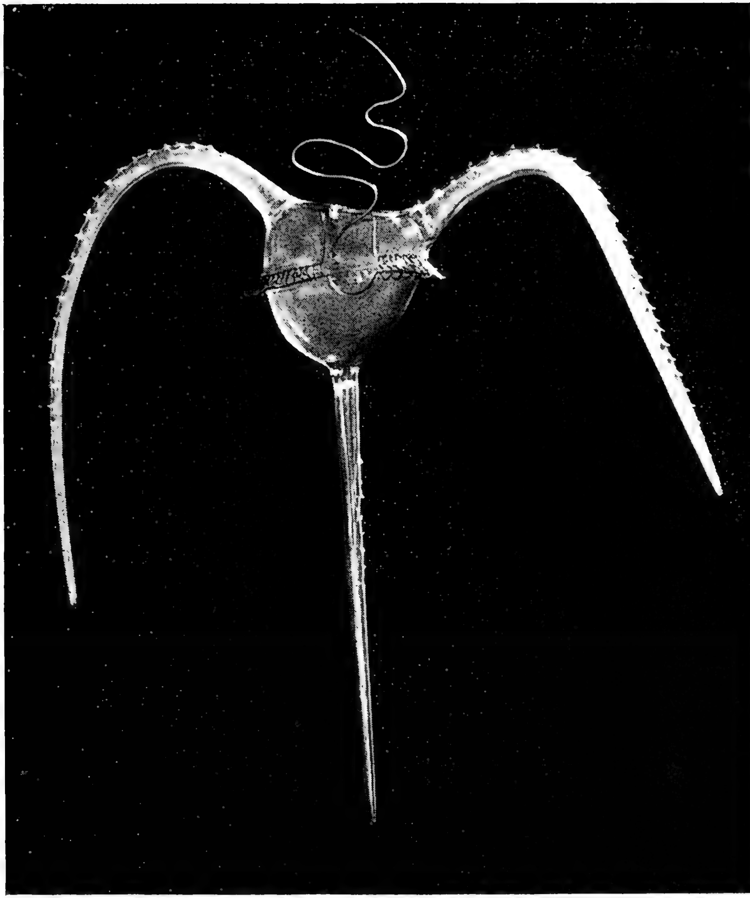
Sand dollars at 200 feet, Georges Bank.

Ocean bottom at 636 feet, one hundred miles south of Woods Hole. Pairs of small antennae protruding from mud like blades of grass are thought to belong to crustaceans resembling crayfish.

Sea pens, starfish and hermit crabs in 300 feet of water. Tracks of sea worms and starfish are visible.



Globigerina. The many-chambered limestone shells which Globigerina build form the ooze which is the principal constituent of the floor of the Atlantic Ocean. (Glass model by Herman Mueller.)



Dinoflagellate—the Protozoan Ceratium. These microscopic creatures are abundant in tropic seas. Their luminescent bodies cause the sea to glow at night. (Glass model by Herman Mueller.)

White pelican habitat group, Klamath Lake, California.

Of all birds pelicans seem to be the most awkward and amusing. When they take off from the water, they must paddle furiously with their feet, and when they land, they either skid to a stop on outstretched feet or fold up their wings and plummet into the water with a resounding thump. They are quite tame, and will eat as much as you give them, until they cannot even fly. The young pelican in the photograph is eating a predigested meal from its mother's stomach.

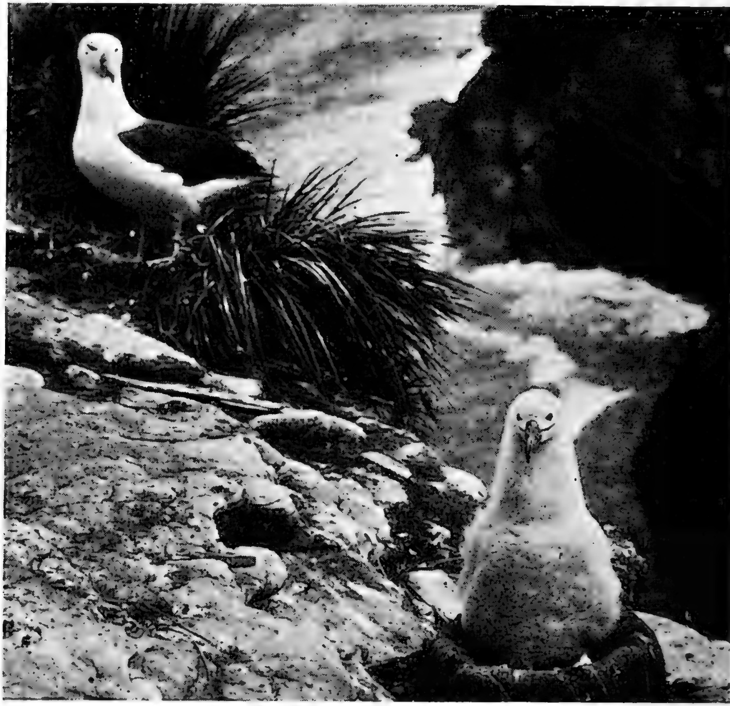
Man-of-war bird and booby habitat group, Cay Verde, Bahamas.

The booby has received its name because of its stupidity. It may actually be caught by hand. The man-of-war bird is quite the opposite. It is a solitary flyer, an excellent diver for fish, adept at catching flying fish in the air, and at stealing food from other smaller birds.

Detail of view of the atoll of Hao, Tuamotu Islands, showing man-of-war birds.

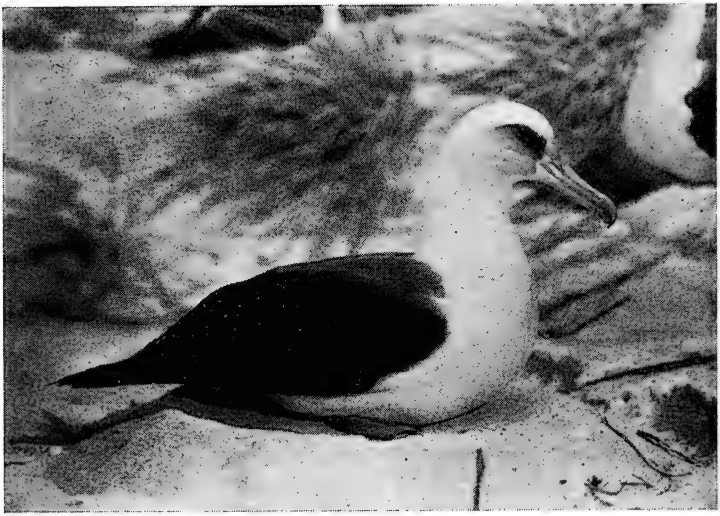
Giant fulmar on nest, Falkland Islands.

The albatross is a peculiar bird, given to strange antics and victuals, often following a ship for days. As a result sailors



West Point Island in the Falklands. Black-browed albatross with young and nest.

regard him with a kind of superstitious awe. The wandering albatross is the largest of all sea birds, attaining the amazing wingspread of eleven feet.

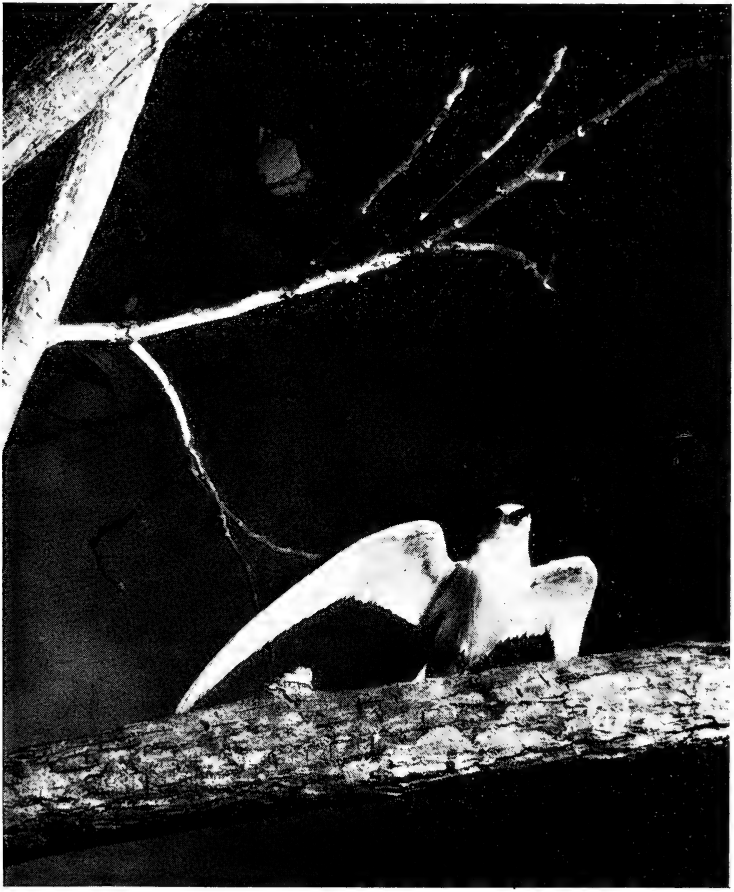


Laysan albatross on egg.

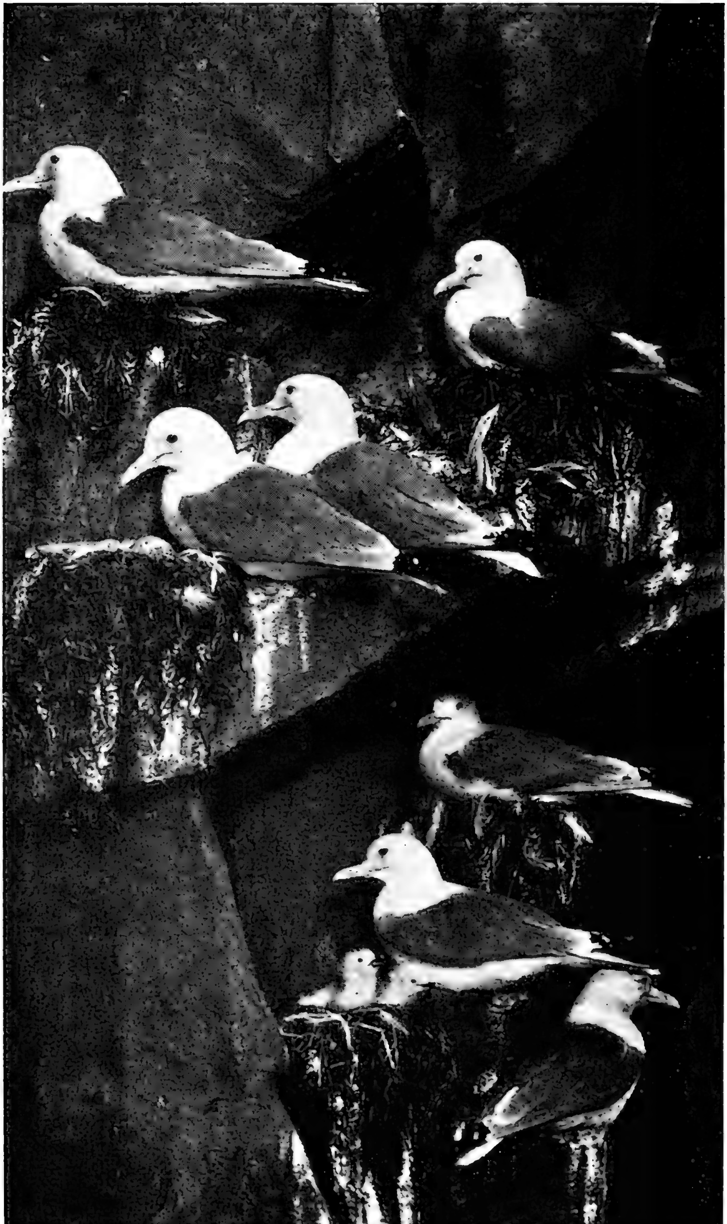
Little auks on talus slope, Etah, Greenland.

Arctic tern with fish in mouth and a Long-tailed jaeger, Hudson Bay region.

The arctic tern migrates farther than any other bird, traveling all the way between the Arctic and Antarctic twice a year. The jaeger derives its name from the German word for "hunter." It is a vicious robber of the sea, and preys particularly upon kittiwakes.



Fairy tern.



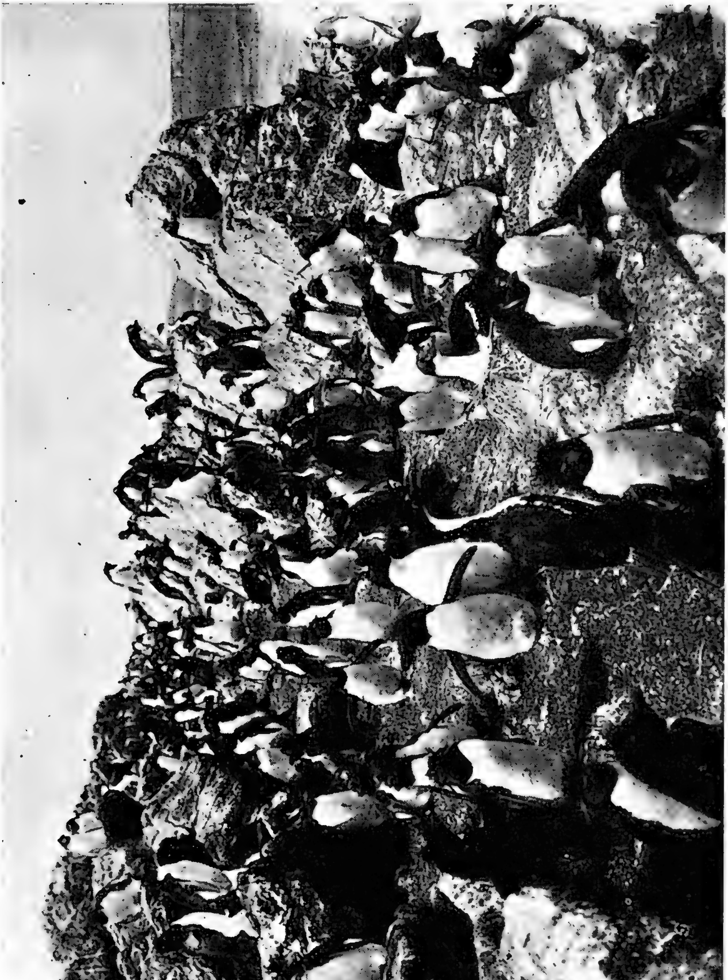
Pacific kittiwakes (Diomede Island bird group).

Pacific kittiwakes, puffins (the squat birds with big beaks), pelagic cormorants, Pallas's murres (the birds with white breasts, black heads, and "lapels" on their coats) and crested auklet are all shown in the picture below.

Diomede Island bird group.

Penguins are inhabitants of antarctic regions. Birds only in name, they have lost their ability to fly. They are very social and intelligent animals.

Jackass penguins ashore from a choppy sea, East Falkland Island.



Rockhopper penguin colony, Falkland Islands.

Red-tailed tropic bird on its egg, Hao Atoll, Tuamotu Island.

The tropic-bird is another ship-follower, but unlike the albatross and man-of-war bird must move its wings steadily to stay in flight. Sailors also call them bo's'n birds.

Bibliography

It would be unfair to bring the reader just so far in the science of the sea and then to leave him stranded. Several books and papers are mentioned in the text, but it is clear that they are not completely representative. Therefore, it is in order to mention a few works that will prove helpful in following the subject further.

For a general, technical survey of the field of oceanography, the reader can do no better than to obtain a copy of *The Oceans* by Sverdrup, Johnson and Fleming, Prentice-Hall, Inc. New York, 1942. It is a rather formidable volume, replete with exhaustive tables, mathematical formulas, etc., but it also contains portions that are readable for a layman.

For those who are interested in ocean waves, a very good book is *Ocean Waves and Kindred Geophysical Phenomena* by Vaughan Cornish, Cambridge University Press, 1934. The book itself is not nearly as terrifyingly technical as one might infer from the title, and it is beautifully illustrated.

G. P. Putnam's Sons has published a series of nature field books of a size that can easily be carried in the pocket. Volumes of the series that might be of interest are:

Alexander, *Birds of the Ocean*

Breder, *Field Book of Marine Fishes of the Atlantic Coast*

Olcott, *Field Book of the Skies.*

An interesting geological book is *The Changing World of*

the Ice Age by Reginald Daly, Yale University Press, New Haven, 1934.

As the reader branches out into some field which particularly interests him, he will come across further references to look up and gradually he will become familiar with the literature of that domain. Reference to the subject cards of a library catalogue will be found helpful. There are also excellent articles on many particular subjects in the *Encyclopaedia Britannica.*

Quizzing the Seven Seas

What causes waves? *(page 3)* How fast do they travel? *(page 7)*

Can a ship at sea feel an earthquake? *(page 10)*

Can an island explode without being hit by an atomic bomb? *(page 13)*

Are there any "sea serpents"? *(page 20)*

How deep is the ocean? *(pages 24-25)* How much gold does it have? *(page 33)*

How can you make light without heat? *(page 40)* How do some fish create this "cold" light? *(page 40)*

Why are icebergs free from salt? *(pages 50-51)*

What waves are "bores" and how tall can they be? *(pages 61-62)*

What was Darwin's theory of the origin of coral atolls? *(page 67)*

Can continents move? *(pages 68-69)*

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Woods Hole oceanographer wins international award

By MICHAEL BOSTWICK
Staff Writer

WOODS HOLE — A senior scientist at the Woods Hole Oceanographic Institution has won the second annual Crafoord Prize, a major international award, for his work in physical oceanography.

Henry Stommel, 62, of WHOI's physical oceanography department, received a telegram yesterday informing him that the Royal Swedish Academy of Sciences voted Wednesday to give the Crafoord Prize to him and to Edward Lorenz, a professor at Massachusetts Institute of Technology, said Shelley Lauzon, head of the WHOI public relations department.

In addition to gold medals, Stommel and Lorenz each will receive a cash award of 200,000 Swedish crowns, about $27,400.

Established with a bequest from Swedish industrialist Holger Crafoord, who died in 1982, the prize honors no more than three scientists annually for work in mathematics, astronomy, biological sciences, geosciences or arthritis. The award was given for the first time last year in mathematics.

"The Crafoord prize was made up to cover some of the fields the Nobel Prizes don't," Ms. Lauzon said. When the first winners of the prize were announced last year, "Discover" Magazine called it a "Nobel Supplement."

The prize will be given on a rotating basis, so that researchers from each of the five designated disciplines are honored every five years. Distinguished scientists throughout the world are invited to nominate candidates from their field of expertise.

The Royal Swedish Academy decided this year to give the award in the area of geosciences, and specified that it should be for work with the global motions of the atmosphere and sea, she said. Stommel was a natural for such a designation.

A WHOI colleague has called Stommel "the authorized biographer of the Gulf Stream," the huge current that runs like a warm river through the cold ocean from the Caribbean north along the U.S. coast and east to Europe. But his interest is not limited even to something so grand as the Gulf Stream.

According to his WHOI curriculum vitae, provided by Ms. Lauzon, Stommel's research interests also include the general circulation of the ocean, the Kuroshio current, eddy dynamics, equatorial currents, deep water convection , planetary flow patterns, climate, the Indian Ocean and monsoons.

In its congratulatory telegram, the Swedish Academy praises him "for (his) fundamental contributions in the field of geophysical hydrodynamics that in a unique way contributed to our understanding of the large-scale circulation of the atmosphere and the sea."

Prizes are nothing new for him. Among the many Stommel has received, Ms. Lauzon said, are the Agassiz Medal from the National Academy of Sciences, the Bowie Medal from the American Geophysical Union, the Huntsman Award from the Bedford Institute of Oceanography in Halifax, Nova Scotia, the Bigelow Medal for outstanding accomplishment from WHOI, the Rosenstiel Award from the American Association for the Advancement of Science and the Sverdrup Medal from the American Meteorological Society.

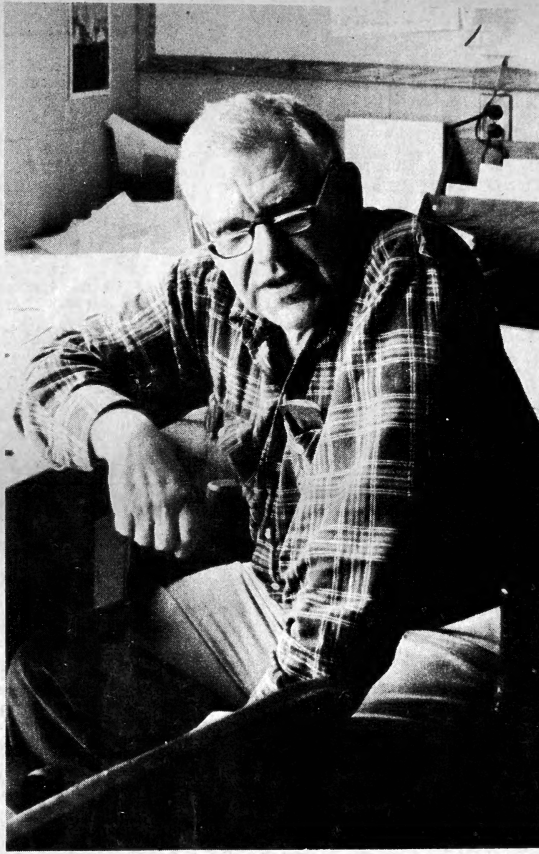
He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences, and a fellow of the American Geophysical Union.

In 1976, he was elected a member of the Soviet Academy of Sciences.

Stommel is a Phi Beta Kappa graduate of Yale University with a B.S. in physics. He holds an honorary M.A. from Harvard University, and honorary Ph.Ds. from Goteborg Universitet in Sweden, Yale and the University of Chicago.

He was a professor of oceanography at Harvard from 1960 to 1963 and at the Massachusetts Institute of Technology from 1963 to 1978.

He has been affiliated with the Woods Hole Oceanographic Institution in capacities ranging from research assistant to senior scientist from 1942 to the present.



HENRY STOMMEL
..."biographer of the Gulf Stream"

CAPE COD TIMES Mar. 11, 1983

(Continued from front flap)

are building new lands for future aeons. The sea is also guardian of the past — in its depths live creatures who found earth life too difficult and retreated to the protecting ocean while their less flexible contemporaries merely subsided into extinction.

IN SCIENCE OF THE SEVEN SEAS, a seagoing scientist explains how Nature's laws govern the unquiet waves, the shape and movement of clouds drifting through the sky in seeming aimlessness, the storms of wind and rain and snow that peril ships at sea.

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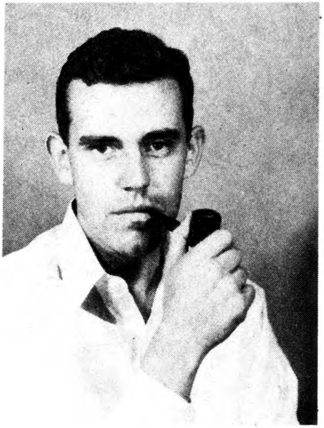

HENRY STOMMEL is our youngest author. "I was born," he writes, "on Sept. 27, 1920, in Wilmington, Delaware. Brought up in Freeport, New York, I spent much of my time in small boats and tinkering around with scientific gadgets, microscopes and aquatic bugs, chemical experiments.

"I went to Yale University, joined the Corinthian Yacht Club there, graduated in 1942 after majoring in physics. Upon graduation I was appointed an assistant in the Physics Department and then promoted to Instructor of Navigation and Nautical Astronomy. Besides physics and navigation, I also taught undergraduate mathematics as the occasion demanded. In 1943 I was appointed Fellow of Pierson College.

"Pierson College was one of four Navy V-12 colleges at Yale. It was my good fortune to become very well acquainted with the Navy trainees in our college. I suppose I still could pick all 400 of them out by first name. I found them very much interested in the science of the seas, and so I thought it might be worth while to set down some facts about the oceans in book form.

"In October 1944, the National Defense Research Council requested that I take up some research work for them, at which task I am now employed.

"I am sorry this biography is so small, but I really haven't lived much yet."