lighting a piece of cloth) so that its movement may be seen. Explain the principle of a lamp; of a fireplace. How is your schoolhouse ventilated? Does the fresh air come in above or below? Why? (11) Place a brick and a pan of water (as deep as the thickness of the brick) on a hot stove or over a Bunsen burner. Carefully weigh each before placing them there. When the brick has become warm, take the temperature of each at the top. At the bottom. Why is one the same temperature throughout, the other hot at the bottom and only warm at the top? Which shows the higher temperature? Why? When cool, weigh them again. Has either lost weight? Why? (12) Do the same with water and soil, leaving a thermometer in each and recording the changes. In which does the temperature rise faster? Which cools faster? (13) Take the temperature at 6, 8, 10, 12, 2, 4, 6, 8, and 10 o'clock for one day. Construct a curve similar to Fig. 395. Keep records for a week, and construct curves to see if they are all alike. (14) A seasonal curve can also be made, getting the data from the Annual Report of the United States Weather Bureau, in which daily averages are given for many places. (15) With a bicycle pump illustrate the warming of air by compression, and cooling by expansion (p. 241). A little fog can be produced by placing a dish of hot water where the escaping cool air passes over it. (16) Make observations on condensation, — blowing on a cold window, for example. In warm, damp air, watch drops collect on a glass of ice water. That the water does not come from within the glass may be proved by placing a glass, without water, on ice until it is cold, then putting it in the room. The same thing may also be shown by putting salt and ice in a bright tin dipper. The temperature of dew point can be determined by putting a thermometer in the salt and ice, reading the temperature at the moment water begins to cloud the surface of the dipper. (17) Study frost: the time of its coming; the places where it comes first; and any other facts you can find out by observation. (18) For a few days observe the clouds carefully, classifying those you see.

Reference Books. — Davis, *Elementary Meteorology*, Ginn & Co., Boston, 1894, $2.70; Ward, *Practical Exercises in Elementary Meteorology*, Ginn & Co., Boston, 1896, $1.12; Waldo, *Modern Meteorology*, Scribner's Sons, New York, 1893, $1.50; *Elementary Meteorology*, American Book Co., New York, 1896, $1.50; Russell, *Meteorology*, Macmillan & Co., New York, 1894, $4.00; Tyndall, *The Forms of Water*, Appleton & Co., New York, 1872, $1.50; *Illustrative Cloud Forms*, U. S. Hydrographic Office, Washington, 1897, $1.00; *Annual Reports* and *Monthly Weather Reviews*, U. S. Weather Bureau, Washington; Bartholomew, *Physical Atlas*, Vol. III, *Meteorology*, Archibald Constable, London, 1899, $13.00.

CHAPTER XIII.

WINDS AND STORMS.

WINDS.

173. Relation between Winds and Air Pressure. — Winds are the result of differences in the air pressure, or weight. It is easier to understand their cause if we consider the atmosphere to be composed of a great number of air columns which gravity holds to the earth. If the sun's heat warms the air in one place, the columns at that place become lighter than in places not so warmed (p. 231). Light air is said to have a *low pressure*, heavy air a *high pressure*, because the heavier the air, the higher it pushes the mercury up in the tube of the barometer (Appendix G). The air moves, or flows, from places of high toward places of low pressure, thus causing winds. On a larger scale, it is much the same as the movement of the cooler and heavier air which crowds up the warm, lighter air in a lamp (p. 236).

The difference in air pressure which causes winds is often known as the *barometric gradient*. It is so named because the air flows from a region of high pressure, or high barometer, to one of low, as if it were going down a grade, or gradient, as flowing water does. It is not to be understood, of course, that there is a real slope or grade, but merely lighter air in one place than in another. If the difference in pressure is great, the barometric gradient is so high that the air moves swiftly, as water flows down a steep grade.

Summary. — *Winds are due to a flowing of air from regions of heavy air, or high pressure, to regions of low pressure; and the difference in pressure is known as the barometric gradient.*

174. Sea and Land Breezes. — A simple illustration of winds is often found along ocean and lake shores on hot days. On such days the land, and the air over it, become much warmer than the water (p. 238). Soon the heavier air from the water flows in as a cool, refreshing *sea breeze*, pushing upward the warm, lighter air that rests on the land.

When the sea breeze begins to blow, the temperature, which may have risen to 80° or 90°, commences to fall, and the rest of the day is pleasantly cool. It is partly because of the cool sea breezes that so many people go to the seashore to spend their summer vacations. Along tropical coasts, sea breezes are very pronounced and of almost daily occurrence.

At night a *land breeze* often blows out over the water. The reason for this is that the land cools by radiation faster than the water (p. 238), and the cool land air slides out over the sea, pushing up the warmer air that rests there. Sailboats, becalmed off shore when the sea breeze dies down, are able to reach port late in the evening when the land breeze begins to blow.

Summary. — *Sea breezes are caused by cool air from the sea flowing in on hot days and pushing up the warm, light air over the land. At night, land breezes blow out over the sea from the cooler land.*

175. Mountain Valley Breezes. — Winds similar to the land breezes are noticed at night in hilly and mountainous regions. As the land cools by radiation, the cool, heavy air slides down the slopes, causing winds that often gain great force late at night. During the day, as the valley sides are warmed, the air moves up the valleys; but this movement does not cause winds so strong as those at night, when the air is flowing down grade and gathering from many tributary valleys into one main valley.

Summary. — *At night, cool air slides down valleys, forming winds; and air passing up the valleys during the day causes lighter breezes.*

176. Monsoon Winds. — On some of the continents, there are changes in wind direction from summer to winter. These seasonal winds, known as *monsoons*, are best developed in Asia (p. 259).

In summer the land becomes warmer than the water, and air, therefore, blows from the Pacific and Indian oceans toward the warm interior, forming the summer monsoon. In winter, when radiation cools the Asiatic highlands, the heavy air

FIG. 405. — The summer (left hand) and winter (right hand) monsoons of India.

moves outward toward the warmer oceans, forming the winter monsoons. Thus twice each year the winds change. In India the changes are so regular, and the winds so steady, that in early times sailing vessels went there in summer and left in winter, in order to have fair winds both ways.

All continents show some tendency toward the development of monsoon winds; but in most cases other winds are too well established for the monsoons to develop perfectly. For example, the regular winds of northeastern United States are from the west; but they are much steadier in winter than in summer (Figs. 409, 410). The reason for this is that in winter the outflow of cold air from the land strengthens the west winds, while in summer the inflow of cool air from the ocean weakens them; but the summer inflow is not strong enough to completely destroy the west wind movement and form regular monsoons.

Summary. — *Monsoon winds, best developed in Asia, are due to the inflow of air from the ocean to the warmer land in summer, and the outflow of air from the cold land in winter.*

177. Wind Systems of the Earth. — Even greater air movements than those just described are caused by differences in temperature between the warm tropical belt and the cooler zones north and south of it. The winds thus started affect all zones, all continents, and all oceans.

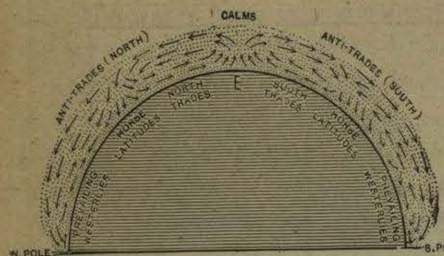

FIG. 406. — A diagram to illustrate the air circulation of the earth. *E* is equator.

(A) *Comparison with a Stove.* — In certain respects this great circulation may be compared to the movements of air in a room heated by a stove. The air around the stove is warmed, and the cooler, heavier air in other parts of the room crowds in and pushes the warm air upward. There is, therefore, (1) a movement toward the stove; (2) a rising above it; (3) an upper current away from it; and (4) a settling at a distance from it.

Because of the heated belt of the tropical zone there are similar movements on the earth (Fig. 406). These are (1) a movement of air along the surface toward the equator; (2) a rising in the torrid zone; (3) an upward movement away from this zone; and (4) a settling north and south of it.

Summary. — *Both in a room heated by a stove, and on the earth, warmed in the torrid zone, there is a movement of air toward the warm place, a rising, an outflow above, and a settling.*

(B) *Effect of Rotation.* — While air currents in a room move straight toward the stove, the winds of the earth are gradually turned from a straight course by the influence of the earth's rotation. Currents of air, like water (p. 191), are turned, or deflected, in the northern hemisphere toward the right, in the southern toward the left. This effect of rotation is therefore called *right-hand deflection* in the northern hemisphere, and *left-hand deflection* in the southern.

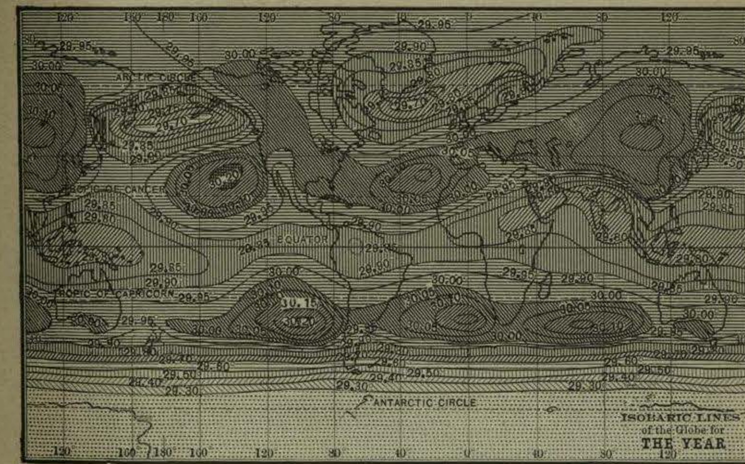

FIG. 407. — Isobars (lines of equal pressure) for the world. The dark shading represents high pressure. The figures (29.85 for example) are inches to which the mercury in a barometer rises, being highest where the air pressure is greatest. In the dark zones of high pressure, the horse latitude belt, air is settling; it moves thence toward the low pressure belt of the warm torrid zone, forming the trade winds, and toward the low pressure areas near the poles, forming the prevailing westerlies.

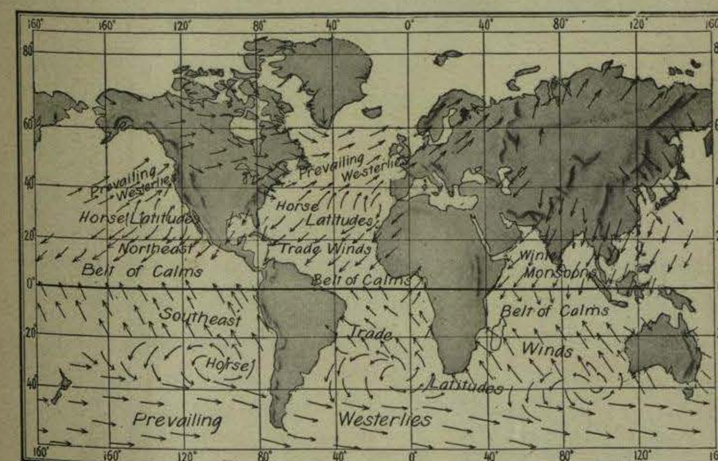

FIG. 408. — A sketch map showing the prevailing winds and wind belts of the earth in winter.

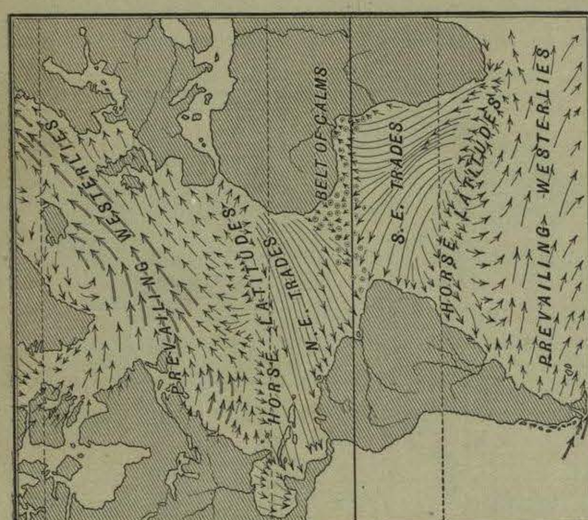

Fig. 409. — Wind belts of the Atlantic in winter. Compare with Fig. 410 to see migration of the wind belts. Length of arrows indicates steadiness; double line, strong winds; circles, calms.

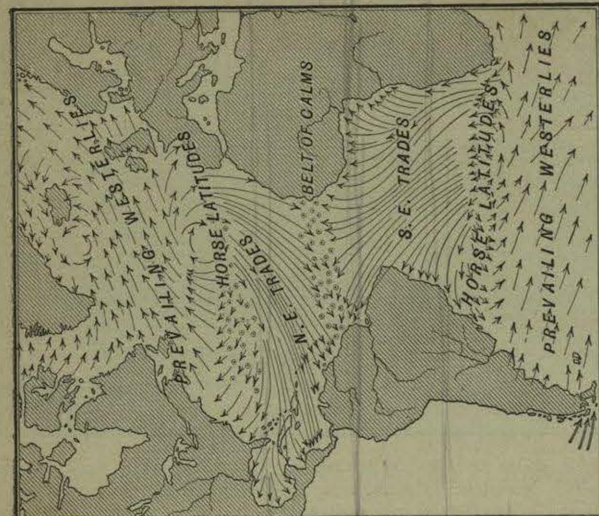

Fig. 410. — Wind belts of the Atlantic in summer. Notice how much more poorly the prevailing westerlies are developed than in winter (Fig. 409), when cold air from the interior flows outward from North America.

Summary. — *The effect of the earth's rotation turns winds toward the right (right-hand deflection) in the northern hemisphere, and toward the left (left-hand deflection) in the southern.*

(C) *Belt of Calms.* — In the torrid zone, where the air is rising, there is little wind, because the air movement is vertical (Fig. 406) instead of horizontal. This is a region of baffling calms, sometimes called the *doldrums*, sometimes the *belt of calms* (Figs. 408–410). This belt does not remain stationary, but, as the belt of greatest heat changes position with the season (Figs. 439, 440), migrates northward and southward.

Summary. — *Where the air is rising, in the torrid zone, there is a region of calms which changes position with the season.*

(D) *Trade Winds.* — The air currents that move toward the belt of calms, known as the *trade winds* (Figs. 406, 408–410), blow with great steadiness, especially over the ocean. Indeed, islands in the trade-wind belts commonly have steep, wave-cut cliffs on the windward side, against which the surf is ever beating. Instead of blowing directly from the north in the northern hemisphere, and from the south in the southern, the trades are deflected by the influence of rotation, becoming northeast winds in the northern hemisphere and southeast in the southern. These are, therefore, called the *northeast trades* and *southeast trades* respectively.

As the belt of calms migrates northward and southward each season, the trade winds also change position, being farther north in summer than in winter. For this reason, places near the border of the trade-wind and calm belts have alternate seasons of calms and trade winds (Figs. 439, 440).

The reason why the monsoons are best developed in Asia (p. 256) is the nearness of the belt of calms. The winter outflow of cold air strengthens the northeast trades; but in summer, when the belt of calms has migrated northward to the land, the southeast trades extend across the equator to the land. That is, in summer the land is so warm that, in this region, the southeast trades are strengthened and the northeast trades destroyed.

Summary. — *The steady movement of air toward the torrid zone forms the trade winds, which, deflected by rotation, blow from the northeast in the northern hemisphere and the southeast in the southern. These belts migrate northward in summer, southward in winter.*

(E) *Antitrades.* — The air that rises in the belt of calms flows northward and southward, high above the earth (Fig. 406). Turned by the influence of rotation, these upper currents, or *antitrades*, move from the southwest in the northern hemisphere and from the northwest in the southern hemisphere; that is, opposite in direction to the lower trade winds. The movement of higher clouds, and of ash erupted from volcanoes, proves this. On high peaks which rise above the trade winds, as in the Hawaiian Islands, the antitrades may be felt.

Summary. — *The outflow of air that rises in the belt of calms is known as the antitrades, which blow above the trades.*

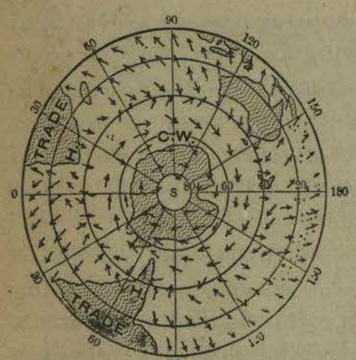

FIG. 411. — Ideal circulation of air near the surface in the southern hemisphere. Trade = trade-wind belt. *H*, *H* = horse latitudes. *C. W.* = circumpolar whirl.

(F) *Prevailing Westerlies.* — On its way toward the poles some of the upper air settles to the surface, but much continues on to high latitudes. There is, therefore, a movement of air from a broad belt in the torrid zone toward the small area around each pole. It may be compared to the movement of water toward the small outlet of a wash basin. In its attempt to reach this outlet the water commences to whirl about it; and, in a similar way, the air forms a whirl about each pole known as the *circumpolar whirl* (Fig. 411).

The direction that this whirl of air takes is determined by the influence of rotation; that is, the air currents are turned toward the right in the northern hemisphere and toward the left in the southern. This causes winds from a westerly direction in each hemisphere. Therefore these wind belts are called the *prevailing westerlies* (Figs. 406, 408–411). They cover the greater part of the two temperate and the two frigid zones.

These winds, as well as the others, are interfered with by various causes. For example, they are often strongest during the day, because of differences in pressure, caused by the warmth of the sun. When the sun sets the wind often dies down. Storms, sea breezes, and the effects of topography, such as the influence of valleys, also interfere with the force and direction of the winds.

Winds are commonly less steady and strong on land than on water. The reason for this is that the roughness of the land, and its differences in temperature, interfere with their movement. Since in the southern hemisphere there is so little land to interfere with the regular winds, the prevailing westerlies are better developed there than in the northern hemisphere (Figs. 408–411). Indeed, in the great Southern Ocean, a vessel can sail eastward around the earth with prevailing fair winds.

There is so much land in the northern hemisphere that the westerlies are greatly interfered with; but high in the air, above the influence of the surface, they blow with great strength and steadiness. Any one can prove this for himself by watching the upper clouds and noticing how uniformly they move eastward, even when the wind at the surface is from the opposite direction.

Summary. — *Some of the air of the antitrades continues on, forming the circumpolar whirls. Turned by the influence of rotation, these winds blow from westerly directions in both hemispheres, forming the prevailing westerlies. They are better developed over the Southern Ocean, and high in the air, than at the surface of the northern hemisphere, where they are interfered with by irregular land and by local winds.*

(G) *Horse Latitudes.* — Between the trades and westerlies, in each hemisphere, there is a belt known as the *horse latitudes*, in which the air of the antitrades is steadily settling (Figs. 406, 407). Since the air movement is vertical, this is a belt of relative calm, with irregular, unsteady winds, quite in contrast to the steady trades on one side and west winds on the other (Figs. 408–410). As the belt of calms and the trade-wind belts migrate northward and southward with the seasons (p. 259), the horse latitude belts also shift.

Summary. — *The horse latitudes are belts (one in each hemisphere) of relative calm, where the air of the antitrades is settling.*

STORMS.[1]

178. Cyclonic Storms. — (A) *Characteristics.* — The United States weather map (Fig. 413) shows an area where the air pressure is light. It is, therefore, called a *low pressure area*, or a *Low* (p. 255). Around this center of low pressure the mercury in the barometer stands higher, and this fact is indicated by lines of equal pressure, or *isobars*. Air is moving

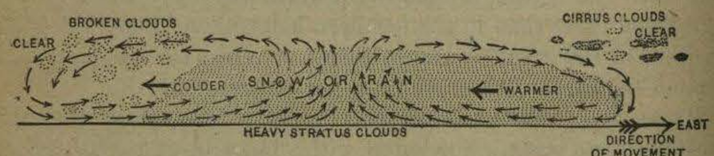

FIG. 412. — Diagram showing theoretical movement of air (by arrows), and other conditions, in a low pressure or cyclonic storm area. Describe this diagram.

from all directions toward the low pressure area. Next day (Fig. 414) the Low has moved eastward; but winds still blow toward it, and around its center rain falls. This area of low pressure is known as a *cyclonic storm*. The following day the storm has moved still farther east (Fig. 415), and, if we should continue to follow it, we could trace it out into the Atlantic, and possibly even across northern Europe into Asia.

Summary. — *A cyclonic storm is an area of low air pressure toward which winds blow from all directions, and in which rain falls. Such storms move eastward.*

[1] See also Appendix H, and pp. 289–293.

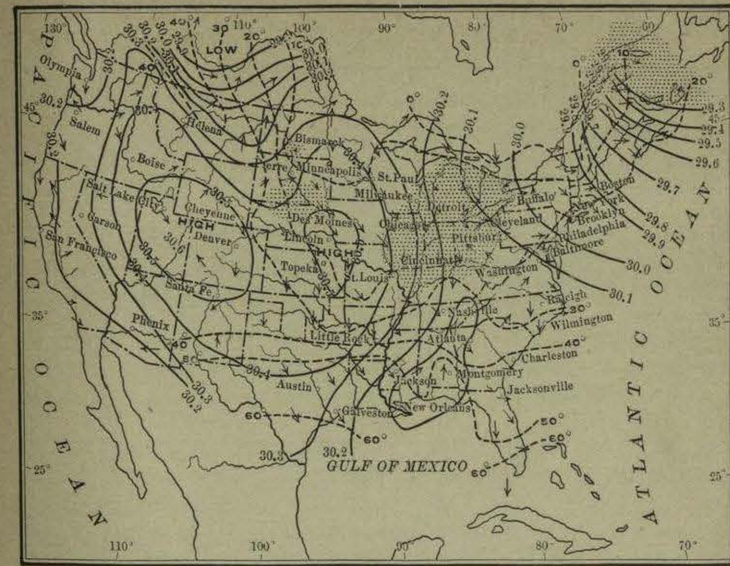

FIG. 413. — Chart to show weather conditions, January 7, 1893. Isobars, heavy lines; isotherms dotted; wind's direction indicated by arrows; areas of rain shaded. Compare with Figs. 414 and 415.

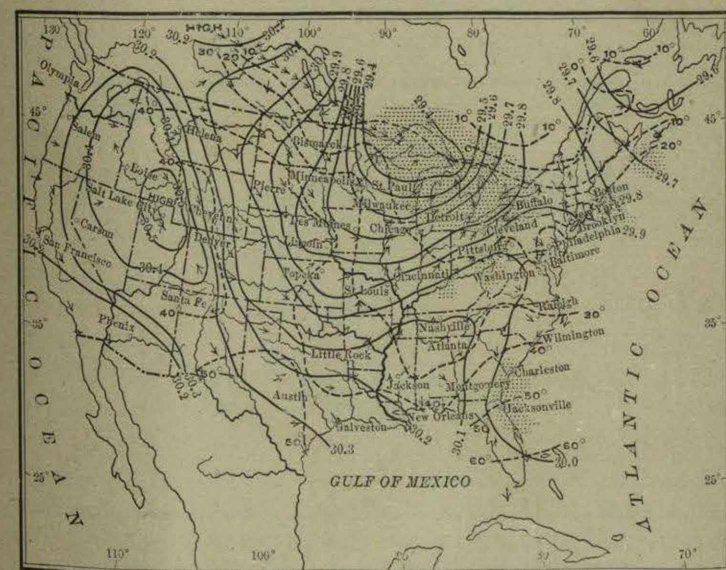

FIG. 414. — Weather map for next day, January 8, 1893. Path pursued by storm center indicated by chain of arrows.

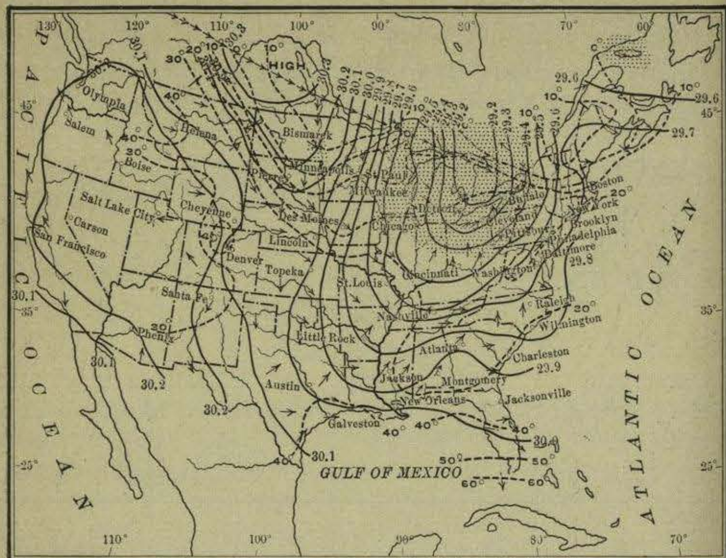

FIG. 415. — Same storm as Figs. 413 and 414, showing its position on January 9, 1893. Trace the changes for these three days.

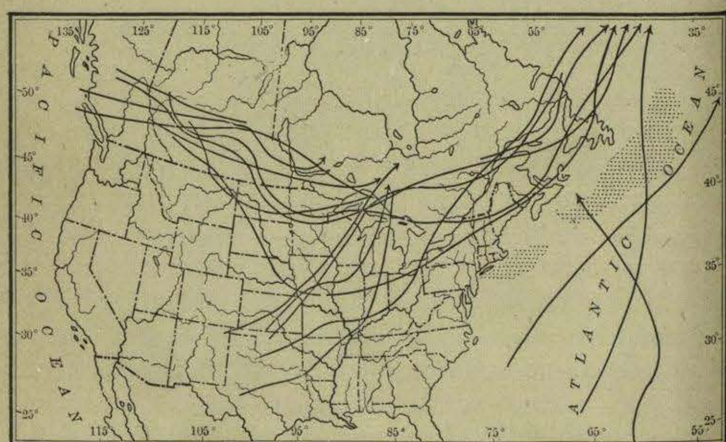

FIG. 416. — Paths followed by a number of low pressure areas during the month of November, 1891. The three in the ocean are hurricanes.

(B) *Anticyclones.* — West of the cyclonic storm (Fig. 414) is an area of high pressure (marked *High*), from which winds

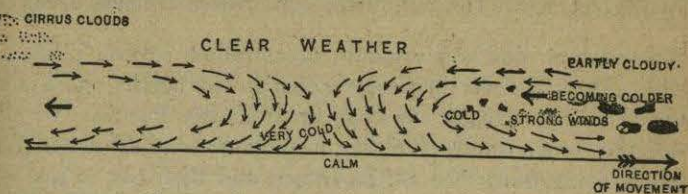

FIG. 417. — Diagram showing theoretical circulation (by arrows), and other conditions, in a high pressure, or anticyclonic, area. Describe this diagram.

blow outward in all directions, while the sky is clear and no rain falls. Such a high pressure area is often called an *anticyclone*, because in it conditions are the reverse of those in cyclones. Anticyclones move eastward as cyclonic storms do, even crossing the Atlantic.

Summary. — *Anticyclones are areas of high pressure with outward blowing winds and clear sky. They also move eastward.*

(C) *Succession of Cyclones and Anticyclones.* — Almost every weather map shows similar areas of high and low pressure (see Figs. 448–453). At intervals of from three to seven days, places in northern United States are liable to be visited, in fairly regular succession, by two low pressure areas with a high between (Fig. 418).

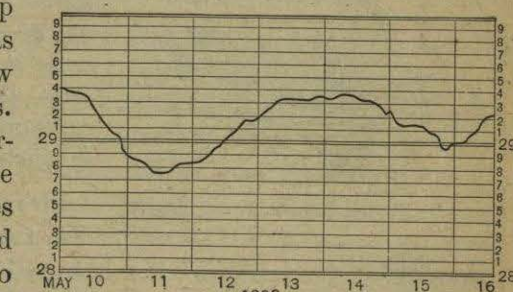

FIG. 418. — Diagram showing change of pressure for seven successive days at Ithaca, N.Y. Figures in vertical column indicate inches and tenths of inches of mercury in the barometer. The two drops in the curve were caused by the passage of two low pressure areas.

The passage of these areas is readily observed by watching the rising and falling of the barometer, or by observing the weather. Cloudy weather, rain, and high temperatures usually accompany the lows, and clear, cool or cold weather, the highs; while the wind direction varies as these areas pass.

These high and low pressure areas follow several paths (Fig. 416). Most of them originate either in the northwest or southwest, but some reach the country from the Pacific. In either case, they move toward the east, usually crossing the Great Lakes region, going down the St. Lawrence, and then out to sea. The centers move 500 to 1000 miles a day.

Not all low pressure areas are true storms, for those in which the pressure is not very low have light winds and little, if any, rain. These poorly developed low pressure areas sometimes die out entirely; in other cases they rapidly develop into vigorous storms. It is such irregularities as these that make storm prediction uncertain; but, because they usually follow regular courses, most storms can be accurately predicted.

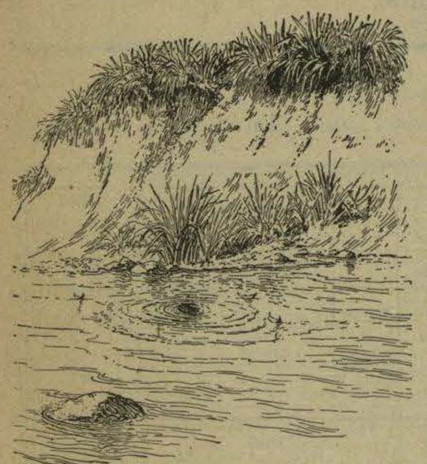

FIG. 419.—An eddy moving downstream, but with water whirling toward its center.

Summary. — *Cyclonic storms and anticyclones usually develop in the northwest or southwest, but often come from the Pacific, passing eastward across the country in fairly regular succession.*

(D) *Cause of Cyclonic Storms.* — Cyclonic storms are great eddies in the prevailing westerlies, and they occur both in the northern and southern hemispheres. They may be compared to the eddies in a river (Fig. 419), that move downstream with the current at the same time that water is whirling from all directions toward their centers.

In the same way, while the storm whirls are moving eastward with the prevailing westerlies, the air in them is eddying from all sides toward their centers.

Why these eddies develop is not certainly known. One theory is that they are started by the warming of air in some place, causing it to be light and therefore to rise, as air rises over a stove. Opposed to this theory is the fact that these storms are most common and best developed in winter, when heat is least likely to cause low pressure areas.

Another theory is that the highs and lows are air waves started in the westerlies. The regularity with which they come, their strength in winter when the west winds are best developed, and other facts, point to this as the more probable explanation. In either case, whether the air is warmed, or whether it is caused to rise and fall in waves, one part will have a lower pressure than another, and toward it air will flow, starting a whirl.

Summary. — *Cyclonic storms are eddies in the prevailing westerlies, with air whirling toward their centers from all sides. These eddies are low pressure areas, caused either by the warming of air or, more probably, by air waves started in the westerlies.*

(E) *Influence of Cyclones and Anticyclones on Weather.* — WINDS. (See also p. 289.) During the passage of high and low pressure areas the wind changes. On the east side of a storm the wind is from an easterly quarter, on the south side from the south, and between the cyclone and the anticyclone, from the west. The winds do not move along straight lines toward the center, but are turned by the effect of rotation so that they blow spirally; and if the differences in pressure are considerable, they blow with great force. Near the center the air rises (Fig. 412); but in an anticyclone it is steadily settling (Fig. 417).

TEMPERATURE. With these variations in wind direction the temperature also changes. Air from the south is warm, from the north, cool or cold. The settling air of the anticyclones brings to the earth some of the cool upper air. For these reasons, when low pressure areas pass over a region there is usually hot, humid air in summer, and damp air and rising temperature in winter. But when the high pressure areas approach, the air becomes clear and cool in summer, and cold in winter. Radiation through the clear air of an anticyclone cools the ground far more than through the humid, cloudy air which mantles the earth during the passage of a low pressure area.

RAIN. When air is settling it is growing warmer, and, therefore, its vapor does not condense. Consequently anticyclones cause periods of dryness. In cyclonic storms, on the other hand, the rising air is becoming cooler, and its vapor is condensing, forming clouds and rain. The cloudy and rainy portions of a well-developed cyclonic storm may cover an area with a diameter of over 1000 miles.

There are two other important reasons for rain in these storms: (1) those winds which are blowing from the south are steadily advancing toward a cooler region; (2) in some places the air is forced to rise over highlands, like the Appalachians and New England. If, in either case, the air cools until it reaches the dew point, some of its vapor condenses.

In central and eastern United States the rain-bearing winds of cyclonic storms are mainly from the south and east. Winds from these quarters bear vapor from the ocean, and those from the south are, in addition, blowing toward cooler regions. In New England, well-developed cyclonic storms are commonly called *northeast storms*, because of the damp ocean winds then blowing from that quarter toward the center of low pressure.

When vapor condenses to form clouds and rain, the so-called "latent heat" (p. 238) is liberated, and this helps warm the air. It is partly for this reason that storms commonly increase in violence in passing over the Great Lakes and the ocean; for in these places more vapor is provided, and the heat from its condensation causes lower pressure and, therefore, a more rapid inflow and rising of air. A cyclonic storm has been called a great engine, furnishing some of its own energy as the vapor condenses.

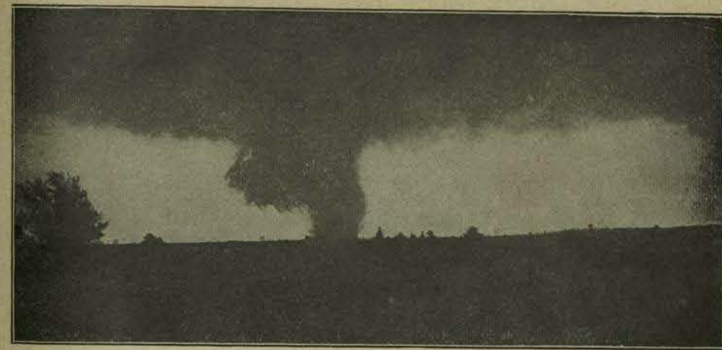

FIG. 420. — Photograph of a tornado at Mt. Morris, Ill.

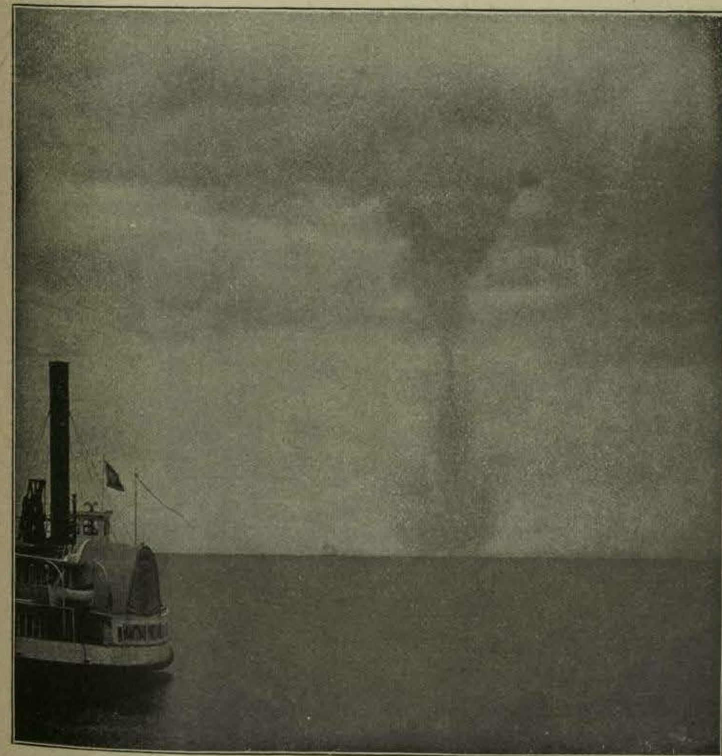

FIG. 421. — A waterspout off Marthas Vineyard, Mass.

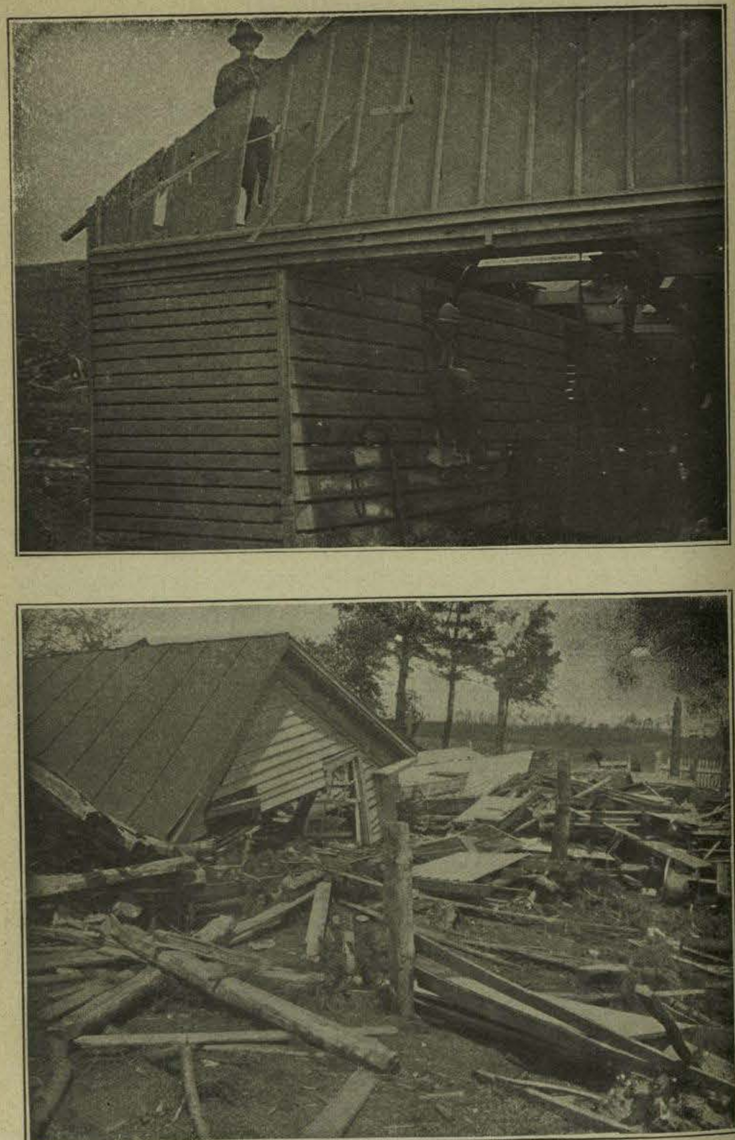

Fig. 422. — Destruction done by the tornado at Mt. Morris (Fig. 420). In the roof of the upper figure, notice the laths driven through boards by the force of the wind.

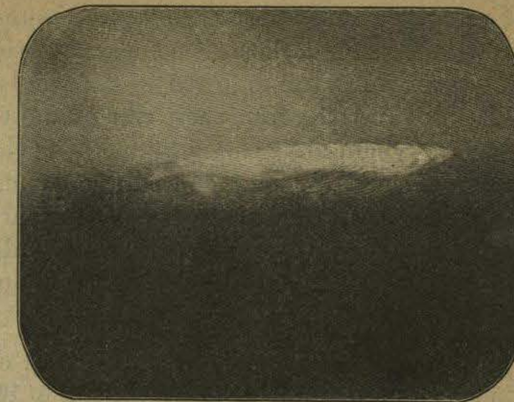

Fig. 423. — Photograph of a distant thunder storm.

Summary. — *As high and low pressure areas pass, the winds vary in direction, the lows bringing warm air, clouds, and rain, the highs cool, clear air settling from aloft. The rain of cyclonic storms is caused (1) by the rising of air, (2) by its passage from warmer to cooler regions, and (3) by its rising over highlands. The heat liberated by condensing vapor causes the air to rise with increasing energy, and, therefore, over water storms increase in vigor.*

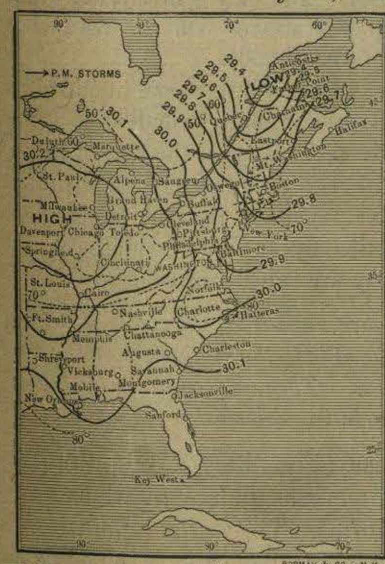

Fig. 424. — Part of a weather map, July 16, 1891, showing a low pressure area with thunder storms (indicated by arrows) in its southern part.

179. Thunder Storms and Tornadoes. — (A) *Thunder Storms.* — These are local storms which develop in low pressure areas, usually in the southern portion where warm, humid air is slowly moving from the south. On such muggy, oppressive days the air is not rising fast enough to form a blanket of clouds; but, as the ground is warmed during the day, the humid air rises, and patches of cumulus clouds appear (p. 248). As the day passes these grow larger and darker, rising as masses of rolling, surging cloud, perhaps a full mile above the level base.

Rain finally falls from these clouds, and thunder and lightning are produced. The lightning is an electric spark, passing from cloud to cloud, or from the clouds to the earth, the electricity being produced when the air currents are swirling violently about and the vapor rapidly condensing. Thunder is the noise caused by the spark, and its rolling is the result of echoes among the clouds.

Thunder storms are often small, perhaps only a few hundred yards in area; but sometimes they are 50 to 100 miles long, 15 to 25 miles broad, and 3 to 5 miles high. They travel eastward in the west winds at the rate of 20 to 50 miles an hour, and may last from 2 to 10 hours before dying out. The rain is heavy, the winds often strong, and the lightning destructive. On the borders of thunder storms, hail frequently falls (p. 250).

Thunder storms occur in other places where warm, humid air is rising to a level at which its vapor rapidly condenses. For example, they are of almost daily occurrence in the belt of calms. Around mountains, too, as the air rises on a hot day, clouds often gather and develop into thunder storms. In arid lands these storms are sometimes accompanied by so rapid condensation of vapor and so heavy rain that they are called "*cloudbursts*."

Summary. — *Thunder storms are caused by the rising of warm, humid air in low pressure areas, usually in the southern portion; they are over-developed cumulus clouds. They also occur in the belt of calms, and where air is rising around mountains.*

(B) *Tornadoes.* — Tornadoes (Fig. 420) develop in the southern portion of low pressure areas under conditions similar to those causing thunder storms. The warm, humid, lower layers of air, brought by south winds, have above them cooler layers moving from the west. As the lower air warms and rises, a whirl starts around the center of rising, and the winds blow with great force. Like thunder storms, tornadoes often

occur in groups, perhaps a score or more developing at one time, and not very far apart. Heavy rain and hail fall at the margin of the whirl, and thunder and lightning occur.

The winds of the tornado whirl are so strong that houses are overturned, heavy bodies picked up and carried long distances, trees uprooted, and paths cut through the forest. In the center of the whirl there is a partial vacuum, and, as it passes, the air inside of houses expands with such force as to blow out the windows, and even the walls. The path of great destruction is only a few score yards wide, though it may reach a length of several miles before the tornado dies out. Although the passage of a tornado lasts but a minute or two, its work of destruction is so complete (Fig. 422) that tornadoes are much dreaded; and, in regions visited by them, holes, called "cyclone cellars," are made in the ground for shelter.

Fortunately tornadoes do not occur everywhere. They are especially abundant in the Mississippi valley. In that level, open country it is easily possible for warm, humid air from the Gulf of Mexico to slide in under the cooler, upper air and thus bring about the unstable conditions which are so favorable to tornado formation. They do not develop in arid countries, because the air is not humid enough; nor are they common in mountainous or hilly lands, because the irregular surface causes a mixture of warm and cool air layers. They rarely occur east of the northern Appalachians.

Summary. — *Warm, humid air, creeping under cooler layers in the southern part of low pressure areas, especially on the level plains, causes an unstable condition; and at times, as the air rises, the in-moving winds start a violent whirl, forming a tornado.*

(C) *Waterspouts.* — At sea conditions favoring tornadoes produce waterspouts (Fig. 421). In their center the water is raised in a low cone, and some salt water is actually carried up into the spout.

Summary. — *Waterspouts are tornadoes at sea.*

180. Hurricanes and Typhoons. — Very violent storms, known in the Pacific as *typhoons*, and in the Atlantic as *hurricanes*, develop in the tropical zone and move into the temperate zones. On passing into the cooler temperate zones they become larger and less violent, and then closely resemble cyclonic storms. The path followed by the Atlantic hurricanes is usually across the West Indies, off the coast of the southern Atlantic States, then out to sea, curving eastward under the influence of the earth's rotation. Sometimes they depart from this course (Fig. 427), visiting the Gulf coast and even the Great Lakes. The typhoons of the Pacific and Indian oceans have various courses, some of those in the northern hemisphere passing over the Philippines.

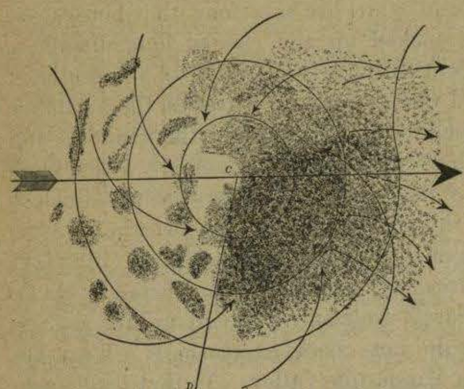

Fig. 425. — Diagram of a hurricane, showing direction of movement (long arrow), rain area (shaded), and winds eddying toward low pressure center, *C*.

These storms start by the rising of warm, humid air in the torrid belt, forming a whirl similar to that in a tornado, though much larger (Fig. 426). They originate on the ocean rather than on the land, because the humid air over the sea supplies much vapor, which, on condensing, liberates heat that warms the air and causes it to rise still more rapidly.

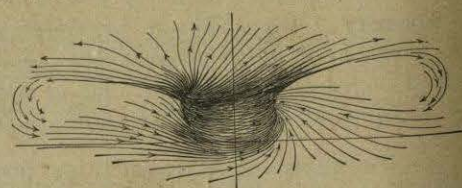

Fig. 426. — Graphic sketch to illustrate wind movement in a hurricane.

The pressure is very low in the center, though not approaching a vacuum. Toward this center violent winds

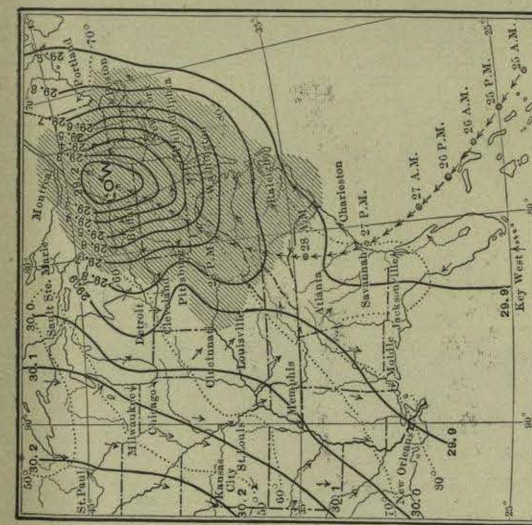

Fig. 427. — A hurricane, showing its path from the West Indies. It has gone a little out of the usual course (Fig. 416) and passed over the land. Rain area shaded.

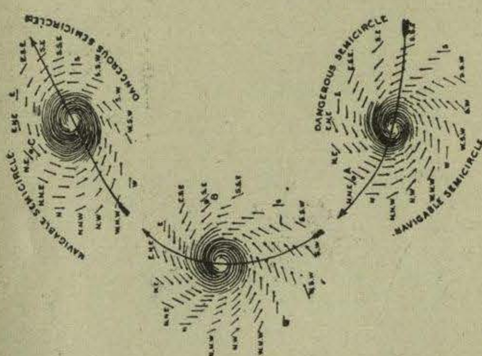

Fig. 428. — Diagram of spirally inflowing winds of a hurricane, together with the path pursued by the storm.

Fig. 429. — A photograph in Galveston after the passage of the hurricane of 1900.

blow (Figs. 425–428), often with such force as to overturn trees and houses. Towns have been devastated and many vessels lost, as at Samoa in 1889, when several war ships were destroyed during a typhoon. Along the Atlantic coast of the United States the most violent storms are hurricanes, which often leave the coast strewn with wreckage.

Heavy rains, vivid lightning, and loud thunder accompany these storms. With them also travels a wave of high water, which, advancing on low coasts, causes much destruction, destroying houses, towns, and life. It was one of these waves, rising over Galveston, that, together with the winds, caused such terrible destruction in 1900, killing thousands of people and almost destroying the city (Fig. 429). Such a wave is due to two causes: (1) drifting of water toward the storm center by the spirally in-blowing winds (Figs. 425–428); (2) rising of water in the center because the weight of the air there is less than in the ring surrounding it.

Most hurricanes occur in late summer and early fall, because then the belt of greatest heat is farthest north. At the equator, winds are not turned by the influence of rotation; but, as the distance from the equator increases, they are turned more and more. Whirls can develop only when the winds are turned to one side so as to start a spiral movement around the center of rising. For this reason hurricanes cannot start at or near the equator; but they can start in the hot belt when it has migrated some distance from it. In the North Atlantic the period when the belt of calms is farthest from the equator is in late summer, and then hurricane whirls start in the rising air.

Summary. — *Hurricanes and typhoons are violent whirls, starting in the torrid zone, and resembling tornadoes, though larger and less violent. They start over the ocean because of the great amount of vapor, whose condensation supplies heat which causes more rapid rising. Their fierce winds, and the water wave which accompanies them, cause great destruction. They occur late in summer, or early in autumn, when the belt of calms is farthest from the equator, because then the effect of rotation can deflect the winds and start the spiral movement which causes the whirl.*

TOPICAL OUTLINE, QUESTIONS, AND SUGGESTIONS.

TOPICAL OUTLINE. — 173. **Relation between Winds and Air Pressure.** — Air columns; effect of heat; low pressure; high pressure; cause of winds; barometric gradient; strong winds.

174. **Sea and Land Breezes.** — Cause of sea breezes; effects; land breezes.

175. **Mountain Valley Breezes.** — Movement down valleys; up valleys.

176. **Monsoon Winds.** — Place of best development; summer monsoon; winter monsoon; importance to sailing vessels; reason for lack of development elsewhere; condition in northeastern United States.

177. **Wind Systems of the Earth.** — (A) *Comparison with a Stove:* air movements in room heated by stove; on earth. (B) *Effect of Rotation:* right-hand deflection; left-hand deflection. (C) *Belt of Calms:* cause; doldrums; migration. (D) *Trade Winds:* steadiness; deflection; southeast trades; northeast trades; change in position; relation of Asiatic monsoons to trades. (E) *Antitrades:* upper outflow; direction; proof of existence. (F) *Prevailing Westerlies:* source of air; circumpolar whirl; effect of rotation; prevailing westerlies; interference with winds; westerlies over Southern Ocean; in northern hemisphere; high in the air. (G) *Horse Latitudes:* location; settling air; condition of winds; shifting of belts.

178. **Cyclonic Storms.** — (A) *Characteristics:* low pressure area; isobars; winds; rain; cyclonic storm; movement. (B) *Anticyclones:* pressure; winds; sky; name; movement. (C) *Succession of Cyclones and Anticyclones:* regular succession; weather changes; places of origin; paths; weak lows; irregularities. (D) *Cause of Cyclonic Storms:* comparison with river eddies; theory of heat origin; theory of wave origin; relation of eddies to low pressure. (E) *Influence of Cyclones and Anticyclones on Weather:* (*a*) Winds, — variation in direction; deflection; variation in force; rising air in lows; settling in highs. (*b*) Temperature, — south winds; north winds; settling air; passage of lows; of highs; radiation. (*c*) Rain, — reason for dryness in highs; effect of rising in lows; other causes for rain; source of vapor; northeast storms; effect of liberation of heat; storms over water.

179. **Thunder Storms and Tornadoes.** — (A) *Thunder Storms:* place of occurrence in low pressure areas; cause; growth; lightning; thunder; size; path; rate of movement; occurrence elsewhere; cloudbursts. (B) *Tornadoes:* favoring conditions; the whirl; comparison with thunder storms; effect of winds; condition in center; path; time of passage; cyclone cellars; occurrence in Mississippi valley; absence in other sections. (C) *Waterspouts.*

180. **Hurricanes and Typhoons.** — Typhoons; hurricanes; places of development; movement into temperate zones; paths followed; cause; reason for development over the sea; accompanying phenomena; effects of water wave; cause of wave; time of occurrence; explanation of this.

QUESTIONS. — 173. What is the cause of wind? What is barometric gradient? When are winds strong?

174. Explain sea breezes; land breezes.

175. Explain the day and night breezes of mountain valleys.

176. Where are monsoons best developed? Explain them. What is the condition in northeastern United States?

177. (A) Compare the circulation in a room heated by a stove with that of the earth. (B) In what direction, and why, are winds turned from a straight course? (C) What is the condition in the belt of calms? Why does it change position? (D) What are the directions of the trade winds? Why? What effect has the migration of the belt of calms? Why are the monsoons so well developed in Asia? (E) What is the direction of the antitrades? How is this known? (F) What is the circumpolar whirl? What is the direction of the winds? Why? What are the prevailing westerlies? What interferes with the regular winds? How do the westerlies of the northern and southern hemispheres differ? (G) What are the conditions in the horse latitudes? Why?

178. (A) What is a low pressure area? What are isobars? A cyclonic storm? State its characteristics. (B) What are anticyclones? Contrast with cyclonic storms. (C) What changes accompany the highs and lows? What paths are pursued? What irregularities are noticed? (D) Compare cyclonic storms with eddies in a river. State the two theories for these storms. What facts favor one rather than the other? (E) What is the nature of the winds in high and low pressure areas? What changes in temperature occur as these areas pass over a region? What are the causes of rain in the cyclonic storms? Why do storms commonly increase in violence when passing over large water bodies?

179. (A) Under what conditions do thunder storms appear in low pressure areas? Why? What is the lightning? The thunder? What are the characteristics of these storms? Where else do thunder storms occur? (B) Under what conditions do tornadoes develop? What are some results of tornadoes? Where are they most common? Why? In what situation are tornadoes rare? (C) What are waterspouts?

180. What are hurricanes? Typhoons? What paths do they follow? Why do they start over the sea? What destruction do they accomplish? Give instances. What destruction is done by the water wave? What is the cause of this wave? When are these storms most common? Why at that season?

SUGGESTIONS. — (1) Recall the previous experiments on convection (Chapter XII, 10). (2) Open a window on a cold day when no wind is blowing. Why does the cold air enter the room? (3) Keep a record of the wind direction for twenty days. How many days did the wind blow from each of the four quarters (north, east, south, and west)? For the same period keep a record of the direction that the higher clouds are moving. How many days do they move from each quarter? (4) On an outline map make a sketch of the winds of the globe similar to Fig. 408. Make a sketch to show the change in position of the belt of calms (Figs. 439, 440). (5) If the instruments are available, keep a record of the wind direction and force, humidity, temperature, clouds and rain, and barometric pressure (Appendix G). Tell when cyclonic storms and anticyclones are passing, and carefully record the relation between air pressure and the other phenomena. From your observations predict the weather for the following day. (6) Study weather maps (Appendix H). (7) With apparatus obtained from the physics laboratory make an electric spark. This is a lightning flash on a small scale, and the noise is thunder. A similar flash and noise may often be noticed as a trolley car passes. (8) If thunder storms occur, keep a record of all the phenomena and report upon them. (9) Read, say in *Harper's Weekly* for the autumn of 1900, an account of the destruction of Galveston. Be on the outlook next fall for newspaper reports of hurricanes or typhoons; also, next summer, for reports of tornadoes.

Reference Books. — HARRINGTON, *Rainfall and Snow of United States*, Bulletin C, U. S. Weather Bureau, Washington, D.C., 1894; FERREL, *Popular Treatise on the Wind*, Wiley & Sons, New York, 1889, $4.00; FINLEY, *Tornadoes*, Hine, New York, 1887, $1.00. (See also references at end of Chapter XII.)

CHAPTER XIV.

WEATHER AND CLIMATE.

181. Difference between Weather and Climate. — *Weather* refers to daily changes in temperature, wind, clouds, and rain. *Climate* is the average result of these weather changes. For example, certain parts of the tropical zone are said to have a rainy climate. This does not mean that it rains every day, but that, though the weather on some days is clear, on still more it is rainy. Thus the average condition, or the climate, is rainy.

The following are some of the more important kinds of climate: dry, hot desert climates; hot, rainy climates, as in the belt of calms; damp, equable ocean climates; extreme and variable climates, common in the interior of continents; and frigid climates. The greater part of the United States has a variable climate. These different climates, and the reasons for them, can best be understood by studying the conditions in various parts of the world.

Summary. — *Climate is the average of weather, which is the daily condition of temperature, wind, clouds, and rain. There are a number of very different climates on the earth.*

182. Zones of Heat. — (A) *The Five Zones.* — The most widespread cause for variations in climate is the distribution of sun's heat from equator to poles. This results from the differences in angle at which the sun's rays reach the earth in different latitudes (p. 239). From this has arisen the common division of the earth into five climatic zones, — two frigid, two temperate, and one torrid, or tropical (Fig. 430).