SUGGESTIONS. — (1) Take some angular fragments of a soft rock, or brick, and shake them for a few moments in a fruit jar containing water. What causes the water to become muddy? Find out how marbles are rounded. (2) In a shallow pan, mold an irregular land of clay. Carefully pour in water until the land is partly drowned. Study the land forms produced. Blow on the water surface, causing the waves to reach the coast diagonally. Are any bars formed? Any other coast-line features? Study and describe them. Now draw off some of the water to leave the shore line elevated. Describe the new coast line. How does it differ from the former? Cause waves to attack it, and describe the result. By using care, and by making the land of materials varying in hardness, much concerning shore-line phenomena may be simply and easily illustrated. (3) If the school is near the seashore or the shore of a lake, at least one excursion should be made to study shore phenomena. Are there beaches? Where does the material come from? Are there cliffs? What is happening there? Have any portions been recently removed by the waves? Do the bowlders or pebbles show signs of rounding? What is the cause? Where does the finer ground-up material go? Are there any mud flats? What is the source of the material? Ask some fisherman what material covers the bottom offshore. Are there salt marshes? What are their characteristics? Are tidal currents performing any work? (4) If the school is on a sea or lake port, the harbor should be studied; its form; depth (making use of a Coast Survey map); cause; nature of bottom; improvements made; others needed; light-houses; other guides and aids to entrance; source of principal materials received for shipment; of principal imports; places to which these are distributed; reasons for importance of port. If not on a harbor, the nearest large port should be studied in a similar way by means of the Coast Survey or Lake Survey charts (see Appendix J).

Reference Books. — SHALER, *Sea and Land*, Scribner's Sons, New York, 1894, $2.50; TARR, Chapter X, *Physical Geography of New York State*, Macmillan Co., New York, 1902, $3.50; SHALER, *Beaches and Tidal Marshes of the Atlantic Coast*, *National Geographic Monographs*, American Book Co., New York, 1895, $2.50; GILBERT, *Features of Lake Shores*, 5th Annual U. S. Geological Survey, p. 75; SHALER, *Salt Marshes*, 6th Annual U. S. Geological Survey, p. 359; SHALER, *Harbors*, 13th Annual U. S. Geological Survey, p. 99; DARWIN, *Structure and Distribution of Coral Reefs*, Appleton & Co., New York, 1889, $2.00; DANA, *Corals and Coral Islands*, Dodd, Mead & Co., New York, 1895, $5.00.

CHAPTER XII.

THE ATMOSPHERE.

162. Composition of the Air. — (A) *Oxygen, Nitrogen, and Carbon Dioxide.* — Until recently air was believed to be a mixture of two gases, *oxygen* (about 21 per cent) and *nitrogen* (about 79 per cent).[1] Oxyen is of vital importance to animals, for all breathe it; but nitrogen, though used by some plants, is of far less importance. It, however, increases the bulk of the air and dilutes the oxygen. Man probably could not live in an atmosphere of pure oxygen, for it would cause too rapid changes in the tissues of the body.

About 0.04 per cent of the air is carbon dioxide (often called carbonic acid gas), which, in spite of its small quantity, is very important. It is composed of one part of carbon and two of oxygen, and plants have the power of separating them, building the carbon into their tissues.

In the bodies of animals, on the other hand, oxygen unites with carbon by a process of slow combustion, and with each breath carbon dioxide is returned to the air. Fire is a more rapid form of combustion, oxygen combining with the carbon of the wood, coal, oil, etc., and forming carbon dioxide. All forms of combustion, whether rapid or slow, produce heat. In such rapid combustion as fire, sufficient heat is produced to do much work, — for example, the formation of steam, whose energy may be used to run locomotives or

[1] In 1895 a new element, *argon*, was discovered in the atmosphere, and since then several other inert elements have been found in it. They resemble nitrogen so closely that, although they are taken with every breath, they were never before detected.

machinery. By slow combustion the necessary heat is produced to form the energy which animals need for life.

Summary. — *The atmosphere is a mixture of gases. Argon and nitrogen are quite inert; carbon dioxide, which exists in very small quantities, is of vital importance to plants; oxygen is breathed by all animals, in which it produces slow combustion, giving the necessary heat for life. It also causes rapid combustion in fire.*

(B) *Water Vapor.* — Vapor rises from all damp surfaces and water bodies; that is, liquid water is *evaporating* or changing to an invisible gas. This is the reason why wet clothes become dry when hung on a line, and sidewalks, after a rain. The amount of vapor water varies from place to place, some regions having very dry air, others damp or humid air. Even in the same place the amount of vapor differs from time to time, some days being humid, others dry. When the air is dry, evaporation is rapid and the sky clear; but when there is much vapor, there may be clouds and rain. The condensation of this water vapor gives rise to dew, frost, fog, clouds, rain, snow, and hail.

Summary. — *Invisible water vapor, which rises from water bodies and damp surfaces, is also mixed with the air, in varying amounts.*

(C) *Dust Particles.* — Solid particles that float in the air are called dust. Some of these are whirled up from the ground by winds; some are bits of carbon from smoke, or pollen of plants, or microbes. Dust particles accumulate around cities, causing a dull, hazy atmosphere; but during long periods of drought, or when forest fires are burning, the air even in the country becomes hazy with dust. Rain washes dust from the air, so that it is usually clearer after a rain storm. Over the ocean, and on high mountains, the air is quite free from dust particles.

Dust is important in furnishing solid particles around which vapor condenses to form fog and rain. The microbes are drifted about by the winds, thus helping to spread disease.

Summary. — *Particles of dust, smoke, microbes, and other solids often cause the air to be hazy, especially near cities.*

163. Effect of Gravity. — Although light and invisible, air has perceptible weight. One particle, drawn down by gravity, presses on those below it, as stones in a pile press on those beneath. Since the air extends to a height of two hundred miles or more, this great column has a weight that can be measured. At sea level, its average weight is 15 pounds to every square inch of surface. This is equal to a column of about 30 feet of water, or 30 inches of mercury.

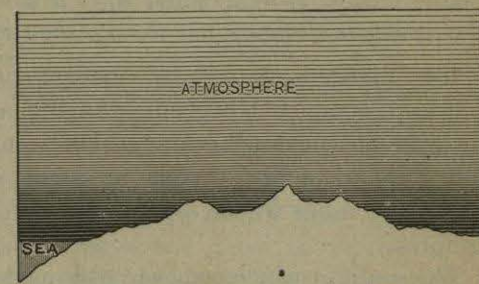

FIG. 391. — To illustrate the decrease in density of the atmosphere from sea level to higher regions.

Since there are many square inches on the surface of a human body, it is evident that each of us bears a great weight of air; but as the pressure is equal, both inside and out, we do not notice it (p. 181). If this pressure were suddenly removed from the outside, the expansion of the air within our bodies would burst many of the tissues.

Pressure pushes the molecules of gases closer together; and, therefore, the air is denser near the earth than higher up (Fig. 391). As a result of this, fully two thirds of the atmosphere is within six miles of sea level; and the air is about half as dense at the top of a high mountain, like Mt. St. Elias, as at its base. The air on mountain tops is so thin, or *rarefied*, that it is difficult to breathe oxygen enough for the needs of the body. Some men and animals have become accustomed to this rarefied air and are able to live in high altitudes; but a traveler from lower levels finds his breathing greatly quickened by the effort to get enough oxygen, and not uncommonly he becomes quite exhausted.

Air is so extremely elastic that even slight differences in temperature change its density or weight. For example, the air filling a room 10×20×20 feet weighs 301 pounds at 60°; but when the temperature is raised to 80°, the air is so expanded that there are only 291 pounds in the room.

The pull of gravity is greater on heavy than on light air, and these differences in weight start movements of the air, causing winds (p. 255).

Summary. — *Air has weight, at sea level about fifteen pounds to the square inch. It is compressed, or more dense, at the bottom; and lighter, or more rarefied, higher up. It is very elastic, varying in density with temperature, and being easily set in motion.*

164. Light.[1] — A form of energy, commonly called light and heat, is emitted by bodies having a high temperature; for example, burning coal, red-hot iron, and the white-hot sun. This energy travels at great speed, crossing the 93,000,000 miles which separates earth and sun in about 8 minutes.

The sunlight which comes to us is made of a series of waves, differing in length and color, whose union forms white light. If a beam of sunlight is allowed to pass through a three-cornered glass prism these waves are turned, each at a slightly different angle. The beam enters as white light, but comes out with the color waves separated, among which violet, indigo, blue, green, yellow, orange, and red may be recognized. This bending of light rays is called *refraction;* the colors are called the *colors of the spectrum*, or of the rainbow.

Some of the rays that reach a body pass away from it, or are *reflected*. This is especially true of smooth surfaces, like water, or the glass of a mirror; but it is true even of irregular surfaces, like the ground. It is reflected sunlight that makes the moon and planets appear light; and the earth would have the same appearance if seen from them.

Refraction and reflection cause many changes in light as it passes through the atmosphere. *Mirage* is caused by reflection

[1] A thorough study of the nature and behavior of light belongs to physics; but the student of physical geography should understand the main reasons for the color phenomena of the atmosphere.

when layers of air have different temperatures and, consequently, different densities. It is especially perfect in deserts and on the sea, commonly showing objects inverted — a vessel with the masts downward, for instance. In deserts mirage causes an appearance of water which is often very deceptive.

Rainbows are caused by refraction of light in its passage through raindrops, and reflection of the spectrum colors thus produced. The *halos* around sun and moon are due to similar changes in the light rays, in their passage through the ice crystals of thin, fleecy clouds high in the air.

The colors of leaves, flowers, and other objects are due to reflection. When light reaches some objects, for example white paper, all the waves are reflected and the paper appears white. Other objects, like black cloth, reflect very little light, the rays being absorbed. Still other objects absorb some of the waves and reflect others, thus giving color. A red flower, for instance, reflects an excess of red waves; and green leaves, green waves.

Diffraction, or *selective scattering*, is an important cause for color effect in the sky. Dust in the air interferes with the passage of light waves, as small pebbles in shallow water interfere with water waves. By this interference, some of the waves that make the white light are turned aside, or *scattered*. The waves having the shortest length, or those on the violet end of the spectrum, are most easily turned aside; that is, they are selected for scattering.

The blue color of the sky is due to the selective scattering of the short blue waves. When there is much dust in the air, the longer red and yellow rays are scattered, giving red and yellow colors to the sky. These colors are especially common at sunrise and sunset, when the rays pass for a long distance through the lower dust-filled layers of the air (Fig. 392). The varied cloud colors of sunrise and sunset are the result of reflection of colors caused by refraction and diffraction.

Summary. — *White light is made by the union of a number of waves of different length, which, when separated by refraction, give the colors of the spectrum. These colors may be reflected, as in colored objects, rainbows, halos, and clouds at sunset. The scattering,* *or diffraction, of waves by the interference of dust gives the blue color to the sky and the reds and yellows of sunrise and sunset.*

165. Heat. — (A) *Radiant Energy.* — On approaching a hot stove one feels its warmth, even at a distance of several feet. Waves of heat from the stove have passed that distance through the air. If the stove is very hot, the cover may be red; then the waves from it produce not only heat, but the sensation of light on the eye. This form of energy, which we call heat and light, is known as *radiant energy*, and the process of emitting it is called *radiation*. The greatest well-known center of radiant energy is the sun; but doubtless some of the stars are still larger and hotter, though so far away that they do not influence us.

Radiation causes a loss of heat, and by it bodies grow cooler; thus, in a few hours, a stove with the fire out will radiate all its heat and become cold. The sun is also losing heat, radiating it outward in all directions; but millions of years will be required for so large and hot a body as the sun to grow cold. A very small proportion of the heat radiated from the sun is intercepted by the earth (Fig. 15), where it causes many important effects.

Summary. — *Radiant energy, heat and light, which is emitted from hot bodies, is being radiated in all directions from the sun, which is, therefore, slowly growing cooler.*

(B) *Passage of Radiant Energy.* — Certain substances, like glass and the gases of the air, allow light to pass so freely that they are said to be *transparent*. They also allow heat to pass freely, or are *diathermanous*. For this reason, notwithstanding the thickness of the atmosphere, the sun's rays at midday reach the earth's surface with little change.

Dust particles interfere with the passage of light rays, as we have seen; and, in much the same way, they interfere with the passage of heat. This is clearly proved by the difference in brightness and warmth of the sun at midday and

late in the afternoon; for we may often actually look at the setting sun. At that time many of the rays are intercepted in their passage through the great thickness of dust-laden air near the surface (Fig. 392).

Summary. — *Air and other substances transparent to light allow heat to freely pass, or are diathermanous. The interference of dust greatly lessens the sun's power when it low is in the heavens.*

(C) *Radiation from the Earth.* — Bodies that are warmer than their surroundings emit waves of radiant energy. The earth itself is radiating into space the heat that comes to it from the sun; if this were not so, it would grow warmer and warmer. During the day more heat comes than can be radiated; but at night, when the sun's rays are cut off, radiation cools the ground. In summer, when the days are longer than the nights, the ground grows steadily warmer; but in winter, when the days are short and the sun low in the heavens, radiation is so far in excess of the supply of heat that the ground becomes cold.

Some bodies are much better radiators than others. Rocks and earth radiate heat better than water, and hence cool more quickly. This is one reason why, in winter, the land becomes colder than the water. On cold nights those objects that radiate their heat most quickly have most frost. Perhaps you can observe this difference early some frosty morning.

Summary. — *The earth is always radiating heat, and this is why it becomes cool or cold at night and in winter. Some objects, like water, are poorer radiators than others, like the ground.*

(D) *Reflection and Absorption.* — Bodies that reflect light also reflect heat. Water, for example, reflects a large percentage of the rays that reach its surface, and this is why one becomes sun-burned so easily on water. Quarries and city streets are warmer than the open country, partly because the sun's rays are reflected from their walls.

Some bodies reflect little, the sun's rays being used mainly in warming them. Such bodies are said to *absorb* heat. This is especially true of black objects, while white objects reflect; therefore white clothing is cooler than black. This can be readily proved in winter by placing two pieces of cloth, one black, the other white, on a bank of snow in the sunlight. The black cloth soon sinks into the snow because the sun warms it, while the white cloth remains at the surface.

Summary. — *Some bodies, such as water and white objects, reflect much heat; others, such as black objects, absorb heat and, therefore, warm more rapidly.*

(E) *Conduction.* — With a fire inside of it a stove becomes warm; and an iron placed on the stove is also heated. In this case heat from the fire is transmitted, or *conducted*, through the stove. In the same way, some of the sun's heat is conducted below the surface of the water or ground, and some of it into the air which rests on these; but water, air, and ground are not so good conductors as iron. The ground is so poor a conductor that, at a depth of from ten to twenty feet, there is practically no difference in temperature from summer to winter.

Summary. — *Heat is transmitted, or conducted, into the water and ground, and from these into the air, but air, water, and ground are all poor conductors.*

(F) *Convection.* — The lower layers of water in a kettle on a stove are warmed by conduction. Warm water is lighter than cooler water, and, since gravity tends to draw the heavy water to the bottom, these warm lower layers cannot stay there. They are, therefore, crowded up by the settling of the cooler layers from above. This is convection, and, if the water continues to warm, boiling finally takes place.

Similar convection occurs in air warmed by a lamp. As fast as it is warmed near the lamp it grows lighter and is pushed up by heavier surrounding air. The movement of heavier air to crowd up warm air is what causes the draft in a fire; and the crowding upward of the warm air is what causes it to go up the chimney.

Heat from the sun is the cause for very extensive convection of the air in all parts of the earth. Warmed in one place, usually by conduction of heat from the ground or water, the warm light air is pushed away by heavier air drawn down by gravity. This is the cause of winds (p. 255).

Summary. — *Heat makes both water and air lighter; and gravity, by drawing down heavier air, causes a rising, or convection, of the warmer lower layers. Winds are thus caused.*

166. Warming of Land, Water, and Air. — (A) *The Lands.* — The lands are warmed by absorption during the day, and some of the heat is conducted into the ground, warming the upper few feet into which the roots of plants reach. The ground nowhere becomes excessively warm, because much of the heat is lost by reflection, by radiation, and by conduction into the air. Everywhere the ground warms during a hot, sunny day, and cools by radiation at night.

In the tropical zone the ground does not become very cool at night, because radiation is unable to remove all the heat that comes during the long, hot days. A similar condition exists during summer in the temperate zones; but, in winter, radiation during the long nights so chills the ground that it freezes. In the frigid zones, radiation during the long winter causes the ground to freeze to depths of hundreds of feet, and the short, cool summer supplies only heat enough to melt the upper two or three feet.

There are other differences in the warming of the lands. For example, dark-colored surfaces warm more quickly than light, and bare earth more quickly than that covered by vegetation. There are also differences according to exposure; for instance, between shady north slopes and sunny south slopes, and between hilltops and valleys, whose sides reflect heat into the valley and also interfere with winds and with radiation.

Summary. — *The lands are warmed by absorption and cooled by reflection, conduction, and radiation. The effect of sun's heat varies in different zones; also according to the color of the surface, the cover of vegetation, and the exposure.*

(B) *The Waters.* — It is a well-known fact that water warms less quickly than land. There are several reasons for this. (1) Water reflects heat more readily than land, and, consequently, there is less heat to warm it. (2) When one part is warmed more than another, it is set in motion, so that there is a tendency for the heat to be distributed. (3) Water is so transparent that, unlike ground, some of the rays pass into it, warming layers below the surface. Sunlight penetrates, though dimly, to depths of several hundred feet. (4) Twice as much heat is required to raise the temperature of a pound of water one degree as of an equal quantity of rock. Some of the heat is expended in evaporating the water, and this is called "latent heat," or *heat of vaporization.*

It is for these reasons that even a small body of water warms more slowly during the day, and during summer, than the neighboring land (p. 165). At night-time and in winter, on the other hand, because it is a very poor radiator, water cools more slowly than land. Therefore, from day to night, and from summer to winter, there is slight range of temperature in large water bodies, and the climate over them is far less extreme than over land. A climate with such slight changes of temperature is called *equable.*

Summary. — *Water warms more slowly than land because it reflects more heat, is movable, is transparent, and some of its heat is expended in evaporation. It cools more slowly because it is a poorer radiator. Therefore near large water bodies the climate is equable.*

(C) *The Air.* — The air is not perfectly diathermanous. Therefore, some of the sun's rays, and some of the heat rays radiated from the earth, are intercepted in their passage through the atmosphere. Dust is especially effective in

intercepting heat waves (p. 234). A still more important cause for the warming of air is conduction from the ground to the lower layers, which, being lighter, are then forced to rise by convection. In the same way a stove warms the air in a room, by radiation, conduction, and convection. At night and in winter the air cools by radiation; and contact with the ground is another important cause for cooling.

Vapor and dust interfere with radiation, and for this reason more heat is retained in the lower atmosphere on hazy and muggy days than in clear, dry weather. At such times radiation fails to cool the ground, and a hot, muggy day may be followed by an oppressive, almost stifling night. It is under such conditions that our most oppressive summer weather comes.

Summary — *The air is warmed somewhat by the passage of heat rays through it, but far more by conduction from the ground, and by convection. It is cooled by radiation, and by conduction from the ground. Vapor and dust interfere with radiation.*

167. Causes for Differences in Temperature on the Earth. — (A) *Position of Sun.* — The sun is higher in the heavens at noon than in early morning and late afternoon; in summer than in winter; and in tropical than in temperate zones. When low in the heavens, the sun's power is less than when high, because (1) the rays pass through a great thickness of dust-laden air when the sun is low (Figs. 392, 394) and (2) fewer rays then reach a given surface (Fig. 393).

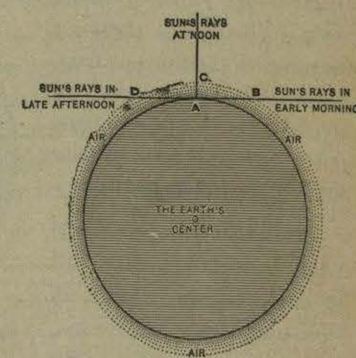

FIG. 392. — To show that the sun's rays pass through more air when the sun is low in the heavens than when it is high.

There are three important results of these different positions of the sun. (1) Every day, as the angle at which the

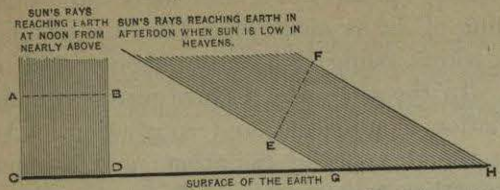

FIG. 393. — Two bundles of rays having the same width (*AB* and *EF*); but, owing to the difference in angle at which they reach the surface *CH*, those that are inclined cover about twice as much ground as those that come straight down from above. Therefore, on the same area there are about half as many inclined rays as vertical.

sun's rays pass through the air varies (Fig. 392), the amount of heat given out by them varies. (2) As the sun changes position, from high in the heavens to lower, the seasons of summer and winter occur in both hemispheres. (3) Where the sun is highest, that is in the tropical zone, the climate is hottest; and the climate grows cooler away from the equator as the sun gets lower in the heavens (Fig. 394).

Summary. — *When the sun is low in the heavens it warms less than when high, because* (1) *the rays pass through so much air, and* (2) *fewer rays reach a given area. Changes in the sun's position in the heavens from morning to night, from season to season, and from place to place, therefore cause differences in temperature.*

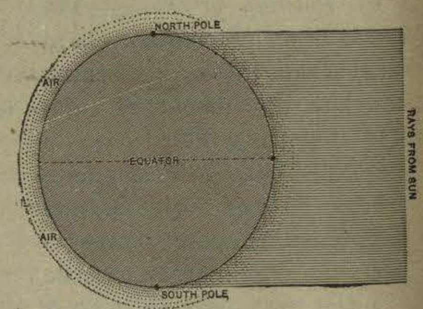

FIG. 394. — To show that near the poles the sun's rays reach the earth in a more slanting way, and after passing through more air, than at the equator.

(B) *Altitude.* — Observations on mountains and in balloons show that, as the elevation increases, there is a gradual decrease in temperature at the rate of about 1° for every 300 feet. There is no warm ground to impart heat to these upper layers of the atmosphere; and warm air, rising from the surface, expands and cools as it rises. Because the upper air is so cool, a frigid climate is found at the equator

at a height of a few miles; and highlands are everywhere cooler than neighboring lowlands.

That air cools on expanding may be proved by a bicycle pump. Air pumped into the tire is compressed, or made more dense, and therefore warmed. When this compressed air is allowed to escape, it expands and cools, and its coolness may be felt.

Although surrounded by cold air, parts of highlands exposed to direct rays of the sun may become quite warm at midday. On a high mountain one may, therefore, be very warm in a protected, sunny place, while a few feet away, in a shady spot, or one exposed to the wind, it is very cold. Radiation is so rapid in the clear, thin, upper layers of air that even the warm places quickly cool off when the sun disappears; in fact, the temperature may rise to 90° at midday and descend to 10° at night.

Summary. —*Highlands are cooler than lowlands, the temperature changing about* 1° *for every* 300 *feet. There is no warm land to warm the upper air, and air cools as it rises and expands. Rapid radiation in the clear, thin air causes cold nights.*

(C) *Other Reasons for Differences.* — We have already learned several reasons for differences in temperature according to situation; for example, nature of rock, exposure (p. 237), and influence of water bodies (p. 238). The nature and direction of the wind also influence temperature (p. 265). These causes for differences in temperature are more fully studied in Chapter XIV.

168. Daily and Seasonal Temperature Changes. — (A) *Daily Range.* — The warmest period is not midday, when the sun is highest, but two or three hours after noon (Fig. 395). The reason for this is that in the morning it is first necessary to warm the ground that was cooled by radiation the night before. After the ground is warmed, the temperature continues

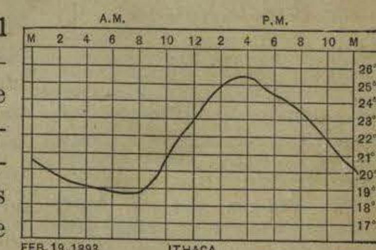

FIG. 395. — Normal daily temperature range in winter at Ithaca, N.Y.

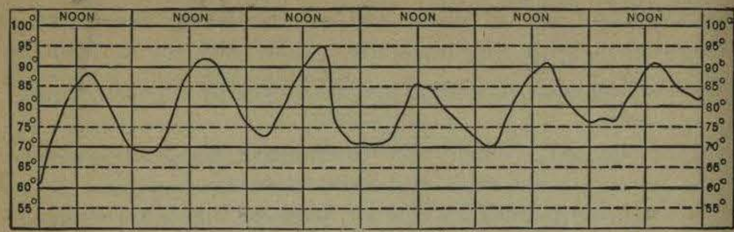

FIG. 396. — Change in temperature for six successive summer days at Ithaca, N.Y.

to rise until the sun has sunk so low that heat is radiated away faster than it is received. Then the ground and air commence to cool, continuing to do so until sunrise. Therefore the coldest period is not midnight, but just before sunrise (Fig. 395). Because of these conditions there is a normal daily change, or range, of temperature similar to that shown in the diagram (Fig. 395).

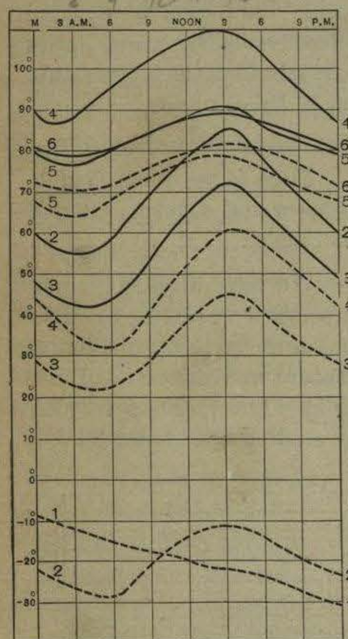

FIG. 397. — Normal summer (heavy line) and winter (dotted line) daily temperature range for several places. (1) Arctic; (2) St. Vincent, Minn.; (3) Djarling, India; (4) Jacobabad, India; (5) Key West, Fla.; (6) Galle, India; 5 and 6 are near the warm ocean.

There are a number of conditions which may occasionally interfere with the normal daily range (Fig. 396). A cloudy sky, interfering with the passage of the sun's rays, may prevent the temperature from rising after noon; or winds may bring air so cold that the temperature falls, even during the daytime; or warm winds may cause the temperature to rise throughout the night.

The amount of change from day to night differs from time to time and from place to place. Thus the range is great when warm days are followed by cool nights, and less when cool days are followed by cool nights. The daily range in winter is quite different from that in summer; it is different at the equator from what it is in temperate latitudes; and on the land from what it is at sea (Fig. 397).

Summary. — *In the normal daily range the temperature is highest after midday, and lowest just before sunrise. The amount of daily range varies from time to time and from place to place.*

(B) *Seasonal Range.* — The yearly range of temperature closely resembles the daily range. If the average temperature for each day is kept, it will be found that in the northern hemisphere there is a steady rise from March to August, and then a gradual fall until February (Fig. 398). The reason why the coldest weather comes after midwinter (December 21) is that radiation continues to cool the ground and air until the days become long enough, and the sun high enough, to overbalance the effect of radiation. The hottest period of the year comes after midsummer (June 21), for the same reason that the hottest time of day is after noon.

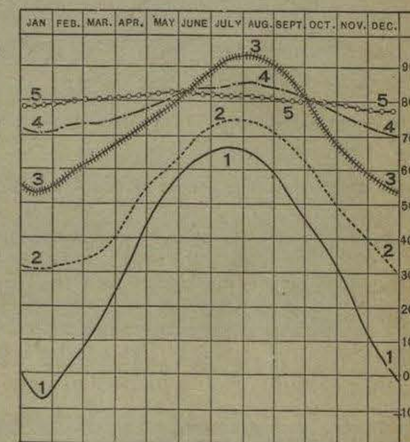

FIG. 398. — Seasonal temperature range in several places. (1) St. Vincent, Minn.; (2) New York State; (3) Yuma, Ariz.; (4) Key West, Fla.; (5) Galle, India; 4 and 5 are near the equable ocean.

While there is a normal seasonal curve as described, it differs greatly in various parts of the world (Fig. 398). For example, the midwinter temperature at the equator is very high, in the frigid zones very low; the range over the equable ocean is far less than that over the land; in the southern hemisphere the lowest temperature comes at the time of our summer. There are also differences caused by altitude, deserts, and other influences.

Summary. — *The average temperature rises until after midsummer and descends until after midwinter. The normal curve of seasonal temperature range varies from place to place.*

FORMS OF WATER.

169. Humidity. — Water vapor, which rises from the ocean, and all damp surfaces (p. 230), is diffused through the air and drifted about with it. It finds its way to all parts of the earth; not even the Sahara has absolutely dry air. The *actual amount* of vapor in the air, that is, the amount in pounds or quarts, is known as the *absolute humidity*. If there is as much as possible, the air is said to be *saturated*. For example, in a room 10 × 20 × 20 feet, the air at a temperature of 80°, if saturated, has 6¼ pounds of water in the form of vapor. This is its absolute humidity.

To represent the amount of vapor present in air, compared with the amount that might be there, the term *relative humidity* is employed. Relative humidity is measured in percentages. Thus the relative humidity of saturated air is 100 per cent, for it has all it can contain; of absolutely dry air, 0 per cent; and of air having only half as much as it might carry, 50 per cent.

If the relative humidity is low, as in deserts, there is a chance for so much more vapor in the dry air that evaporation is rapid; if the humidity is high, as in the tropical forest, there can be little evaporation, and surfaces remain damp. We notice this difference in summer, for some days are clear and dry, others are humid or muggy. When the humidity is great, the weather is most oppressive; we perspire easily, and are very uncomfortable, because there can be little evaporation from the surface of the body.

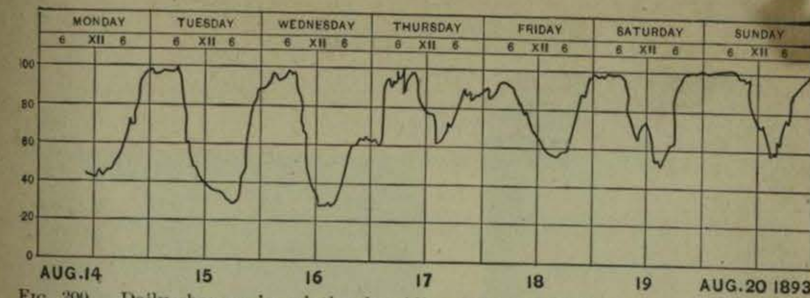

FIG. 399. — Daily changes in relative humidity at Ithaca, N.Y., for one week. Notice that at night the humidity rises nearly or quite to the dew point (100 per cent), but in the warmest part of the day is very low. This does not mean any change in the absolute humidity, but is the result of changes in temperature from day to night.

FIG. 400. — Above the clouds, mountain tops projecting through.

FIG. 401. — Clouds forming on a mountain side. Damp winds blowing upon the cold mountain slopes are here chilled until the dew point is reached.

Cirro-cumulus. Cirrus.

Alto-cumulus (or high cumulus) in rolls. Cumulus.

Fig. 402. — A group of cloud pictures.

Warm air can carry more water vapor than cool air, for the amount of vapor possible depends on temperature. For this reason, when the temperature in the room mentioned above is 60° there can be only $3\frac{1}{4}$ pounds of water vapor in the air. There is, therefore, far less vapor in the frigid than in the tropical zone.

From this it is evident that if saturated air is warmed, it ceases to be saturated; that is, its relative humidity falls (Fig. 399) and evaporation is possible. This is illustrated by the Sahara. There the winds are blowing toward a warmer region, and the relative humidity is being constantly lowered, making the air so dry that the ground is dried and a desert produced. If, on the other hand, damp air is cooled, its relative humidity increases, and the point is soon reached when it becomes saturated. Further cooling then forces some of the vapor to condense to liquid water, or, if the temperature is below freezing, to snow or ice. This is known as *precipitation*.

These facts explain many phenomena. Thus, when one breathes against a cool window pane the breath is cooled to the point of saturation, and some of the vapor caused to condense. A glass of water "sweats" on warm, muggy days, because the cool glass reduces the temperature of the air near it, and raises the relative humidity to the point of saturation. Then some of the vapor must condense. This point of saturation is often called the "dew point," because, when it is reached, dew forms on the ground. Precipitation is caused whenever the air is chilled to the dew point.

Summary. — *Absolute humidity is the actual amount of water vapor in the air at a given time; relative humidity is the percentage present compared to what might be present at that temperature. The relative humidity decreases with rising temperature, and increases with falling temperature. When it decreases, evaporation becomes more rapid; when it increases, if it reaches the point of saturation, or the "dew point," there is precipitation.*

170. Dew and Frost. — (A) *Dew.* — At night the lower air is chilled by contact with the ground, which is cooled by radiation. If the air is damp, some of the vapor is then condensed as dew; and if it is *very* humid, dew may begin to form even before sunset. The formation of dew is checked (1) when the air is quite dry, (2) when winds stir the air and keep it from reaching the dew point, or (3) when radiation is interfered with by clouds.

One reason why dew forms so readily on grass is that vegetation is a good radiator and hence cools quickly. Another reason is that there is water rising from the plants, as there is also, to less extent, from the ground. During the day this water disappears by evaporation and is, therefore, unnoticed; but at night, when the air is saturated, evaporation is so checked that the water gathers on the surface of the leaves and grass.

Summary. — *Dew is caused* (1) *by the chilling of air to the dew point by the cool ground, and* (2) *by the rising of water from plants. Dry air, winds, and clouds are unfavorable to the formation of dew.*

(B) *Frost.* — Frost is not frozen dew, but the solid form assumed when vapor condenses at temperatures below freezing. Even when the general temperature is above freezing, frost may visit some localities. Low, swampy ground is first affected because (1) the air is damper, and (2) air cooled on the hillsides slides down to these low places.

Sometimes frost comes so early in the fall that fruit not yet quite ripe is destroyed; and late spring frosts often do great damage to buds. Such frosts occur during nights when the air is so clear that radiation proceeds readily. Frosts cause the leaves to change color, and finally to fall; then for a time the trees are dormant, bursting forth into new life with the return of warmth in the spring. Many plants are killed by the first frost, leaving only their seeds, bulbs, or roots to grow the next season.

Summary. — *Frost is the solid form assumed by condensed vapor at temperatures below freezing. Frosts first occur in low, damp places; and early fall and late spring frosts do damage to plants.*

171. Fog and Clouds. — (A) *Fog.* — When we breath into cold air, the vapor of the breath is condensed into particles of water so small that they float, forming a tiny fog. Fog is formed when damp air is chilled in other ways. For example, it often forms at night when the air over low, damp land is chilled to the dew point; or it may form when two currents of air are mixed, one cool, the other damp and warm. Fogs at sea are often caused in this way.

One of the foggiest places in the world is on the path of trans-atlantic steamers south of Newfoundland. Here the warm Gulf Stream drift and the cold Labrador current are near together; and winds from one to the other cause vapor to condense into fog particles. Vessels rarely pass the Banks of Newfoundland without encountering some fog; and in it many a boat has been lost by collision with another, or with an iceberg, or by running aground on the shoals. Fog is one of the most dreaded dangers of the sea, and cautious captains reduce their speed, and keep the fog-horns blowing to warn other vessels of their approach. In harbors, navigation is sometimes completely stopped by dense fogs.

Dust particles, by supplying solids on which the water may collect, aid in the formation of fog. It is believed that the fogginess of London is partly due to the large amount of dust in the neighborhood of that great city. The fog of London is sometimes so dense that it is necessary to stop all traffic on the streets, and even to close the stores.

Summary. — *Fog is caused by the chilling of air to the dew point, forcing some of the vapor to condense to tiny drops. Dust particles supply solids for the water to condense on.*

(B) *Clouds.* — Clouds are also made by the condensation of vapor. Most clouds are fog or mist, though the higher ones, where the temperature is below freezing, are composed of snow or ice particles. Many clouds, especially on summer days, are caused by the rising of warm, damp air. As the air rises it expands and cools; and when the dew point is reached, fog particles grow, forming clouds. Clouds are also caused when damp air blows against a cold surface, for example, a mountain slope (Fig. 400). Still another cause for clouds is the contact of two currents of air, one above the other, one cold, the other warmer and humid.

Clouds assume many weird and beautiful forms (Fig. 402). Those that overspread the sky, having the appearance of layers, or strata, are called *stratus* clouds. They are common during stormy weather, and are usually low in the sky, often so low that they hide the tops of the hills. Frequently, especially in winter, they cover hundreds of square miles and last two or three days, while from them large quantities of rain fall.

The clouds formed by the rising of air on warm summer days are called *cumulus* clouds (Fig. 402). A flat base, usually several thousand feet above the surface, marks the height at which the rising vapor begins to condense. Extending above this base, sometimes to a height of a mile, are a series of cloud domes which are often very beautiful, especially when lighted and colored by the rays of the setting sun. Cumulus clouds often develop into thunder-heads.

A third common type is the *cirrus* cloud (Fig. 402), which is often five or six miles above the surface. Unlike the other two types, these clouds are made of transparent ice particles; and they are so thin that the sun shines through them. It is in cirrus clouds that rings around the sun and moon are often seen (p. 233). The cirrus clouds vary greatly, some having a most delicate and beautiful feathery and plumed form.

There is every gradation between the three types of clouds. To these intermediate forms compound names are given as follows: cirro-stratus, strato-cirrus, cirro-cumulus, cumulo-cirrus, cumulo-stratus, and strato-cumulus. The rain cloud is called *nimbus*.

Summary. — *Clouds are made of fog, mist, snow, and ice particles. They are caused by the condensing of vapor from various causes, — rising and expanding, blowing against cold surfaces, and contact of cold and warmer, damp currents. Stratus clouds are low, and spread over large areas; cumulus clouds rise in domes above a flat base; cirrus are thin, fleecy clouds high in the air and are made of ice particles. There are many variations between these types.*

172. Rain, Snow, and Hail. — (A) *Rain.* — Fog particles in clouds may grow to such size that they can no longer float. They then fall as raindrops. The growth of raindrops is due to several causes: (1) continued condensation of vapor; (2) union of fog particles, driven together by currents of air; and (3) union of particles as they fall through the cloud. Thus rain is merely the result of a continuation of the process of cloud formation. If the vapor condenses rapidly, as in summer thunder-clouds, the drops may grow to great size.

Rain may evaporate on its way from the clouds and fail to reach the ground. Such streamers of rain, descending part way to the earth, may sometimes be seen in summer. In other cases, rain on its way down may freeze in passing through a cold layer of air, forming *sleet*. Some sleet is snow that has partly melted, and then frozen before reaching the ground.

Summary. — *Continued condensation of vapor in cloud formation, and the union of the fog particles, form raindrops so heavy that they must fall to the earth.*

(B) *Snow.* — Snowflakes are not frozen raindrops, but are formed when vapor is condensing in a cloud at temperatures below freezing point. If the snowflake grows without interference, it is a regular and beautiful crystal (Fig. 403). It grows as regularly as salt or alum crystals in a solution that is slowly evaporating. The feathery frost on window panes is also caused by crystal growth, when vapor condenses at temperatures below the freezing point.

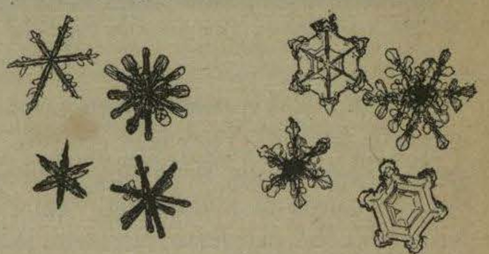

FIG. 403. — Snow crystals.

There are several reasons why snowflakes are usually irregular: (1) the crystals are often broken; (2) several are often united, forming a matted mass; (3) as the snow falls it is sometimes partly melted in passing through a warmer layer of air. In many cases snow melts entirely, reaching the ground as rain. This is often illustrated in hilly countries, when hilltops are covered with snow while 100 or 200 feet lower, in the valleys, rain is falling.

Summary. — *Snowflakes are crystals, built up by the condensing of vapor at temperatures below freezing. They are often broken, matted, or partly melted on the way down, becoming irregular.*

(C) *Hail.* — Hail is formed in violent storms, such as tornadoes and thunder-storms, where there are strong, whirling currents of air. Hailstones are balls of ice, built up by condensing vapor as they are whirled up and down in the violent currents, freezing, melting, and freezing again as they pass from warm to cold currents. For this reason they are often made of several layers, or shells, of ice. They may grow to great size, and may be kept suspended by the rising currents long after they are heavy enough to fall through quiet air. When they fall, usually at the margin of a storm, they often break window glass and do great damage to crops. Conditions favoring the formation of large hailstones are fortunately not common, and their effects are confined to very limited areas.

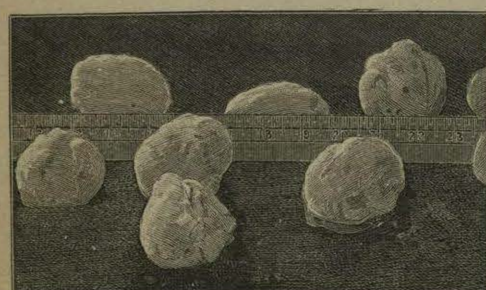
FIG. 404. — Hailstones. Compare with the inches on the ruler.

Summary. — *Hailstones are made of ice, formed by condensing vapor in whirling air currents. They may grow to large size before they fall, then often doing considerable damage.*

TOPICAL OUTLINE, QUESTIONS, AND SUGGESTIONS.

TOPICAL OUTLINE. — 162. **Composition of the Air.** — (A) *Oxygen, Nitrogen, and Carbon Dioxide:* percentage of each; argon; importance of oxygen; of nitrogen; of carbon dioxide; slow combustion in animals; rapid combustion; production of heat. (B) *Water Vapor:* source; evaporation; variation in amount; condensation. (C) *Dust Particles:* nature of materials: distribution; effect on condensation; microbes.

163. **Effect of Gravity.** — Cause of weight; amount at sea level; reason for not noticing pressure; density of lower air; rarefied air; effect; effect of temperature on density of air; movements started by gravity.

164. **Light.** — Nature of light; speed of passage; combination of waves; effect of prism; refraction; colors of spectrum; reflection; instances; mirage; rainbow; halos; color of objects; diffraction; blue color of sky; sunset colors.

165. **Heat.** — (A) *Radiant Energy:* heat from a stove; light from a stove; radiant energy; radiation; radiant energy from bodies in space; effect of radiation on stove; on sun; part reaching earth. (B) *Passage of Radiant Energy:* diathermanous; effect of air on heat; effect of dust. (C) *Radiation from the Earth:* earth as a radiator; cause of cool nights; of cold winter; difference between land and water; difference in frost. (D) *Reflection and Absorption:* water; quarries; black objects; white objects. (E) *Conduction:* in a stove; air, water, and ground as conductors; depth of conduction in the ground. (F) *Convection:* in water; in air, — near a lamp, near a fire, by heat from sun.

166. **Warming of Land, Water, and Air.** — (A) *The Lands:* warming; loss of heat; day and night; tropical zone; temperate zone; frigid zone; color of surface; vegetation; exposure. (B) *The Waters:* comparison with land; heat of vaporization; equable climate. (C) *The Air:* causes for warming; causes for cooling; interference with radiation.

167. **Causes for Differences in Temperature on the Earth.** — (A) *Position of Sun:* differences in height; reasons why sun low in heavens is less powerful; results. (B) *Altitude:* decrease in temperature; explanation; illustration of effect of expansion; sunny spots; effect of radiation. (C) *Other Reasons for Differences:* rock; exposure; water; wind.

168. **Daily and Seasonal Temperature Changes.** — (A) *Daily Range:* warmest period; coolest period; reasons; interference with normal range; difference in amount of range. (B) *Seasonal Range:* resemblance to daily range; coldest period; warmest period; reasons; causes for differences in curve.

169. **Humidity.** — Source; distribution; absolute humidity; saturated air; relative humidity; measuring relative humidity; effect of low humid-

ity; of high humidity; influence of temperature on humidity; cause of deserts; precipitation; illustrations of effect of cooling; dew point.

170. **Dew and Frost.** — (A) *Dew:* cause; unfavorable conditions; reason for dew on grass. (B) *Frost:* cause; most favorable places; early and late frosts; effect of frost on plants.

171. **Fog and Clouds.** — (A) *Fog:* the breath; chilling of air; fog off Newfoundland; dangers to navigation; aid of dust particles; London fog. (B) *Clouds:* materials; causes; stratus; cumulus; cirrus; intermediate forms; nimbus.

172. **Rain, Snow, and Hail.** — (A) *Rain:* reason for falling; causes for drops; large drops; failure to reach earth; sleet. (B) *Snow:* cause; snowflakes; frost on windows; irregularity of snowflakes; melting of falling snow. (C) *Hail:* formation; reason for shells of ice; size; effects.

QUESTIONS. — 162. (A) What elements make up the bulk of the air? What is the importance of each? (B) What is evaporation? What difference is there in the amount of vapor in air? What results when it is condensed? (C) What are dust particles? Where are they most common? What are their effects?

163. Has air weight? Why? How much? Why does not the weight of the air affect us? In what two ways does the density vary?

164. What is light? What is refraction? What is reflection? What phenomena are produced by reflection and refraction of light in its passage through the atmosphere? What is the cause of color in flowers? What is the cause of the blue color of the sky? Of sunset colors?

165. (A) What is radiant energy? What is radiation? What effect is radiation having on the sun? (B) What are diathermanous bodies? Give examples. Why does the sun lose power in late afternoon? (C) Why does the ground become cool at night and cold in winter? What difference is there in the radiation from bodies? (D) Give illustrations of reflection. Give illustrations of absorption. (E) What is conduction? What effect has it on earth, air, and water? (F) What causes convection in water? Give illustrations of convection of air.

166. (A) Why is not the ground excessively warmed? What differences are there in the three zones? What other causes for difference are there? (B) State the reasons why water warms more slowly than land. What is heat of vaporization? Compare land and water in winter and at night. What is an equable climate? (C) How is the air warmed? How is it cooled? Why is muggy air oppressive?

167. (A) Why is the sun less powerful when low than when high? State three important effects of differences in sun's position. (B) Why are highlands cool? Are any parts warm? What is the effect of radiation? (C) What other reasons are there for differences in temperature?

168. (A) When are the warmest and coolest times of day? Why? What causes are there for interference with the normal daily range? For differences in the amount of daily range? (B) When are the warmest and coolest times of the year? Why? What reasons are there for differences in the normal seasonal curve?

169. What is absolute humidity? What is saturated air? What is relative humidity? What is the result of raising the temperature? What is the cause of some deserts? What is the result of lowering the temperature? What causes precipitation? Illustrate. What is dew point?

170. (A) What is the cause of dew? Under what conditions is there no dew? Why is there so much dew on grass? (B) What is frost? Why does frost first visit low, damp places? What are its effects?

171. (A) What are the causes for fog? What are the conditions on the Banks of Newfoundland? Why? What is the effect on navigation? What relation have dust particles to fog? (B) Of what are clouds made? How are they caused? Name and describe each of the cloud types.

172. (A) What is the cause of rain? Why do the drops vary in size? What is sleet? (B) What are snowflakes? How formed? Why are they often irregular? (C) What is the cause of hailstones? Why do they sometimes grow so large?

SUGGESTIONS. — (1) Recall Experiments 1, 2, 3, 4, and 6 of Chapter II, p. 30. (2) Let a beam of sunlight enter a darkened room and notice the dust that it lights. Watch the sky to see if it is sometimes hazy. Is it clearer after a rain? Why? (3) By means of an air pump show that air has pressure. The teacher of physics can tell how this is to be done. (4) Obtain a prism of glass from the physical laboratory and allow a ray of sunlight to pass through it in order to study the prismatic colors. (5) Place a stick in water and notice that it appears to bend below the water. This is due to refraction. (6) Heat a brick or a stone and suspend it by a wire. Why does it become cool? Does the thermometer show rise of temperature when placed near it? Why? (7) Try the experiment with black and white cloth, mentioned on p. 236, using ice instead of snow. (8) Place a thermometer in the shade in such a position that sunlight can be reflected on it by means of a mirror. Does the temperature rise? (9) Place one end of a bar of iron in the fire. Does the other end become warm? Why? Place an equal bulk of several substances — for example, iron, soil, and rock — on the stove for a short period to test which first becomes warm by conduction. Use a thermometer to determine this. It can also be told by putting a thin layer of paraffin on each, noticing on which it first begins to melt. (10) Study convection in water, using a glass dish with muddy water so as to see its movement. Study the convection of air near a lamp, clouding the air with smoke (this can be obtained by 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.*