

**ROBERT
DECOURCY
WARD**

PRACTICAL EXERCISES IN
ELEMENTARY
METEOROLOGY

Robert DeCourcy Ward

**Practical Exercises in
Elementary Meteorology**

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Robert DeCourcy Ward

Practical Exercises in Elementary Meteorology

PREFACE

The advance of meteorology as a school study has been much hampered by the lack of a published outline of work in this subject which may be undertaken during the school years. There are several excellent text-books for more advanced study, but there is no laboratory manual for use in the elementary portions of the science. In many secondary schools some instruction in meteorology is given, and the keeping of meteorological records by the scholars is every year becoming more general. There is yet, however, but little system in this work, and, in consequence, there is little definite result. The object of this book is to supply a guide in the elementary observational and inductive studies in meteorology. This Manual is not intended to replace the text-books, but is designed to prepare the way for their more intelligent use. Simple preliminary exercises in the taking of meteorological observations, and in the study of the daily weather maps, as herein suggested, will lay a good foundation on which later studies, in connection with the text-books, may be built up. Explanations of the various facts discovered through these exercises are not considered to lie within the scope of this book. They may be found in any of the newer text-books.

This Manual lays little claim to originality. Its essential features are based on the recommendations in the Report on Geography of the Committee of Ten. A scheme of laboratory exercises, substantially the same as that proposed in this Report, was, for some fifteen years, the basis of the work in elementary meteorology done in Harvard College under the direction of Professor William M. Davis. The plan proposed by the Committee of Ten has been thoroughly tested by the writer during the past five years, not only in college classes, but also in University Extension work among school teachers, and the present book embodies such modifications of that scheme and additions to it as have been suggested by experience. Emphasis is laid throughout this Manual on the larger lessons to be learned from the individual exercises, and on the relations of various atmospheric phenomena to human life and activities. No attempt is made to specify in exactly what school years this work should be undertaken. At present, and until meteorology attains a recognized position as a school study, teachers must obviously be left to decide this matter according to the opportunities offered in each school. The general outline of the work, however, as herein set forth, is intended to cover the grammar and the high school years, and may readily be adapted by the teacher to fit the circumstances of any particular case.

This book contains specific instructions to the student as to the use of the instruments; the carrying out of meteorological observations; the investigation of special simple problems by means of the instruments; and the practical use of the daily weather maps. The Notes for the Teacher, at the end of the book, are explanatory, and contain suggestions which may be useful in directing the laboratory work of the class.

It has been the privilege of the author during the past ten years to study the science of meteorology, and the methods of teaching that science, under the constant direction of Professor William Morris Davis, of Harvard University. To Professor Davis the author is further indebted for many valuable suggestions in connection with the arrangement and treatment of the subject-matter of this book. Thanks are due also to Mr. William H. Snyder, of Worcester (Mass.) Academy, and to Mr. John W. Smith, Local Forecast Official of the United States Weather Bureau, Boston, Mass., for valued criticisms.

ROBERT DeC. WARD.

Harvard University, Cambridge, Mass.,
September, 1899.

ACKNOWLEDGMENT OF FIGURES

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INTRODUCTION

THE IMPORTANCE OF METEOROLOGY: ITS RELATIONS TO MAN

We live in the laboratory of the earth's atmosphere. The changes from hot to cold, wet to dry, clear to cloudy, or the reverse, profoundly affect us. We make and unmake our daily plans; we study or we enjoy vacations; we vary our amusements and our clothing according to these changes. The weather forecasts for the day in the newspaper are read even before the telegraphic despatches of important events. Sailors about to put to sea govern themselves according to the storm warnings of our Weather Bureau. Farmers and shippers of fruit, meat, and vegetables anxiously watch the bulletins of cold or warm waves, and guard against damage by frost or excessive heat. Steam and electric railways prepare their snow-plows when a severe snowstorm is predicted.

Meteorology, the science of the atmosphere, is thus of very great interest and importance. There is no subject a knowledge of which does more to make our daily life interesting. Since we live in the midst of the atmosphere and cannot escape from the changes that take place in it, we must, consciously or unconsciously, become observers of these changes. Examples of the varying processes at work in the atmosphere are always with us. There is no end to the number and the variety of our illustrations of these processes. Man is so profoundly affected by weather changes from day to day that all civilized countries have established weather services. Observers taking regular weather records are stationed at thousands of different places in all parts of the world, and the observations which they make are used by meteorologists in preparing daily weather maps and forecasts, and in studying the conditions of temperature, winds, and rainfall. In the United States alone there are about 3000 of these observers.

These observations are not made on land only. Hundreds of ship captains on all the oceans of the world are making their regular daily meteorological records, which at the end of the voyage are sent to some central office,¹ where they are studied and employed in the preparation of Pilot Charts for the use of mariners. By means of these ocean meteorological observations, which were first systematized and carried out on a large scale under the direction of Lieutenant Matthew Fontaine Maury (born, 1806; died, 1873), of the United States Navy, it has become possible to lay out the most favorable sailing routes for vessels engaged in commerce in all parts of the world.

So important is a knowledge of the conditions of the winds and the weather, that scientific expeditions into unexplored or little-known regions give much of their time to meteorological observations. On the famous Lady Franklin Bay Expedition (1881-1884) of Lieutenant (now General) A. W. Greely, of the United States Army, meteorological observations were kept up by the few feeble survivors, after death by disease and starvation had almost wiped out the party altogether, and when those who were left had but a few hours to live unless rescue came at once. On Nansen's expedition to the "Farthest North," on Peary's trips to Greenland, and on every recent voyage to the Arctic or the Antarctic, meteorological instruments have formed an important part of the equipment.

Not content with obtaining records from the air near the earth's surface, meteorologists have sent up their instruments by means of small, un-manned balloons to heights of 10 miles; and the use of kites for carrying up such instruments has been so successful that, at Blue Hill Observatory, near Boston, Mass., records have been obtained from a height of over 2 miles. Observatories have

¹ In the United States, marine meteorological observations are forwarded to the United States Hydrographic Office, Navy Department, Washington.

also been established on mountain summits, where meteorological observations have been made with more or less regularity. Such observatories are those on Pike's Peak, Colorado (14,134 feet), Mont Blanc, Switzerland (15,780 feet), and on El Misti, in southern Peru. The latter, 19,200 feet above sea level, is the highest meteorological station in the world.

The study of the meteorological conditions prevailing over the earth has thus become of world-wide importance. In the following exercises we shall carry out, in a small way, investigations similar to those which have occupied and are now occupying the attention of meteorologists all over the world.

PRACTICAL EXERCISES IN ELEMENTARY METEOROLOGY

Part I.—Non-Instrumental Observations

CHAPTER I.

OBSERVATIONS OF TEMPERATURE; WIND DIRECTION AND VELOCITY; STATE OF SKY, AND RAINFALL

Before beginning observations with the ordinary instruments, accustom yourself to making and recording observations of a general character, such as may be carried out without the use of any instruments whatever. Such records include: *Temperature; Wind Direction and Velocity; State of the Sky, and Rainfall.*

Temperature.—In keeping a record² of temperature without the use of a thermometer, excellent practice is given in observations of the temperature actually felt by the human body. Our bodies are not thermometers. They do not indicate, by our sensations of heat or cold, just what is the temperature of the surrounding air, but they try to adjust themselves to the conditions in which they are. This adjustment depends on many things beside the temperature of the air; *e.g.*, the moisture or humidity of the air; the movement of the air; the temperature and the nearness of surrounding objects. In summer, a day on which the temperature reaches 80° or 85° often seems much hotter than another day on which the temperature rises to 95°. In winter, temperatures registered by the thermometer as 10° or 15° above zero often feel a great deal colder than temperatures of -5° or -10°. In recording your observations on temperature, the record book may be divided into columns as follows:—

Sample Record of Temperature.

DATE.	HOUR.	TEMPERATURE.	REMARKS.
Jan. 16	9 A.M.	Chilly	
“ “	12 M.	Warmer	
“ “	4 P.M.	“	Growing slowly warmer all day.
“ 17	8 A.M.	Warm	About the same as Jan. 16, 4 P.M.
“ “	11 A.M.	Cooler	Began to grow cooler about 10 A.M.
“ “	3 P.M.	Colder	Steadily becoming colder.

The following are some of the questions you should ask yourself in carrying out this work. It is not expected that you will be able to answer all these questions at once, but that you will keep them in mind during your studies, and try to discover the answers, as a result of your own observations.

How does it feel to you out of doors to-day? Is it hot, warm, cool, or cold? What is the difference between your feelings yesterday and to-day? Between day before yesterday and to-day? Have you noticed any *regular* change in your feelings as to warmth and cold during three or four successive days? During the past week or two? During the past month? Is there any difference between the temperature of morning, noon, afternoon, and evening? Is there any *regular* variation in temperature during the day? Have there been any *sudden* changes in temperature during the last few days? Have these sudden changes brought warmer or cooler weather? Has the warmer or cooler weather continued

² Each scholar will need a blank book in which to preserve the observations.

for a day or so, or has another change quickly followed the first? Have the sudden changes, if you have noted any, come at any regular times (as morning, afternoon, evening) or at irregular intervals? Does there seem to you to be any definite system, of any kind, in our changes of temperature? In what ways are people in general affected by hot weather? By cold weather? What difference does a very hot or a very cold day make in your own case?

Wind Direction and Velocity.—Wind is an important meteorological element because it has many close relations to human life. It affects very markedly our bodily sensations of heat or cold. A cold, calm day is pleasanter than a cold, windy day. On the other hand, a hot, calm day is usually much more uncomfortable than a hot, windy day. High winds cause wrecks along seacoasts and damage houses, crops, and fruit trees. Sea breezes bring in fresh, cool, pure air from the ocean on hot summer days. In the tropics the sea breeze is so important in preserving the health of Europeans in many places that it is known as “the doctor.” The movement of wind through large cities carries off the foul air which has collected in the narrow streets and alleys, and is thus a great purifying agent.

Record the *direction of the wind* according to the four cardinal points of the compass (N., E., S., and W.) and the four intermediate points (NE., SE., SW., and NW.). The direction of the wind is the point *from* which the wind blows. You can determine the points of the compass roughly by noting where the sun rises and where it sets.

Note the *velocity of the wind* according to the following scale, proposed by Professor H. A. Hazen of the United States Weather Bureau.

- 0 Calm.
- 1 Light; just moving the leaves of trees.
- 2 Moderate; moving branches.
- 3 Brisk; swaying branches; blowing up dust.
- 4 High; blowing up twigs from the ground, swaying whole trees.
- 5 Gale; breaking small branches, loosening bricks on chimneys.
- 6 Hurricane or tornado; destroying everything in its path.

The record book will need two additional columns when wind observations are begun, as follows:—

Sample Record of Temperature and Wind.

DATE.	HOUR.	TEMPERATURE.	WIND DIRECTION.	WIND VELOCITY.	REMARKS.
Oct. 3	7.30 A.M.	Cool	NE.	Moderate	Temperature falling since last evening. Wind velocity increasing.
“	11 A.M.	“	“	Brisk	Temperature the same. Wind velocity still increasing.
“	3 P.M.	“	“	High	Wind velocity still increasing.

What is the direction of the wind to-day? What is its velocity? Has its direction or velocity changed since yesterday? If so, was the change sudden or gradual? Have you noticed any calms? What was the direction of the wind before the calm? What after the calm? Does there seem to be more wind from one compass point than from another? Is there any relation between the direction of the wind and its velocity? *i.e.*, is the NW. wind, for instance, usually a brisk or a high wind, or, is the SE. or S. wind usually moderate? Does the wind usually change its direction gradually, as from SE. to S., then to SW., then to W., etc., or does it jump all at once, as from SE. to W.? Is there any relation between the velocity of the wind and the hour of the day, *i.e.*, does the wind seem stronger or weaker at noon than in the morning or at night? Is it a common occurrence to have a wind from the same direction for several successive days, or are we apt to have different winds almost every day? Do you notice any *systematic* changes in wind direction which are often repeated? What are these changes? Can you make a simple rule for them? In what ways does the wind affect us?

State of the Sky.—By the *state of the sky* is meant the condition of the sky as to its cloudiness. Clouds add much to the beauty and variety of nature. They are often gorgeously colored at sunset. By their changes in form, color, and amount from day to day they relieve what might otherwise be a wearisome succession of the same weather types. Prevaillingly overcast skies have a depressing effect. Prevaillingly clear skies become monotonous. A proper amount of bright sunshine is essential for the ripening of crops, but too much sunshine may parch soil and vegetation, and become injurious. Clouds bring rain; hence a sufficient amount of cloudiness is just as necessary as a sufficient amount of sunshine. The drift of clouds shows us the direction of movement of the air above us, and is of considerable help in forecasting the weather. Fog, which is a very low cloud, is in some cases so common as to be a meteorological element of great importance. In the city of London, where fogs are very prevalent, especially in winter, the average number of hours of bright sunshine in December and January is only fifteen in each month. The London fogs are, in great part, due to the presence in the air of vast numbers of particles of soot and smoke from millions of fires. These particles increase the density of the fog and prolong its duration.

The amount of cloudiness is recorded on a scale of *tenths*. A *clear* sky is one that is less than $\frac{3}{10}$ cloudy; a *fair* sky is from $\frac{3}{10}$ to $\frac{7}{10}$ cloudy; and a *cloudy* sky is over $\frac{7}{10}$ cloudy. In observing the state of the sky, note such points as the times of clouding and of clearing; the arrangement of the clouds, *i.e.*, whether they are few and scattered, or cover the sky with a uniform layer; the common forms of clouds; the changes in the amounts of cloudiness, etc.

Another new column must be added in the record book for the cloudiness. The table will now appear thus:—

Sample Record of Temperature, Wind, and State of the Sky.

DATE.	HOUR.	TEMPERATURE.	WIND DIRECTION.	WIND VELOCITY.	STATE OF SKY.	REMARKS.
Dec. 18	9 A.M.	Very cold	NW.	Brisk	Clear	Very cold all night. Everything frozen up.
" "	5 P.M.	" "	"	"	"	Same conditions.
" 19	8.30 A.M.	A little warmer	"	Moderate	Fair	Wind less violent. Small clouds scattered over the sky.

Is the sky *clear*, *fair*, or *cloudy* to-day? Is there more or less cloud than there was yesterday? Than the day before yesterday? Is to-day a day of increasing or of decreasing cloudiness? Is the sky usually perfectly clear, or is it oftenest somewhat clouded over? How long does it take for the sky to become completely covered with clouds from the time when it first begins to become cloudy? When there are a few clouds in the sky, are these usually scattered all over the sky, or are they in groups? Have you noticed any particular form of clouds which seemed familiar to you? Do clouds seem to have certain definite shapes and appearances which are to be seen often? Do you discover any variation of cloudiness during the day, *i.e.*, is it apt to be more cloudy in the afternoon than in the morning or at night? Can you make a list describing some of the clouds that you see most often? Can you give these common kinds of clouds some names of your own that shall describe them briefly? In what ways does a clear sky, with bright sunshine, affect us?

Rainfall.—Under the general term *rainfall*, meteorologists include, besides *rain* itself, *snow*, *hail*, *sleet*, etc. The term *precipitation* is also often used. Rainfall stands in close relation to human life and occupations. It feeds lakes and rivers, thus furnishing means of transportation, power for running mills and factories, and water supplies for cities. Regions of abundant rainfall are usually heavily forested, like the Amazon valley in South America, and parts of Equatorial Africa. In civilized countries lumbering is apt to be an important occupation in districts of heavy rainfall, as in Oregon and Washington in our own country, and in Southern Chile in South America. Where there is a moderate rainfall, and other conditions are favorable, there agriculture is possible, and farming becomes one of the chief occupations, as in the Mississippi and Missouri valleys in the United States, and in Western Canada. Districts which have a rainfall too small for successful agriculture, but are not by any means

deserts, are often excellent grazing lands, as in the case of parts of Texas, Nebraska, and Kansas in the United States, and the Argentine Republic in South America. Where there is very little rainfall deserts are found. Cities are not built in deserts, because there are no occupations to attract large numbers of men. The inhabitants of the desert are wandering tribes, which move from place to place in search of water and food for themselves and their animals. Rain and snow cleanse the air, washing out impurities such as dust and smoke. Hence they are important agents in preserving health.

Note the *kind* of precipitation (rain, snow, hail, sleet); the *amount* (heavy, moderate, light, trace); and the *time of the beginning and ending* of the storm or shower.

The record book must now be further subdivided into columns, to make room for the rainfall observations, in this manner:—

Sample Record of Temperature, Wind, State of Sky, and Precipitation.

DATE.	HOUR.	TEMPERATURE.	WIND.		STATE OF SKY.	PRECIPITATION.			REMARKS.
			DIRECTION.	VELOCITY.		TIME OF BEGINN.	KIND.	AM'T.	
Mar. 21	8.30 A.M.	Mild	S.	Light	Overcast	8 A.M.	Rain	Light	Raining.
" "	12 M.	"	"	"	Overcast		"	"	"
" "	4 P.M.	"	"	Moderate	Overcast				Stopped raining about 3 P.M.
" 22	8 A.M.	Cool	NW.	Brisk	Clear				Cleared off during the night.

Does most of our rain come in brief showers, or in storms lasting a day or two? Do we have about the same amount of rain or snow every week and every month, or does the amount vary a good deal from week to week and from month to month? Do you notice much difference in the characteristics of successive storms, or do they all seem pretty much alike? Are thunderstorms limited to any particular season of the year? If so, to what season? Have you discovered any rule as to the time of day when rainstorms or snowstorms begin? When thunderstorms begin and end? Is it common or uncommon for us to have a storm lasting three or four days? How long does a thunderstorm usually last? Do we have most hail in winter or in summer? In what ways does a rainy day affect people? How are you yourself affected? How does a heavy snowstorm affect travel and transportation? In what ways does a snowstorm differ from a rainstorm as to the character of the precipitation and its effects?

After studying the *temperature*, *wind*, *state of sky*, and *rainfall* separately, take two elements together and see what relation one has to the other. Try to answer such questions as these:—

Temperature and Wind.—What relations can you discover between the direction of the wind and the temperature? Which winds are the coolest? Which the warmest? Does a hot, calm day seem warmer or cooler than a hot, windy day? Does a cold, calm day seem colder or warmer than a cold, windy day? Does the *velocity* of the wind have any effect on your feeling of cold or of warmth? If so, what effect?

Wind and State of Sky.—Has the direction of the wind anything to do with the cloudiness? Is there more apt to be considerable cloudiness with wind from one direction than from another? What winds are usually accompanied by the largest amount of cloud? What winds usually blow when the sky is clear? Is the relation of cloudiness to certain wind directions so close that, if you know the wind direction, you can make a prediction as to the probable cloudiness? Are the winds with clouds more common in one month than another? In one season than another? If so, which month? which season?

Temperature and State of Sky.—Do you notice any relation between the temperature and the state of the sky? In winter are our coldest days usually cloudy or clear? In summer are our hottest days cloudy or clear? Are the winds that give us the most cloudiness warm or cold winds in winter and in summer? Is a cloudy night colder or warmer than a clear night? Is a cloudy day colder or warmer than a clear day?

State of Sky and Precipitation.—How is rainfall or snowfall related to the cloudiness? Do we ever have rain or snow when the sky is not completely covered with clouds? Does the sky usually

become quickly covered with clouds before a rain? Does a sky wholly covered with clouds always give us rain or snow? Does the sky clear rapidly or slowly after a rain? Are any particular kinds of clouds associated with rain or with snowstorms? With brief showers? With thunderstorms?

Wind and Precipitation.—Are any particular wind directions more likely than others to give us rain or snow? Are these the same winds as those which give us the most cloudiness? What winds are they? Has the velocity of the wind any relation to the rain or snowstorm? Does the wind blow harder before, during, or after the rain or snow? What changes of wind direction have you noted before, during, and after any storm? Have you noticed these same changes in other storms? Are they so common in our storms that you can make a rule as to these changes?

Temperature and Precipitation.—Does a shower or a rainstorm in the hotter months affect the temperature of the air in any way? How? In the winter does the temperature show any changes before a snowstorm? Is it usually warmer or colder then than a day or two before the storm and the day after? Is it usually uncomfortably cold during a snowstorm? Are rainy spells in the spring and the autumn months cooler or warmer than clear dry weather?

Part II.—Instrumental Observations

CHAPTER II. ELEMENTARY INSTRUMENTAL OBSERVATIONS

The non-instrumental observations, suggested in the preceding chapter, prepare the way for the more exact records of the weather elements which are obtainable only by the use of instruments. The non-instrumental records are not to be entirely given up, even after the instrumental work and the weather-map exercises have begun, but should be continued throughout the course. Notes on the forms and changes of clouds, on the times of beginning and ending, and on the character of the precipitation, as outlined in the last chapter, and other observations made without the use of instruments, are an essential part of even the most advanced meteorological records.

The simpler instruments are the *ordinary thermometer*, the *wind vane*, the *rain gauge*, and the *mercurial barometer* (in a modified form). Observations with these instruments, although of a simple character, can be made very useful. The advance over the non-instrumental observations, which latter may be termed observations of *sensation*, is a decided one. In place of the vague and untrustworthy statements concerning hot and cold, warm and cool days, we now have actual degrees of temperature to serve as a basis for comparison of day with day or month with month. The measurements of rain and snowfall enable us to study the amounts brought in different storms, the average precipitation of the various months, etc. The important facts of change of pressure now become known, and also the relation of these changes to the weather. Just as we have, in the earlier work, become familiar with our typical weather changes and types, so we shall now have our eyes opened to the actual values of the temperatures and precipitation connected with these changes.

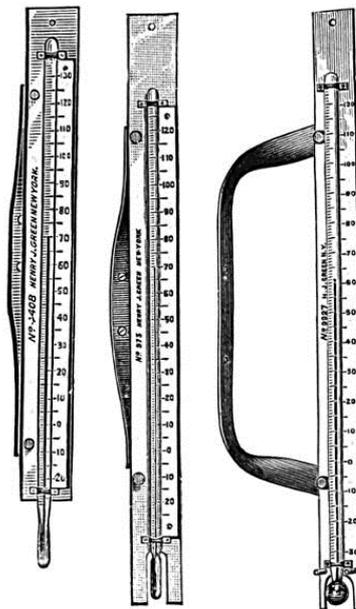


Fig. 1.

The **ordinary thermometer** (Greek: *heat measure*), the most commonly used and most widely known of all meteorological instruments, was in an elementary form known to Galileo, and was used by him in his lectures at the University of Padua during the years 1592 to 1609. Thermometers enable us to measure the temperatures of different bodies by comparison with certain universally accepted

standards of temperature. These standards are the freezing and boiling points of distilled water. In its common form the thermometer consists of a glass tube, closed at the top, and expanding at its lower end into a hollow spherical or cylindrical glass bulb. This bulb and part of the tube are filled with mercury or alcohol. As the temperature rises, the liquid expands, flows out of the bulb, and rises in the tube. As the temperature falls, the mercury or alcohol contracts, and therefore stands at a lower level in the tube. In order that the amount of this rise or fall may be accurately known, some definite scale for measurement must be adopted. The scale commonly used in this country owes its name to Fahrenheit (born in Danzig in 1686; died in 1736), who was the first to settle upon the use of mercury as the liquid in thermometers, and also the first definitely to adopt two fixed points in graduating the scale. The division of this scale into 180° between the freezing point (32°) and the boiling point (212°) seems to have been taken from the graduation of a semicircle. Fahrenheit was a manufacturer of all sorts of physical apparatus, and it has been thought probable that he had some special facilities for dividing his thermometer tubes into 180 parts. Mercury is most commonly used as the liquid in thermometers, because it readily indicates changes of temperature, and because over most of the world the winter cold is not sufficient to freeze it. The freezing point of mercury is about 40° below zero (-40° F.). Alcohol, which has a much lower freezing point, is therefore used in thermometers which are to be employed in very cold regions. Alcohol thermometers must, for instance, be used in Northern Siberia, where the mean January temperature is 60° below zero.

The temperature which meteorologists desire to obtain by the ordinary thermometer is the *temperature of the free air in the shade*. In order that thermometers may indicate this temperature, they must, if possible, be placed in an open space where there is an unobstructed circulation of the air, and they must be protected from the direct rays of the sun. They are, therefore, usually *exposed* inside of a cubical enclosure of wooden lattice work, in an open space away from buildings, and at a height of 4 to 10 feet above the ground, preferably a grass-covered surface. This enclosure is called the *shelter*, and its object is to screen the instrument from the direct and reflected sunshine, to allow free circulation of air around the bulb, and to keep the thermometer dry. Sometimes the shelter, instead of being in an open space on the ground, is built on the roof or against the north wall of a building, or outside of one of the windows. Fig. 2 shows an ordinary shelter.

A still simpler method of exposure is described in the "Instructions for Voluntary Observers" (United States Weather Bureau, 1892) as follows: "Select a north window, preferably of an unoccupied room, especially in winter. Fasten the blinds open at right angles to the wall of the house. Fasten a narrow strip 3 inches wide across the window outside, and from 8 to 12 inches from the window-pane. To this fasten the thermometers." If none of these methods of sheltering the instrument is feasible, the thermometer may be fastened to the window frame, about a foot from the window, and so arranged that it can be read from the inside of the room without opening the window.

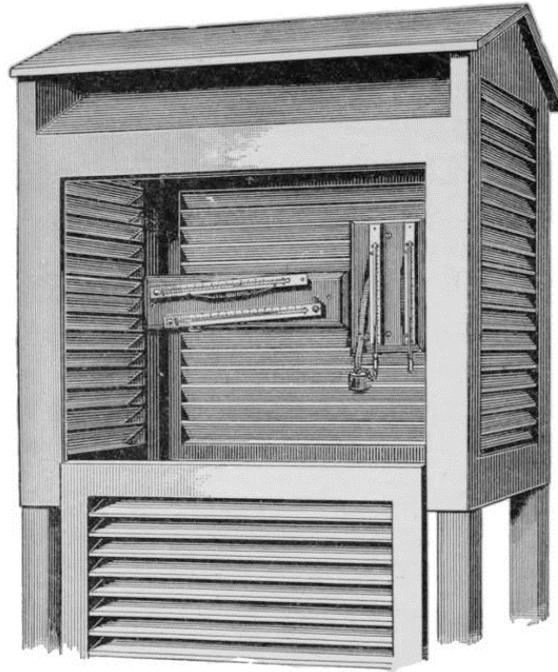


Fig. 2.

Readings of the thermometer, to the nearest degree of temperature indicated on the scale by the top of the mercury column, are to be made at the regular observation hours, and are to be entered in your record book. Temperatures below zero are preceded by a minus sign (-). A table similar to that suggested towards the close of the last chapter (p. 8) may be used in keeping these instrumental records, except that actual thermometer readings can now be entered in the column headed "Temperature," instead of using only the general terms *warm*, *cold*, *chilly*, etc. This is a great gain. You will now be able to give fairly definite answers to many of the questions asked in Chapter I. Answer these questions with the help of your thermometer readings, as fully as you can.

The greater part of the Temperate Zone, in which we live, is peculiar in having frequent and rapid changes of temperature, not only from season to season, but from day to day, and during a single day. In winter, we are apt to have a warm wind immediately after a spell of crisp cold weather. In summer, cloudy, cool days come as a sudden relief when we have been suffering from intense heat, with brilliant sunshine.

These changes give a variety to our climate which is, on the whole, very beneficial to man. The North Temperate Zone, with strong seasonal changes in temperature and weather, is the zone of the highest civilization and of the greatest energy of man. In the Torrid Zone the changes of temperature are, as a whole, small. There is no harsh winter. The climate is monotonous and deadening, rather than enlivening. Man finds it easy to live without much work, and the inhabitants of the Torrid Zone have not, as a rule, advanced far in the scale of civilization.

The **wind vane** used by the Weather Bureau is about 6 feet long, and has a divided tail made of pine boards, the two pieces making an angle of $22\frac{1}{2}^\circ$. The purpose of this divided tail is to steady the vane and to make it more sensitive to light currents.

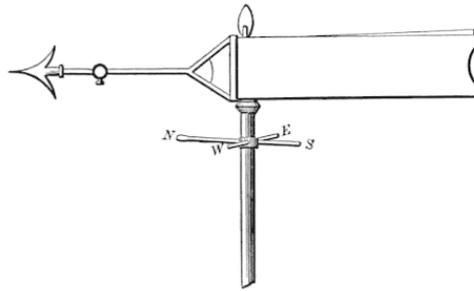


Fig. 3.

A common wind vane on a neighboring church steeple or flagstaff will usually serve sufficiently well for ordinary use. Observations of wind direction (to eight compass points) are to be made as a part of the ordinary weather record, and to be entered in the proper column of the record book.

The **rain gauge** consists of three separate parts, the receiver *A*, the overflow attachment *B*, and the measuring tube *C*.

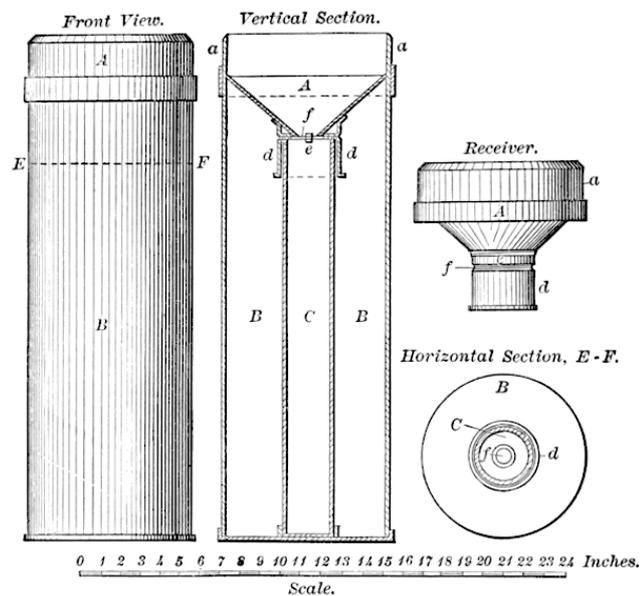


Fig. 4.

The inside diameter of the top of the receiver in the standard Weather Bureau gauge is 8 inches (at *a* in Fig. 4). This receiver has a funnel-shaped bottom, so that all the precipitation which falls into it is carried at once into the measuring tube *C*, whose inside height is 20 inches. The diameter of the measuring tube is 2.53 inches. The rain falling into the receiver *A* fills this tube *C* to a depth greater than the actual rainfall, in proportion as the area of the receiver is greater than the area of the measuring tube. In the standard Weather Bureau gauges the ratio of the area of the receiver to the area of the measuring tube is such that the depth of rainfall is magnified exactly ten times. The object of magnifying the amount in this way is to measure a very small quantity more easily. The narrow portion of the receiver [*d*] fits over the top of the measuring tube, holding the latter firmly in place and preventing any loss of rainfall. An opening, *e*, in the lower portion of the receiver [*d*], just on a level with the top of the measuring tube, serves as an escape for the water into the overflow attachment *B*, in case the rainfall is so heavy as to more than fill the tube. The inside diameter of the overflow attachment is the same as that of the receiver (8 inches), as will be seen from the figure.

The rain gauge should be firmly set in a wooden frame, so arranged that the overflow attachment can readily be removed from the frame. The box in which the gauge is sent out by the manufacturer is usually designed to serve as a permanent support when the gauge is set up. The best exposure for the gauge is an open space unobstructed by large trees, buildings, or fences. Fences, walls, or trees should be at a distance from the gauge not less than their own height. If an exposure upon the ground is out of the question, the gauge may be placed upon a roof, in which case the middle of a flat unobstructed roof is the best position.

Records of Rainfall.—Every rain gauge is provided with a measuring stick, which is graduated into inches and hundredths. It must be remembered that the amount of rain in the measuring tube is, by the construction of the ordinary gauge, ten times greater than the actual rainfall. This fact need not, however, be taken into account by the observer, for the numbers used in graduating the measuring sticks have all been divided by 10, and therefore they represent the actual rainfall. The graduations on the stick indicate hundredths of an inch, and should appear in the record as decimals (.10, .20, etc.). Ten inches of water in the measuring tube will reach the mark 1.00 on the stick; thus 1.00 denotes 1 inch and zero hundredths of rain. One inch of water in the tube will reach the .10 mark, indicating $\frac{10}{100}$ of an inch. The shortest lines on the measuring stick denote successive hundredths of an inch. Thus, if water collected comes to a point halfway between the .10 and .20 lines, the amount is .15 inch, and so on. In measuring rainfall, the stick is lowered through the bottom of the receiver into the measuring tube, and on being withdrawn the wet portion of the stick at once shows the depth of water in the tube. Care must be exercised to put the end of the stick where the numbering begins first into the gauge, and to pass the stick through the middle of the tube. After each observation the gauge should be emptied and drained, and immediately put back into place. When the total rainfall more than fills the measuring tube, *i.e.*, exceeds 2 inches, the receiver should first be lifted off and the tube removed with great care so as not to spill any water. After emptying the tube, the surplus water in the overflow attachment must be poured into the measuring tube and measured. The amount of rainfall thus found is to be added to the 2 inches contained in the measuring tube in order to give the total rainfall. If any water happens to be spilled during its removal from the overflow attachment, then the amount in the tube will be less than 2 inches, and it must be carefully measured before the latter is emptied.

During the winter season, in all regions where snow forms the chief part of the precipitation, the only portion of the rain gauge that need be exposed is the overflow attachment. The snow which falls into the gauge may be measured by first melting the snow and then measuring the water as rainfall. About 10 inches of snow give, on the average, 1 inch of water, but the ratio varies very greatly according to the density of the snow. Besides the measurement of the melted snow collected in the gauge, it is customary to keep a record of the depth of snowfall in inches, as measured by means of an ordinary foot rule or a yardstick, on some level place where there has been little or no drifting.

Measurements of rain and snowfall are usually made once a day, at 8 P.M., and also at the end of every storm. Enter the amounts of precipitation in the column of the table headed "Amount" and state always whether it is *rain* or *melted snow* that you have measured. When there has been no precipitation since the last observation, an entry of 0.00 should be made in the column of the record book devoted to "Amount of Precipitation." When the amount is too small to measure, the entry T (for *Trace*) should be made.

Continue your non-instrumental record of the time of beginning and ending of the precipitation as before. Whenever it is possible, keep a record of the total amount of precipitation in each storm, noting this under "Remarks." Try to answer such questions as are asked in Chapter I with the help of your instrumental record of the rain and snowfall. Note what depths of snow in different snowstorms are necessary, when melted, to make 1 inch of water.

The Mercurial Barometer.—Air has weight. At sea level this weight amounts to nearly 15 pounds on every square inch of surface. Imagine a layer of water, 34 feet deep, covering the earth.

The weight of this water on every square inch of surface would be the same as the weight of the air. Under ordinary circumstances the weight of the air is not noticeable, because air presses equally in all directions, and the pressure within a body is the same as that outside of it. On account of this equal pressure in all directions, we speak of the *pressure* of the air instead of its *weight*. The effects of the air pressure may become apparent when we remove the air from a surface. By working the piston of a pump in a well we may remove the pressure on the surface of the water in the tube of the pump. When this is done, a column of water rises in the tube until the top of this column is about 34 feet above the level of the rest of the water in the well. The pressure of the atmosphere on the water *outside* of the tube holds up this column of water *inside* the tube.

Galileo (1564-1642) first taught that the air has weight. His pupil Torricelli went a step further. Torricelli saw that the column of water, held up by the pressure of the air in the tube of the pump, must exactly balance a similar column of air, reaching from the surface of the water in the well to the top of the atmosphere. The column of water, in other words, exactly replaces this column of air. While working on this subject, Torricelli, in 1643, performed the following experiment. He filled a glass tube, about 3 feet long and closed at one end, with mercury. After filling the tube, he put his finger over the open end and inverted the tube over a vessel containing mercury. When the lower end of the tube was below the surface of the mercury in the dish, he removed his finger. At once the column of mercury fell in the tube until it stood at a height of about 30 inches, leaving a vacant space of 6 inches in the upper part of the tube. This space has since been known as the *Torricellian vacuum*. Torricelli had proved what he had expected, viz., that the height of the column of liquid which replaces and balances an air column of the same size varies with the weight of that liquid. It takes a column of water 34 feet long to balance a similar column of air. It takes a column of mercury only 30 inches long to balance a similar column of air. This, as Torricelli correctly explained, is due to the fact that mercury is so much ($13\frac{1}{2}$ times) heavier than water. The column of water weighs just the same as the column of mercury. Each column exactly balances an air column of similar cross-section. The height of the water or of the mercury is a measure of the weight or pressure of the air. The greater the pressure on the surface of the water in the well, the higher will be the top of the water in the pump. The greater the pressure on the surface of the mercury in the basin, in the experiment of Torricelli, the higher will the mercury column stand in the glass tube. Either water or mercury may be used as the liquid in the barometer. Otto von Guericke (1602-1686), of Magdeburg, constructed a water barometer about 36 feet long, which he attached to the outside wall of his house. This barometer he used for some months, and made predictions of coming weather changes by means of it. A water barometer is, however, a very unwieldy thing to manage, on account of the great length of its tube. Furthermore, water barometers cannot be used in any countries where the temperatures fall to freezing. Mercury is the liquid universally employed in barometers. It is so heavy that only a small column of it is necessary to balance the atmospheric pressure. Therefore a mercurial barometer is portable. Further, mercury does not freeze until the temperature falls to 40° below zero.

Another name which should be mentioned in connection with the barometer is that of Blaise Pascal, who in 1648 fully confirmed Torricelli's results. Pascal saw that if the mercury column is really supported by the weight of the air, the height of that column must be less on the summit of a mountain than at the base, because there is less air over the top of the mountain than at the bottom, and therefore the weight of the air must be less at the summit. To prove this, he asked his brother-in-law Perrier, who lived at Clermont, in France, to carry the Torricellian tube up the Puy-de-Dôme, a mountain somewhat over 3500 feet high in Central France. This Perrier did on Sept. 19, 1648, and he found, as predicted by Pascal, that the mercury fell steadily in the tube as he went up the mountain, and that at the top of the mountain the column of mercury was over 3 inches shorter than at the base.

The pressure of the atmosphere is a weather element which, unlike the other elements already considered, cannot be observed without an instrument. We cannot, under ordinary conditions at sea level, determine by any of our senses whether the pressure is rising or falling, or is stationary. The

pressure on the upper floors of one of our high buildings is shown by a barometer to be considerably lower than it is at the level of the street below, and yet we notice no difference in our feelings at the two levels.

It is only when we ascend far into the air, as in climbing a high mountain or in a balloon, that the much-diminished pressure at these great heights perceptibly influences the human body. Mountain climbers and aëronauts who reach altitudes of 15,000 to 20,000 feet or more, usually suffer from headache, nausea, and faintness, which have their cause in the reduced pressure encountered at these heights.



Fig. 5.

The ordinary mercurial barometer in use to-day is, essentially, nothing more than the glass tube and vessel of Torricelli's famous experiment. A simple form of the mercurial barometer is shown in Fig. 5. It consists of a glass tube about one-quarter of an inch in inside diameter and about 36 inches long. This tube, closed at the top and open at the bottom, is filled with mercury, the lower, open end dipping into a cup of mercury known as the *cistern*. The space above the mercury is a vacuum. The mercury extends inside the tube to a height corresponding to the weight or pressure of the air, the vertical height of the top of the mercury column above the level of the mercury in the cistern, in inches and hundredths of an inch, being the barometer reading. At sea level the normal barometer reading is about 30 inches. There is an opening near the top of the cistern, at the back of the instrument, through which the air gains access to the mercury and holds up the mercury column. It will readily be seen that, as the mercury in the tube rises, the level of the mercury in the cistern falls, and *vice versa*, so that there is a varying relation between the two levels. In order to have the reading accurate, it is necessary that the surface of the mercury in the cistern should be just at the zero of the barometer scale when a reading is made. To accomplish this, the bottom of the cistern consists of a buckskin bag which may be raised or lowered by means of a thumb-screw, seen at the lower end of the instrument. The level of the mercury may thus be changed and adjusted to the top of a black line, marked on the outside of the cistern, and which indicates the zero of the scale. Before making a reading, the surface of the mercury in the cistern must be raised or lowered until it *just* reaches this black line. Then the top of the mercury column will give the pressure of the air. The reading is made on an aluminum scale at the top of the wooden back on which the tube is mounted, this scale being graduated both on the English and on the metric system. This barometer may be hung against the wall of a room.

The **aneroid barometer** (Greek: *without fluid*), although less desirable in many ways than the mercurial, is nevertheless a useful instrument for rough observations. The aneroid is not good for careful scientific work, because its readings are apt to be rather inaccurate. To be of much value in indicating exact pressures, it should frequently be compared with and adjusted to a mercurial barometer. An ordinary aneroid barometer is shown in Fig. 6.

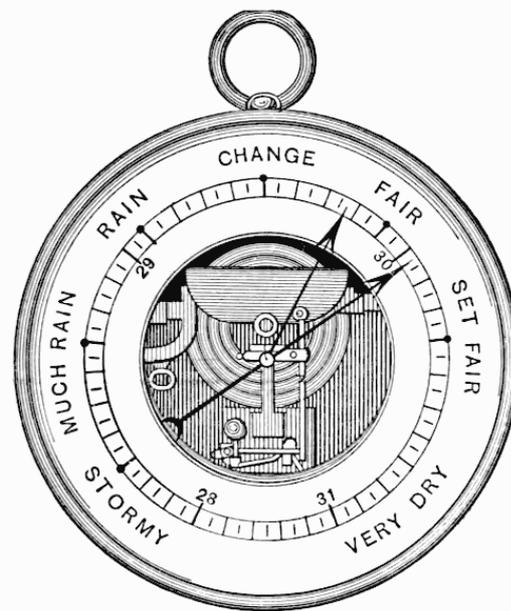


Fig. 6.

In this instrument the changes in atmospheric pressure are measured by their effects in altering the shape of a small metallic box, known as the *vacuum chamber*. The upper and lower surfaces of this box are made of thin circular sheets of corrugated German silver, soldered together around their outer edges, thus forming a short cylinder. From this the air is exhausted, and it is then hermetically sealed. A strong steel spring, inside or outside of the vacuum chamber, holds apart the corrugated surfaces, which tend to collapse, owing to the pressure of the external air upon them. An increase or decrease in the air pressure is accompanied by an approach, or a drawing apart, of the surfaces of the chamber. These slight movements are magnified by means of levers, a chain, and a spindle, and are made to turn an index hand or pointer on the face of the instrument. The outer margin of the face, underneath the glass, is graduated into inches and hundredths, and the pressure may thus be read at once.

As the tension of the steel spring varies with the temperature, aneroids are usually *compensated* for temperature by having one of the levers made of two different metals, *e.g.*, brass and iron, soldered together, or else by leaving a small quantity of air in the vacuum chamber. This air, when heated, expands, and thus tends to compensate for the weaker action of the spring, due to the higher temperature. At best, however, this compensation is but imperfect, and this fact, together with the friction of the different parts, the changes in the spring with age, and the need of frequent adjustments, makes aneroids rather inaccurate. They may be adjusted to mercurial barometers by means of a small screw, whose head may be found on the lower surface of the instrument. The words *fair*, *stormy*, etc., which frequently appear on the face of aneroid barometers, are of little use in foretelling weather changes, as no definite pressures always occur with the same weather conditions. The instrument should be tapped lightly a few times with the finger before a reading is made. The second pointer, which is often found in aneroids, is set by the observer on the position marked by the index hand when

he makes his reading. The difference between the pressure marked by this set pointer and that shown by the index hand at the next observation is the measure of the change of pressure in the interval.

Another column must now be added to the record book (preferably between the columns devoted to *temperature* and *wind*) to receive the "Pressure in Inches and Hundredths."

Is the pressure constant (*i.e.*, are the readings always the same) or does it vary? If it varies, is there any apparent system in the variations? Is there a tendency to a daily maximum? To a daily minimum? If so, about what time do these occur, respectively? What is the average variation (in inches and hundredths) in the course of a day? What is the greatest difference in pressure which you have observed in a day? What is the least? Does the pressure seem to vary more or less in the colder months than in the warmer? Has the height of the mercury column any relation to the weather? Are we likely to have rainy weather with rising barometer? Is the velocity of the wind related to the pressure in any way? How? Can you make any general rules for weather prediction based on the action of the barometer? What rules?

Tabulation of Observations.—The tables suggested in the preceding chapter can be used unchanged with the simple instruments just described.

Summary of Observations.—At the end of each month summarize your instrumental observations in the following way:—

Temperature.—Add together all your temperature readings; divide their sum by the total number of observations of temperature, and the quotient will give you a sufficiently accurate *mean* or *average* temperature for the month in question. It is to be noted that the mean monthly temperatures obtained from these observations will be much more accurate if the thermometer readings are made at 7 A.M. and 7 P.M., at 8 A.M. and 8 P.M., etc., and the mean of these is taken; or if the mean is derived from the maximum and the minimum temperatures, discussed in Chapter III. This *mean* temperature should be written at the bottom of the temperature column, and marked "Mean." The mean monthly temperature is one of the important meteorological data in considering the climatic conditions of any place.

Wind.—Determine the frequency of the different wind directions by counting the total number of times the wind has blown from N., NE., E., etc., during the month. The wind which you have observed the greatest number of times is the *prevailing* wind. It may, of course, happen that two or three directions have been observed an equal number of times. The number of calms should also be recorded.

Rainfall.—The total monthly precipitation is obtained by adding together all the separate amounts of rainfall noted in your record book, and expressing the total, in inches and hundredths, at the bottom of the rainfall column. You now have the means for comparing one month's rainfall with that of another month, and of seeing how these amounts vary.

Examine carefully also your *non-instrumental observations*. See whether you can draw any general conclusions as to the greater prevalence of cloud, or of rain or snow, in one month than in another. Did the last month have more high winds than the one before? Or than the average? Were the temperature changes more sudden and marked? Was there more or less precipitation than in previous months?

CHAPTER III. ADVANCED INSTRUMENTAL OBSERVATIONS

The instruments for more advanced study are the following: *maximum and minimum thermometers, wet and dry-bulb thermometers, sling psychrometer, standard barometer, thermograph, barograph, and anemometer.*

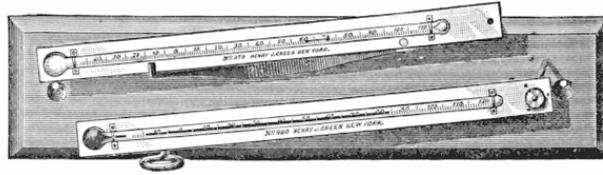


Fig. 7.

Maximum and minimum thermometers are usually mounted together on a board, as shown in Fig. 7, the lower one of the two being the maximum, and the upper the minimum. In the view of the instrument shelter (Fig. 2), these thermometers are seen on the left. The minimum thermometer, when attached to its support, is either exactly horizontal or else slopes downward somewhat towards the bulb end, as shown in Fig. 7. These instruments, as their names imply, register the highest and the lowest temperatures, respectively, which occur during each day of 24 hours. The maximum thermometer is filled with mercury. Its tube is narrowed just above the bulb, in such a way that the mercury passes through the constriction with some difficulty. As the temperature rises, the mercury, in expanding, is forced out from the bulb through this narrow passage. When the temperature falls, however, the mercury above this point cannot get back into the bulb, there being nothing to force it back. The length of the mercury column, therefore, remains the same as it was when the temperature was highest, and the instrument is read by observing the number of degrees indicated by the top, or right-hand end, of the mercury column upon the scale. After reading, the thermometer is set by removing the brass pin upon which the bulb end rests, and whirling the instrument rapidly around the pin to which its upper end is fastened. By this process the mercury is driven back into the bulb, past the constriction. Care must be taken to stop the thermometer safely while it is whirling. After setting, the reading of the maximum thermometer should agree closely with that of the ordinary or dry-bulb thermometer.

The *minimum thermometer* is filled with alcohol, and contains within its tube a small black object, called the *index*, which resembles a double-headed black pin. The instrument is so constructed that this index, when placed with its upper, or right-hand end, at the surface of the alcohol, is left behind, within the alcohol, when the temperature rises. On the other hand, when the temperature falls, the index is drawn towards the bulb by the surface cohesion of the alcohol, the top or right end of the index thus marking the lowest temperature reached. The upper end of the thermometer is firmly fastened, by means of a screw, to a brass support, while the lower end rests upon a notched arm. In setting this instrument, the bulb end is raised until the index slides along the tube to the end of the alcohol column. The thermometer is then carefully lowered back into the notch just referred to. Maximum and minimum thermometers need to be read only once a day, in the evening. The temperatures then recorded are the highest and lowest reached during the preceding 24 hours. The observation hour is preferably 8 P.M., but if this is inconvenient, or impracticable, the reading may be made earlier in the afternoon. The hour, however, should be as late as possible, and should not be varied from day to day. The maximum temperature sometimes occurs in the night. The maximum and the minimum temperatures should be entered every day, in a column headed "Maximum and Minimum Temperatures," in your record book.

The **wet- and dry-bulb thermometers**, together commonly known as the *psychrometer* (Greek: *cold measure*), are simply two ordinary mercurial thermometers, the bulb of one of which is wrapped in muslin, and kept moist by means of a wick leading from the muslin cover to a small vessel of water attached to the frame (see Fig. 8). The wick carries water to the bulb just as a lamp wick carries oil to the flame. The psychrometer is seen inside the shelter on the right in Fig. 2.

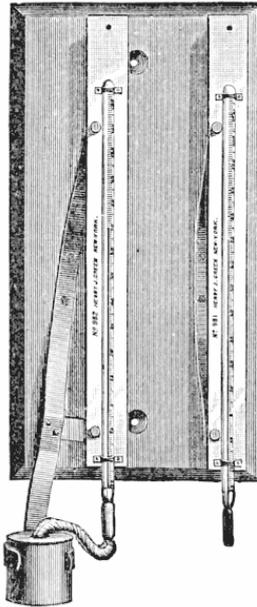


Fig. 8.

The air always has more or less moisture in it. Even the hot, dry air of deserts contains some moisture. This moisture is either invisible or visible. When invisible it is known as *water vapor*, and is a gas. When visible, it appears as *clouds* and *fog*, or in the liquid or solid form of *rain*, *snow*, and *hail*. The amount of moisture in the air, or the *humidity* of the air, varies according to the temperature and other conditions. When the air contains as much water vapor as it can hold, it is said to be *saturated*. Its humidity is then high. When the air is not saturated, evaporation goes on into it from moist surfaces and from plants. Water which changes to vapor is said to *evaporate*.

This process of evaporation needs energy to carry it on, and this energy often comes from the heat of some neighboring body. When you fan yourself on a very hot day in summer, the evaporation of the moisture on your face takes away some of the heat from the skin, and you feel cooler. The drier the air on a hot day, the greater is the evaporation from all moist bodies, and hence the greater the amount of cooling of the surfaces of those bodies. For this reason a hot day in summer, when the air is comparatively dry, that is, not saturated with moisture, is cooler, other things being equal, than a hot day when the air is very moist. Over deserts the air is often so hot and dry that evaporation from the face and hands is very great, and the skin is burned and blistered. Over the oceans, near the equator, the air is hot and excessively damp, so that there is hardly any cooling of the body by evaporation, and the conditions are very uncomfortable. This region is known as the “Doldrums.”

The temperatures that are felt at the surface of the skin, especially where the skin is exposed, as on the face and hands, have been named *sensible temperatures*. Our sense of comfort in hot weather depends on the *sensible* temperatures. These sensible temperatures are not the same as the readings of the ordinary (dry-bulb) thermometer, because our sensation of heat or cold depends very largely on the amount of evaporation from the surface of the body, and the temperature of evaporation is obtained by means of the wet-bulb thermometer. Wet-bulb readings at the various stations of the Weather Bureau are entered on all our daily weather maps. In summer (July) the sensible (wet-bulb) temperatures are 20° below the ordinary air temperature in the dry southwestern portion of the United States (Nevada, Arizona, Utah). The mean July sensible temperatures there are from 50° to 65°; while on the Atlantic coast, from Boston to South Carolina, they are between 65° and 75°. Hence over the latter district the temperatures actually experienced in July average higher than in the former.

Unless the air is saturated with water vapor, the evaporation from the surface of the wet-bulb thermometer will lower the temperature indicated by that instrument below that shown by the dry-

bulb thermometer next to it, from which there is no evaporation. The drier the air, the greater the evaporation, and therefore the greater the difference between the readings of the two thermometers. By means of tables, constructed on the basis of laboratory experiments, we may, knowing the readings of the wet and dry-bulb thermometers, easily determine the *dew-point* and the *relative humidity* of the air—important factors in meteorological observations (see Chapter XXVI). In winter, when the temperature is below freezing, the muslin of the wet-bulb thermometer should be moistened with water a little while before a reading is to be made. The amount of water vapor which air can contain depends on the temperature of the air. The higher the temperature, the greater is the capacity of the air for water vapor. Hence it follows that, if the temperature is lowered when air is saturated, the capacity of the air is diminished. This means that the air can no longer contain the same amount of moisture (invisible water vapor) as before. Part of this moisture is therefore changed, *condensed*, as it is said, from the condition of water vapor into that of cloud, fog, rain, or snow. The temperature at which this change begins is called the *dew-point* of the air.

The *relative humidity* of the air is the ratio between the amount of water vapor which the air contains at any particular time and the total amount which it could contain at the temperature it then has. Relative humidity is expressed in percentages. Thus, air with a relative humidity of 50% has just half as much water vapor in it as it *could* hold.

It is found that the readings of the wet-bulb thermometer are considerably affected by the amount of air movement past the bulb, and that in a light breeze, or in a calm, the reading does not give accurate results as to the humidity of the general body of air outside the shelter.

To overcome this difficulty another form of psychrometer has been devised.

The **slings psychrometer** (Fig. 9) consists simply of a pair of wet and dry-bulb thermometers, fastened together on a board or a strip of metal, to the upper part of which a cord with a loop at the end is attached. In this form of psychrometer there is no vessel of water and no wick, but the muslin cover of the wet-bulb thermometer must be thoroughly wet, by immersion in water, just before each observation. The instrument is then whirled around the hand at the rate of about 12 feet a second. After whirling about 50 times, note the readings, and then whirl the instrument again, and so on, until the wet bulb reaches its lowest reading. The lowest reading of the wet bulb, and the reading of the dry bulb at the same time, are the two observations that should be recorded. Take care to have the muslin wet throughout each observation, and in windy weather stand to leeward of the instrument, so that it may not be affected by the heat of your body. The true reading may be obtained within two or three minutes.

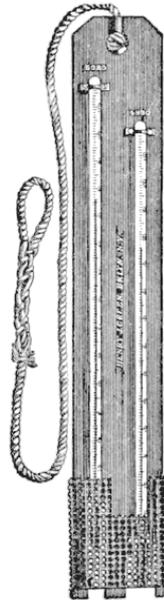


Fig. 9.

Make observations with the wet-bulb thermometer or the sling psychrometer as a part of your regular daily weather record. Note the temperatures indicated by the wet and dry bulbs, and, by means of the table in Chapter XXVI, obtain the *dew-point* and the *relative humidity* of the air at each observation. Enter these data in your record book, in a column headed “Humidity,” and subdivided into two columns, one for the dew-point and one for the relative humidity.



Fig. 10.

By means of observations with the psychrometer you will be able to answer such questions as the following:—

Does the relative humidity vary from day to day? Has it any relation to the direction of the wind? To the state of the sky? To precipitation? Does it show any *regular* variations during the course of a day? How does a high degree of relative humidity affect you in cold weather? In hot weather?

Between what limits of percentages does the relative humidity vary? Do the changes come gradually or suddenly? Are these changes related in any way to the changes in the other weather elements? How do the sensible temperatures vary? In what weather conditions do the sensible temperatures differ most from the air temperatures? In what seasons? Compare the sensible temperatures obtained by your own observations with the sensible temperatures at various stations of the Weather Bureau, as given on the daily weather map. Are there any fairly regular differences between the sensible temperatures observed at your own station and the Weather Bureau stations?

Standard Mercurial Barometer.—A simple form of barometer has been described in Chapter II. The ordinary standard mercurial barometer used by the Weather Bureau (Fig. 10) has the glass tube containing the mercury surrounded by a thin brass covering, through which openings are cut, near the top, on the front and back, exposing to view the glass tube and the top of the mercury column. On one side of this opening there is a strip of metal, graduated to inches and tenths or twentieths, by means of which the height of the barometer is determined. This strip, for barometers used at or near sea level, is about 4 inches long, the variations in pressure under normal conditions not exceeding that amount. In addition to this fixed scale there is a small scale, also graduated, which may be moved up and down the opening in the enclosing brass case by means of a milled head outside and a small rack and pinion inside the brass case. This movable scale, known as the *vernier* from the name of its inventor, Vernier, is an ingenious device, by means of which more accurate readings of the barometer can be made than is possible with the ordinary fixed scale. A *vernier* graduated into twenty-five parts enables the observer to make readings accurately to the one-thousandth part of an inch. On the front of the barometer there is a small thermometer, known as the *attached thermometer*. The bulb of this thermometer, concealed within the metal casing of the barometer, is nearly in contact with the glass tube containing the mercury. The air, upon whose weight the height of the mercury column depends, gains access to the top of the cistern through leather joints, by which the cistern is joined to the glass tube.

Mercurial barometers of the Weather Bureau pattern are best hung in a barometer box, fastened securely against the wall of a room, where there is a good light on the instrument and where the temperature is as constant as possible.

In all accurate work certain corrections have to be applied to barometer readings to make them strictly comparable. These are: (1) *correction for altitude*; (2) *correction for temperature*; and (3) *correction for latitude*. The first is necessary because of the fact that the weight of the air decreases upwards, and a barometer reading on a hill or a mountain is not comparable with one at sea level unless the former has been corrected by the addition of the weight of the column of air between the hill or mountain and sea level. The correction for temperature is rendered necessary by the fact that with increasing temperature the mercury in the barometer tube expands more than the metallic scale, because mercury is more sensitive to heat, and unless some allowance is made for this fact, barometer readings made at high temperatures will show somewhat too high a pressure. The readings of the attached thermometer give the temperature of the mercury and are used in making the corrections for temperature. As gravity varies from a maximum value at the poles to a minimum value at the equator, barometer readings made at different latitudes are *corrected for latitude*, which means that they are reduced to latitude 45° , midway between 0° and 90° . The correction is $+0.08''$ at the poles and $-0.08''$ at the equator. Tables for use in correcting barometer readings for altitude and for temperature are given in Chapter XXVI.

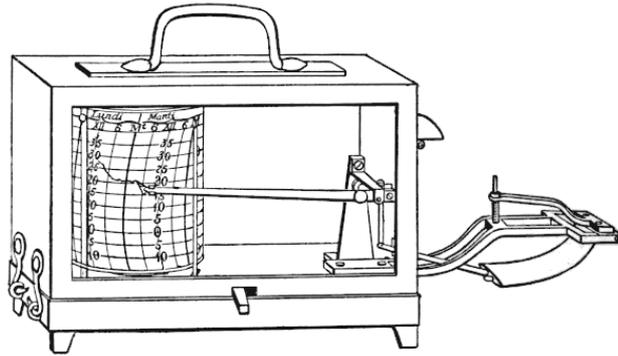


Fig. 11.

Thermograph and Barograph.—Two instruments of much interest are the self-recording thermometer, or *thermograph*, and the self-recording barometer, or *barograph*, manufactured by Richard Brothers of Paris. In the thermograph (Fig. 11) there is a brass cylinder around which a sheet of paper is wound, this paper being divided into two-hour intervals of time and into spaces representing differences of 5° or 10° of temperature. The cylinder revolves once in a week, being driven by clock-work contained within it. The thermometer consists of a flat, bent, hollow brass tube containing alcohol, one end of the tube being fastened to the metallic frame seen at the right of the figure, and the other end being free to move. With rising temperature, the liquid in the tube expanding more than the metallic casing, by reason of its greater sensitiveness to heat, tends to straighten the tube, while with falling temperature the elasticity of the tube turns it into a sharper curve. These movements of the free end of the tube are carried through a train of levers and thus magnified. At the end of the last lever is a metallic pen filled with ink, which rests lightly against the paper on the revolving drum. A rise or fall in temperature is thus recorded by a rise or fall of the pen on the record sheet, and a continuous curve of temperature is secured. The pen of the thermograph should be frequently adjusted to make the reading of the instrument accord with that of a standard mercurial thermometer, and care should be taken to have the clock keep good time. These adjustments can readily be made by means of a screw and a regulator, respectively. The thermograph should be exposed in the instrument shelter with the other thermometers. The sheets should be changed, the clock wound, and the pen filled once a week, preferably on Monday, at 8 A.M., or at noon.

The continuous records written by a thermograph are a valuable addition to the fragmentary observations which are the result of eye readings of the ordinary thermometer. From the former any omitted thermometer readings may be supplied. The interest of thermograph records may be seen in the following figure (Fig. 12), in which curves traced under different conditions are reproduced. Curve *a* illustrates a period of clear warming weather at Nashua, N. H., April 27-30, 1889. Curve *b* was traced during a spell of cloudy weather at Nashua, accompanying the passage of a West India hurricane, Sept. 13-16, 1889. Curve *c* illustrates the change from a time of moderate winter weather to a cold spell (Nashua, Feb. 22-25, 1889). Curve *d* exhibits a steady fall of temperature from the night of one day over the next noon to the following night, during the approach of a winter cold spell (Nashua, Jan. 19-21, 1889). Curve *e* shows a reverse condition, viz., a continuous rise of temperature through a night from noon to noon (Nashua, Dec. 16-17, 1888). Curve *f* shows the occurrence of a high temperature at night, caused by warm southerly winds, followed by cold westerly winds (Cambridge, Mass., Nov. 30-Dec. 1, 1890). Curve *g* illustrates the sudden rise of temperature due to the coming of a hot, dry wind (chinook) at Fort Assiniboine, Mont. (Jan. 19, 1892). A study of such records leads to the discovery of many important facts, which would be completely lost sight of without a continuous record.

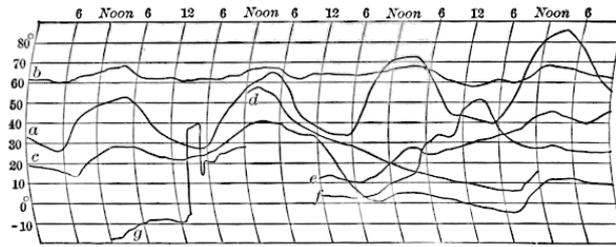


Fig. 12.

The **barograph** (Fig. 13) is very similar to the thermograph in general appearance. The essential portion of this instrument consists of a series of six or eight hollow shells of corrugated metal screwed one over the other in a vertical column. These shells are exhausted of air, and form, in reality, an aneroid barometer which is six or eight times as sensitive as the ordinary single-chamber aneroid. The springs for distending the shells are inside. The base of the column being fixed, the upper end rises and falls with the variations in pressure. The movements of the shells are magnified by being carried through a series of levers, and, as in the thermograph, the motion is finally given to a pen at the end of the long lever. The compensation for temperature is the same as in the ordinary aneroid. A small quantity of air is left in one of the shells to counteract, by its own expansion at increased temperature, the tendency of the barometer to register too low on account of the weakening of the springs. The barograph may be placed upon a shelf in the schoolroom, where it can remain free from disturbance, and yet where the record may be clearly seen. The general care of the barograph is the same as that of the thermograph. Brief instructions concerning the care and adjustments of these instruments are sent out by the makers with each instrument. Frequent comparison with a mercurial barometer is necessary, the adjustment of the barograph being made by turning a screw, underneath the column of shells, on the lower side of the wooden case.

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