TM 3-24

WAR DEPARTMENT

TECHNICAL MANUAL

METEOROLOGY

March 7, 1942

TECHNICAL MANUAL

METEOROLOGY

CHANGES No. 1

WAR DEPARTMENT,
WASHINGTON, December 29, 1942.

TM 3-240, March 7, 1942, is changed as follows:

29. Local forecasting.

* * * * * * *

d. (Added.) *Buys Ballot's Law.*—(1) If one stands with his back to the wind in the Northern Hemisphere, the pressure on the left is lower than on his right and the pressure to the left front is lower than to the left rear.

(2) If one stands with his back to the wind in the Southern Hemisphere, the pressure on the right is lower than on the left and the pressure to the right front is lower than to the right rear.

[A. G. 062.11 (12-14-42).] (C 1, Dec. 29, 1942.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
J. A. ULIO,
Major General,
The Adjutant General.

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TECHNICAL MANUAL
No. 3-240

WAR DEPARTMENT,
WASHINGTON, March 7, 1942.

METEOROLOGY

Prepared under direction of the
Chief of the Chemical Warfare Service

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SECTION I

WEATHER ELEMENTS

1. Influence of weather.—*a. Military operations in general.*—Every phase of military operations is directly or indirectly influenced by the weather. Therefore every arm and service is interested in the meteorological information applicable to its operations. In artillery firing, corrections for departures from standard atmospheric conditions are habitually applied when time and conditions permit. The Air Corps requires frequent reports showing air movement and visibility at all levels up to the highest at which airplanes are likely to operate. Nearly all units are interested in the duration of sunlight and moonlight in every 24-hour period. Logistics as well as tactics can be both aided and hindered by weather conditions.

b. Chemical operations.—Chemical munitions are influenced by weather to a greater extent than any other type of munitions. Chemical operations are dependent on the stability, temperature, density, and movement of the air, since the possible concentration and drift of gas clouds or smoke screens are controlled by these factors. Weather also determines very largely the kind of gas that may be used in a particular operation. The chemical officer must therefore have at least a working understanding of meteorology and must be able to make reasonably accurate forecasts of weather probabilities.

2. Weather elements.—*a. Enumeration.*—The condition of the atmosphere at any given time and place is determined by six factors called weather elements. These are wind, temperature, precipitation, clouds, humidity, and pressure.

b. Evaluation.—The elements are observed and reported according to certain numerical values. For example, wind velocity is given in miles per hour; wind direction by points of a circle; temperature in degrees; precipitation in inches; humidity in percent; and pressure in inches or in millibars of a supported mercury column.

c. Measurement.—The six elements to be considered together with the instruments and units used for the measurement of each are—

Weather element	Instrument for measuring	Unit of measurement
Wind:		
Direction	Wind vane	64 points of circle.
Velocity	Anemometer	Miles per hour.
Temperature	Thermometer	Degree (F.).
Precipitation	Rain gage	Inch.
Clouds	None (estimated by eye)	Tenths of sky.
Humidity	Psychrometer	Percent (relative).
Pressure	Barometer	Inch (mercury) or millibars.

3. Wind.—*a. Definition.*—Wind is air in motion along and nearly parallel to the surface of the earth. All other air mass motions are spoken of as air currents.

b. Measurement.—There are three wind factors to be determined or measured by instruments: direction, velocity, and force or pressure. Of these, direction and velocity are most important in chemical warfare.

c. Movement.—(1) The flow of air near the surface of the earth is never steady. It is not a streamline flow but a movement in successive gusts and lulls of a few seconds' duration. This turbulence is most pronounced when the wind velocity is high; it is greater over land than over ocean surfaces, and is more pronounced over forests than over bare, level ground. Turbulence is caused in part at least by surface irregularities and friction.

(2) Friction at the earth's surface induces gustiness by checking the flow of the lowest layer, letting the layers above break over it like waves along a beach. Surface obstacles turn the air out of its course and into numerous cross-currents and eddies. Obstacles such as buildings increase the wind velocity near them and also cause gusts. The effect of such obstructions extends to five or six times their dimensions.

(3) There is a marked increase in wind velocity with altitude. In general the velocity at a height of 33 feet is about twice that at 1½ feet.

(4) These combined factors tend to cause a complete mixing of the atmosphere and consequently the dilution of a gas or smoke cloud as well as erratic cloud travel.

d. Wind direction.—(1) *General.*—Wind direction is designated as that direction from which wind *comes*. Thus if the air moves from the north toward the south, it is called a north wind.

(*a*) In noting wind direction the cardinal and intermediate points of the compass are generally used; namely, north, northeast, east, southeast, south, southwest, west, and northwest. However, in military work it is more convenient to indicate wind direction on a basis of 64 points of the circle, each point representing 100 mils. Thus 16 indicates that the wind is blowing from the east, while a wind from the south is indicated by 32, etc. On this scale intermediate points, such as NE, SE, SW, and NW, are represented by 8, 24, 40, and 56, respectively. (See fig. 1.) This system, making use of the mil, is a convenience in plotting wind direction on maps with the mil scale protractor without conversion. This method is also used in the artillery meteorological message described in paragraph 9.

64 POINT (100 MIL) AND COMPASS SYSTEMS COMBINED

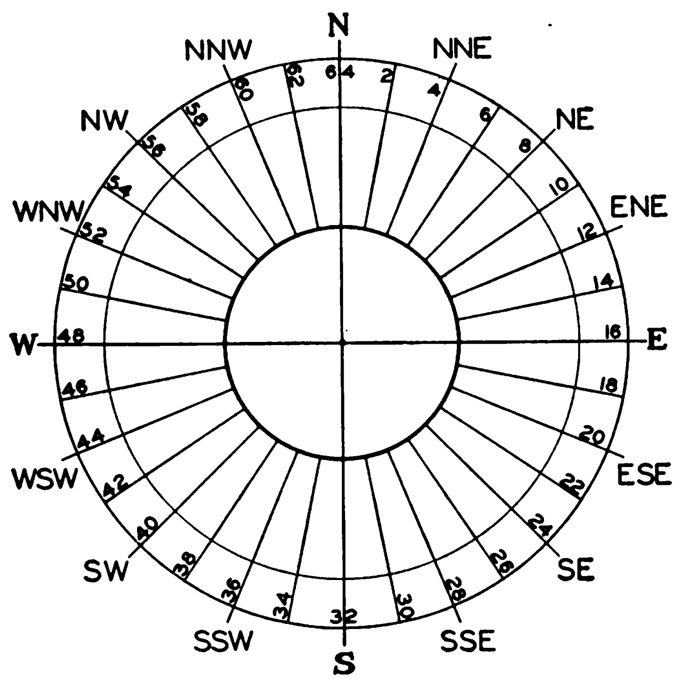


FIGURE 1.—Wind circle.

(*b*) The direction from which the wind comes is called "windward" or "upwind," and the direction toward which it goes is called "leeward" or "downwind." Whenever the wind direction changes steadily in a clockwise direction, e. g., N to NE to E, etc., it is said to *veer*. When the direction changes steadily in a counterclockwise direction, e. g., N to NW to W, etc., it is said to *back*.

(2) *Measurement.*—Measurement with wind vanes has been conducted since ancient times. Many types of such vanes have been developed and used.

(*a*) The military instrument used in the field for measuring wind direction is known as the wind vane ML-73 (fig. 2). This consists of a wind vane proper, three rods, and two carrying cases. The wind vane support consists of 3 sections of rod, each 29½ inches long. One section is equipped with a point for insertion in the ground; the others are provided with joints permitting them to be assembled. The sup-

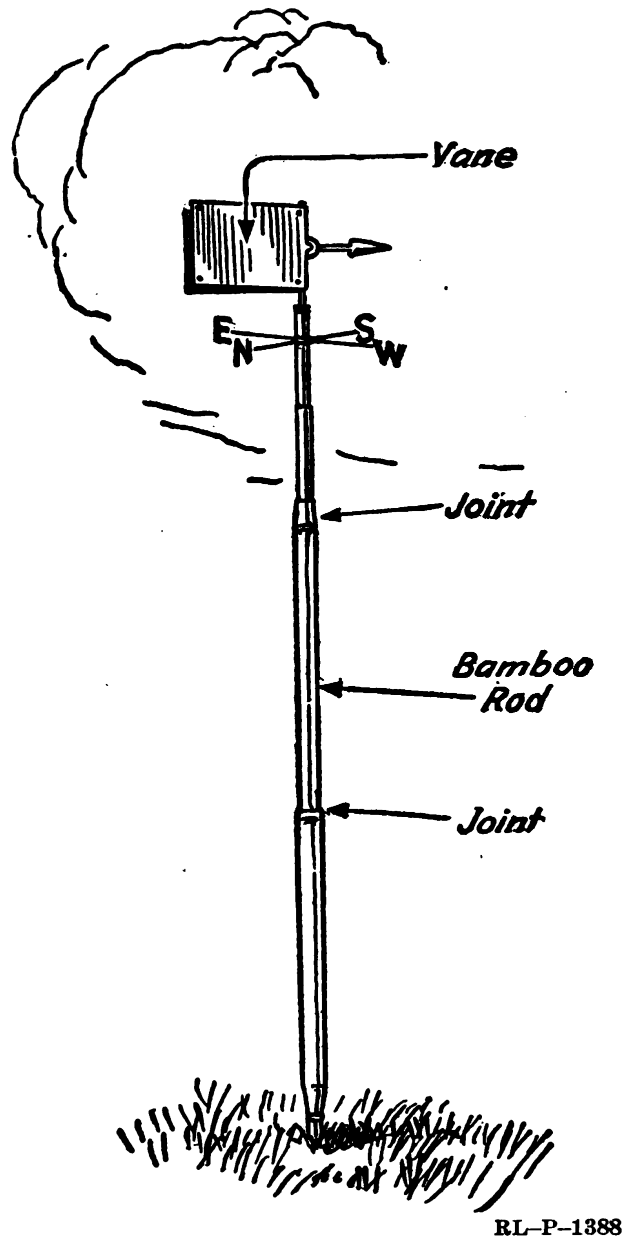


FIGURE 2.—Wind vane ML-73.

port may be used either as a 3-joint support or as a 2-joint support. The former is 85 inches high and the latter is 57 inches high.

(*b*) The wind vane head consists of a cylinder closed at one end and surmounted at the closed end by a rod, the axis being coincident with that of the cylinder. The cylinder is provided with a brass ring which is drilled with four holes equally spaced around its circumference. Four direction markers (N, E, S, W) are provided for insertion in the four holes of the ring. A direction pointer mounted to turn on the vertical rod completes the wind vane. The direction markers must be oriented by a magnetic compass or other suitable means.

(*c*) In the absence of a wind vane, many improvised means or expedients may be resorted to in the field to determine the approximate wind direction, such as observation of the drift of smoke, dust, or any light material.

e. Wind velocity.—(1) *General.*—Wind velocity causes moving air to exert a force or pressure against objects in its path, that force being proportional to the square of its velocity. The relation of pressure and velocity may be expressed by the simple formula, $P=0.004V^2$, in which P is the pressure in pounds per square foot, and V is the velocity in miles per hour. By reason of this force exerted by the wind, its velocity can be estimated by its effect on surrounding objects or, for more accurate measurements, by operating any of the various types of anemometers.

(2) *Measurement.*—Measurement is made in the field with the hand anemometer ML–62 (fig. 3). This includes a vane wheel geared to a counter or recording dial which indicates air speed in meters.

(*a*) A stop watch is an integral part of this anemometer and is built into the instrument to the left of the recording dial. The vane wheel or fan may be put in or out of gear with the dial by means of a sliding knob or gearshift on the right side of the housing. When the gearshift is pushed up it disengages the vane wheel gear from the recording dial, and the pointer may be set to any desired position by means of a knob on the back of the frame.

(*b*) To determine the wind velocity the anemometer is held in both hands forward and above the head or at one side of the body, facing directly into the wind to insure that the wind will blow unobstructedly through the fan or vane wheel of the instrument. The anemometer should not be held in front of the body. It is most convenient to have the pointer set at about 80 or 90 meters, that is, just to the left of the zero of the dial.

(*c*) The gear is engaged by pushing down on the gearshift knob with the right thumb. As the pointer reaches zero, the stop watch is started by pressing once on the stem. It is generally most convenient to read for 1 minute. The reading on the dial will then be in meters of air speed for 1 minute. However, this must be converted into miles per hour by multiplying meters per minute by 0.037. (For all practical purposes 0.04 may be used.) The reciprocal of 0.037 is 27, or 27 meters per minute equals 1 mile per hour; hence, meters per minute divided by 27 give miles per hour. As wind velocity varies during the time of taking a reading, the velocity is the mean of the reading and therefore is usually reported to the nearest mile per hour.

(*d*) It is convenient to have a conversion table with the anemometer to avoid the necessity of figuring the conversion in the field. This can be made on a card as follows and carried in the instrument case:

Meters per minute	Miles per hour	Meters per minute	Miles per hour
27	1	270	10
54	2	297	11
81	3	324	12
108	4	351	13
135	5	378	14
162	6	405	15
189	7	540	20
216	8	675	25
243	9	810	30

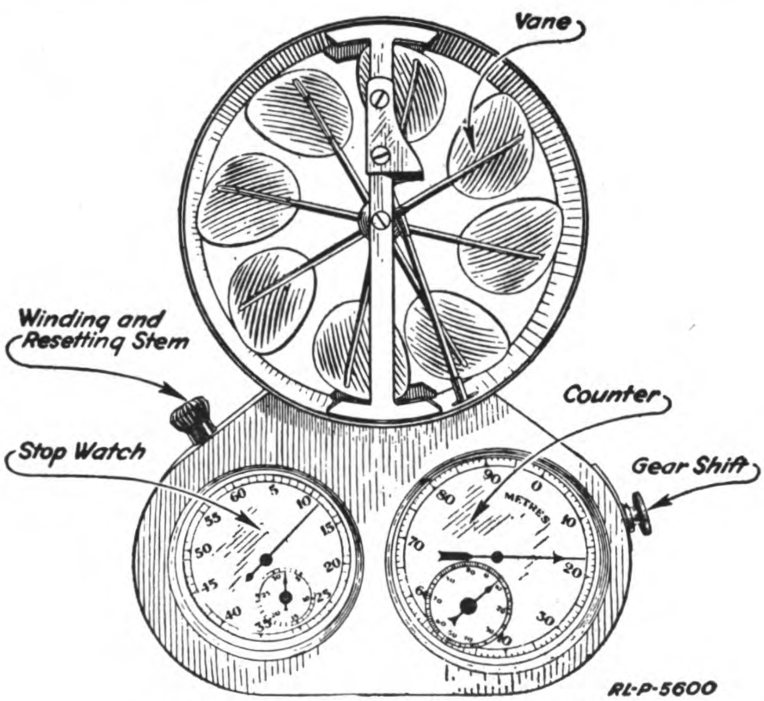


FIGURE 3.—Hand anemometer ML-62.

(*e*) The ML-62 anemometer is an expensive and delicate instrument and must be handled, transported, and used in the field with extreme care. Another disadvantage is that the instrument must be kept directed into the wind in order to obtain accurate readings. To eliminate some of the disadvantages of the hand anemometer ML-62, there has been developed an anemometer for direct reading in miles per hour. It does not require a stop watch, and

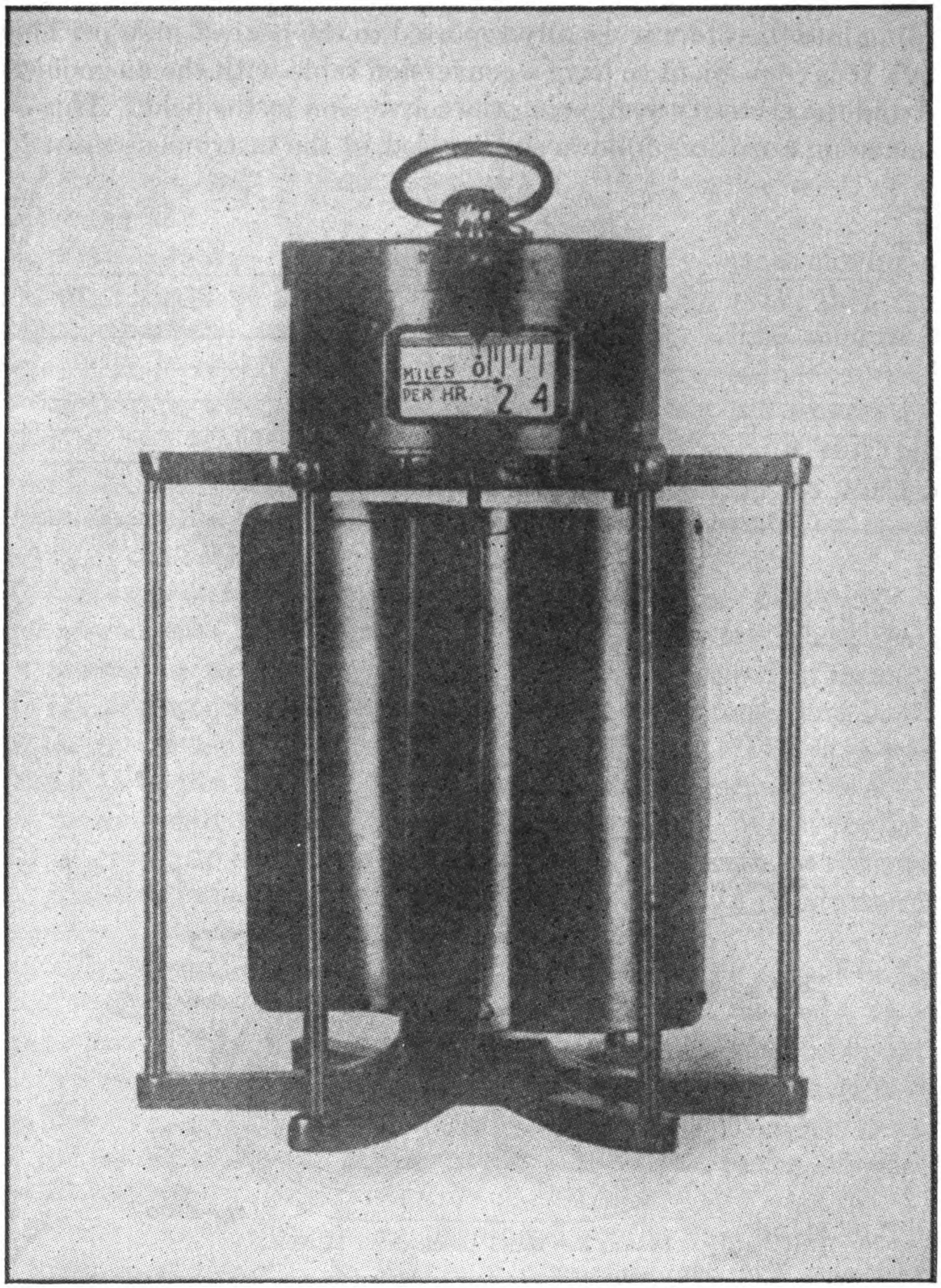


FIGURE 4.—Hand anemometer, direct reading.

the instrument does not have to be kept directed into the wind. (See fig. 4.)

(*f*) This direct reading anemometer consists of three curved blades mounted on a vertical shaft which operates a speed dial encased in the top part of the instrument. Thus the wind velocity in miles per hour can be read as on an automobile speedometer. A screw on the top of the case, when turned down, disconnects the speed dial and locks it to protect the mechanism when not in use. To operate, turn up the screw on top of the case until it releases the speed dial. Hold the anemometer away from the body so as not to obstruct the wind and note the readings on the dial which are the instantaneous values of the wind speed in miles per hour. No time measurement is required; however, to obtain an average of the wind velocity the mean of the maximum and minimum readings for a period of approximately 2 minutes should be taken.

(*g*) Various other types of instruments have been developed to operate by deflection, pressure, and rotation. The anemometer used by the United States Weather Bureau stations is permanently installed, usually on a high building, and hence is not applicable for field use in the military service except at permanent or semipermanent stations. For complete description see "Meteorology" by Milham.

(3) *Estimating.*—Various methods of estimating wind velocity have been devised and used for many years. An example is the Beaufort 12-point wind scale which follows:

TABLE I.—*Beaufort 12-point wind scale*

Beaufort number	Explanatory titles	Specifications for use on land	Miles per hour	Terms used in weather bureau forecasts
0	Calm	Smoke rises vertically	Less than 1	Light.
1	Light air	Direction of wind shown by smoke drift, but not by wind vanes.	1–3	
2	Slight breeze	Wind felt on face, leaves rustle, ordinary vane moved by wind.	4–7	
3	Gentle breeze	Leaves and small twigs in constant motion, wind extends light flag.	8–12	Gentle.
4	Moderate breeze.	Raises dust and loose paper, small branches are moved.	13–18	Moderate.
5	Fresh breeze	Small trees in leaf begin to sway, crested wavelets form on inland water.	19–24	Fresh.
6	Strong breeze	Large branches in motion, whistling heard in telegraph wires, umbrellas used with difficulty.	25–31	Strong.
7	High wind	Whole trees in motion, inconvenience felt in walking against wind.	32–38	

TABLE I.—*Beaufort 12-point wind scale*—Continued

Beaufort number	Explanatory titles	Specifications for use on land	Miles per hour	Terms used in weather bureau forecasts
8	Gale	Breaks twigs off trees, generally impedes progress.	39–46	Gale.
9	Strong gale	Slight structural damage occurs (chimney pots and slate removed).	47–54	
10	Whole gale	Seldom experienced inland, trees uprooted, considerable damage occurs.	55–63	Whole gale.
11	Storm	Very rarely experienced, accompanied by widespread damage.	64–75	
12	Hurricane		Above 75	Hurricane.

4. Temperature.—*a. Definition.*—Temperature is defined as the "degree of hotness or coldness measured on a definite scale based on some physical phenomenon," e. g., as the expansion and contraction of certain materials.

b. Measurements.—The thermometer (heat meter) generally used in weather observations in the United States is graduated according to the Fahrenheit scale, on which 32° represents the melting point of ice and 212° the boiling point of water.

(1) *Maximum and minimum thermometers* are instruments that record the highest and lowest temperatures which have occurred during the interval since the thermometers were set. The maximum thermometer is known as the ML-4 and the minimum thermometer as the ML-5.

(2) The *sling thermometer* (sling psychrometer) consists usually of two thermometers attached to a frame that can be whirled rapidly. It is used to obtain real air temperature and also to determine humidity.

(3) The *thermograph* makes a continuous record of temperature. It is so constructed that variations in temperature are communicated by a system of levers to a pen that traces a continuous record on a drum driven by clockwork.

(4) The *soil thermograph* gives a continuous record of the temperature of the soil at any depth to which the bulb is buried. It differs from the thermograph only in that there is a means of transmitting the motion to the pen from a distance.

5. Clouds.—*a. Definition.*—Minute masses of water floating visibly in the air are termed "clouds." When in contact with the earth the same phenomena are termed "fogs."

b. Cloud observation.—From the direction and velocity of cloud movement can be determined approximately the movement of high or low pressure areas past the point of observation. Certain cloud formations indicate the possibility of rain, while the expectancy of rain is slight when other formations are present. Observation of clouds and an understanding of their classification are therefore important to chemical officers.

c. Measurement.—Cloud height and direction and velocity of motion can be measured by special instruments. Otherwise, clouds are

FIGURE 5.—Dense cirrus of the type derived from thunderstorms.

estimated by eye and their type must be known to the observer from experience. The amount of cloudiness is estimated in tenths of the sky that is covered. In weather reports three terms are used: clear, partly cloudy, and cloudy. *Clear* sky is from 0 to $\frac{3}{10}$ covered with cloud; *partly cloudy* sky is from $\frac{3}{10}$ to $\frac{7}{10}$ clouded; while *cloudy* designates a sky from $\frac{7}{10}$ to wholly covered with cloud.

d. Classification.—Classification of clouds is based on their form and appearance and their altitude. The following classifications and descriptions are based on the International Cloud Atlas (1932). The ten distinct cloud formations as recognized and recorded in meteorological observation are divided into the following four groups:

(1) *Cirrus* or high cloud group includes three types, none of which come under 20,000 feet in altitude.

(*a*) Cirrus clouds (figs. 5 and 6) are detached formations of delicate and fibrous appearance without shading, generally white in color, and often of silky appearance. They are always composed of ice crystals. These clouds when near the horizon may be of yellowish color.

(*b*) Cirrocumulus clouds (fig. 7) are layers or patches of small white flakes without shadows, which appear as lines or ripples in the sky.

FIGURE 6.—Cirrus in parallel trails and small patches.

(*c*) Cirrostratus formations (fig. 8) are quite diffuse and give the sky a milky appearance.

(2) *Alto* or middle clouds occupy altitudes between 20,000 and 6,500 feet. Rain or snow may be expected from these clouds.

(*a*) Altostratus (fig. 9) resembles cirrostratus except for lower altitude, the typical formation being fibrous and gray or blue in color.

(*b*) Altocumulus (figs. 10 and 11) includes layers or patches composed of laminae or flattened globular masses, the smallest element of the regularly arranged layer being fairly small and thin, with or without shade.

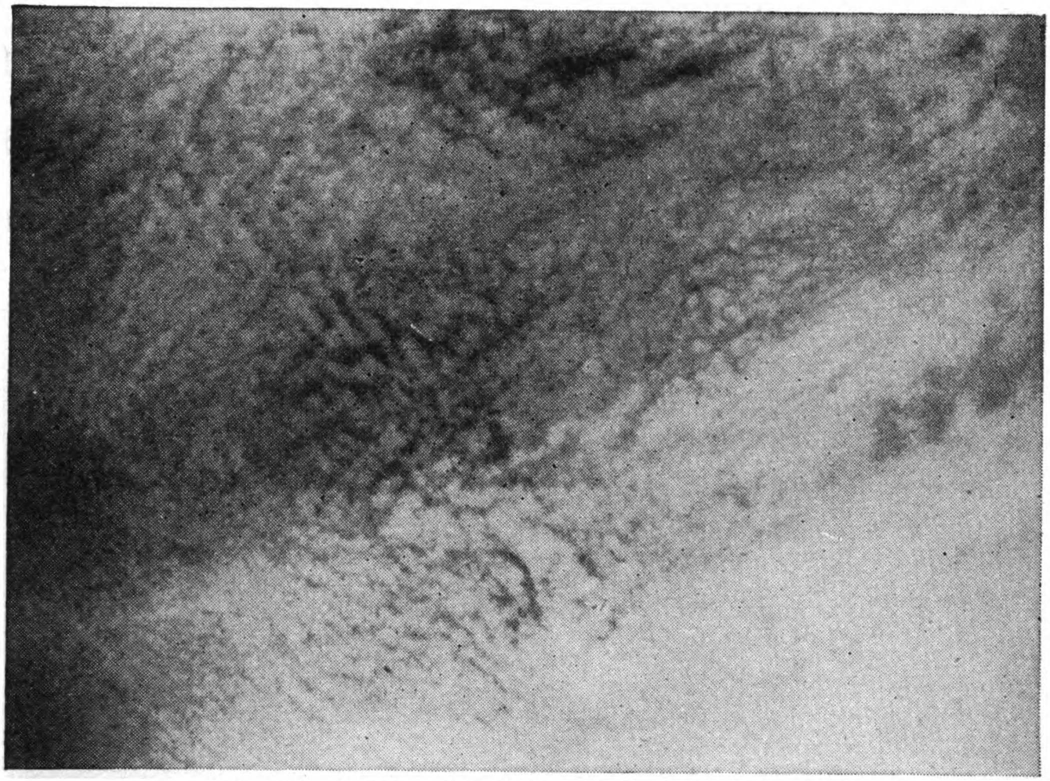


FIGURE 7.—Cirrocumulus (cirrus in lower right portion).

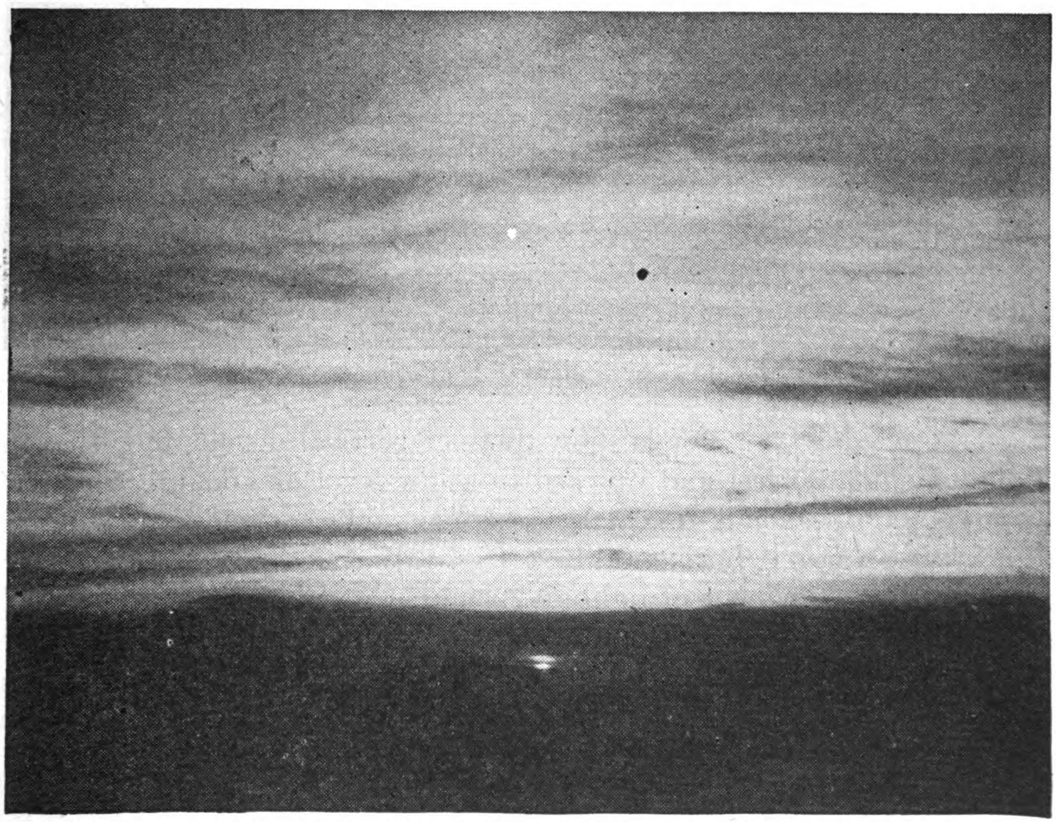


FIGURE 8.—Cirrostratus in fibrous veil at sunrise.

(3) *Stratus* or low cloud formations extend from close to the surface to altitudes of 6,500 feet. Precipitation may be expected from all such clouds.

(*a*) The stratus formation proper is nearly a uniform layer of cloud resembling fog yet not actually in contact with the earth.

(*b*) Stratocumulus (fig. 12) resembles altocumulus except that it is much lower and often covers the whole sky with a wavy formation.

(*c*) Nimbostratus is low, dark gray, usually uniform in formation, frequently accompanied by continued rain or snow.

FIGURE 9.—Complete veil of altostratus becoming thicker in places.

(4) *Cumulus* type clouds show distinct vertical development from heights of 20,000 feet and upward to a low level of about 1,600 feet.

(*a*) Cumulus clouds are thick, the upper surface often dome-shaped but having a nearly horizontal base (fig. 13). Such clouds frequently exhibit strong contrasts of light and shade.

(*b*) Cumulonimbus types vary from cumulus clouds in that they are more massive in formation with pronounced vertical developments that sometimes rise in the form of mountains or towers, the upper parts having fibrous texture and often spreading out in the shape of an anvil (fig. 14).

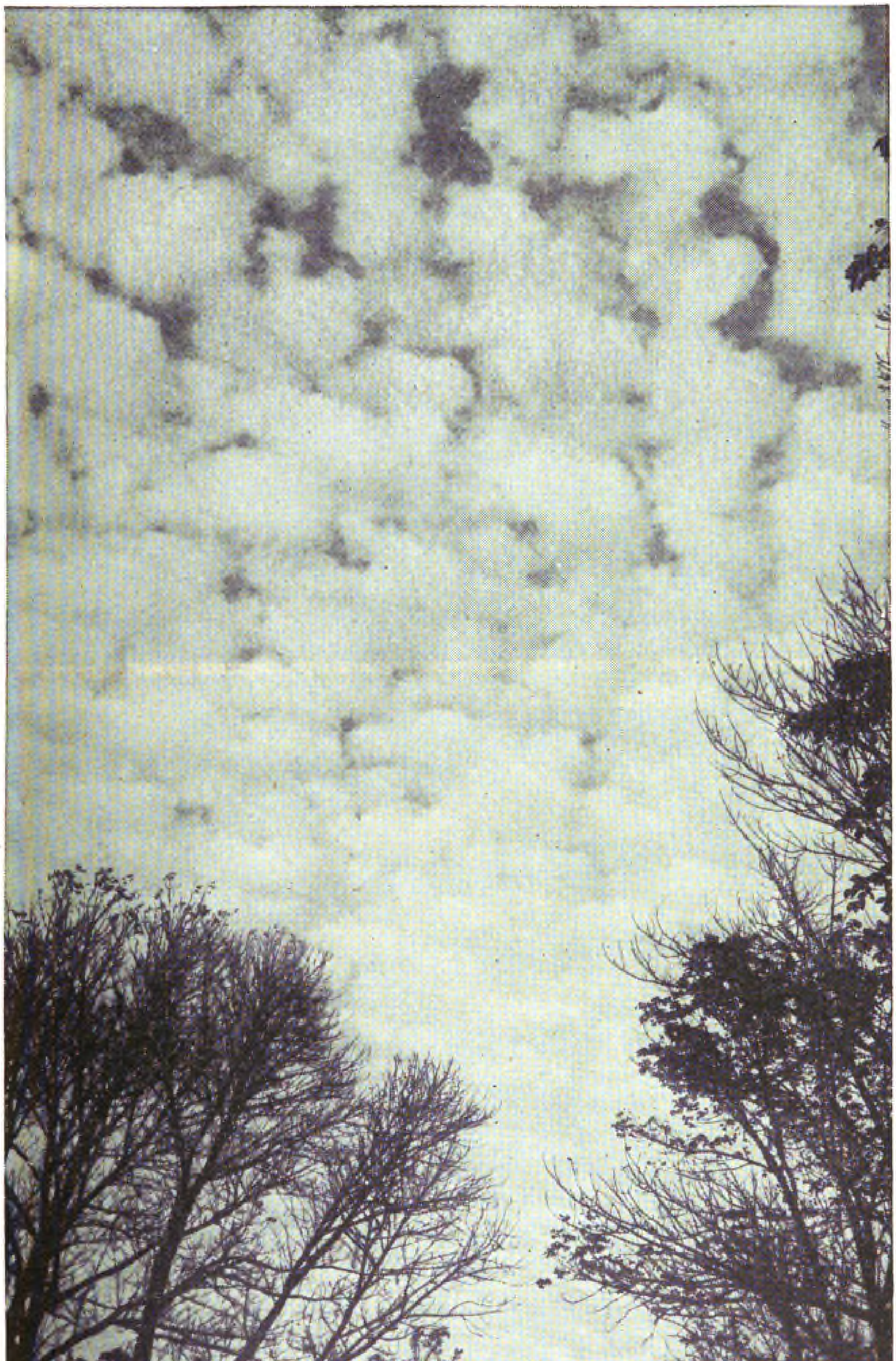


FIGURE 10.—Altocumulus, active form.

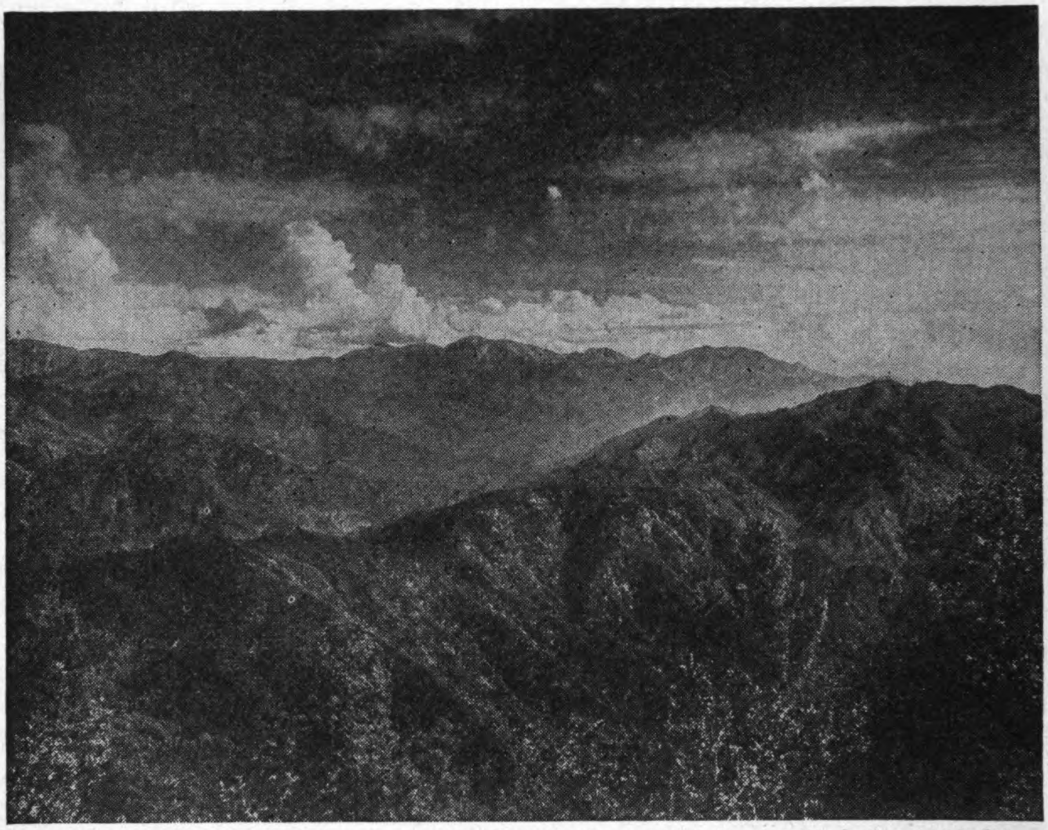


FIGURE 11.—Turreted altocumulus (castellatus) above and tall cumulus below (at left).

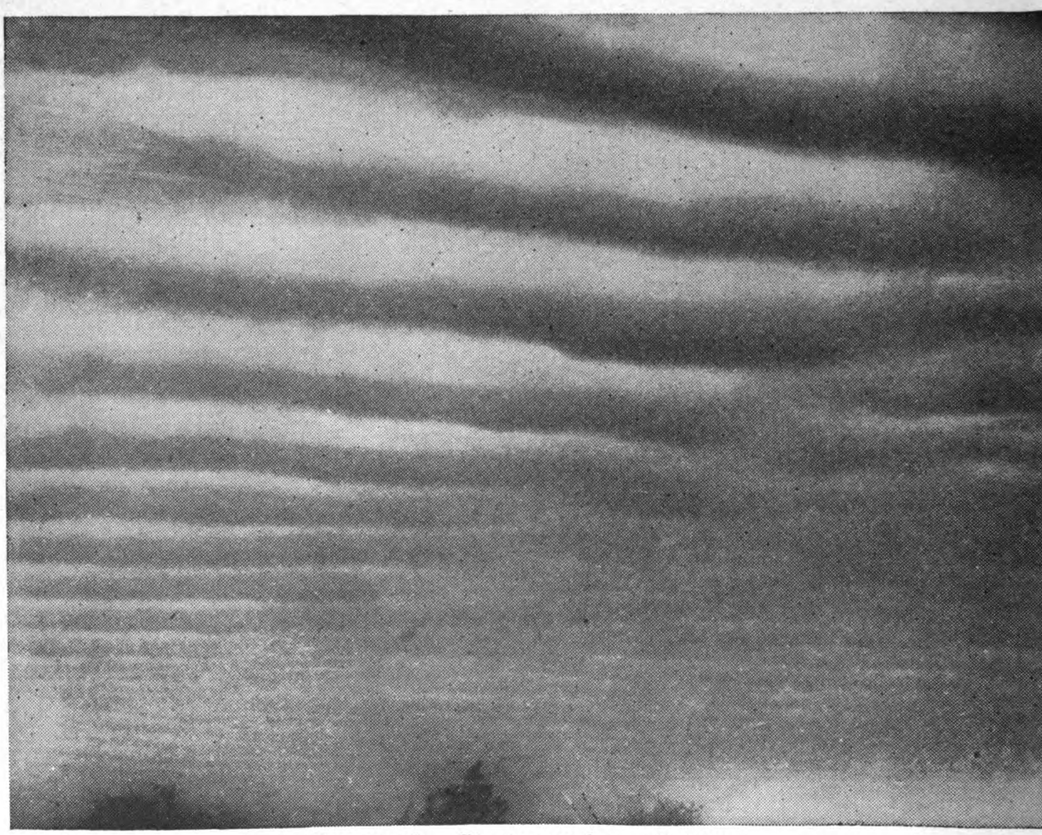


FIGURE 12.—Stratocumulus, roll type.

FIGURE 13.—Cumulus (fair weather) clouds.

FIGURE 14.—Large cumulus cloud growing into cumulonimbus.

e. Summary.—The foregoing general characteristics together with the figures will assist in identifying the several cloud formations. Frequently, however, one type will merge into another so as to make positive identification difficult unless the sky has been observed for a period long enough to witness the evolution of cloud formations (fig. 14). In general it should be noted that cirrus cirrocumulus, altocumulus, and cumulus clouds (which appear in detached masses covering only a portion of the sky) are "fair weather" clouds. On the other hand altostratus, stratus, stratocumulus, nimbostratus, and cumulonimbus clouds (forming more or less continuous layers often covering the entire sky) usually indicate precipitation.

6. Precipitation.—*a. Formation.*—Condensation of water vapor in the atmosphere causes precipitation. This takes various forms, depending upon the temperature at which condensation takes place and the conditions encountered as the particles fall through the air. The three principal forms are rain, snow, and hail.

(1) *Rain* refers specifically to moisture which has condensed at temperatures above the freezing point of water and which falls to the earth in its liquid state. Raindrops vary in diameter from 0.004 inch to 0.2 inch, large drops falling through quiet air breaking up into smaller drops as the rate of fall increases.

(2) *Snow and hail.*—Condensation occurring in the air after the temperature has fallen below 32° F. takes the form of snow. Hail consists of hard, rounded pellets of ice, or of ice and compact snow. Sleet (a variation of hail) consists of small particles of clear ice, originally formed as raindrops and later frozen as they fall through a layer of cold air.

b. Measurement.—The only measurement made of rainfall is of its amount; that is, the thickness of the layer of water which the rainfall would produce on a level surface provided none was lost. Two measurements are made of snowfall: direct measurement and measurement of depth when melted.

c. Rain gage.—The standard instrument for measuring precipitation is the United States Weather Bureau rain gage (fig. 15). It consists of a cylindrical can 8 inches in diameter by 20 inches high. It is provided with a funnel-shaped cover or receiver, with a beveled rim sharp on the inside and accurately circular in order to catch the exact amount of rain which falls on a definite area. The funnel opens into an inside brass cylinder which has just *one-tenth* the area of the outer can and funnel (2.53 inches). For a given length, the volume of the measuring tube is therefore just one-tenth of the volume of the receiver. The depth of the rainfall is accordingly magnified ten times. The depth of the water in the inner cylinder or measuring tube is determined by a measuring stick graduated in inches and tenths. Since measurements are read to tenths of an inch, the amount of precipitation is determined to hundreds of an inch.

d. Snowfall determination.—(1) Snow may be caught in the outer can of the rain gage when the funnel and inner cylinder have been

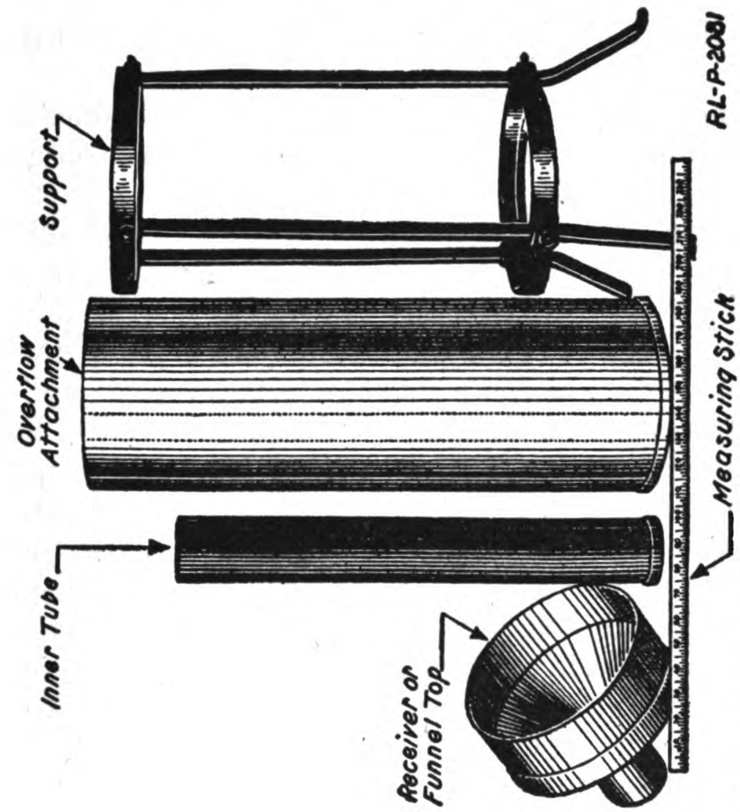
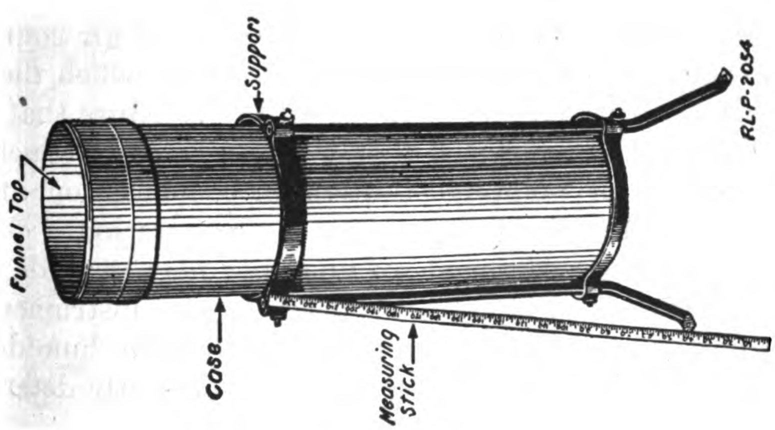


FIGURE 15.—Standard 8-inch rain gage.



removed. It is then melted down and poured into the measuring tube and the water equivalent thus determined. Another method is to invert the outer can and force it down through a layer of snow of average depth, melting the sample thus obtained and determining the water equivalent as before.

(2) The actual depth of snowfall may also be made by direct measurements at several representative points. The average of these measurements is then taken as the depth of the snow, recorded in inches and tenths.

(3) It requires from 6 to 30 inches of snow to produce an inch of water, depending upon the weight of the snow. The average is about 10 inches.

7. Humidity.—*a. General.*—The state of the atmosphere as regards moisture is referred to as humidity. If the air were absolutely dry, its humidity would be zero. As water content of the air increases, humidity rises. It is the humidity as much as the temperature which makes one uncomfortable on a hot, sultry day. A moist, hot day in summer is much more oppressive than a dry, hot day because the moisture in the atmosphere prevents free evaporation of perspiration. Cold is also more penetrating on a damp day than on a dry day because the moisture makes clothing a better conductor of heat and hence permits body heat to be dissipated faster.

b. Evaluation.—Humidity is referred to as absolute or relative.

(1) *Absolute* humidity refers to the actual quantity of moisture present in a given quantity of air. It may be expressed in grains per cubic foot or in grams per cubic meter.

(2) *Relative* humidity may be defined as the ratio of the actual amount of water vapor present in the atmosphere to the quantity which could be there *at the same temperature* if the atmosphere were completely saturated. Relative humidity is always expressed in percent. It is of more general interest in meteorology than absolute humidity.

c. Dew point.—If the temperature of a quantity of air containing moisture is lowered, a point will finally be reached at which the given quantity of air is saturated and contains all the moisture that it can hold. This temperature is termed the dew point. Any reduction in temperature below this point must result in condensation of some of the moisture into dew, frost, fog, cloud, or precipitation.

d. Measurements.—Measurements of humidity may be made by the psychrometer (wet and dry bulb thermometer). This instrument does not directly indicate either absolute humidity, relative humidity, or dew point; however, all three of these may be indirectly determined from its readings.

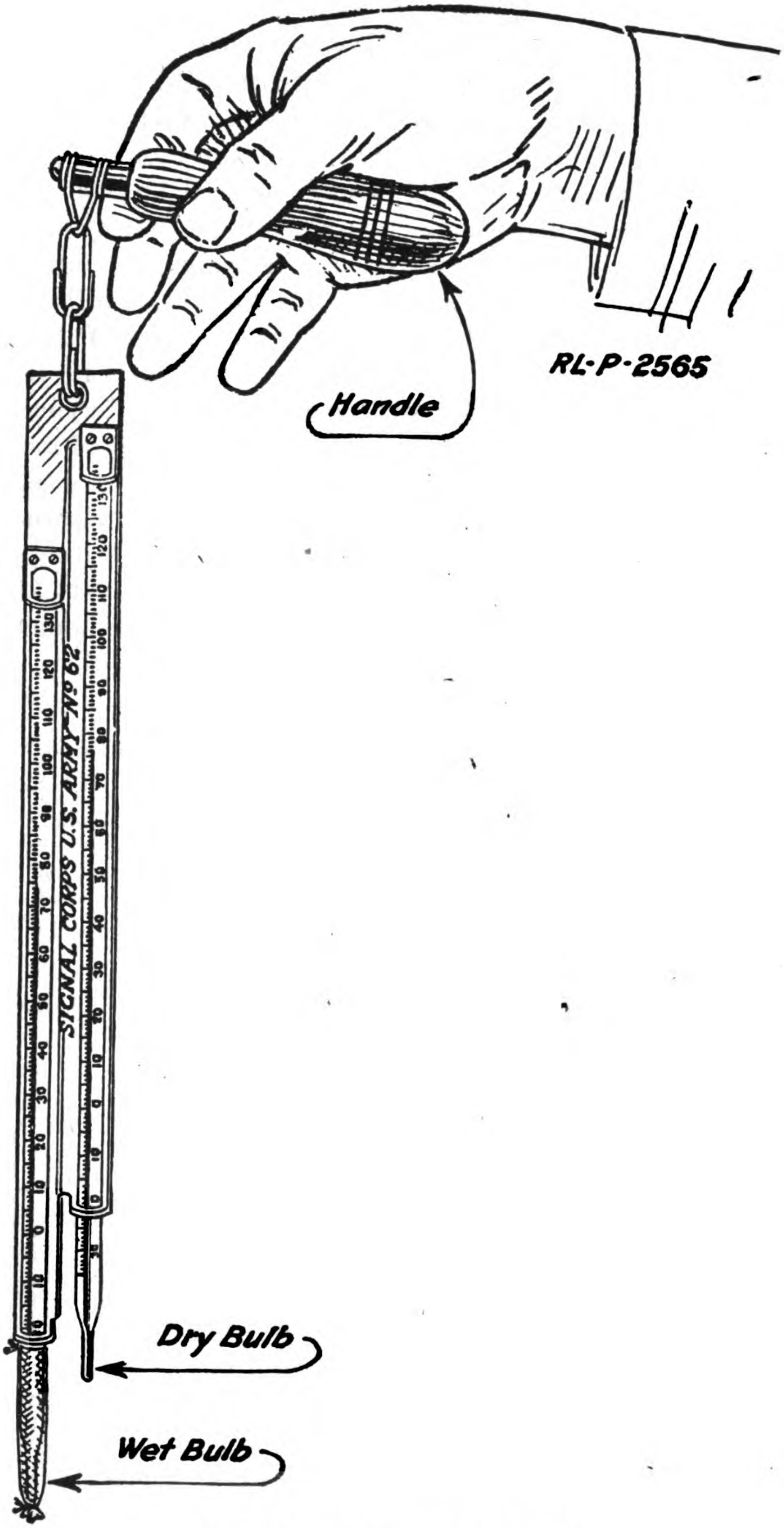


FIGURE 16.—Psychrometer (whirled).

(1) A portable instrument convenient for use in the field is known as the sling psychrometer (fig. 16) which consists of two identical mercurial thermometers attached to a frame and provided with a handle so that the instrument may be rapidly whirled. The bulb of one thermometer (referred to as the wet bulb thermometer) is covered with a linen jacket or wick. This wick-covered bulb is thoroughly saturated with water of the same temperature as that of the air to be measured. By a simple movement of the wrist, the instrument is whirled for about 1 minute. After reading the wet bulb thermometer, the operation is repeated until two identical readings of the wet bulb thermometer are obtained. At the same time the readings of the dry bulb thermometer are noted and recorded. The difference between the two readings is roughly proportional to the amount of moisture in the air. (See table II.)

(2) The following table gives relative humidity in terms of air temperature in comparison to cooling of the wet bulb thermometer. It will be seen for example that the relative humidity is 55 percent when the air temperature is 70° and the wet bulb thermometer reads 10° lower.

TABLE II.—Psychrometric table

[The relation between dry bulb readings and cooling of the wet bulb thermometer approximates relative humidity. Barometric pressure: 30 inches.]

Air temperature °F. (dry bulb reading)	Depression of wet bulb thermometer under dry bulb reading													
	1°	2°	3°	4°	6°	8°	10°	12°	14°	16°	18°	20°	25°	30°
0	67	33	1											
5	73	46	20											
10	78	56	34	13										
15	82	64	46	29										
20	85	70	55	40	12									
25	87	74	62	49	25	1								
30	89	78	67	56	36	16								
35	91	81	72	63	45	27	10							
40	92	83	75	68	52	37	22	7						
45	93	86	78	71	57	44	31	18	6					
50	93	87	80	74	61	49	38	27	16	5				
55	94	88	82	76	65	54	43	33	23	14	5			
60	94	89	83	78	68	58	48	39	30	21	13	5		
65	95	90	85	80	70	61	52	44	35	27	20	12		
70	95	90	86	81	72	64	55	48	40	33	25	19	3	
75	96	91	86	82	74	66	58	51	44	37	30	24	9	
80	96	91	87	83	75	68	61	54	47	41	35	29	15	3
85	96	92	88	84	76	70	63	56	50	44	38	32	20	8
90	96	92	89	85	78	71	65	58	52	47	41	36	24	13
95	96	93	89	86	79	72	66	60	54	49	44	38	27	17
100	96	93	89	86	80	73	68	62	56	51	46	41	30	21

8. Pressure.—*a. Definition.*—The atmosphere has mass and is acted upon by gravity; thus it possesses weight and exerts a downward pressure. The weight of the column of air extending to the limits of the atmosphere above the observing station is the atmospheric pressure at that point.

b. Variability.—Since the atmosphere is a gas, the pressure (as in the case of all fluids) is exerted in all directions. If there were no temperature differences, and thus no winds, the pressure would be the same at all points on a level surface. This is not the case, however; the pressure is different at different points at the same level and is also constantly changing at the same station. It is thus necessary to have instruments for determining the pressure of the atmosphere and its variations. The most important of these are the mercurial barometer and the aneroid barometer.

c. Mercurial barometer.—This instrument consists essentially of a glass tube more than 34 inches long, filled with mercury, and inverted over a vessel containing mercury (the cistern). The whole is inclosed in a protective brass case which is cut away at the top, exposing the glass tube containing mercury. A scale and vernier are provided for reading the height of mercury in the tube. To this reading certain corrections are ordinarily applied to compensate for instrumental errors and also to translate the station pressure into pressure at mean sea level.

d. Aneroid barometer (fig. 17).—This device is fluidless and operates mechanically. It consists essentially of a vacuum box about 1½ inches in diameter and ¼ inch thick made of german silver with corrugated top and bottom. The sealed box is kept from collapsing by a strong leaf spring. When the pressure increases, the box is pressed together against the action of the spring; and as the pressure decreases, the elasticity of the spring causes the box to expand slightly. These small motions are magnified by a system of levers attached to a pointer which moves over a dial, graduated in inches corresponding to the mercurial barometer. The instrument is less accurate than the mercurial barometer. Its advantages are portability, cheapness, and convenience in reading.

9. Meteorological message.—*a. Purpose.*—This is a conventional arrangement for transmitting weather data, particularly for use of artillery. In addition to other data, the message gives latest observations as to wind direction, wind velocity, and temperature. This message is sent in a simple letter and figure code which should be understood by all chemical and gas officers.

b. Construction.—The typical message includes one line of letters followed by several lines of figures.

(1) The first letter of the lettered line, M, denotes a meteorological message. The two following letters designate the sending station. These three letters are usually repeated.

(2) The first line of (five) figures may commence with either 2 or 3. The figure 3 indicates that the message is intended for artillery; such messages are applicable also to chemical observers. The two succeeding figures denote the altitude of the sending station in hundreds of feet. The last two figures indicate the temperature in whole degrees Fahrenheit.

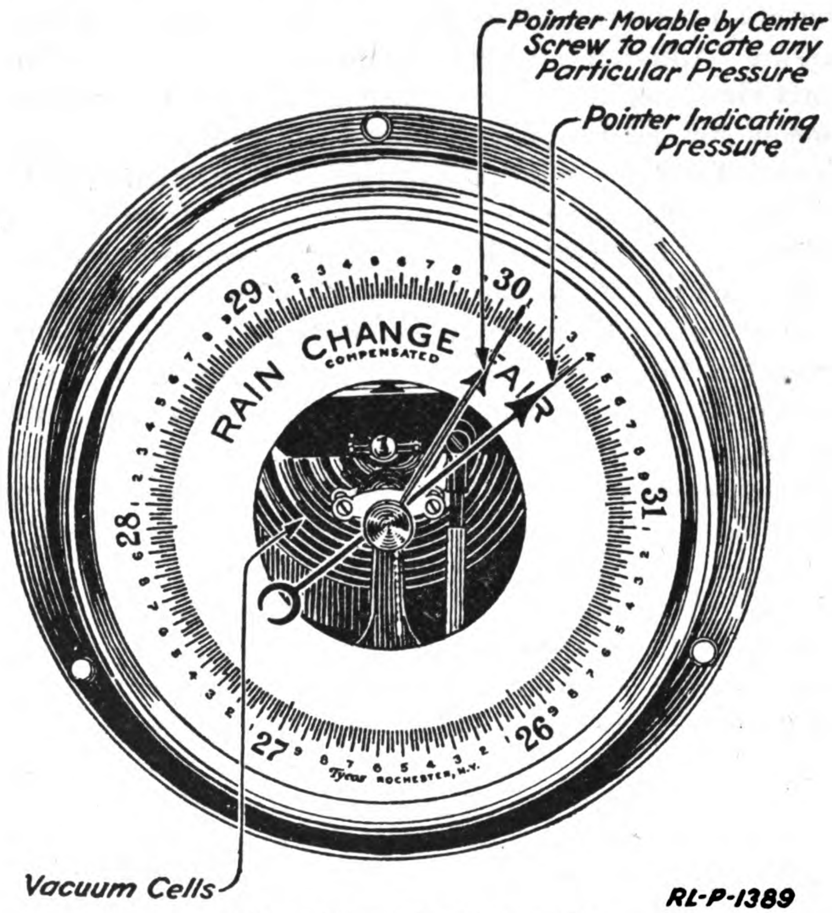


FIGURE 17.—Aneroid barometer.

(3) The second line of figures gives surface meteorological data as is indicated by the first figure, 0. The second and third figures of the group indicate the direction from which the wind is blowing on a basis of 64 points to the circle. (See par. 3*d*.) The fourth and fifth figures of the group indicate the speed of the wind in miles per hour. The sixth and seventh figures indicate relative ballistic density.

(4) Subsequent lines of figures give for various altitudes similar data that are useful principally in connection with artillery fire.

Section II

EFFECT OF WEATHER ON CHEMICAL AGENTS

10. Wind.—*a.* On persistent agents the effect of wind is limited, since these agents are dispersed on the ground and vegetation in liquid form. However, during high winds, vapors are continuously carried away as evaporation takes place while during periods of calm, concentrations of the gas are built up. Therefore, on account of danger of casualties from gas when blown back upon friendly troops, persistent agents are not fired in large quantities on areas within 1,000 yards of the position of such troops.

b. Nonpersistent agents, being released in gaseous state, are materially affected by wind.

(1) Wind direction is important when cylinders or irritant candles are employed. In such cases, the direction of the wind must be such that it will carry the agent to the target but not onto any portion of the user's own position. The same consideration applies when projector or mortar shell are to be impacted close to friendly troops. Where nonpersistent chemicals are discharged on distant areas, the wind direction can usually be disregarded.

(2) Wind velocities lower than 3 miles per hour preclude use of cylinders and irritant candles because of the variability of such winds. When chemicals are disseminated by artillery, mortars, projectors, or aircraft, this lower limit of wind velocity need not be considered unless the target is very close to friendly lines. On the other hand, wind velocity in excess of 12 miles per hour tears clouds apart and quickly dissipates concentrations of gas. The higher the wind velocity, the faster a cloud will pass over the target, the shorter the time of exposure, and the less effective is the gas. With high wind velocities the cloud may also be so torn apart that groups of men in the target area will be left in gas-free "islands" and escape the effect of the gas entirely.

(3) Steadiness both in direction and velocity of wind is requisite to effective nonpersistent gas operations.

c. Smoke, like nonpersistent gas, requires favoring winds. Velocities in excess of 12 miles per hour are unsatisfactory. Steadiness also is important since it tends to prevent the occurrence of gaps in the smoke screen. Rising air currents (convection currents) lift smoke clouds high in the air and often prevent satisfactory screening.

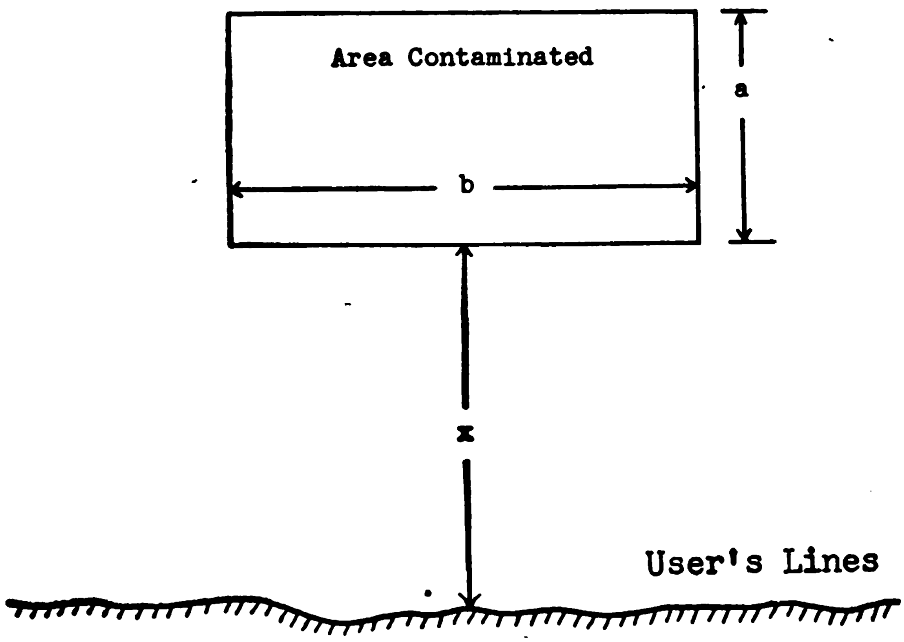


FIGURE 18.—Safety limits for vesicant agents.

Let x=Safe distance from user's lines to near edge of contaminated area
a=Depth of area in direction of fire
b=Width of area
Then $x=a+\frac{1}{2}b$

This equation does not apply in the case of gas mine barriers less than 500 yards in depth; however, such barriers ordinarily will not be placed closer than 1,000 yards to friendly troops.

DISCUSSION

The time of day, direction and velocity of wind, topography, temperature of air and ground, size of area, amount of agent fired, and length of time consumed in firing determine the vapor concentration set up on the downwind edge of a mustard-gas target and the concentration that will exist at various distances downwind. The foregoing guide is given for average conditions. If the prevailing wind is blowing from 6 o'clock, the safe distance may be reduced.

If there is a sharp valley from the target to the user's lines, the safe distance must be increased when the prevailing wind is blowing toward these lines from the target area.

11. Lateral spread.—*a. Extent.*—Even a reasonably steady wind shifts constantly back and forth on both sides of the *mean* direction. This fact must be taken into consideration when studying the effect of wind on chemical operations because this action causes a lateral spread of gas or smoke clouds. From observation of the travel of these clouds it has been determined that such a lateral spread extends from a minimum of 10 percent of the distance traveled to as much as 50 percent under extreme conditions.

b. Danger areas.—Since as a general rule a cloud of gas or smoke will spread 15° (270 mils) on each side of the mean line of wind direction from the point of release, any position along the path of

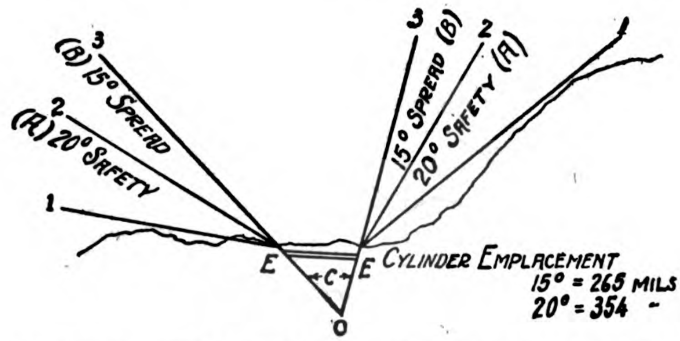


FIGURE 19.—Wind limits for cylinders and irritant candles.

DIRECTIONS

1. Plot front line of friendly troops for a distance of 6 miles on each side of the emplacement.
2. Plot to scale the cylinder or candle emplacement (*E*—*E'*).
3. From the ends of the emplacement *E*—*E'* draw the lines *E*—1 and *E'*—1' to clear all salients in friendly lines for a distance of 6 miles.
4. Draw the lines *E*—2 and *E'*—2' making angles of 360 mils (20°) with the lines *E*—1 and *E'*—1'. The angles *A* and *A'* are the safety angles.
5. Draw the lines *E*—3 and *E'*—3' making angles of 270 mils (15°) with the lines *E*—2 and *E'*—2'. Angles *B* and *B'* are the angles of spread.
6. Angle *C*, remaining between the lines 3—*O*—3', gives the *wind limits* for the operation. If the direction of the wind plotted through *O* (the point of release of the gas) is toward the hostile position and between the lines *O*—3 and *O*—3', it is a suitable wind; if otherwise, the operation must be postponed.

Angles *A* and *A'* = Safety angles = 360 mils = (20°)
Angles *B* and *B'* = Angles of spread = 270 mils = (15°)
Angle *C* = Wind limit angle

a gas cloud that is within 15° of this line is to be regarded as dangerous. Consequently in determining danger areas for cloud attacks with candles or cylinders, a suitable safety zone must be established.

c. Persistent agents may be fired with the wind blowing in any direction and without restrictions as to velocity provided the area fired upon meets certain safety requirements as to distance from friendly troops. A general guide for the use of mustard gas or other highly persistent vesicants is shown in figure 18.

d. Nonpersistent agents being largely dependent on wind conditions, it is necessary to establish definite rules governing their use with respect to wind velocity and direction. Wind direction limits are prescribed primarily in the interest of safety to friendly troops, while wind velocity limits relate to the technical effectiveness of the operation. Safety precautions require wind limits for the portable cylinder,

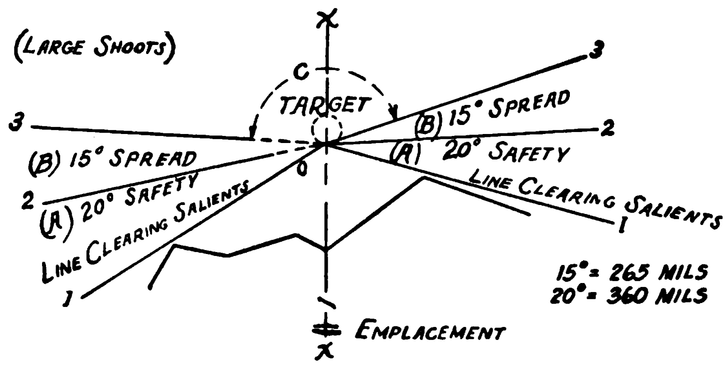


FIGURE 20.—Wind limits for projectors and mortars (wind velocity 3 to 12 mph).

DIRECTIONS

1. Plot front line of friendly troops for a distance of 3 miles on each side of the emplacement.
2. Plot the projector or mortar emplacement.
3. Plot to scale the target *T*.
4. Draw the line *X—X''* through the center of the emplacement and the target. From the intersection *O* of the line of fire *X—X'* and the near edge of the target draw the lines *O*—1 and *O*—1' to clear all salients in friendly lines for a distance of 3 miles.
5. Draw the lines *O*—2 and *O*—2' making angles of 360 mils (20°) with the lines *O*—1 and *O*—1'. Angles *A* and *A'* are the safety angles.
6. Draw the lines *O*—3' and *O*—3' making angles of 270 mils (15°) with the lines *O*—2 and *O*—2'. Angles *B* and *B'* are the angles of spread.
7. Angle *C* remaining between the lines 3 and 3' gives the wind limits for the operation. If the direction of the wind plotted through *O* is from the friendly position toward the enemy and between the lines *O*—3 and *O*—3', it is a suitable wind; if otherwise, the operation must be postponed.

Angles *A* and *A'* =Safety angle=360 mils=(20°)
Angles *B* and *B'* =Angle of spread=270 mils=(15°)
Angle *C*=Wind limit angle.

the irritant smoke candle, the livens projector, and the 4-inch chemical mortar. They are not required for artillery weapons nor for the 4.2-inch chemical mortar unless the range is less than 1,200 yards. Decision whether nonpersistent agents may be used under prevailing wind conditions without endangering friendly troops is determined by constructing diagrams as shown in figures 19 and 20.

12. Temperature.—*a. Persistent agents.*—Temperature is an important consideration in the use of persistent vesicant agents, since upon it largely depends the vapor concentration developed by the agent. In low temperatures sufficient vapor is not given off by these agents to cause blistering, although eye casualties may result; and the agents in liquid or solid form will still seriously injure anyone coming into actual contact with them. Hot weather without rising air currents is most effective for persistent chemicals.

b. Nonpersistent agents.—High temperatures accelerate the dissipation of nonpersistent agents. They cause the air near the ground to become heated, creating a tendency to raise the surface air which is displaced by fresh, cooler air. These convection currents will cause a gas cloud to rise rapidly and to become diluted. Such currents are especially prevalent in the afternoon over dry or plowed ground that is free from vegetation. Yet on days of low temperature, the lower layers of air remain cool and there is no tendency for an overturning of the atmosphere. Since high temperatures usually occur on bright, sunny days, these are generally unfavorable for nonpersistent gas attacks. The cooler parts of the day, especially between midnight and dawn, are the more favorable.

c. Smoke.—Temperature has very little effect on screening smokes insofar as the formation of the original cloud is concerned. The cloud once formed is affected in the same way as clouds of nonpersistent gas.

d. Temperature differences during the daytime over a limited area are not great unless there is marked variation in the topography or soil. At night the layer of air next to the ground grows colder and denser, flowing like water into valleys and places of lower elevation. If the wind is insufficient to remove these pockets of cold air then marked differences in temperature will be experienced. But when wind velocity remains higher than 3 miles per hour, cold air pockets are quickly moved and mixed with air at other points, thus equalizing temperature.

e. At night, particularly on calm nights, the tendency of surface air to cool and flow into valleys and depressions will cause such localities to accumulate dangerous concentrations of toxic agents.

13. Clouds.—No direct effect on any chemical agent can be attributed to clouds. Their effects are indirectly noticed, however, through their influence on temperature. Clouds shut off sun rays and thus shield the surface of the earth from heat. A clear, hot day favors production of convection currents which cause rapid rise of chemicals from the ground. A sunshiny day, then, is unfavorable to the success of chemical attacks, whereas a cloudy day is favorable.

14. Precipitation.—*a. Persistent agents.*—The effect of precipitation on persistent agents depends upon the quantity and kind of precipitation. Heavy rain is unfavorable to the use of any chemical agent. Mustard gas does not hydrolyze to any great extent, but lewisite does readily hydrolyze, forming toxic solids.

b. Nonpersistent agents.—The effect of precipitation on nonpersistent agents is more pronounced. The concentration of clouds of nonpersistent agents is immediately lowered by rain, due to washing out from the air. Snow and hail to a lesser extent act in the same way. Phosgene is readily hydrolyzed, forming products that are ordinarily not toxic in the field. Most other nonpersistent agents hydrolyze slowly.

c. Irritant smokes are not hydrolyzed; light rains and mists therefore are to some extent favorable since they tend to hide the characteristic color of the chemical cloud. However, heavy rains wash such agents from the air in the same way that they clear the air of other dust particles. Heavy snow will also remove toxic smokes from the air.

d. Screening smokes are favored by light precipitation, fogs, and mists since the necessary water is furnished for the hydrolysis reaction. Fog, light rain, or mist restrict visibility and reduce the amount of screening smoke necessary. This is due to the obscuring power of the mist and to the increased efficiency of the smoke in the damp air. But heavy precipitation tends to beat the smoke cloud down and wash it from the atmosphere.

15. Humidity.—*a. Effects on gases.*—Moisture in the air has no appreciable effect on the persistent agents regardless of how they may be released. Nonpersistent agents are hydrolyzed to some extent by water vapor; however, the extent of this action will depend on the temperature and the amount of water vapor in the air. Thus the *front* of a phosgene cloud moving through an extremely damp atmosphere will have a lower content of phosgene than the following portions of the cloud. Humidity has no effect on irritant smokes since these hydrolyze very slowly.

b. High humidity is favorable for screening smokes because their production is caused or aided by the reaction of the chemical with water vapor. If the humidity is low and other conditions are favorable, a satisfactory screen will require the use of a greater quantity of agent than when the humidity is high.

16. Atmospheric pressure.—Except as it controls vertical air currents and winds, atmospheric pressure has little effect on chemical warfare.

a. Rising air currents are unfavorable since they cause gas clouds to be carried upward and rise over the heads of troops. These currents are often formed when the pressure is low, and they tend to follow the center of the low area.

b. Descending air currents tend to carry chemicals downward, thus holding the cloud close to the surface of the earth where it is most effective. These currents are characteristic of high pressure areas.

c. General effects.—Following is a general classification of the effects of weather elements on the use of chemical agents:

TABLE III.—General effects of weather

	Favorable for chemicals	Satisfactory for chemicals	Unfavorable for chemicals
Wind:			
Gas projectiles	Steady: 0–4 mph	Slightly shifting: 4–9 mph.	Variable or over 9 mph.
Smoke	Steady: 5–8 mph	Slightly shifting: 8–12 mph.	Variable or over 12 mph.
Temperature	Ground cooler than air.	Air-ground temperature equal.	Ground warmer than air.[1]
Precipitation	No rain	Light rain	Heavy rain.
Clouds	Overcast	Partly overcast	Clear.
Humidity:			
Nonpersistent gas.			
Persistent gas	High [2]		
Screening smoke	High	Moderate	Low.
Pressure	High	Moderate	Low.

[1] Temperature below 50° F. is unfavorable for use of HS and CNS.
[2] Although humidity has no direct effect on the use of HS, this agent is more effective on *moist* skin.

SECTION III

WEATHER FORECASTING

Paragraph

17. Scope.—The treatment of weather forecasting in this manual is necessarily elementary. However, if the methods herein outlined are practiced daily with the weather maps issued by the United States Weather Bureau, a fair degree of accuracy can soon be acquired in forecasting weather from maps. This manual should therefore be studied in conjunction with weather maps. Familiarity with the elements of forecasting thus attained will prove of value in predicting weather changes in the field even when general forecasts are not available.

18. Value.—To the chemical officer, this ability is important, for while official weather forecasts are made by experts, these forecasts are general in nature, cover relatively long periods of time, and must be interpreted in the light of local conditions. A qualified chemical officer can often predict a coming change in the wind or other weather elements to within an hour or two. This may be very valuable from a tactical standpoint in indicating the approximate hour of the launching of an expected gas attack.

19. Factors in forecasting.—*a. Fundamental.*—From a study of weather maps, two fundamentals stand out: weather travels, and the character of the weather which is largely determined by atmospheric pressure distribution, that is, whether the locality is under the influence of a high-pressure area or a low-pressure area. The latter two formations, commonly known as "highs" and "lows," exert the chief influence on weather.

b. Local.—Factors of local influence are not of great importance except in restricted areas. For example, in forecasting weather for New York State the presence of the Great Lakes plays an important part, particularly in the late autumn and early winter when these water areas are still much warmer than the land and are putting large quantities of moisture into the atmosphere.

20. Low pressure area.—*a. Form.*—An area of low barometric pressure is characterized by spirally inflowing winds which turn counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. The general form of such an area is indicated in figure 21. This is typical only. Considerable variation from this form may be encountered in weather maps.

b. Isobars.—The black lines forming the ovals in figure 21 are called isobars. These lines are drawn to connect all points having the same atmospheric pressure. The black numbers appearing on the isobars show this pressure in inches of mercury. The central pressure averages about 29.6 inches, although this may vary from just under 30 to below 28 inches in some cases. The isobars are usually oval in form, the ratio of the two axes being 1.9 to 1, with the direction of the longer axis usually northeast-southwest.

c. Wind movement.—Winds blow spirally into the low in a counterclockwise direction. The wind direction makes an angle with the isobaric lines which is greatest in the northeast quadrant where it averages from 30° to 40°, and is least in the southwest quadrant where

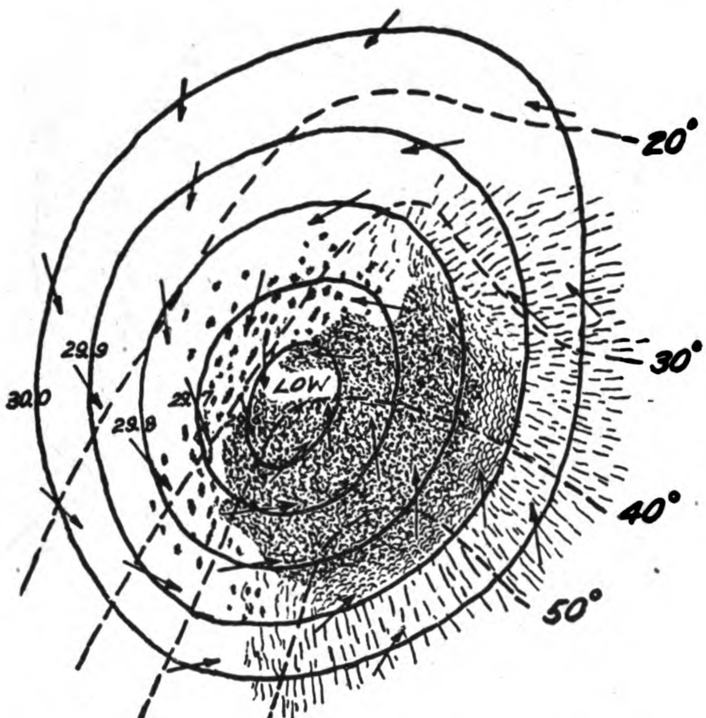


FIGURE 21.—Distribution of the meteorological elements about a typical low.

its value is from 15° to 25°. The wind velocity is usually *moderate;* only in rare cases does it become destructive.

d. Clouds.—The shaded portions of the diagram represent cloudy areas. In winter there is a large, continuous storm cloud area mostly in the southeast quadrant of the typical low, and precipitation falls steadily over this area. In summer this storm cloud area is usually lacking; in its place are some forms of cirrus clouds so that whenever local convection takes place a thunder shower is the result.

e. Temperature.—The broken lines in figure 21 are *isotherms* or lines connecting places having the same temperature. There is a marked rise of temperature on the south and east side of the low pressure area where the winds blow from a southerly quarter, and a decided drop in temperature on the west side where the winds blow from a northerly quarter.

f. Wind shift line.—About 14 percent of all low pressure areas moving across the United States have their southern quadrants

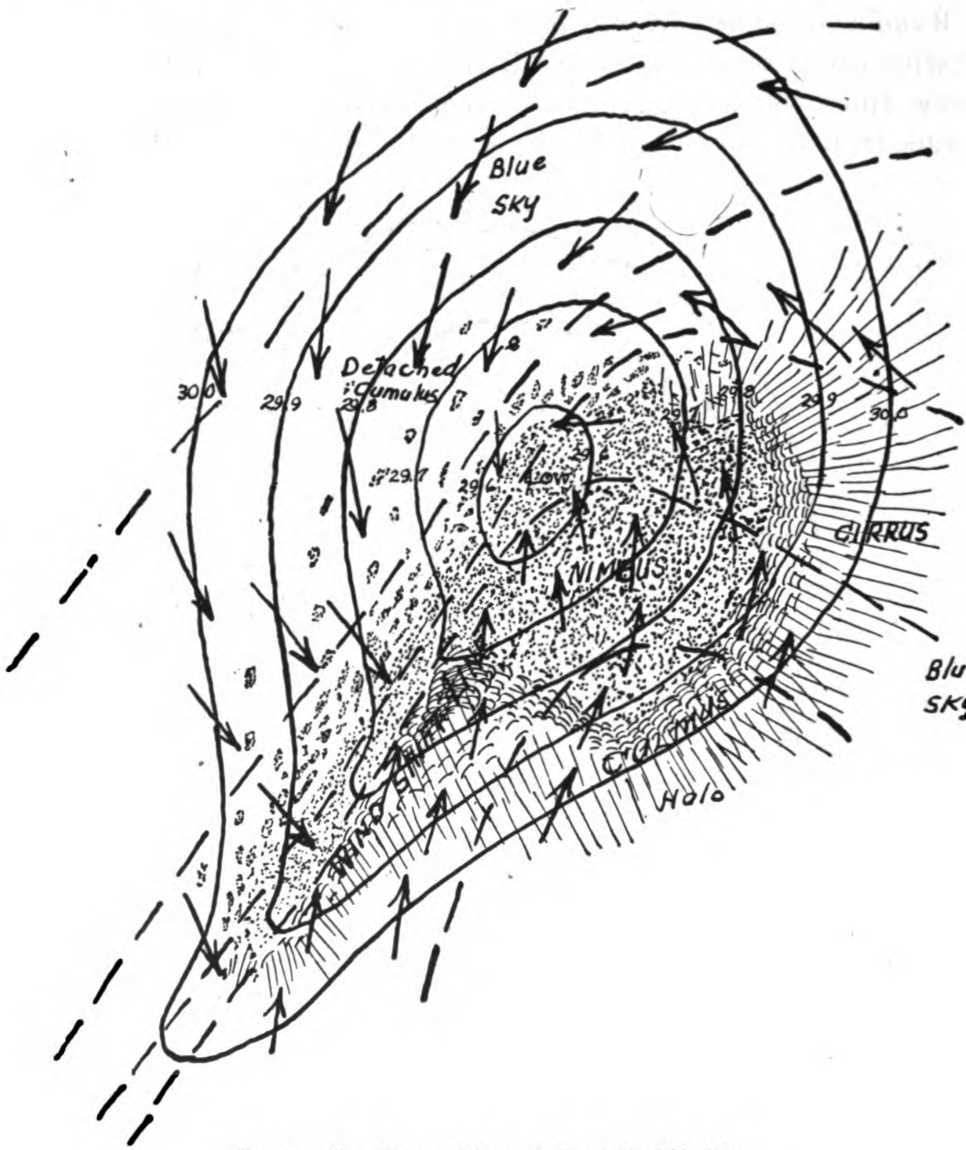


FIGURE 22.—Low with typical wind shift line.

extended in a V shape instead of being oval (fig. 22). These V-shaped depressions usually have a well-marked *wind shift line* running along the tips of the V's to the center of the low and then out to the northeastward. From points east of this line the warm air is moving in from the south with low velocity. From points west of the line, strong colder winds are blowing from the northwest. Along this line the air is very turbulent with the temperature falling rapidly as one moves toward the west.

21. Fronts.—Weather maps published by the Department of Commerce have recently been changed. The weather information—behavior and characteristics—as reviewed previously is still good for the discussion of local forecasting. However, the following may be noted with reference to the use of the new form of weather map as now distributed:

a. The *cold front* now indicated on the weather map is the old *wind shift line.*

b. The *warm front* is the advance of a body of warm air which is being forced to rise by the cold front.

c. Each low as it forms has both a warm front and a cold front.

d. When a cold front overtakes a warm front the result is called an *occluded front.*

e. The occluded front is the same thing as the (typical) low or the extra tropical cyclone. The occluded front is a dying depression and continues to travel as a low.

f. A boundary between two air masses which shows little tendency at the time of observation to advance into either the warm or the cold air areas is called a *stationary front.*

g. The fronts as shown on the weather map now travel in much the same way as the lows which are described in paragraph 24. The lows tend to travel in the direction of the isobars of the warm sector of the depression. (See fig. 23.)

22. High-pressure area.—*a. Form.*—An area of high barometric pressure is marked by spirally *outflowing* winds which turn clockwise in the Northern Hemisphere, typically as shown by figure 24.

b. Characteristic features.—In a high pressure area, wind velocity is usually moderate and calms are frequent. Few clouds are seen and precipitation is normally slight. The whole formation may range from several hundred to several thousand miles in diameter, usually averaging about 2,000 miles. The isobars are often irregular in form, and in the center there may be several highs instead of a single peak of high pressure. The more usual form however is the oval with the longer axis extending generally northeast-southwest, north-south, or northwest-southeast. The central pressure averages about 30.6 inches, although this varies at times from slightly over 30 to more than 31 inches.

c. Wind.—The wind direction makes an angle with the isobars which is least in the northeast portion where it averages from 20° to 30°, and is greatest in the southwest portion where it averages from

60° to 70°. Wind velocity decreases toward the center where calms are frequent, particularly at night.

d. Temperature.—As shown by the isotherms in figure 24, there is a decided drop in temperature in the northeast portion of high-pressure

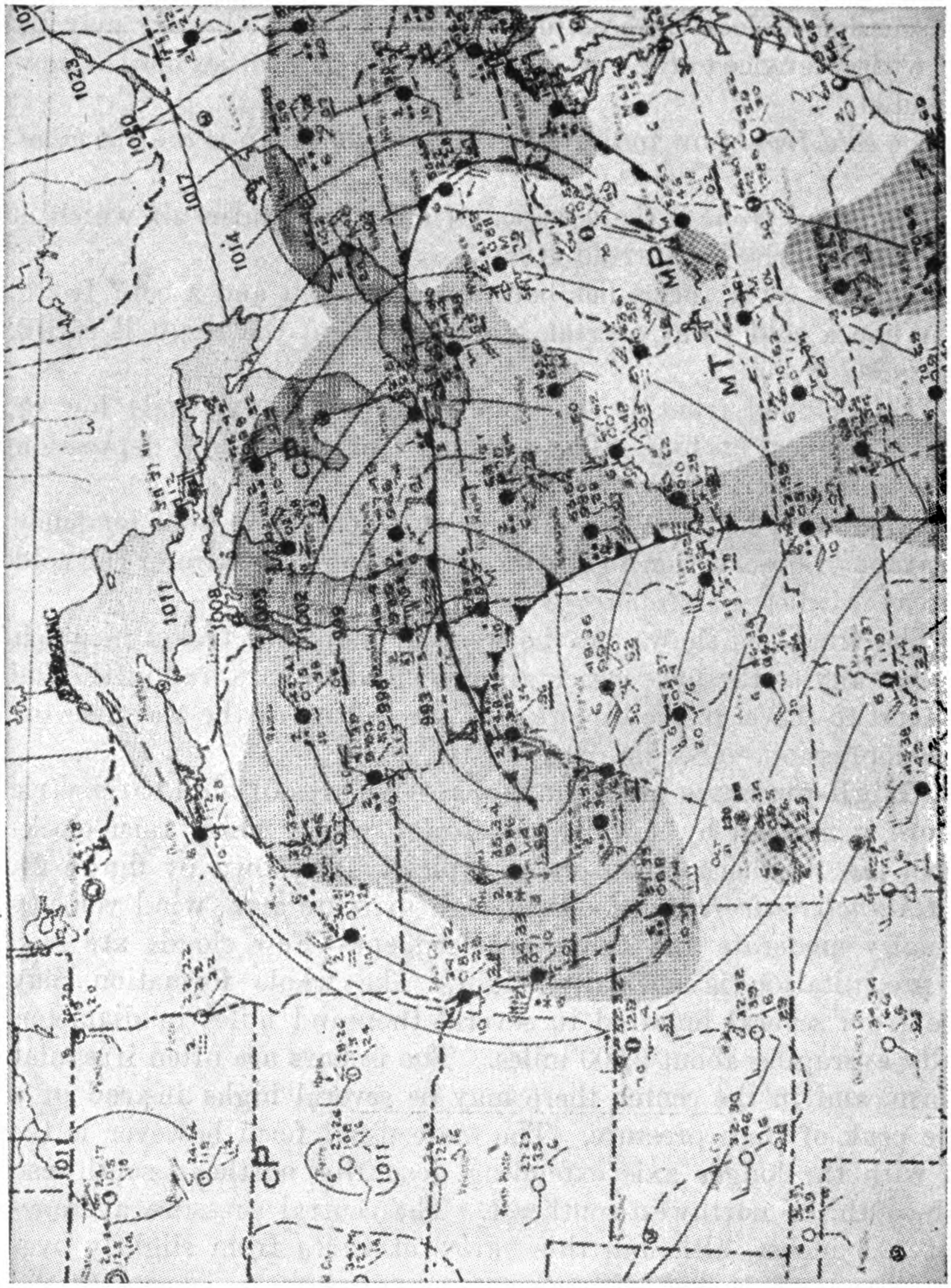


FIGURE 23.—Low with typical fronts.

areas where winds are from the north, and a decided rise in temperature in the southwest and west portions where winds are from the south.

23. Reciprocal effect of highs and lows.—When studying any pressure area, neighboring highs and lows which are near enough to exert an influence should also be considered. These will sometimes change or control the speed and direction of the dominating formation, and will affect wind directions and velocities. For example, if a low is following a high across the country, the high may affect

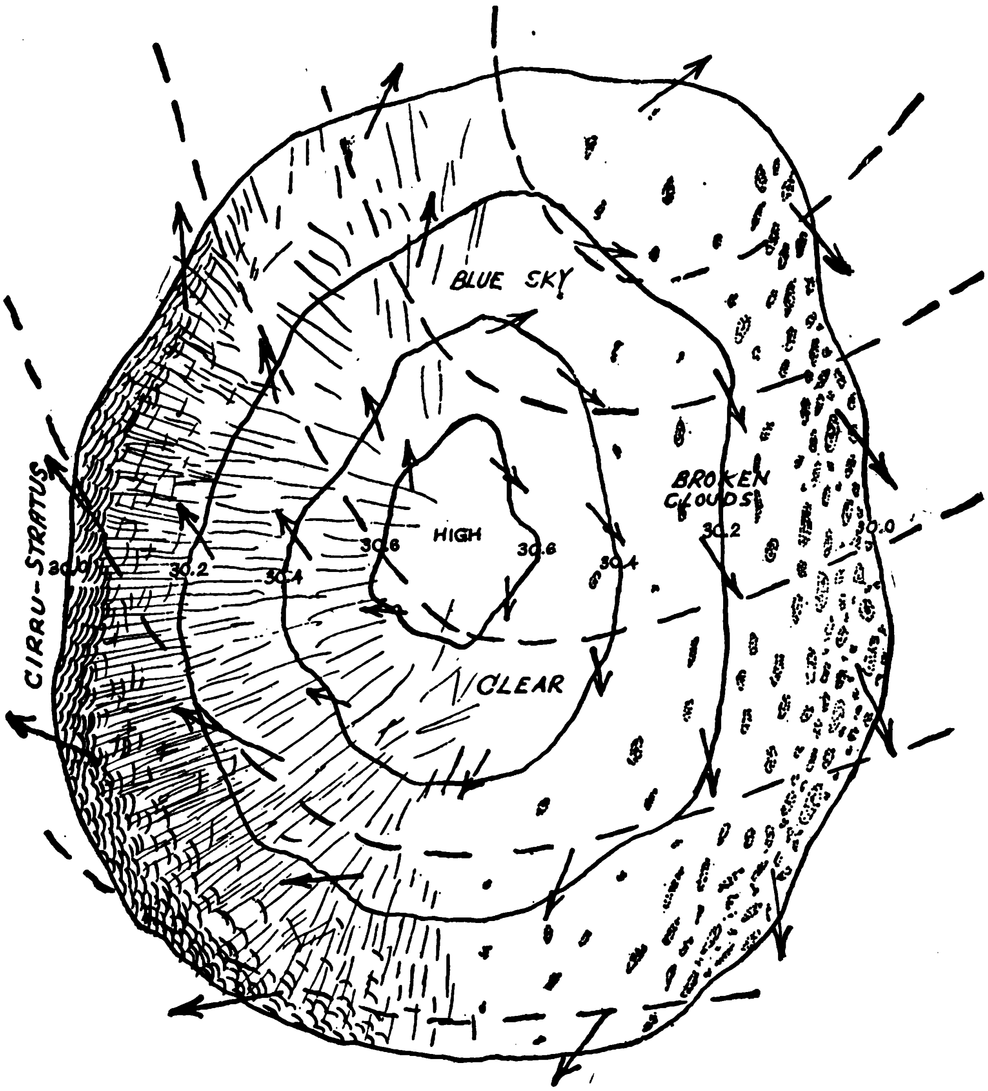


FIGURE 24.—Distribution of the meteorological elements about a typical high.

the low by holding it back or may deflect it to the northeast or southeast.

24. Movements of highs and lows.—*a. General direction.*—Highs and lows may originate at any place over land or sea. They follow one another across the United States, generally from west to east, but have no fixed route. They sometimes travel southeast, sometimes northeast. They often change direction, but most of them leave the United States in the vicinity of the St. Lawrence Valley. They may travel at any speed, increasing or diminishing velocity from day to day.

b. Origin of lows.—(1) Low-pressure areas not originating in the United States will enter from the northwest, west, or from the south.

(2) Those entering from the northwest move generally southeast until crossing the Mississippi River, then recurve toward the northeast.

(3) Those entering from the south and west also move northeast after crossing the Mississippi.

(4) In the late summer and early autumn, hurricane storms occasionally move up from the Tropics. They are smaller in area and more intense and energetic than ordinary lows. The movement of translation of these storms is slow, while the winds within them are generally violent with torrential rainfall. These storms generally move northwest until on a line with the northern boundary of Florida, when they recurve to the northeast, losing most of their intensity.

c. Behavior.—Lows tend to move toward the areas of greatest rainfall during the preceding 24 hours. Those near each other tend to come together and coalesce. However, highs and lows repel one another. If a high is directly in the path of an oncoming low, the low is likely to be retarded or deflected from its track.

d. Velocity of lows.—A low may rush across the country covering 1,600 or 1,700 miles in a day; or it may loiter for a day or two, drifting but 100 or 200 miles in that time. The following general rules are helpful in predicting velocity:

(1) The best guide to velocity and direction of travel of a low is its travel during the last 24 hours, since the tendency is to proceed in the same direction at the same velocity.

(2) If the low has just appeared, it may be assumed that it will travel about 600 miles per day in summer, and 850 miles per day in winter. It will tend to follow the track of the last previous low.

(3) If a low is slow-moving, it tends to retain that characteristic throughout its existence.

(4) Lows tend to move faster as the barometric pressure decreases.

(5) Lows on a curved track tend to move faster after they begin to travel northeastward.

(6) Lows travel faster across the Northern States than the Southern States.

e. Direction and velocity of highs.—(1) Highs are more erratic than lows, as regards both the track followed and the velocity of motion. They usually enter the United States in the northwest or west and leave it at the northeast, east, or southeast.

(2) A high of large size often remains stationary for a day or two and sometimes for a week.

(3) If a new high has just appeared it may be assumed that it will travel 400 miles per day in summer and 600 miles per day in winter.

(4) Small highs, particularly those wedged in between lows, usually move with the velocity of the lows.

25. General observations.—The United States Weather Bureau, after investigating a large number of maps, published the following peculiar relations between certain characteristics which are valuable aids in weather forecasting:

a. When there is an area of high pressure over the southeast and a cold wave in the northwest threatens, there will be a storm development in the southwest and precipitation will be general.

b. If a storm forms in the southwest and is forced to the left of a normal track, another storm will immediately begin to develop in the southwest and it becomes a sure rain producer. Storms that develop in the southwest and move normally are quickly followed by clearing weather.

c. Troughs of low pressure moving from the west are of two types: narrow and wide. The former moves eastward slowly and storm centers develop in the extreme northern and the extreme southern ends. When the trough is wide, the development of an extensive storm area is not uncommon, especially if the wide intervening area between the highs shows relatively high temperatures.

d. When the northern end of a trough moves eastward faster than the southern end, the weather conditions in the south and southwest remain unsettled and the chances are that a storm will form southwest of the high that follows. When the southern end moves faster than the northern end, settled weather follows.

e. Storms that start in the northwest and move southeastward do not gather great intensity until they begin to recurve to the northward. At the time of recurving they move slowly as a rule, and care must be exercised in predicting clearing weather.

f. Marked changes in temperature in the southeast and northwest quadrants imply an increase in intensity of the storm, but slight temperature changes do not indicate a further development of the storm.

g. Abnormally high temperatures northwest of a storm indicate that it will either move backward or remain stationary.

h. East of the Rocky Mountains, a storm which moves to the left of its normal track increases in intensity.

i. Storms with isobars closely crowded on the west and northwest generally move slowly and to the east or southeast, and precipitation and high winds are maintained unusually long in the northern and western quadrants.

j. Storms with the isobars closely crowded in the south and southeast quadrants move rapidly northeastward and the weather quickly clears after the passage of the storm center.

26. General rules for forecasting.—*a. Predictions needed.*—Weather forecasts of interest to chemical officers include predictions as to—

Wind, direction and velocity.
Temperature.
Clouds and precipitation.

b. Procedure.—The following steps should be taken in making a forecast from a weather map:

(1) Examine the weather map, plotting the position of the station for which the forecast is to be made.

(2) Determine the most likely position of the high or low which will be dominating the weather at the time for which the forecast is to be made, by applying the rules for the movement of highs and lows as given in paragraph 24. Note general observations in paragraph 25 for any reason why the formation may not reach these positions.

(3) Plot the predicted position of the pressure area on the map. Also plot the estimated positions of other highs or lows which may be near enough to influence the weather.

(4) From a consideration of the direction of winds caused by highs and lows, estimate the future direction of the wind at the station. The velocity of the wind will depend largely on the steepness of the pressure gradient, that is, on how close the isobars are packed together. In general, the greater the difference in pressure between the place from which the wind is blowing and the place to which it is blowing, the greater the velocity of the wind.

(5) If the predicted wind blows from a place where the weather as shown by the isotherms is warmer, the prediction should be for higher temperatures. If it blows from a place that is colder, the prediction should be for lower temperatures.

(6) If the predicted wind or winds indicate that cold air and warm moisture-laden air will both be blowing into an area, clouds and precipitation are likely. The cold, heavier air will force the warm, lighter air upward. As the warmer air rises, it expands and is cooled. If cooled below the condensation point, clouds or precipitation may result, depending upon the degree of saturation of the warm air and the extent to which it is cooled.

27. Illustrative problem.—*a. Use of weather map.*—The rules given in paragraph 26 should be applied in the consideration of a typical weather map such as is shown in figure 25. It will be noted that the distribution of the meteorological elements about the high and low areas shown on this map follows, in general, the outline given for these formations. The conventional signs are explained in paragraph 28.

b. Application of rules.—(1) Assuming that the forecast is to be made for Edgewood Arsenal, Md., the first step is to show this position on the map.

(2) It will be seen that the weather at this point is under the influence of a well-defined low. It may be stated that this low will travel during the next 24 hours in the same direction and with the same speed as it has traveled during the past 24 hours. From the map of the previous day it is learned that the low has traveled approximately 700 miles.

(3) Placing the center of the low 700 miles ahead in the same direction that it is traveling, the center will then be a little northeast of the mouth of the St. Lawrence River.

(4) As the low passes over Edgewood Arsenal it may be expected that the wind will change from southwest and west to strong northwest winds.

(5) As the warm southwest winds change to strong northwest winds, a decided drop in temperature is to be anticipated.

(6) Further probabilities are that the rain will cease and that the weather will clear as the warmer moisture-laden air from the south will no longer be flowing into this area, its place being taken by dry, cold winds.

(7) Therefore the correct prediction for Edgewood Arsenal on October 29, 1941, is: strong northwest winds, much colder, and clear.

28. Weather map data and forecast.—*a. General.*—The following three subparagraphs devoted to data, symbols, and forecasts are printed upon each weather map. In this instance the daily forecast is for Wednesday, October 29, 1941.

(1) *Forecast* (see fig. 25).

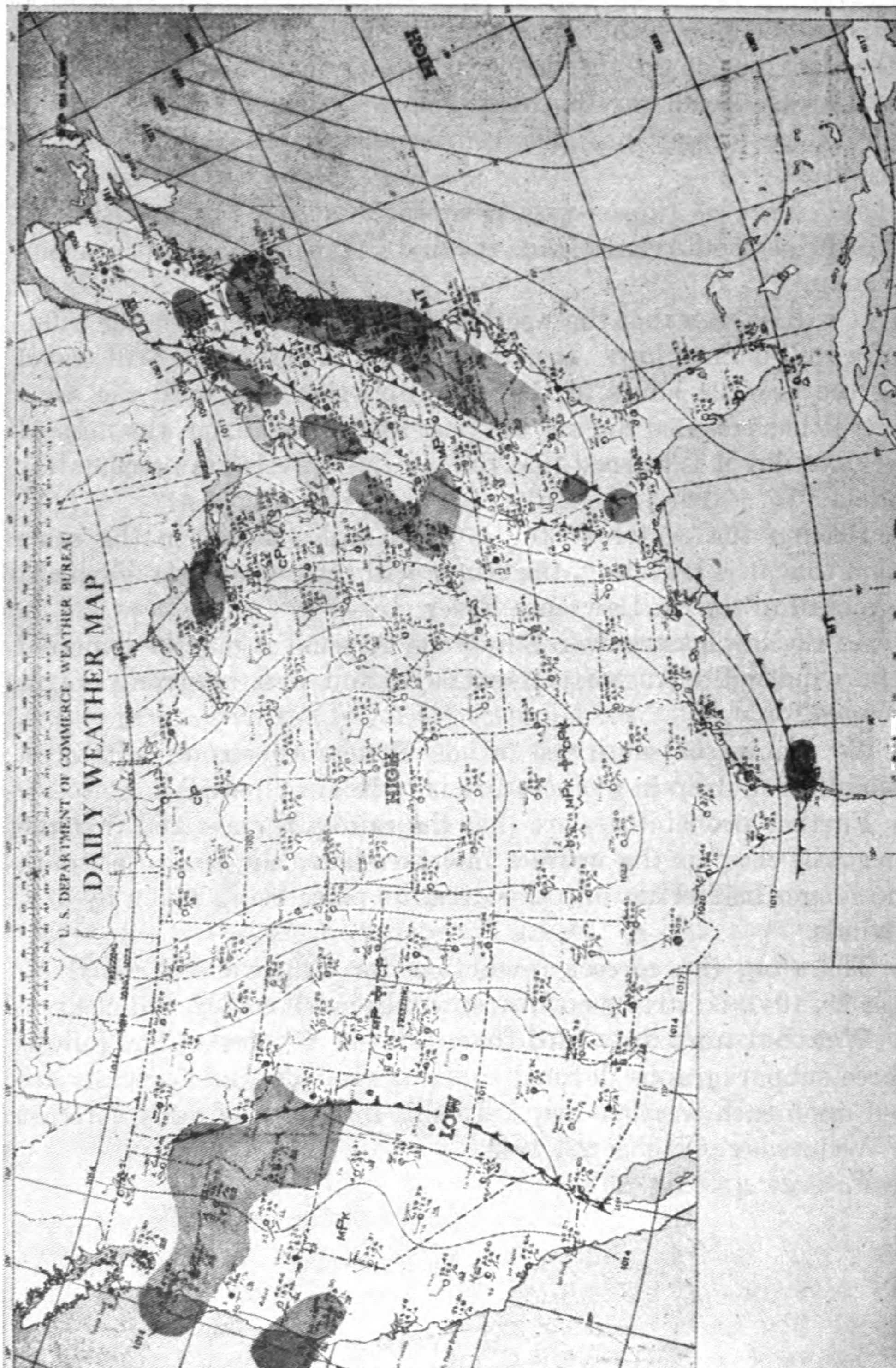


FIGURE 25.—Weather map.

FORECASTS AND GENERAL WEATHER INFORMATION

UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.

ADMINISTRATIVE OFFICE: 24th and M Streets NW. AIRPORT OFFICE: Washington National Airport

WEATHER INFORMATION (ALL HOURS): MIchigan 1442

LATEST WEATHER FORECASTS BY AUTOMATIC TELEPHONE: WEather 1212

TUESDAY, OCTOBER 28, 1941

STATE FORECASTS

District of Columbia, cloudy this morning, followed by partly cloudy and cooler this afternoon; fair and much cooler tonight with lowest temperature tonight about 38°; fair and quite cool Wednesday; fresh northwest winds today.

Maryland and Virginia, mostly cloudy and cooler, much cooler in west portion, scattered showers in the mountains today and showers on the coast this morning; generally fair and much cooler tonight; Wednesday fair and quite cool; fresh southwest, shifting to fresh to strong northwest winds on the bay and coast today.

Eastern New York, cloudy and colder with light showers in the interior today and showers on the coast this morning; clearing and colder tonight; Wednesday fair.

Western New York, cloudy and somewhat colder today and tonight; Wednesday fair.

New Jersey and Delaware, showers this morning followed by mostly cloudy and much colder this afternoon and tonight; Wednesday fair and quite cool.

Eastern Pennsylvania, scattered showers this morning, followed by cloudy and much cooler today and tonight; Wednesday fair and quite cool.

Western Pennsylvania, mostly cloudy and somewhat colder today and tonight with light showers in the mountains today; Wednesday fair.

West Virginia, mostly cloudy and much cooler with light showers in the mountains today; clearing and colder tonight; Wednesday fair.

GENERAL FORECAST

Middle Atlantic States, the lower Lake Region, the Ohio Valley, and Tennessee: Indications are for considerable cloudiness in the Washington forecast district with occasional rain on the coast and brief showers in the mountains today, followed by fair weather over most sections Wednesday. It will be much cooler.

MARINE FORECAST

Block Island to Hatteras, fresh southwest winds, shifting to fresh to strong northwest over north and central portions today, and over extreme south portion tonight; occasional rain today.

STORM INFORMATION

Storm warnings are displayed from Eastport, Maine, to Block Island, R. I., and small craft warnings are displayed south of Block Island, R. I., to Delaware Breakwater, Delaware.

WEATHER CONDITIONS LAST 24 HOURS

The warm and moist tropical air over the Atlantic States is being rapidly displaced by rather cold air of polar origin which is spreading eastward over the Appalachians and southward into the Gulf States. Freezing temperature reached as far south as Kansas and Missouri, and most portions of Indiana and Illinois. Since yesterday morning there have been rather general rains over most of the Atlantic States, the Lake Region, the Ohio Valley, and along the Gulf States. Precipitation also occurred over the Plateau Region in the North Pacific States.

(2) *Explanation of map.*

At 1:30 a. m., E. S. T., observations of the weather are taken at several hundred stations throughout the United States. Reports from 170 of those stations are inscribed on the above map. Temperature, wind direction and velocity, amount and kind of clouds, state of weather, amount of precipitation, and other meteorological data are indicated for each station.

The heavy lines are called "fronts" and separate the air masses of different characteristics. The labels which are made up of letter combinations indicate particular types of air masses. Fronts and labels are described in the boxes to the right (see below).

The light, continuous lines are called isobars and pass through points of equal sea-level pressure. The dashed line (when present) is an isotherm and passes through all points where the current temperature is 32° F. This line is labeled "Freezing" and separates the respective areas which are above and below the freezing temperature of 32° F.

The figures and symbols for the data always occupy the same relative positions around the station circle, as shown on the adjacent "Station Model." Occasionally there may be a slight displacement of the normal position of some of the data in order to provide room for the wind arrow.

The amount of precipitation at each station in the past 18 hours is heavily underlined and the geographical area where precipitation is falling at 1:30 a. m., E. S. T., is covered with dot shading. The letter "T" is used to indicate a "Trace" of precipitation, which is an amount too small to measure. Figures for precipitation will be omitted when the 18-hour amount is zero.

When the observed visibility is 12 miles or more, the figures for "visibility" are omitted. When the observed cloud ceiling is 10,000 feet or more, the figures for "ceiling" are omitted. When the figures are omitted visibility and ceiling will be understood to be "unlimited."

The amount of solid black shading within the station circle indicates the amount of cloudiness. For example, the symbol ◔ indicates that the sky is 2 or 3 tenths covered; ◐ is 4, 5, or 6 tenths; ◕ is 7 or 8 tenths; and ● is 10 tenths, or completely overcast.

The symbol directly to the left of the station circle represents the current state of weather and may be any one of 96 separate symbols. The basic symbols for precipitation are: ❟ drizzle; ● rain; ✳ snow; ▽ showers; ⩫ thunderstorm. A symbol for current state of weather is always used when precipitation is falling or when unusual conditions are observed. Some of the frequently used symbols are as follows: ∞ haze; ⪡ distant lightning; = light fog; ⬭ smoke; ✱] snow in last hour, but not at time of observation; § dust storm; ≡ fog, sky not discernible; ,’, continuous moderate drizzle; • intermittent light rain; ✱✱ continuous light snow; ▽̇ light or moderate rain showers; ⌈⦚ thunderstorm with rain. Symbols are entered singly or in combination, for example, a ● represents rain and three bars ≡ represents fog. Three bars and a dot ≡̇ represent rain and fog. The bracket sign] means "in past hour, but not at time of observation."

The shaft of the arrow extends from the station circle in the direction *from which* the wind blows and the feathers on the shaft show the force of the wind on the Beaufort Scale. Each feather represents *two* units of force and each *half feather* represents one unit of force. For example, a wind blowing *from the east* at 5 miles an hour would be drawn O——\ and would be described as an "east wind, force 2"; ⫽——O is a "west-southwest wind, force 5." The adjacent table shows the complete Beaufort Scale and the wind velocity equivalents in miles per hour.

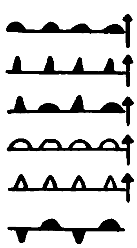
The Weather Bureau will furnish upon request a more complete and detailed explanation of this map and the symbols and tables. Inquiries should be addressed to "Chief, U. S. Weather Bureau, Washington, D. C."

The subscription price of this map (daily, including Sundays and holidays) is $3.60 a year, or 30 cents a month; daily, except Sundays, is $3.00 a year, or 25 cents a month. Send subscriptions (check or money order) to "Superintendent of Documents, Washington, D. C."

(3) *Symbols.*

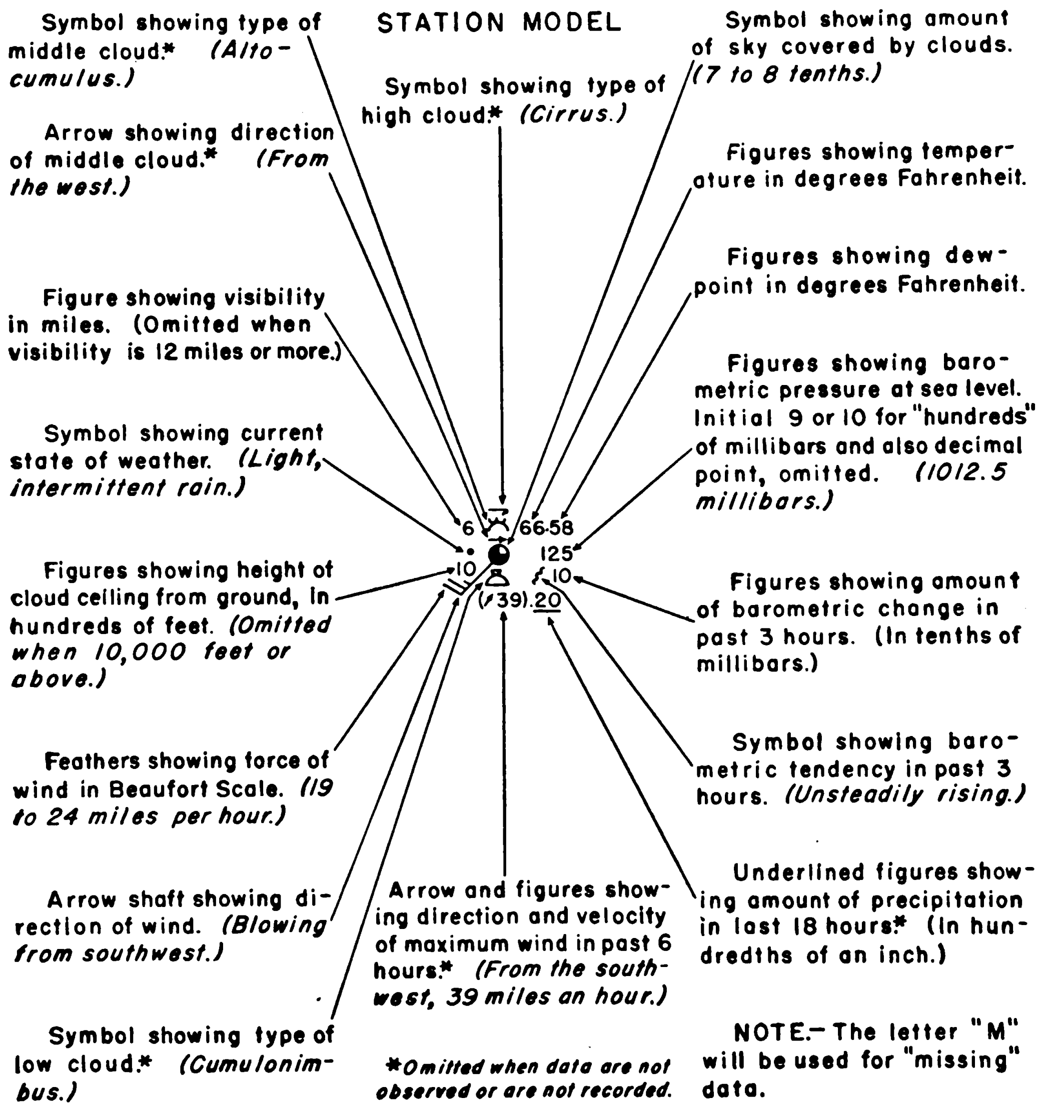
FRONTS AND LABELS

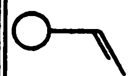
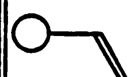
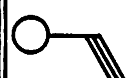
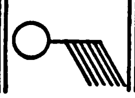
The boundary between two different air masses is called a "front." Important changes in weather often occur with the passage of a front. The half circle and triangular points placed on the "front" lines are symbols to indicate the classification of the front and its direction of movement. The boundary of relatively cold air of polar origin advancing into an area occupied by warmer air of tropical origin is called a "cold front." The boundary of relatively warm air advancing into an area occupied by colder air of polar origin is called a "warm front." The line along which a cold front overtakes a warm front is called an "occluded front." A boundary between two air masses which shows little tendency at the time of observation to advance into either the warm or the cold air areas is called a "stationary" front. The front symbols, with arrows to show their direction of movement, are given below:



Warm front at the ground.
Cold front at the ground.
Occluded front.
Warm front above the ground.
Cold front above the ground.
Stationary front.

The word "HIGH" and "LOW" indicate high and low barometric pressure.


STATION MODEL
Symbol showing type of middle cloud.* (Alto-cumulus.)
Arrow showing direction of middle cloud.* (From the west.)
Figure showing visibility in miles. (Omitted when visibility is 12 miles or more.)
Symbol showing current state of weather. (Light, intermittent rain.)
Figures showing height of cloud ceiling from ground, in hundreds of feet. (Omitted when 10,000 feet or above.)
Feathers showing force of wind in Beaufort Scale. (19 to 24 miles per hour.)
Arrow shaft showing direction of wind. (Blowing from southwest.)
Symbol showing type of low cloud.* (Cumulonimbus.)
Symbol showing type of high cloud.* (Cirrus.)
Arrow and figures showing direction and velocity of maximum wind in past 6 hours.* (From the southwest, 39 miles an hour.)
*Omitted when data are not observed or are not recorded.
Symbol showing amount of sky covered by clouds. (7 to 8 tenths.)
Figures showing temperature in degrees Fahrenheit.
Figures showing dew-point in degrees Fahrenheit.
Figures showing barometric pressure at sea level. Initial 9 or 10 for "hundreds" of millibars and also decimal point, omitted. (1012.5 millibars.)
Figures showing amount of barometric change in past 3 hours. (In tenths of millibars.)
Symbol showing barometric tendency in past 3 hours. (Unsteadily rising.)
Underlined figures showing amount of precipitation in last 18 hours.* (In hundredths of an inch.)
NOTE.—The letter "M" will be used for "missing" data.
6
66 58
125
10
10
(39)
20

BEAUFORT SCALE OF WIND FORCE		
No.	Symbol	Miles per hour
0		CALM
1		1 - 3
2		4 - 7
3		8 - 12
4		13 - 18
5		19 - 24
6		25 - 31
7		32 - 38
8		39 - 46
9		47 - 54
10		55 - 63
11		64 - 75
12		ABOVE 75

Masses of air are classified into several different types which indicate their origin and basic characteristics. For example, the letter "P" denotes the polar type of relatively dry and cold air from northerly or polar regions. The letter "T" denotes the tropical type of relatively moist and warm air from southerly and tropical regions. The letters placed *before* the letters "T" and "P" show that the air mass is classified as Maritime (M) or Continental (C). The letters placed *after* "T" and "P" show that the air mass is colder (K) or warmer (W) than the surface over which the air is moving. Mixtures of air masses are denoted by plus signs (+), and transitional changes of air masses from one type to another are indicated by arrows (⇒). One air mass superimposed upon another is indicated by placing a line between the two labels.

P=Polar; C=Continental; T=Tropical; M=Maritime; S=Superior (very dry); K=Colder; W=Warmer.

b. Pressure measurement.—On United States Weather Bureau Daily Weather maps published after July 1, 1939, atmospheric pressure is shown in *millibars*. The bar is an international unit of atmospheric pressure and in meteorological usage equals 1,000,000 dynes per square centimeter. A dyne is a unit of force approximately equal to the weight of a milligram. Under standard conditions of temperature and gravity a pressure of 29.53 inches equals 1 bar which equals 1,000 millibars; the normal atmosphere of 29.92 inches therefore equals 1,013.2 millibars. (For some purposes 1,000 millibars is now used as a standard atmosphere.) A conversion scale is now printed on all United States Weather Bureau maps. Conversion tables of inches and millibars are as follows:

Inches of mercury into millibars

Inches	Millibars									
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
25	847	850	853	857	860	864	867	870	874	877
26	880	884	887	891	894	897	901	904	908	911
27	914	918	921	924	928	931	935	938	941	945
28	948	952	955	958	962	965	968	972	975	979
29	982	985	989	992	996	999	1,002	1,006	1,009	1,013
30	1,016	1,019	1,023	1,026	1,030	1,033	1,036	1,040	1,043	1,046
31	1,050	1,053	1,057	1,060	1,063	1,067	1,070	1,074	1,077	1,080

Millibars into inches of mercury

Millibars	Inches					
	0	5	10	15	20	25
860	25. 40	25. 54	25. 69	25. 84	25. 99	26. 13
890	26. 28	26. 43	26. 58	26. 72	26. 87	27. 02
920	27. 17	27. 32	27. 46	27. 61	27. 76	27. 91
950	28. 05	28. 20	28. 35	28. 50	28. 64	28. 79
980	28. 94	29. 09	29. 23	29. 38	29. 53	29. 68
1,010	29. 83	29. 97	30. 12	30. 27	30. 42	30. 56
1,040	30. 71	30. 86	31. 01	31. 15	31. 30	31. 45

Additional conversion factors are given as follows:
1 inch, mercury=25.4 millimeters=33.86395 millibars.
1 millimeter, mercury=0.03937 inch=1.3332 millibars.
1 millibar=0.02953 inch=0.75006 millimeter.

29. Local forecasting.—*a. General rule.*—When weather reports and weather maps are not available as will often be the case in the field, fairly reliable predictions can be made of wind change and general weather conditions that may be expected, by use of a pocket aneroid barometer and by observing the wind. The following rule printed on all United States Weather Bureau daily maps is reliable:

When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or to the north of the observer within 12 to 24 hours, with wind shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast, and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours, with winds shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and amount of the fall in the barometer.

b. Significance of barometer and wind direction.—The foregoing rule may be augmented by the significance of the condition of the barometer in connection with wind direction as follows:

	Barometer	Wind from	Weather indicated
(1)	High and steady	SW. to NW.	Fair and little temperature change for 1 to 2 days.
(2)	High and rising rapidly	SW. to NW.	Fair, followed by warmer and rain within 2 days.
(3)	High and falling slowly	SW. to NW.	Rain in 24 to 36 hours.
(4)	Very high falling slowly	SW. to NW.	Fair and slowly rising temperature for 2 days.
(5)	High and falling slowly	S. to SE.	Rain within 24 hours.
(6)	High and falling rapidly	S. to SE.	Increasing wind, with rain in 12 to 24 hours.

	Barometer	Wind from	Weather indicated
(7)	High and falling slowly	SE. to NE	Rain in 12 to 18 hours.
(8)	High and falling rapidly	SE. to NE	Increasing wind, with rain in 12 hours.
(9)	High and falling slowly	E. to NE	Summer, light winds, fair; Winter, rain in 24 hours.
(10)	High and falling rapidly	E. to NE	Summer, rain in 12 to 24 hours; Winter, rain or snow with increasing winds.
(11)	Low and falling slowly	SE. to NE	Rain will continue 1 or 2 days.
(12)	Low and falling rapidly	SE. to NE	Rain and high wind, clearing and cooler in 24 hours.
(13)	Low and rising slowly	S. to SW	Clearing soon, and fair several days.
(14)	Low and falling rapidly	S. to SE	Severe storm soon, clearing and cooler in 24 hours.
(15)	Low and falling rapidly	E. to N	NE. gales with heavy rain or snow, followed in winter by cold wave.
(16)	Low and rising rapidly	Going to W	Clearing and colder.

c. Barometric variations for altitude.—When using a portable aneroid barometer in the field, any change in altitude will cause a change in the barometer reading. As one ascends, the barometer goes *down;* conversely, as one descends the barometer goes *up.* It is possible to note a change in the reading on a good aneroid barometer for a difference of elevation of 20 feet or less. A change in elevation of 100 feet causes a change of about 0.1 of an inch in barometer reading. Hence, if changing position in the field and elevations of the old and new positions can be ascertained, a correction in barometer reading may be made according to this rule.

30. List of publications for further study.—The following list of publications is given as a guide to further study of meteorology.

a. General elementary treatises.

Blair, T. A., *Weather Elements*, Prentice Hall, Inc., New York, N. Y.

Brunt, David, *Meteorology*, Oxford University Press, London.

Davis, W. M., *Elementary Meteorology*, Ginn & Co., Boston, Mass.

Milham, W. I., *Meteorology*, The Macmillan Co., New York, N. Y.

Pettersson, S., *Introduction to Meteorology*, McGraw-Hill Book Co., New York, N. Y.

Talman, C. F., *Our Weather*, Reynolds Publishing Co., New York, N. Y.

b. Advanced treatises.

Brunt, David, *Physical and Dynamical Meteorology*, Cambridge University Press.

Humphreys, W. J., *Physics of the Air*, 2d edition, McGraw-Hill Book Co., New York, N. Y.

Pettersson, S., *Weather Analysis and Forecasting*, McGraw-Hill Book Co., New York, N. Y.

c. Air mass analysis.

Namias, Jerome, and others, *An Introduction to the Study of Air Mass Analysis*, 3d edition with appendix on *Properties of North American Air Masses*, by H. C. Willett, American Meteorological Society, Milton, Mass.

d. Subdivisions of meteorology.

Clayton, H. H., *World Weather*, The Macmillan Co., New York, N. Y.
Cline, I. M., *Tropical Cyclones*, The Macmillan Co., New York, N. Y.
Humphreys, W. J., *Fogs and Clouds*, Williams & Wilkins Co., Baltimore, Md.
United States Weather Bureau, *Weather Forecasting in the United States*, Government Printing Office, Washington, D. C.

e. United States Weather Bureau Daily Weather Maps may be obtained from Superintendent of Documents, Washingon, D. C., at the following subscription rates:

Price: Daily (including Sundays and holidays), $3.60 a year, 30 cents a month; daily, except Sundays, $3.00 a year, 25 cents a month.

[A. G. 062.11 (12-13-41).]

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