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THE MARINE OBSERVER'S HANDBOOK

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MARINE OBSERVER'S HANDBOOK

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INTRODUCTION

The voluntary observing fleet and the corps of marine observers act as a nucleus and a guide for the whole Merchant Navy's meteorological work in aid of navigation, so that the service specified in Article 35 of the Convention for Safety of Life at Sea may be effective.

The earlier editions of this book were a guide to the specialized observation and return of meteorological information to the Meteorological Office. This edition is intended to have a wider scope as a general guide to seamen in meteorological observation in daily life at sea, and also to fulfil its previous function.

It is arranged in two parts. Part I deals generally with observation of weather, currents, and ice, common to all seamen, whether they be of the corps of voluntary marine observers or not. It is in fact a companion to the "Handbook of Weather, Currents, and Ice for Seamen" published in 1935 to replace the "Barometer Manual" and the "Seamen's Handbook of Meteorology".

Part II deals with organized voluntary meteorological observation at sea, and collection of data. It gives details of some observations already dealt with in Part I, including scales, and the more specialized work of the corps of voluntary marine observers.

PART I

CHAPTER I

OBSERVATIONS OF WIND, CLOUD AND WEATHER, SEA AND SWELL

The Natural Observations of Seamen

The observations which seamen make without instrumental aid are estimates of practised eyes. The skilled judgment that comes with practice in making the natural observations of seamen, particularly those of wind, sea and swell, is slowly acquired and is difficult to define, but is passed on gradually from senior to junior, from generation to generation. No one lives in more constant contact with their work than seamen, and in constant observation they acquire good judgment. In sailing ships seamen learnt to estimate the wind with accuracy, which was essential for good seamanship. The method used for estimating wind in steamships is the same.

Wind Force and Direction

Wind force is expressed numerically on a scale from 0 to 12. This scale, with a statement explanatory of the respective wind conditions to which the numbers refer, was originally devised by Captain, afterwards Admiral, Sir Francis Beaufort, in the year 1808, for use on board ships of the Royal Navy. Although especially applicable to the full-rigged frigate of that date, the scale soon came into general use, not only in the Royal Navy, but also in the Merchant Navy. Since Admiral Beaufort's time, however, so many changes had taken place in the build, rig, and tonnage of sea-going vessels that in 1874 Beaufort's scale was adapted to the full-rigged ship of that period, with double topsails. In 1926, the International Meteorological Committee re-affirmed this scale. For the specification of the Beaufort scale, see Chapter VIII, pages 64–65. Beaufort Scale of Wind Force.

Estimation of wind force by the appearance of the sea is the method generally used at sea. The general appearance of the sea surface is the best indication, and experience enables the observer to associate different degrees of sea disturbance with the various wind forces of the Beaufort scale. Exact descriptions of the appearance of the sea surface to correspond with each number of the Beaufort scale cannot be devised, as circumstances vary very much. The length of time the wind has been blowing, the area of open sea over which it has blown, the rate at which it has increased or decreased in force, changes Estimation of Wind Force.

in direction, squalls, etc., as well as the depth of the sea, all affect the appearance of the water. It is therefore only by experience that allowance for these different factors can be made. It must also be borne in mind that tides or strong currents affect the appearance of the sea surface, a wind against tide or current naturally causing more " lop "—a weather tide—and a wind in the same direction as a tide or current producing less disturbance of the sea surface—a lee tide. Polar winds tend to cause more sea than equatorial winds, on account of the greater density of the colder air. Rain, if at all heavy, has a smoothing effect.

In modern, large, fast vessels the tendency is probably for an inexperienced observer to overestimate slightly the force of light winds and to underestimate the strong ones.

Wind Direction. Wind direction is logged as the true, not the compass, direction and is given to the nearest point. The exposed position that a ship's standard compass usually occupies gives a clear all-round view and from it the observer notes the tops of the seas, the ripples, the spray and the faint lines that generally show along the wind. It is generally best to look to windward in judging wind direction, but in some lights direction is more evident when looking to leeward.

Accuracy of Wind Estimation. Comparison has shown that the accuracy of the estimations of wind force and direction made in British ships is generally good.

Wind Estimation at Night. Estimation of wind force and direction can usually be made in the same way at night, but it is sometimes impossible on very dark nights to see the effect of the lighter winds on the sea surface. In such cases the apparent wind force and direction must be estimated by feel. Allowance must then be made for the ship's course and speed. In a fast ship considerable difference exists between the apparent and true wind directions. When the wind is dead aft and of the same velocity as the ship's speed there is apparent calm on board the ship. In a calm a ship steaming 10 knots will have an apparent head wind of 10 knots velocity, but as soon as the wind blows from any direction out of the fore and aft line, the difference between the apparent and true directions varies with each angle on the bow, and each force of the wind. The true wind may be obtained from the apparent wind by use of the parallelogram of forces, or TABLE XIV, as explained below.

In FIGURE 1, if for instance the ship is travelling along the line AB with speed 15 knots, and the wind appears to be coming from the direction DA with velocity 29 knots (Beaufort scale 7), the true direction of the wind is along CA, and its velocity will be 18 knots. This result is easily obtained graphically by

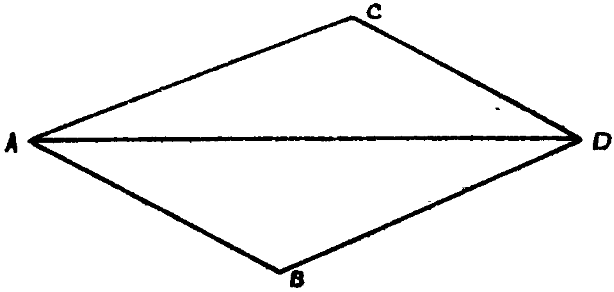

FIG. 1.

drawing the figure, making BA proportional to 15 and DA proportional to 29 and then measuring DB, which is equal to CA, where ABDC is a parallelogram. The angle CAD, which is the same as BDA, is measured with a protractor and gives the difference between the true and apparent directions of the wind. Instead of using the graphical method the force and direction of the true wind may be worked out by trigonometry, if preferred. To do this use the formula $BD^2 = AB^2 + AD^2 - 2AB, AD \cos BAD$ and then obtain the angle BDA by the rule of sines. TABLE XIV gives these by inspection.

Hand Anemometers.

Hand anemometers are occasionally used at sea and if the instrument is used with judgment and skill, to give the apparent wind force, the true wind force may be obtained by application of the parallelogram of forces.

Anemometers in the Royal Navy.

Anemometers for observation of wind force and direction have been in use in some of H.M. ships for some years. They are pressure-tubes and other kinds.

Use of terms veering and backing.

At the International Meteorological Conference held at Innsbruck in 1905, it was recommended :—

> "That meteorologists in the southern hemisphere, as in the northern hemisphere, are requested—without regard to other weather phenomena—to employ the term 'backing' whether at an observing station or on board ship, exclusively to denote a change in direction against the hands of a watch, i.e. W-S-E-N : and the term 'veering' for changes in the opposite direction, with the hands of a watch, i.e. W-N-E-S."

This usage was also recommended to seamen and has become general.

Sea and Swell

For observing the state of the sea and swell, the Douglas Sea and Swell Scale is used. This scale was devised by Captain (now Admiral) H. P. DOUGLAS, C.M.G., R.N. At the meeting of the International Meteorological Conference, held at Copenhagen in 1929, it was recommended for international use.

The Douglas Sea and Swell Scale is given in Chapter VIII, page 66.

In taking the observations careful distinction should be made between sea and swell whenever possible; sea being the waves caused by wind at the place and time of observation, while swells are waves due to winds which have persisted in the locality previous to the time of observation, or waves caused by wind at a distance from the place of observation.

The true directions from which sea and swell are coming are observed by compass, separately whenever possible.

Cloud

Amount of Cloud.

The proportion of the sky covered by cloud should be judged on a numerical scale running from 0, cloudless, to 10, completely overcast; in other words, estimate the number of tenths of the area of the sky covered by the clouds present. The estimation refers solely to the amount of the sky covered and not to the density, height or other quality of the cloud.

In estimating, the observer may well subdivide the sky into quadrants. An estimate is then formed for each quadrant separately.

Cloud Forms. Howard's classification.

LUKE HOWARD, whose classification of cloud forms at the beginning of the XIXth century is the basis of the system now in use, distinguished three principal cloud forms, viz.:—

(1) Cirrus cloud (of fibrous or feathery appearance, "'mares' tails").

(2) Cumulus cloud (having rounded top).

(3) Stratus cloud (arranged in horizontal sheets or layers).

Many forms intermediate between these primary forms were found to occur and these were specified by compounding the names of the primary forms. A fourth name, nimbus, the rain cloud, was given to one of Luke Howard's compound forms of cloud.

Modern classification.

As the observation of cloud forms became more general it was found necessary to increase the number of forms and to have definitions for them. Ten main forms of cloud are now recognised and are as follows:—

Upper Clouds

(1) Cirrus.
(2) Cirrocumulus.
(3) Cirrostratus.

Middle Clouds

(4) Altocumulus.
(5) Altostratus.

Lower Clouds

(6) Stratocumulus.
(7) Stratus.
(8) Nimbostratus (formerly called Nimbus).
(9) Cumulus.
(10) Cumulonimbus.

Popular Names.

Cirrocumulus is popularly known as "Mackerel Sky," but is a rare form of cloud; altocumulus, if the cloudlets are not too large, gives a similar dappled appearance to the sky. Cumulus is the cloud of summer afternoons in temperate latitudes, while the small cumulus clouds of the trade-wind regions are well-known to seamen. Cumulus when fully developed, with rounded heads, is popularly known as the "Wool-pack" cloud. Cumulonimbus is well-known as the "Thundercloud," "Anvil" cloud or "Shower" cloud.

Cloud Sheets.

All the forms of cloud given above, except cumulus and cumulonimbus, occur in the form of sheets or layers, the thickness of the cloud being small in proportion to its extent. Cumulus and cumulonimbus differ from all others in having considerable, and sometimes great, vertical height. These are included as lower clouds because their bases are at a relatively low height.

Appearance of clouds.

The feathery or streaky cirrus clouds, occurring in blue sky, are well-known. Cirrostratus, altostratus and stratus represent more or less unbroken cloud over the whole sky, at upper, middle and lower heights respectively. On the other hand cirrocumulus, altocumulus and stratocumulus are collections of clouds of rounded form, covering considerable areas, or the whole sky, but showing blue sky between. Owing to their greater height the separate clouds of cirrocumulus appear the smallest while those of stratocumulus are usually the largest.

Height of clouds.

The height of clouds varies considerably at any given place, and also varies with latitude. The upper clouds range between about 4 and 7 miles high in temperate latitudes, but in the tropics may be 9 or 10 miles. Middle clouds usually lie between heights of a little over a mile and about 3½ miles, while lower cloud is below a mile in height and is sometimes almost down to the earth's surface. It is hardly possible in a ship steaming at speed to determine cloud height by any of the methods of observation ordinarily used at sea.

Cloud Prognostics.

Many skies are very complex, a number of cloud forms being visible at the same time and there are also many varieties of appearance of the same cloud form. Layers of different kinds of cloud may occur one above the other. The recognition of cloud forms is therefore often difficult, especially until experience is gained. The seaman judges the general appearance of the sky and whether it denotes settled weather or probable changes in the weather.

Weather

The state of the weather is observed and named by letters of the Beaufort notation, which was introduced by Captain, afterwards Admiral, Sir Francis Beaufort. This notation is given in Chapter VIII, pages 79–80. These letters provide for the recording of the general appearance of the sky and for all ordinary phenomena such as fog, rain, squalls, thunderstorms, etc.

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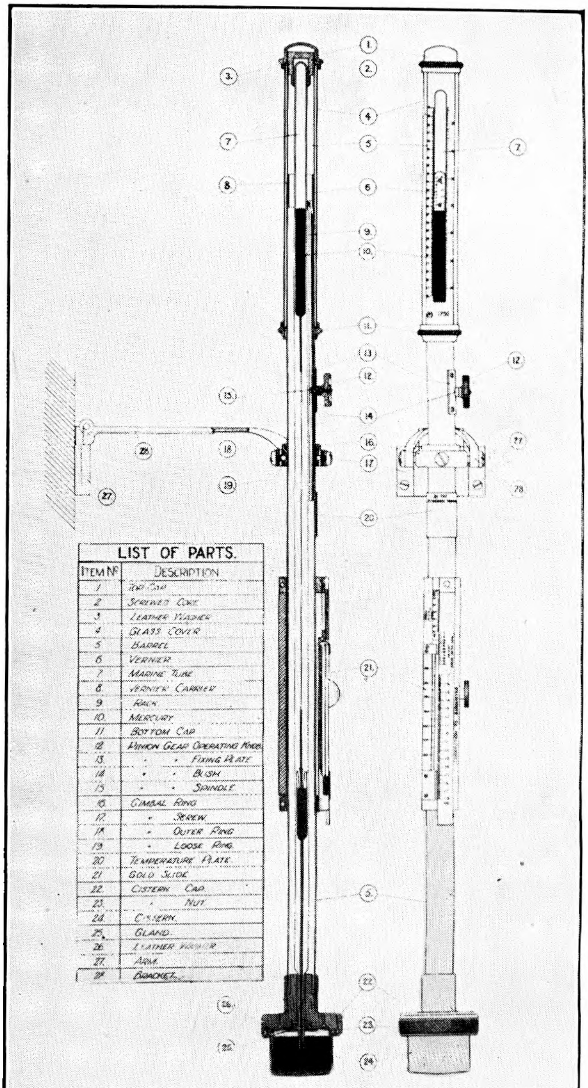


STANDARD PATTERN MARINE BAROMETER
With Gold Slide for effecting corrections.

FIG. 2

CHAPTER II

DESCRIPTION OF METEOROLOGICAL INSTRUMENTS

The Mercury Barometer.

The barometer is an instrument with which the weight or pressure of the atmosphere can be measured. The principle of the mercury barometer was discovered by Torricelli in 1643.

In its simplest form a mercury barometer consists of a glass tube closed at one end, which is completely filled with mercury to exclude all air in the tube and its open end immersed in a small cistern also containing mercury. The mercury column falls until the weight of the mercury column above the level of the mercury in the cistern just balances the atmospheric pressure, which is exerted on the free surface of the mercury in the cistern.

The mercury barometer only gradually passed from its original simple form as a scientific experiment to that of a practical and portable instrument, so that it was not used by seamen until a century had elapsed.

The Kew Pattern Marine Mercurial Barometer.

The Kew Pattern Marine Mercurial Barometer consists of a glass tube and cistern enclosed in a metal protecting case. In the upper part of the cistern is a small hole which admits the air, and a washer over the mercury in the cistern prevents the mercury from escaping. The glass tube, which in later patterns has a bore at the upper part of ·315 inch, is considerably contracted for the greater part of its length to prevent unsteadiness or pumping of the mercury, and for part of this contraction is reduced to a fine capillary tube. On this account, the Marine Barometer is sluggish, the lagging time being about four and a half minutes in the latest pattern. There is an air trap in the tube to prevent air getting to the top of the tube.

On the metal protecting case is a scale, with a vernier for reading the height of the mercury.

For the purpose of ascertaining the temperature of the barometer itself, a thermometer is attached. This is an ordinary thermometer; on barometers graduated in millibars, the thermometer is graduated in degrees Absolute; on inch barometers, it is graduated in degrees Fahrenheit.

Graduation of Barometer Scales.

From the invention of the barometer until recent years the reading was expressed as the length of the mercury column necessary to balance the atmospheric pressure at the time. In the British Isles, atmospheric pressure was, therefore, given in inches and decimals of an inch, while countries using the metre as a unit of length gave the pressure in millimetres and decimals of a millimetre. Barometer scales graduated in inches were readable by vernier to a thousandth of an inch (·001). As a length cannot be a pressure, this really meant that the atmospheric pressure per unit area was the same as the weight of a given length of mercury column per unit area. This length depended on what liquid is used in the barometer. Mercury has always been used in practice on account of its high density.

Graduation in Pressure Units.

With development it was found more convenient for the purpose of meteorologists to express the barometer reading in actual pressure units instead of in units of length.

Millibars.

Since May, 1914, atmospheric pressures have, therefore, been stated by the Meteorological Office in " millibars " instead of in inches. The millibar is the adopted unit of pressure on the C.G.S. (centimetre-gramme-second) system and is defined as a pressure of 1,000 dynes per square centimetre. The explanation of the dyne and other units of the C.G.S. system will be found in Appendix II, page 105.

Millibar barometers are graduated in millibars, with a longer line at each tenth millibar. Ten millibars equal one centibar and the scale is numbered in centibars. Thus the figure 101 equals 1,010 millibars. By means of the vernier the pressure can be read to one-tenth of a millibar. Readings are always expressed in millibars; for example, 1,012·6 " mb.", not 101·26 centibars. One thousand millibars, or one hundred centibars, equals one bar. One bar is equivalent to a pressure of 29·53 inches or 750·1 millimetres of mercury, at the freezing point of water in latitude 45°, and is thus very nearly equal to the average pressure of the atmosphere at sea level. An increase of one millibar in atmosphere pressure, therefore, indicates an increase of about a thousandth of the previous pressure.

A practical advantage of the millibar scale is that the subsequent reduction and correction of the reading is simpler than with an inch barometer.

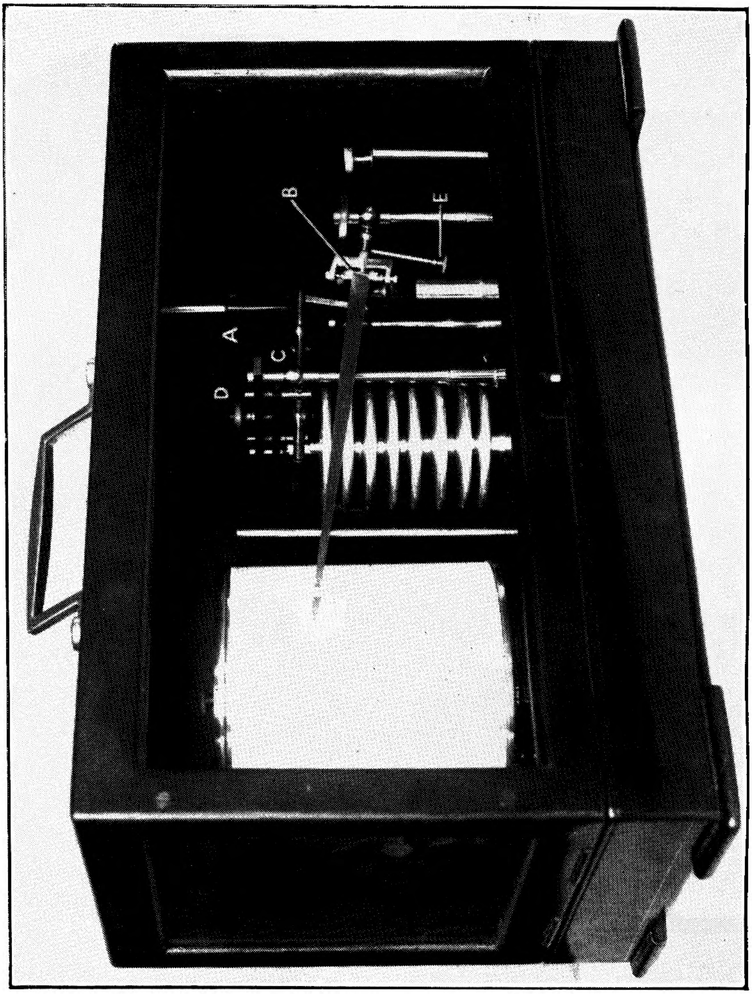
Gold Correction Slide.

Some barometers are fitted with a Gold Slide. This attachment still further simplifies the reduction and correction of millibar barometer readings and obviates the use of Tables.

A scale marked " Correction to Barometer " is mounted beside the thermometer and is movable by rack and pinion. At the top of the slide are two scales, one marked " Latitude " and the other marked " Height above Water Line ". The whole is clamped to the barometer by means of screws. The latitude scale is engraved on a strip of metal, which is adjusted alongside an " Index Scale ", to allow for the index error of the instrument. This scale is adjusted before sale or issue and the latitude scale should, therefore, not be moved.

To face page 9.

PLATE I



THE BAROGRAPH

There are a number of older pattern scales in use, in which the " Index " scale is omitted; but these scales are also adjusted for index error of the instrument before issue.

The method of using the Gold Slide is given on page 27.

The Aneroid Barometer.

The aneroid barometer was invented in 1843.

It is an instrument specially adapted for noting changes in pressure, and consists of a circular metallic chamber partially exhausted of air and hermetically sealed. Variations of atmospheric pressure produce variations in the volume of the vacuum chamber. These variations are transmitted, by an arrangement of levers and springs, to a pointer which rotates round a graduated dial.

The aneroid requires frequent careful comparison with barometers of known constant accuracy, for being a mechanical arrangement it is more subject to changes than is the mercurial barometer.

The Barograph.

The portable barograph is shown in PLATE I. It is constructed on exactly the same principle as the aneroid barometer, but has a series of small metal vacuum boxes with elastic lids instead of the single one of the aneroid. This series of boxes is connected with the revolving drum by means of a lever carrying a pen filled with specially prepared ink. The variations of the volume of the boxes are thus transformed into up and down movements of the pen arm. A chart on which the pen writes is fastened round the drum and shows the variations of atmospheric pressure for one week, the clockwork contained in the drum effecting one revolution of the drum in this period. The chart with the continuous trace upon it is called a barogram.

Continuous record of atmospheric pressure.

The barograph is a valuable adjunct to the mercury barometer in ships, as it gives a continuous record of atmospheric pressure. It thus records fluctuations of pressure which may not be detected by reading the mercury barometer at fixed times.

"Joggles" in the trace, concurrent with showers, and not infrequently with a transient increase of wind, are interesting features in barograms, showing the close connexion existing between weather changes and variations in atmospheric pressure.

For the purpose of making time marks, barographs have a small lever, termed a time marker, which on being depressed moves the pen slightly.

The barograph illustrated in PLATE I is a recent type. Differences in detail, for example in the method of suspending the pen arm, may be found in other barographs.

The Thermometer.

The thermometer is an instrument with which the temperature of the air, or any gas or liquid in which it may be immersed, can be measured. It consists of a glass tube of very small bore, closed at one end, and united at the other to a bulb, which is commonly filled with mercury. Almost all substances expand when they are heated, and contract when they are cooled, but they do not all expand equally. Mercury expands more than glass, and so, when the thermometer is heated, the mercury in the bulb expands, and that portion of it that can be no longer contained in the bulb rises in the tube in the form of a thin thread. The tube being very minute, a small expansion of the mercury in the bulb, which it would be difficult to measure directly, becomes readily perceived as a thread of considerable length in the tube. When the instrument is cooled, the mercury shrinks, and the thin thread becomes shorter as the mercury subsides towards the bulb. By observing the length of the thread of mercury in the tube, as measured by the graduation on the scale at its side, or marked on the tube, the thermometer shows the temperature of the bulb at the time, which indicates the temperature of the surrounding air, or other substance in which the bulb is immersed. Since the mercury is in a closed tube its readings are not sensibly affected by variations of atmospheric pressure.

Invention of Thermometer.

The thermometer was invented at approximately the same time as the barometer. GALILEO made a crude kind of thermometer in which the liquid was open to the air. True thermometers were first brought into general use by the Grand Duke Ferdinand II of Tuscany, who is said to have possessed such instruments in 1654. The liquid used in these early thermometers was alcohol. While mercury is the most satisfactory liquid for general thermometric use, thermometers intended for very cold climates contain pure alcohol. The reason for this is that mercury would solidify at the low temperature of the polar regions. Mercury freezes at about −38° F. while alcohol freezes only at −202° F. though it becomes a thick liquid, and therefore useless for thermometric purposes, at −130° F.

Graduation of Thermometric Scales.

The indications of a thermometer are recorded in degrees. The earliest graduation was that of Sir ISAAC NEWTON in 1701, who divided the range of temperature between the freezing point of water and the temperature of the human body into twelve degrees.

Graduation of Thermometers.

The principle of thermometric graduation is simple. The temperature at which ice melts is always the same, and water boils always at the same temperature under a given atmospheric pressure. The position of the mercury in the tube is marked for each of these temperatures and the interval between the marks can then be divided into a number of equal degrees. There are four systems of graduation now in use, in all of which the boiling point of water is taken as the temperature at which water boils under a standard atmospheric pressure, corresponding to a barometer reading of 29·92 inches of mercury. The four systems are as follows :—

(1) The Fahrenheit Scale. The melting point of ice is 32° and the boiling point of water 212°, the space between being divided into 180 degrees. Continued downwards, the zero of the scale indicates a temperature of 32° below freezing point. The Fahrenheit scale was devised by FAHRENHEIT, a native of Danzig, in 1721 and is that in ordinary use in the British Isles. It is indicated by the letter F., thus " 56° F."

(2) The Centigrade Scale. In 1742, CELSIUS, a professor in Upsala, suggested that the freezing point be called 100° and the boiling point 0°. The Centigrade scale is identical with this except that the figures are reversed, the freezing point being 0° and the boiling point 100°. The Centigrade scale is in general use in most continental countries. It is indicated by the letter C., thus " 15° C."

(3) The Réaumur Scale. In this scale the freezing and boiling points are 0° and 80° respectively. It is used in some foreign countries and is indicated by the letter R., thus " 12° R."

(4) The Absolute Scale. In all the above scales temperatures below the zero of the scale have to be indicated as negative temperatures. Thus a temperature of 5° below zero on the Centigrade scale must be written as —5° C. The Absolute scale of temperature is the Centigrade scale with 273 added to every graduation and is indicated by the letter A. Thus the freezing point of water is 273° A. and the boiling point is 373° A., while a temperature of —5° C. is 268° A. The principal advantage of the Absolute scale for meteorological work is that all negative values are avoided, and all calculations of the pressure and density of air are reduced to simple proportion. The zero of the Absolute scale (—273° C. or —459° F.) was not chosen at random. It represents approximately, so far as our present knowledge goes, the temperature at which any substance whatever has no heat at all, the whole of its previous heat having been converted into some other form of energy. Temperature on the Absolute scale is therefore an indication of the actual heat of a body, independent of reference to such temperatures as the freezing and boiling points of water.

Conversion of Thermometer Scales.

To convert Centigrade readings to Fahrenheit use the following rule:—Multiply by $\frac{9}{5}$ and add 32. Similarly, to convert from Fahrenheit to Centigrade, subtract 32 and multiply by $\frac{5}{9}$. From Fahrenheit to Absolute, proceed as for Centigrade and add 273. TABLE X, Appendix I, page 100, gives the values on the Centigrade and Absolute scales corresponding to each degree Fahrenheit, from 0° F. to 119° F.

Air and Sea Thermometer Protectors.

In order to minimize the breakage of thermometers, mahogany protectors are used as illustrated in FIGURE 3. A protector consists of a mahogany frame into which the thermometer is fitted by unscrewing a metal plate at the top. At the bottom of the bed is a metal guard to protect the bulb of the thermometer. The protector for use with a dry or wet bulb thermometer has an open guard, but in that for use in measuring sea surface temperature the guard is closed in, thereby forming a reservoir for retaining a small quantity of sea water around the bulb while the temperature is being read.

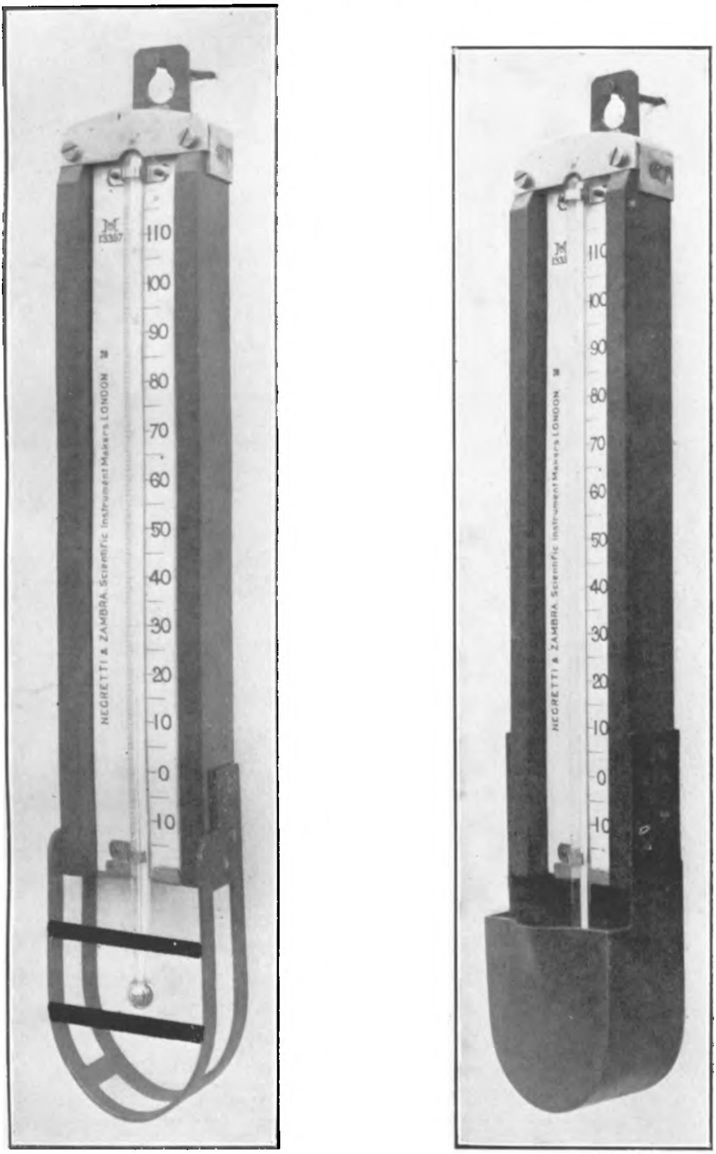
The Hygrometer.

An instrument for measuring the humidity of the air is called a hygrometer. There are several kinds of hygrometer but the form in common use, the dry and wet bulb thermometers, also known as Mason's hygrometer, is the simplest and easiest to handle. Of the two thermometers the dry bulb thermometer is the ordinary one used for obtaining the temperature of the air. The second or wet bulb thermometer is exactly similar, but is fitted with a single thickness of fine muslin or cambric secured lightly round the bulb. This coating is kept damp by means of a few strands of cotton wick, which are passed round the glass stem close to the bulb so as to touch the muslin, and have their lower ends dipping into a water container placed beside the thermometer. Water is thus slowly conducted by capillary action to the muslin round the bulb, where it gradually evaporates. This thermometer will usually show a temperature lower than that shown by the dry bulb thermometer, and the amount of the difference is commonly called the depression of the wet bulb.

Action of the Wet Bulb Thermometer.

The principle of the dry and wet bulb thermometers is simple. When water evaporates from the muslin cover of the wet bulb thermometer, it passes into the state of invisible vapour, and in so doing absorbs heat from the bulb and the mercury it contains, which consequently indicates a temperature lower than the temperature of the air. If the air becomes less humid the rate of evaporation is greater, and the fall of temperature of the wet bulb is also greater; accordingly the difference in readings between the dry and the wet bulb is also greater. The difference sometimes amounts to 15° or 20° in England, and to more in some other parts of the world, but at sea the difference seldom exceeds 10° except in fine, clear

Mahogany Protectors for Thermometers



Air Protector

Sea Protector

Fig. 3

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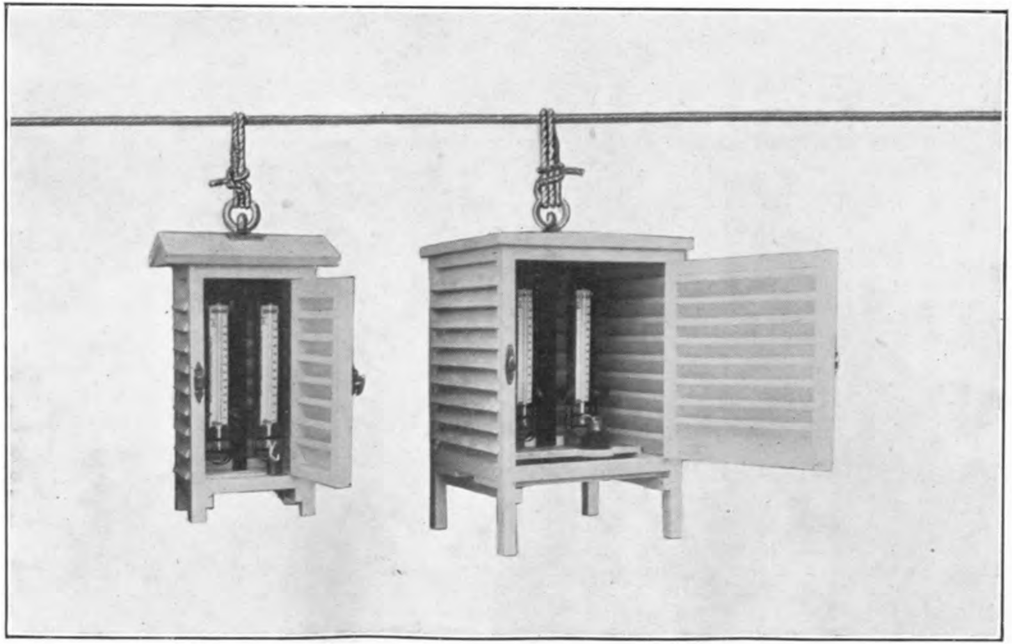
METEOROLOGICAL OFFICE

SHIP'S THERMOMETER SCREENS



Modified with Thermometer Protectors.

Portable, with Thermometer Protectors.

PLATE II

weather in the tropics. When the humidity of the atmosphere is very great, during or just before rain, or when fog is prevalent or dew is forming, there is little or no evaporation, and the two thermometers give the same, or very nearly the same, reading.

The Thermometer Screen.

To ensure correct records of the temperature and humidity of the air, the dry and wet bulb thermometers must be placed in a screen, the sides of which are protected from the sun and rain by "jalousies" or louvres, which however let the air in freely. This screen is often called a Stevenson screen, after the inventor's name. Various patterns of this screen are made; the two types selected for use at sea, shown in PLATE II, are known as the Portable (large) and the Modified (small). Both are louvred on all four sides.

Since the air temperature required is that of the air in shade, the necessity of protecting the thermometer from the direct heat of the sun is obvious. A thermometer exposed to the sun does not indicate the temperature of the air; it merely shows the temperature to which the thermometer itself has been raised when subject to direct solar radiation, and the reading is thus much higher than the air temperature in the immediate vicinity of the thermometer, since the thermometer absorbs more of the sun's heat than the air does. The thermometer screen is equally necessary at night, as it prevents the thermometer from then reading too low. Radiation is the process by which heat is transferred from one body to another without altering the temperature of the intervening medium. The earth and all objects on it, including the thermometers, radiate heat into space both during night and day. During the day the earth receives more heat than it radiates away; at night the earth radiates heat comparatively quickly if the sky be clear, and consequently a thermometer not protected by a screen would also radiate its own heat and show too low a temperature. The air, of which the temperature is desired, does not lose heat so quickly during the night as do the earth and all objects on it.

The Thermograph.

This instrument is carried in some ships. It gives with suitable exposure a continuous record of air temperature, which, if studied in connection with the record of a barograph for the same period, will show the relation existing between the fluctuations of air temperature and pressure. After the observer has had some little experience, the instrument will be found to be an aid in foretelling changes in weather conditions.

Most thermographs are made on the bi-metallic principle, that is to say, the temperature is measured by the difference in expansion of two strips of metal. These strips are fixed side by side in a spiral, one end of which is secured rigidly to the instrument, while the other is attached to a system of levers which actuates the recording pen as the spiral coils or uncoils.

A distant thermograph is now in use in some ships. A bulb containing mercury is exposed in a selected position. This communicates through tubes to a recording pen arm in any desired part of the ship.

The Sea Thermometer.

An ordinary thermometer fitted with a sea thermometer protector, see FIGURE 3, is used for sea surface temperature observation.

The Sea Thermograph.

A thermograph for reading the sea temperature at the depth of the ship's main inlet has been used with success in some ships. The instrument is attached to the main inlet in the engine room, and keeps a continuous record of the temperature of the sea through which the ship steams.

Hydrometer.

This instrument is employed for determining the specific gravity of liquids. The hydrometer used at sea is constructed of glass. The form of the instrument in common use is shown in FIGURE 4. It consists of a glass tube and a float, with a bulb at the end partly filled with small shot to act as ballast and to make the instrument float steadily in a vertical position. From the neck of the bulb the glass expands into an oval or cylindrical shape, to give the instrument sufficient volume for flotation; above this it is tapered off to a narrow upright stem closed at the top, attached to which is a scale. The divisions of the scale read downwards, so as to measure the length of the stem which stands above the surface of any fluid in which the hydrometer is floated. The denser the fluid, and therefore the greater its specific gravity, the higher will the instrument rise; the rarer the fluid, or the smaller its specific gravity, the lower it will sink.

FIG. 4.

The indications depend upon the well-known principle that the weight of the quantity of fluid displaced by any floating body is equal to the weight of the floating body itself. According, therefore, as the specific gravities of fluids differ from each other, so will the quantities of the fluids displaced by any floating body, i.e. the depth of its immersion, vary, when it is floated successively in each.

Specific Gravity.

The true specific gravity of a sample of sea-water is the ratio of its weight to the weight of an equal volume of pure water at standard temperature, namely 277° A. (4° C., or

39·2° F.). A hydrometer will show the zero of its scale when it floats in distilled water at that temperature, or in any sample of water or other liquid of the same specific gravity. If the specific gravity of water be increased, as it is by the presence of salts in solution, the hydrometer will rise ; if on the contrary the specific gravity be diminished, as by a rise of temperature, the hydrometer will sink so that the zero of its scale is under water.

CHAPTER III

THE POSITION, SETTING UP, AND CARE OF INSTRUMENTS

The Position for Instruments on board Ship.

In steamships the thermometer screen is usually placed on the bridge and the mercury barometer in the chart room, for practical convenience. The chart room is not always the best place for the barometer, as it is often in an exposed position. Furthermore the pumping of a marine barometer is reduced to a minimum when the instrument is near the centre of gravity of the ship, but except in small vessels, the inconvenience of so doing makes it impracticable.

It is not possible to give fixed rules for the precise location of these instruments, as circumstances vary in different ships. The following points should however be carefully observed:

(1) They must be out of the way of unauthorized persons.

(2) They must not be exposed to the direct rays of the sun, with the exception of the thermometer screen, which may be so exposed.

(3) They must not be exposed to suddenly varying conditions due to causes within the ship, such as draughts of air from boilers, engine room, etc.

(4) The light used by night should fall on the instruments from the same direction as daylight does. By day and night the light should come from behind or from the side of the observer.

Thermometer Screen.

The screen containing the wet and dry bulb thermometers, whether it be of the Portable (large) or the Modified (small) type, should be placed in a suitable position in the open air, and for convenience in reading the thermometers, about 5 ft. above the deck. It may be exposed in sun or shade, preferably slung from an awning spar or ridge rope, so as to have an unimpeded circulation of air flowing through it.

The position of the thermometer screen requires great attention. It cannot be too strongly emphasized that the temperature of the free air is required, not that affected by heat from the ship, and that therefore the weather side of the ship is usually most suitable. The position of the screen for observations, to be aimed at, is where the air will come direct on to the screen from the sea before passing over any part of the ship. The ship is a source of local heat; radiation takes place from the hull and from sunny decks, deck houses, etc., especially in the tropics. Radiation of heat, or warm draughts of air, may be felt from galleys, engine and boiler rooms, stokehold and funnel. The thermometer screen should be as far as possible removed from all such sources of local heating which will tend to cause false air temperatures, particularly on days when the wind is light. The choice of the bridge will avoid some of these sources of heating.

The position of the screen may require to be changed with shifts of wind or alterations of course. When not in use it may be stowed as most convenient.

The lighting arrangement should be good to make sure that it cannot affect the temperature of the thermometers.

Barograph.

The barograph when used on board ship, should be placed on a suitably cushioned bed or carried in a cradle slung fore and aft from the deck above, or a spring suspension bracket may be used. It should be located in a position where it will be least affected by concussion, vibration or movement of the ship.

Setting up the Instruments

The Barometer.

The mercurial barometer is so constructed that it swings in gimbals and so preserves itself nearly erect, when the ship is rolling. In order to give the instrument swinging room it is supported by a bracket which is securely screwed on to a bulkhead. The height of this arm should be so regulated that the top of the mercury at its highest probable position is just below the height of eye of the average observer. A barometer that is too high is almost certain to cause errors of parallax.

The bracket having been screwed to the bulkhead, the instrument should be carefully lifted, the hinged part of the suspension arm bent back, and the barometer shipped into the bracket. The mercury should then fall gradually, and the instrument will be ready for observation in about an hour; local temperature affects the instrument slowly. Sometimes in a new tube the mercury does not readily quit the top of the tube. If, after an hour or so, the mercury has not descended, tap the cistern end rather sharply, or make the instrument swing a little in its gimbals, which should cause the mercury to fall in the tube. If this method does not succeed, the force of the tap must be slightly increased, but violence must not be used.

Whenever a barometer has to be unshipped and placed in its box, first lift the instrument out of its bracket, and bring it gradually into an inclined position, to allow the mercury to flow very gently up to the top of the glass tube, avoiding any sudden movement which would cause the mercury to strike the top of the tube with violence. The absence of air in the tube makes the force of the blow little different from that of a solid rod of metal, so that it might break the tube. The barometer should then be taken lengthwise and laid in its box. To be carried with safety it should be held with the cistern end upwards, or lying flat; and it must on no account be subject to jars or concussions. Barometers should always be unshipped when heavy guns are fired, or there are violent concussions on board the ship.

FIGURE 5 shows a case, with suspension arm socket secured within it and barometer in sea position. Such a case should be firmly secured to the bulkhead. The socket is screwed to the bottom of the case, and a clip "A" is provided to hold the barometer in its stowed position when in port. A hook should be fitted to secure the lid open while at sea.

To check that the Gold Slide is correctly adjusted when the instrument is first placed in position, set the height scale so that zero for height coincides with 45° on the latitude scale. Then read the temperature scale corresponding to zero on the "correction to barometer" scale. If this reading of the temperature scale is identical with the standard temperature of the barometer, the apparatus is in correct adjustment.

Thermometers.

To set up the thermometers in the screen, the instruments in their protectors are secured into position and the water vessel is so placed that the wick from the wet bulb is well immersed. This water vessel should be placed in the holder provided for it, which is below and a little to one side of the wet bulb of the thermometer. The side remote from the dry bulb is selected in order that the latter may not be affected by moisture rising from the water.

Barograph.

Two points require attention in setting up this instrument. The pressure of the pen upon the chart on which it writes is a delicate adjustment. This pressure should therefore be tested and, if necessary, adjusted as described on pages 20–21. The second point is that the reading should be in as good agreement as possible with that of the marine barometer, after the reading of the latter has been corrected. The readings of the two instruments should therefore be compared and the position of the pen on the chart of the barograph adjusted, if necessary, as described on page 21.

The Care of Instruments

Meteorological instruments are very delicate and costly and thus require special care in handling. All instruments should be kept clean and dry. The sea thermometer and its case need particular care in this respect. Attention should also be given to the maintenance of instruments in good condition and efficient working order. Special instructions for certain instruments are given below. Instruments, when not in use, and especially spare instruments that are stowed for a

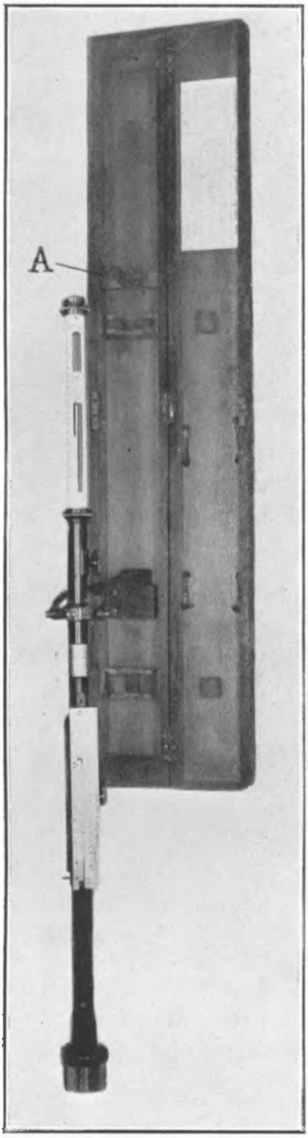


FIG. 5

considerable period, should be inspected occasionally; the store in which they are placed must be cool and dry. Instruments must never be jarred or subject to concussion.

Gold Slide of the Marine Barometer.

The scales, which are silvered, may be kept clean by using a soft cloth to remove any dust or dirt. Metal polish should never be applied. A very little clock oil may occasionally be used for lubrication.

If the rack and pinion become very stiff a responsible officer may overhaul as follows. Remove the slide from the barometer and place it face downward. A small brass block securing the pinion in position will then be seen. Remove this by taking out the four screws. Wipe the pinion and its bearing with a soft rag to remove dirt and old oil; apply a little fresh clock oil. Now remove the four small screws, two at each end of the rack. The slider can then be taken out. Wipe off all dirt and old oil from the rack and bearing surfaces. Put a drop of fresh clock oil on the rack and on the back of slider. Reassemble, taking care to see that the pinion is properly engaged in the rack before tightening the screws. The slider should then move up and down quite smoothly.

The screws which secure the latitude scale should not be touched during this operation. Before replacing the slide on the barometer it is desirable to check the adjustment by the method described on page 18.

Thermometers.

The mercury column of a thermometer sometimes separates in one or more places. To join it together, swing the instrument briskly at arm's length repeating the process if necessary.

Wet Bulb Thermometer.

The wet bulb thermometer needs most careful attention in order to get correct readings. The water vessel must be kept as far from the dry bulb thermometer as possible and it is desirable to place a cover over it, with a small hole for the wick to pass through. This prevents moistening of the whole of the air inside the screen by evaporation.

To place the muslin and wick in position a single thickness of fine muslin or cambric should be fitted over the thermometer bulb as smoothly as possible. The muslin is kept in place by attaching the cotton wick in the following way. Take a round turn in the wick with the strands middled on the bight and pass the ends through the bight forming a round turn and cow hitch. Any superfluous muslin or loose ends should then be trimmed off. The strands should be long enough to reach two or three inches below the lowest part of the bulb, in order that their lower ends can be immersed in the water vessel, but not long enough to hang in a bight, or water will drip off the wick at the lowest point of the curve until the reservoir is emptied.

To get correct readings the muslin must be damp but not dripping. If too wet, the reading of the thermometer will be too high. If not wet enough it will also be too high. Both defects may be remedied by adjusting the distance between the water vessel and the thermometer bulb.

The water used should be the purest obtainable, as the effect of the constant evaporation is to cause any impurities to be deposited on the bulb. Either distilled or rain water should be used, or if this be not procurable, the softest fresh water available, to avoid the deposit of lime, or other impurity on the bulb. To avoid breakage of the water vessel during frost it should be only about two-thirds filled.

The muslin and wick should be changed once a month or oftener. The presence of salt in the water will cause the thermometer to read too high, and should spray have reached the instrument the muslin and wick should be replaced by a new one. It is advisable to do this in any case after bad weather. If it be found that an incrustation of lime or other impurity has formed on the thermometer bulb, this should be scraped off.

Aneroid Barometer.

The reading of this instrument should be frequently compared with that of the mercury barometer after the latter has been corrected. The reading of the aneroid should be corrected, when necessary, by means of the adjusting screw at the back. Whenever such an alteration of the index error is made the fact should be noted, with date.

Barograph and Thermograph.

Self-recording instruments require constant attention and care. Friction between the working parts of the apparatus must be avoided as far as possible. The bearings should be cleaned occasionally and oiled with good clock oil, care being taken to remove excess of oil.

Thermographs for meteorological use should be exposed on deck, preferably in a louvred screen, and hence it is necessary to clean and oil their bearings much more frequently than is the case with barographs.

Most of the friction generally occurs between the pen and paper on which it writes. The pressure of the pen on the paper should be reduced to the minimum consistent with a continuous trace, for which simple contact with the paper will suffice. This pressure should be tested from time to time.

In the older type of instruments, in which the elasticity of the style is used to keep the pen in contact with the paper, the pressure should be adjusted by means of the milled head near the base of the style, so that the pen falls away from the paper, when the instrument is tilted slightly.

In a recent type of barograph (illustrated in PLATE I) the style which carries the pen is suspended like a gate and it is so arranged that the slope of the gate bearings is adjustable. It is thus possible to regulate the pressure of the pen on the chart, from zero upwards. In the Plate, B denotes the gate suspension and the adjustment is made by means of the milled head C which clamps the rod carrying the bearing in any desired position in its cylindrical socket.

Excess of ink in the pen should be avoided. Special care must be taken not to let ink come in contact with the metal style which carries the pen, as this will cause the pen to adhere firmly to the style, so that it cannot be removed and cleaned. The ink may also cause the metal to become brittle and break. Should the style be accidentally inked, it should be immediately washed, and slightly oiled. A thin, clear trace should be aimed at, for if the trace be thick and blurred many of the smaller variations become obliterated. The pen should be well washed from time to time in water or methylated spirit.

The point of the pen should be fine so as to give a narrow trace, but it must not be so fine as to scratch or stick to the paper. A new pen may frequently be improved by drawing the point once or twice along an oil stone, but any trace of oil should afterwards be carefully removed.

The timepiece may be regulated by moving the pointer on the balance of the clockwork. Should the timepiece be fast the pointer should be moved in the direction R.S. (*retard*, slow) ; if slow, in the direction A.F. (*avance*, fast). Frequent movement of the pointer should be avoided.

The barograph is set to give the correct reading by comparison with the reading of the mercury barometer, after the latter has been corrected by means of the Gold Slide or the tables in Appendix I.

In the type of barograph shown in PLATE I, the setting is made by adjusting the height of the fulcrum of the principal lever C by means of the milled head screw D on the central bridge. In other instruments the adjustment is made by raising or lowering the point in the base plate to which the lowest of the set of aneroid boxes is fixed. This is done either by a milled head screw on the base plate near the aneroid boxes or by a screw or square head underneath the instrument.

The readings of the thermograph also require frequent checking by comparison with standard instruments. The thermograph may be set by comparing its indications with the reading of the dry bulb thermometer placed beside it in the screen. The setting should only be attempted at times when the temperature is constant or changing slowly, and only when the pen is near the middle of its range. As one end of the bi-metallic strips of the thermograph is in thermal contact with the body of the instrument, being rigidly fixed to it, the thermograph is apt to be somewhat sluggish when the changes of temperature are rapid, since the instrument as a whole takes an appreciable time to alter in temperature.

CHAPTER IV

INSTRUMENTAL OBSERVATIONS

The Barometer

Reading a Mercury Barometer of the Kew Pattern Graduated in Millibars.

The temperature is read to the nearest whole degree on the scale of the attached thermometer.

After the temperature of the barometer has been read the barometer may be touched with the hand, but care should be taken to do this as lightly as possible. Tap gently with the finger until the tapping no longer affects the shape of the mercury surface in the tube. Turn the milled head at the side of the instrument, until the lower edge of the vernier and the lower edge of the sliding piece at the back of the instrument, which moves with the vernier, are in line and appear just to touch the uppermost part of the domed surface of the mercury.

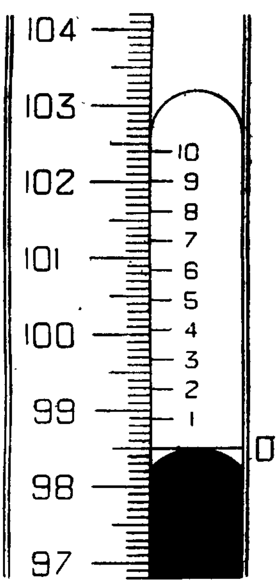


FIG. 6.

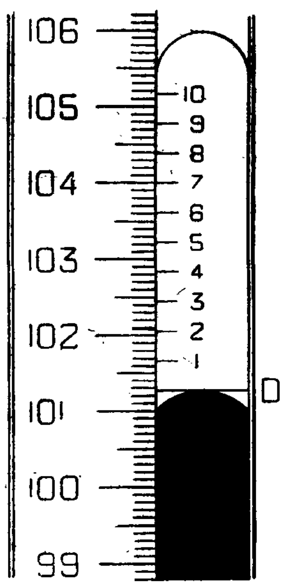


FIG. 7.

READING THE SCALE

If a piece of white paper is placed behind the instrument it assists the eye. An electric torch may be used at night ; a lighted match or other naked light should not be placed behind the barometer, as this may lead to very inaccurate setting.

If the eye is not in line with both the bottom of the vernier and the sliding piece at the back, the reading will be incorrect owing to errors of parallax.

FIGURES 6 and 7 illustrate the process of reading the vernier, which is done in the same way as that of a sextant. The reading will be speedily mastered by examining these figures, the reading of FIGURES 6 being 985·0 millibars, and that of FIGURE 7–1012·7 millibars.

Errors in reading the Main Scale.

The simplest error that can be made in reading the barometer is that of making an actual mistake of 10 mb. or 1 mb. The only means of guarding against this is care. After a reading has been logged it should be checked to make sure that no misreading has been made. In making the first reading attention should be concentrated on the accuracy of the decimal; in the check reading attention should be concentrated on the tens and units.

Errors due to Parallax.

These have been referred to above in the instructions for reading the barometer. If the eye is too high, the reading will be too high. If the eye is too low, the reading will also be too high. In reading the barometer, if the eye is too high, only the front of the vernier can be seen and this will be lined with the top of the mercury column and the eye. If the eye is too low the sliding piece at the back of the vernier will be lined with the top of the mercury column and the eye, the lower front edge of the vernier being indistinguishable.

Error due to Wind.

It is found that in strong winds the effect of having the door of the charthouse, in which the barometer is situated, open may alter the height of the mercury column. The doors should, therefore, be closed while the barometer is being read, if there is much wind. This applies quite as much to the lee door as to the weather door.

Errors due to Pumping.

When a ship is in a seaway, the mercury of the barometer may oscillate up and down in the barometer tube. This is termed pumping and is due to the following causes :—

(*a*) The mobility of the mercury being acted on by the heaving of the ship and her vibration.

(*b*) The mercury being acted on by the swinging of the instrument.

(*c*) The effect of the wind gusts on the air pressure of the room in which the barometer is hung.

(*d*) The variation of atmospheric pressure following the change of height of the ship above mean sea level due to her vertical motion on the waves.

Of these (*a*), (*c*) and (*d*) are oscillations about a mean position, the mercury being as likely to be high as to be low, while for (*b*) the oscillation is always above the true position. Observations should be recorded for the mean position, to obtain which the vernier should be set by eye midway between the highest and lowest positions of the mercury column. Observers who wish to obtain an exact mean should take three pairs of readings, one of each pair being the highest reading obtainable and the other the lowest. The result recorded is the mean of the whole set. Thus, if observations were obtained as follows :—

Highest Reading.		Lowest Reading
1007·6 mb. ..	..	1006·5 mb.
1007·5 mb. ..	..	1006·6 mb.
1007·7 mb. ..	..	1006·6 mb.

The mean reading would be 1007·1 mb.

Reading a Mercury Barometer of the Kew Pattern graduated in inches.

The general instructions for reading millibar barometers, and the remarks on errors of reading, given above, apply also to inch barometers. The same precautions have to be observed in setting the vernier.

In the barometers graduated only in inches, now in use at sea, the verniers are usually subdivided so as to read to a thousandth of an inch.

To convert readings of the barometer to true atmospheric pressure at sea level.

The reading of a barometer gives the weight of the atmosphere at the place of observation, but this reading is subject to variations due to the temperature of the instrument, its height above the sea, and the latitude of the place affecting gravity.

Other corrections are due to the facts that the brass scale of the instrument expands with heat, that capillarity tends to depress the mercury in the tube, and that the quantity of mercury in the cistern varies according to the height of the mercury column in the tube. These latter corrections are due to the instrument itself and allowance can be made for them in the process of construction. There is with every instrument a final small "index error" which is measured at the National Physical Laboratory, and of which a certificate is pasted in the case of instruments tested at that institute.

With millibar barometers this certificate is put in a slightly different form from that in which it is put with inch barometers. In the latter the index correction is given as so many thousandths of an inch to be added to or subtracted from the barometric reading; in the millibar barometer the standard temperature on the Absolute scale is given. The standard temperature is the temperature of the barometer, as indicated by the attached thermometer, at which the reading of the barometer, in latitude 45° and at mean sea level, is comparable with that of any other barometer. If the instrument is at any other temperature, a correction must be applied.

If the latitude is not 45°, the reading will not be correct at the standard temperature, but there will be a temperature at which the reading would be correct, if it is so chosen that the latitude correction just balances the temperature correction. This temperature, at which the readings of the barometer need no correction, is called the fiducial temperature for the barometer in the particular latitude. For a barometer on land in a fixed latitude the fiducial temperature remains the same, but at sea the fiducial temperature changes with latitude.

To allow for the barometer not being at sea level the fiducial temperature can be adjusted, because, in the ordinary circumstances in which the barometer is used at sea, the allowance to be made for 100 ft. of height lies between 3·3 mb. and 3·9 mb., according to the temperature of the air as shown by the dry bulb thermometer in the screen. A fixed correction of 3·6 mb. for 100 ft., and proportionately for lesser heights, is therefore little in error in most cases and is used in the method of correction given here. The correction of the millibar barometer is thus simplified, as it is unnecessary to take the temperature of the air into account.

Correcting Millibar Barometers by Tables.

To make the process of correction as simple as possible tables have been made out and are given in Appendix I, TABLES I and II, pages 88 to 93. They are used as follows :—

The height of the cistern above sea level having been determined, TABLE I, pages 88 and 89, is used and the value of the fiducial temperature for the latitude of the ship is made out by adding or subtracting the figures given in that table to the standard temperature.

Having determined the adjusted fiducial temperature for the latitude, TABLE II, pages 90 to 93, is used to compare it with the attached thermometer. Enter the table with the attached thermometer reading on the left-hand side, and in the column under the adjusted fiducial temperature will be found the correction in millibars to be applied to the barometric reading.

TABLE II is not quite accurate if the barometric pressure is either very high or very low. To correct exceptional readings the rule is " add 1 per cent. of the correction given in the table for each 10 millibars above 1,000 and subtract 1 per cent. for each 10 millibars below ". Such correction of the values obtained from the table is, however, not always large enough to affect the corrected barometer reading.

EXAMPLE :—M.O. Barometer No. 922 has a standard temperature of 285·0°A. at 1,000 millibars. In latitude 32° 39′ N., the reading of the barometer was 1016·9 mb., and of the attached thermometer 293·0°A. The height of the barometer cistern was 42 ft. above sea level.

Standard temperature of barometer.. ..		285·0°A.
Ship's latitude, 32° 39′ / Height of barometer above sea level, 42 ft.	Correction from Table I ..	+ 2·4°A.
Adjusted fiducial temperature		287·4°A.
Attached thermometer reading		293·0°A.
Correction from TABLE II		— 1·0 mb.
Observed barometric reading		1016·9 mb.
Correction as above		— 1·0 mb.
Corrected barometric reading		1015·9 mb.

After reading the barometer, move the Gold Slide up or down so that the height of the barometer above the water line, indicated by the scale, coincides with the latitude of the ship on the latitude scale. The correction to be applied to the barometer reading is then read off in line with the top of the mercury column in the thermometer. *Correcting Millibar Barometers with Gold Slides.*

Tables of correction for temperature, height and gravity are given in Appendix I, TABLES III to V, pages 94 to 96. In addition to these the index correction must be made. The corrections in the case of the inch barometer, have simply to be added to or subtracted from the reading. *Correcting Inch Barometers.*

EXAMPLE:—In latitude 51° N., barometer reads 30·240 in. at a height of 36 ft. above sea level. The attached thermometer reads 58° F., the dry bulb in the screen reads 58° F. and the index error is + ·005.

	Inches.
Uncorrected reading	30·240
Index error correction	+ ·005
	30·245
Temperature correction for 58° F. (TABLE III)	— ·080
	30·165
Height correction for 36 ft. at air temperature of 58° F. (TABLE IV)	+ ·039
	30·204
Gravity correction in latitude 51° N. (TABLE V)	+ ·016
Corrected barometer reading	30·220

Conversion of millibars to inches.

A table for the conversion of barometer readings in millibars to inches, or vice versa, is given in Appendix I, Table VI, page 97. This table also contains the conversion values of barometer readings expressed in millimetres of mercury, which are used in many foreign countries.

It must be clearly understood that in barometers graduated with both millibar and inch scales, the uncorrected readings taken at the same time will differ. The reason for this is that the millibar graduation is constructed to give the true atmospheric pressure at its standard temperature of about 285° A. (54° F.) at sea level in latitude 45°; whereas the inch scale is graduated to give true atmospheric pressure at a temperature of 28·6° F. at sea level in latitude 45°. It will thus be seen that the correction for temperature is different for each scale, and it is only when both readings have been fully corrected that they will agree, on conversion.

Change of Barometer.

The change or tendency of the barometer, always a valuable observation to seamen, has enhanced value with the methods of weather forecasting made possible by wireless communication.

In all well-ordered ships the barometer is logged at the end of each watch, and sometimes every two hours. It is therefore generally possible to ascertain the exact change or tendency of the barometer.

In equatorial regions the normal diurnal range of the barometer is clearly indicated by a rise and fall twice daily. Barometric changes in these regions, unless they exceed those of the diurnal range, do not indicate changes in the weather. Tables for correcting pressure for diurnal variation will be found on page 32 of "A Handbook of Weather, Currents and Ice, for Seamen", M.O. 379.

For reporting the change or tendency of the barometer in code by wireless, Table VII, Appendix I, page 98, adapted from the International Ships' Weather Telegraphy Code, may be used. To find and record the tendency of the barometer with this table, take the difference and the interval between recorded readings; it is not necessary to correct the readings, as is done to find the absolute pressures. If the interval is not exactly 2, 3 or 4 hours, interpolate between the values given in Table VII. When possible, an interval of exactly 3 hours should be used.

To estimate the true tendency of the barometer in a ship under way, it is necessary to allow for course and speed, and, therefore, in reporting tendency the course and speed made during the interval of observation should be given.

The barometer tendency should not be corrected for changes due to normal diurnal variation.

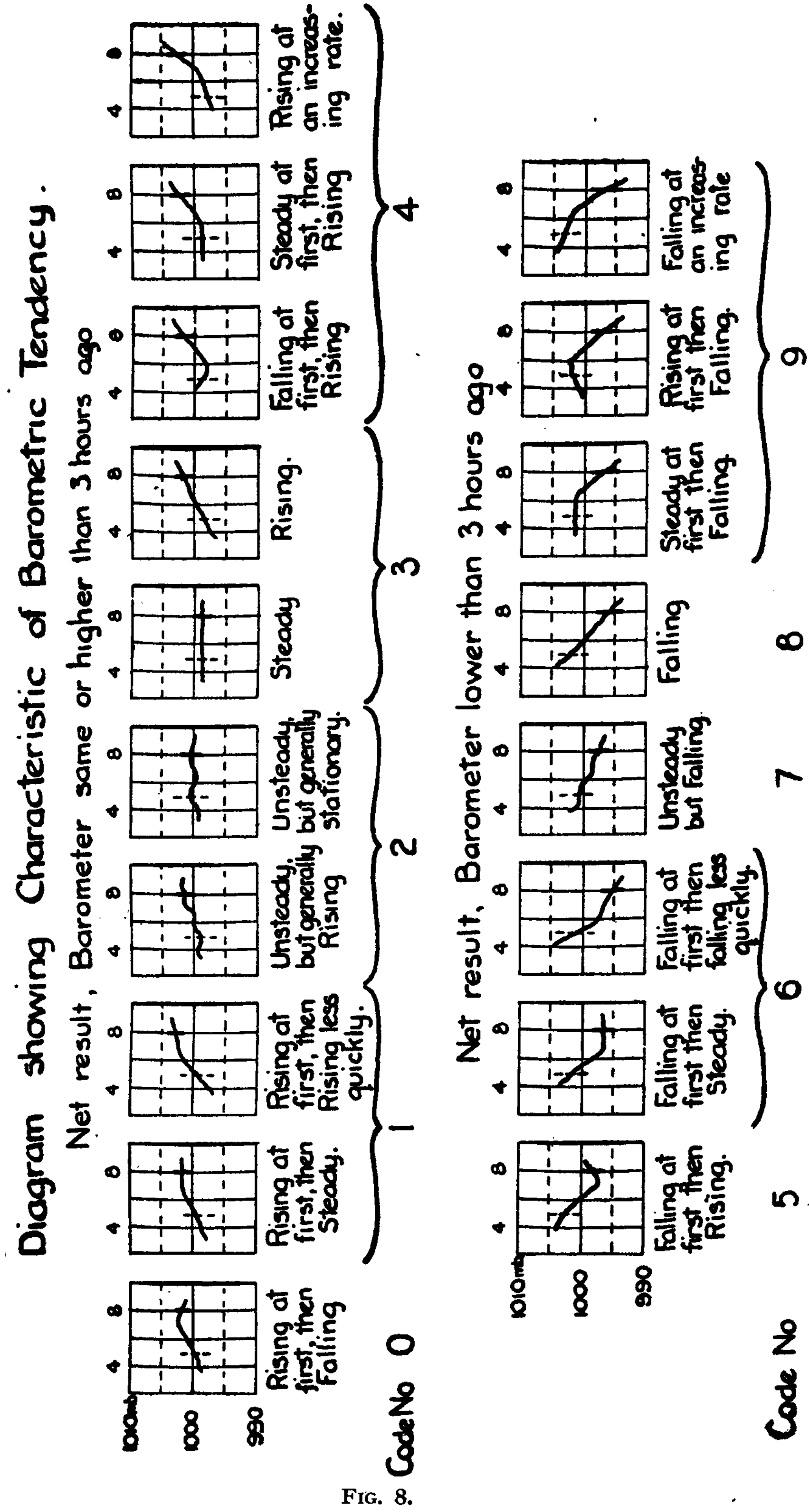


Diagram showing Characteristic of Barometric Tendency.
Net result, Barometer same or higher than 3 hours ago
1010mb
1000
990
4
8
Rising at first, then Falling
Rising at first, then Steady.
Rising at first, then Rising less quickly.
Unsteady, but generally Rising
Unsteady, but generally stationary.
Steady
Rising.
Falling at first, then Rising
Steady at first, then Rising
Rising at an increasing rate.
Code No 0
1
2
3
4
Net result, Barometer lower than 3 hours ago
Falling at first then Rising.
Falling at first then Steady.
Falling at first then falling less quickly.
Unsteady but Falling
Falling
Steady at first then Falling.
Rising at first then Falling.
Falling at an increasing rate
Code No 5
6
7
8
9

FIG. 8.

The Barograph

The barograph should be kept to Greenwich Mean Time throughout the voyage. Time marks should be made each day at noon, ship's time.

Change or Tendency of the Barometer by Barograph.

By means of the barograph it is possible to report exactly what the changes have been. TABLE VIII, Appendix I, page 98, adapted from the International Ships' Weather Telegraphy Code, gives what is called the " Characteristic " of the changes of the barometer during the last three hours.

FIGURE 8 illustrates each of the characteristics given in TABLE VIII, and from TABLE IX, Appendix I, page 99, the amount of the change, rise or fall, otherwise known as the tendency, may be given, by comparing the level of the pen at at the time of observation with its level as indicated on the trace three hours previously.

The Aneroid Barometer

Readings of aneroids do not require correction for temperature or latitude, but only for height above sea level and index error. For practical purposes these are usually combined as one error, to be added to or subtracted from the reading.

The Dry and Wet Bulb Thermometers

Reading Thermometers.

The thermometers should be read with care. Though graduated to one degree only, as far as possible the reading should be given by estimation to the nearest tenth of a degree.

If the wet bulb reading is higher than the dry bulb, the wet bulb is not working, and attention should be given on the lines indicated in the previous chapter.

The Wet Bulb Reading during Frost.

During frost, when the muslin is thinly coated with ice, the readings are still valid, because evaporation takes place from a surface of ice as freely as from that of water. If the muslin is dry and there is no coating of ice the bulb must be coated with a thin layer of ice, by wetting the muslin slightly with ice-cold water by a camel-hair brush or other means. The water will usually take 10 to 15 minutes to freeze. Excess of water must not be used as it takes much longer to freeze and will also not give accurate readings. After the wetting of the muslin the temperature generally remains steady at 32° F. until all the water has been converted to ice. It then begins to fall gradually to the true wet bulb reading. No reading must be recorded until the temperature of the wet bulb has fallen below that of the dry bulb and remains steady.

Dry windy weather may cause the ice to evaporate completely before the time of the next reading, in which case the procedure of wetting the bulb must be gone through again. The original coating of ice will give satisfactory readings as long as it lasts.

Use TABLES XI and XII, Appendix I, pages 101 and 102. In each table a line is ruled to call attention to the fact that above the line evaporation is going on from a water surface but below the line it is going on from an ice surface. Owing to this, interpolation must not be made between figures on different sides of this line. **To find the Relative Humidity and the Dew-point.**

The Sea Thermometer

The water employed for taking the sea surface temperature should be drawn in a canvas bucket from over the ship's side, forward of all ejection pipes.

The bulb and lower part of the thermometer must be well immersed for a sufficient time to ensure that the correct temperature of the water is reached. The time necessary will vary with the difference of sea and air temperature, and the thermometer should be watched to see when it ceases to change. Three or four minutes is generally sufficient.

The thermometer is then withdrawn and promptly read. It is essential that the bulb of the instrument should be under water at the time of reading, hence the reservoir around the bulb. If it is not covered, evaporation will take place from the drops of water adhering to it, and it will act as a wet bulb thermometer, and may give too low a reading.

Sea water freezes at 28° F. in normal conditions. In freezing, crystals are formed that are free from salt, but there is brine intermingled with these crystals in the ice.

The Thermograph

The remarks made for the barograph regarding the use of G.M.T. and the daily time mark (see page 30) apply also to the thermograph.

The Hydrometer

The specific gravity of sea water should be taken in the same water as the sea surface temperature. The hydrometer should be lightly spun in the centre of the bucket; when it has lost all up and down motion, and before the turning motion has entirely ceased, the scale is read. **Reading Hydrometers.**

The hydrometer needs most careful handling to obtain the best results. It is an instrument of which the weight is very nicely balanced and which will, therefore, be made inaccurate by any foreign matter which adheres to it. The hydrometer should be washed occasionally in fresh water and care must be taken that it is always scrupulously clean, all dirt or grease being removed by wiping with a clean, soft cloth before and after use.

Care must be taken to avoid parallax, which is very likely to occur in reading this instrument. It will be noticed that the surface of the water is curved up round the stem of the instrument by capillarity. The point of the scale to be observed is that point which is on a level with the general surface of the water, not with the highest point to which it is drawn up around the stem.

The specific gravity of a sample of sea water is defined as the ratio of its weight to the weight of an equal volume of pure water at 277° A. The volume of water changes with its temperature, but as glass also changes its volume with changes of temperature, the error in the reading of the hydrometer due to this cause is not so great as it would otherwise be. In order to make the error small at the usual temperatures at which the hydrometer is used, the scale on standard hydrometers is so arranged that the reading is correct at a temperature of 288° A. (59° F.).

CHAPTER V

OPTICAL AND GENERAL PHENOMENA

Observation of Optical Phenomena.

Many optical phenomena, such as halos and coronæ, are more strikingly seen if viewed through neutral-tinted glass, not too deep in tone, such as the lightest of the series belonging to a sextant. This method also enables the upper clouds to be better seen. A still better way is to view the sky by reflection from a piece of black glass, but this is not usually available. An efficient substitute may be made by viewing the reflection from the front of a small piece of ordinary glass which has been backed with black paper.

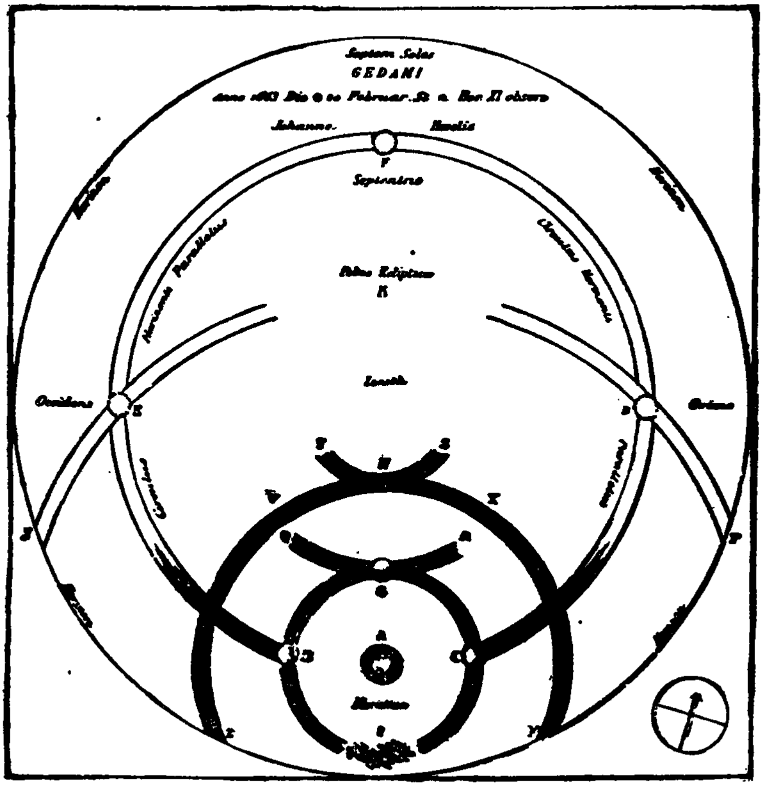


FIG. 9.

It is possible to photograph halos, rainbows, etc., giving a sufficiently short exposure such as would best show the details of the clouds.

Halo Phenomena.

In the following description of halo phenomena it has been assumed that the sun is the source of light, but precisely similar, though rather less brilliant, appearances may be produced by the moon. Halos only occur in presence of cirrus clouds or light ice fog; they are produced by refraction and reflection of the rays of the sun or moon by the ice crystals composing the cloud.

Many different kinds of halo have been observed. FIGURE 9 is a reproduction of a drawing made by the astronomer HEVELIUS on February 20th, 1663, when many of the different kinds of halo phenomena described below were seen at the same time.

Halo of 22°. The most common is the halo of 22°, a large ring CIBG, round the sun. This angular dimension, together with those given below, refers to the radius of the halo measured along a great circle. When of great intensity this halo is white, but when more strongly developed the edge near the sun is red, with orange and yellow in succession outwards. In very favourable circumstances green and blue are seen, both faint and whitish, particularly the blue which is rarely recognizable. The halo thus appears white on its outer edge.

Halo of 46°. The larger halo of radius 46°, VXYZ (FIGURE 9), occurs more rarely and is usually much fainter than that of 22°; the colour sequence if visible is the same, but the colours are purer.

Halo of 90°. A still larger halo is exceedingly rare and is seen only as a faint white ring with a radius of about 90°. In the figure two portions of it, NE and DP, are visible. This halo can never be seen complete unless the sun is in the zenith, which cannot occur in temperate latitudes.

Mock Sun Ring. Occasionally a whitish ring may be seen passing through the sun parallel to the horizon. This is the horizontal circle or mock sun ring, shown in the figure as CDFEB, the portion BC passing through the sun being omitted. This portion is frequently missing though it has been often seen.

Arcs of contact and circumzenithal arc. The halo phenomena so far described often occur in incomplete form, but there are a number of other phenomena which, from their method of formation, can only be seen as arcs. Among these are the arcs of contact and the circumzenithal arc. In FIGURE 9 RGQ is the upper arc of contact to the halo of 22° while THS is the circumzenithal arc, which is observed in contact, or nearly in contact, with the halo of 46°. In both cases the arcs have their convex sides turned towards the sun and are very luminous at the points of contact, so that these have sometimes been described as "mock suns". The colour effects are often brilliant, especially in the case of the circumzenithal arc, the centre of which is at the zenith. In both cases red is nearest to the sun. Arcs of lower contact may occur in connexion with the halos of 22° and 46°, but these are very rare. In FIGURE 10 a portion of the arc of lower contact to

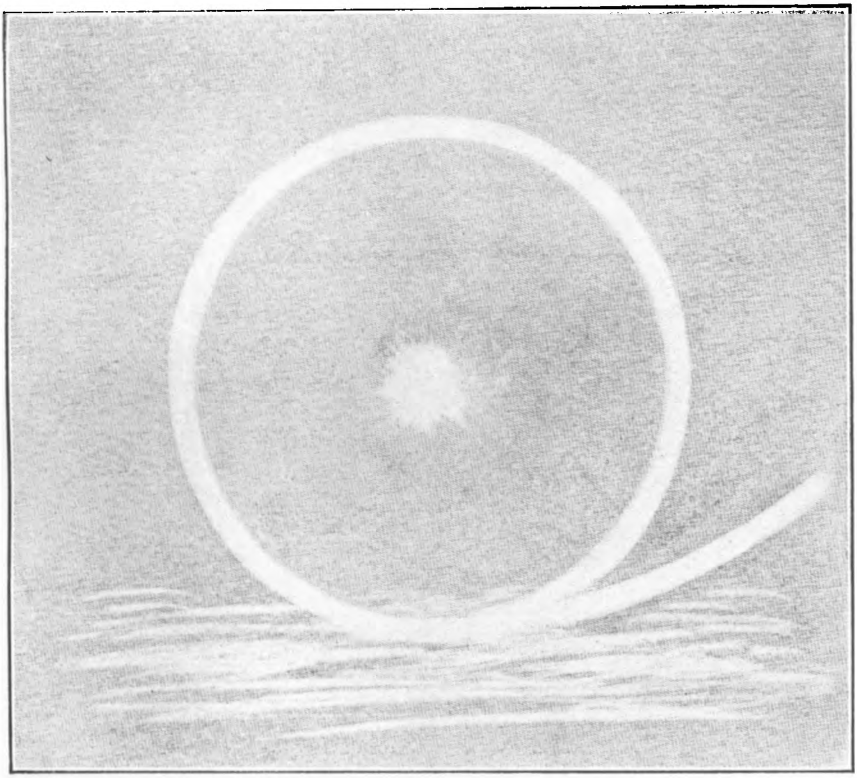


FIG. 10

LUNAR HALO

Witnessed from S.S. *Port Hunter*, Captain S. C. COTTELL, London to Australia, Observer, Mr. C. R. TOWNSEND, 3rd Officer.

" The above sketch represents the lunar halo and arc of contact as observed on the night of February 28th, 1923, in Latitude 16° 16′ S., Longitude 89° 43′ E. (approx.). The complete circle was 22½° radius and showed as a plain white ring, as also did the arc which was only visible for a very short period. The point of contact, although of greater luminosity, was indistinct on account of cirrus clouds covering that position of the circle."

the lunar halo of 22° is shown. Contact arcs appear occasionally at the sides of the same two halos, but are as rare as those of lower contact.

Of all halo phenomena, mock suns (parhelia) and mock moons (paraselenæ) are probably the most admired. These terms are used to describe luminous, or even brilliant, images of the sun which are seen most frequently at or near the intersection of the halo of 22° with the mock sun ring (B and C, FIGURE 9). Very rarely mock suns are seen at or near the intersection of this ring with the halo of 46° (D and E, FIGURE 9). The mock suns of this halo are always very faint, and their colouring is indistinct; mock suns belonging to the halo of 22° are, on the other hand, both frequent and very luminous, and their colours are brilliant. Red is on the side nearest the sun, with yellow, green and blue following in order. Blue is generally indistinct, and violet is usually too faint to be distinguished. As a rule a long and pointed white tail, occasionally attaining a length of 20°, extends from the mock suns along the mock sun ring (see FIGURE 9). Not infrequently one or both mock suns are seen without any of the rings being observed. The mock suns of the halo of 90° (D and E, FIGURE 9) have been observed on a few occasions only since Hevelius' day. **Mock Suns and Moons.**

A brilliant white image of the sun is occasionally observed immediately opposite to it, i.e. 180° from the sun along the mock sun ring. This is known as the counter sun. Mock counter suns, at about 60° along the mock sun ring from the counter sun, have been repeatedly observed, and their distances from the sun have been measured. **Counter Sun.**

Other very beautiful halo phenomena are afforded by sun pillars, which are most easily observed about sunrise or sunset. These frequently extend about 20° above the sun and generally end in a point. At sunset they may be entirely red, but as a rule they are of an intense white and show a marked glittering. If the sun is high in the heavens, white bands may appear vertically above and below him, but these are not very brilliant and often they are very short. Occasionally these white columns appear simultaneously with a portion of the white mock sun ring, and so form another very remarkable phenomenon, viz., the cross, three varieties of which are shown in FIGURE 11. **Sun Pillars.** **Cross.**

A large number of other halo phenomena, complete halos of various other radii, arcs, elliptical halos, mock suns in unusual situations, etc., are known to occur, having been observed more or less rarely; these are classified as "irregular" halo phenomena. A fine example of such an irregular phenomenon is shown in FIGURE 12. Owing to the limited space available it is not possible to describe them more fully here. **"Irregular" Halos.**

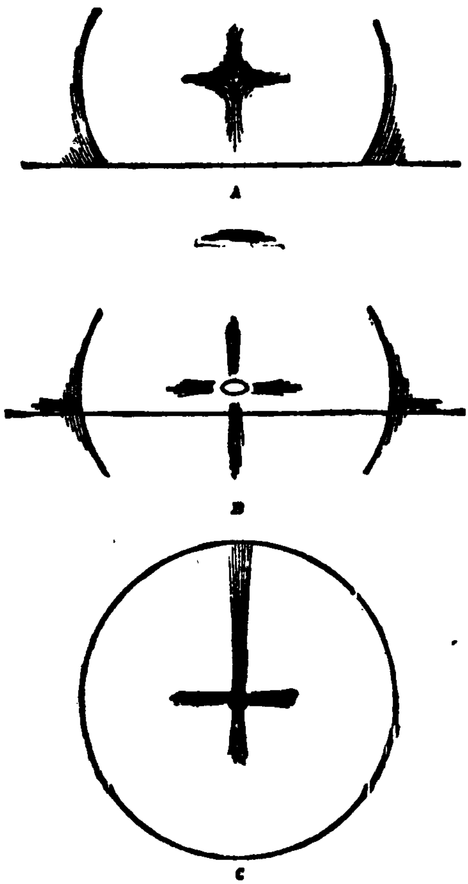


FIG. 11.

The most essential feature of any observation is the measurement of the angular dimensions of the radius, i.e. the angular distance from the sun. Without this the observation of a rare form of halo is of little value. The halo of 22° is too commonly observed, both round the sun and moon, to be of particular interest unless some unusual feature is observed, such as exceptional colour brightness. Observers fortunate enough to observe a complex halo system or any interesting halo feature are asked to sketch and describe what they see, with angular measurements appended. Frequently parts only of the rings and arcs are visible, having apparently no connexion with one another, thus lending a very peculiar appearance to the sky; not infrequently these arcs intersect obliquely, which increases the strangeness of the appearance.

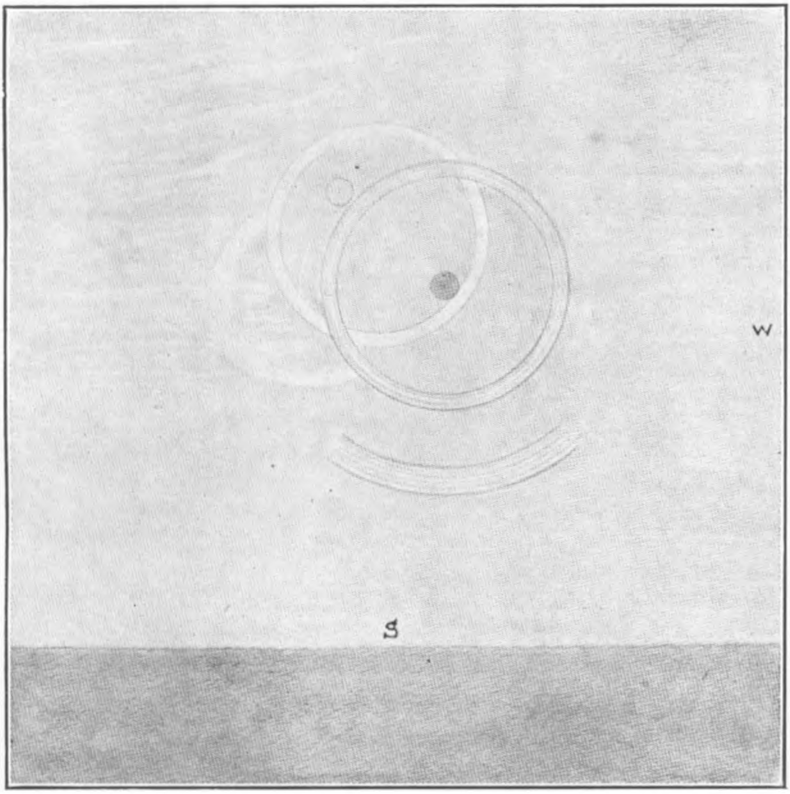


FIG. 12

SOLAR HALOS

CARIBBEAN SEA

Witnessed from S.S. *Tainui*, Captain W. HARTMAN, Southampton to Colon, Observer, Mr. P. S. HORWOOD, 3rd Officer.

"March 6th, 1925. Position at Noon: Latitude 13° 09′ N., Longitude 75° 07′ W. At 11.45 a.m. a halo, showing the colours of the spectrum, formed around the sun with a radius of 21½°, the breadth of the spectrum subtending an angle of ¾°. Shortly afterwards an arc of a second halo appeared to the southward, this arc being concentric with and similar to the first, while a third complete halo and an arc of a fourth were observed. Neither of these two latter showed the spectrum, nor were they concentric one with the other or the sun.

"The greatest brilliancy was attained at 12.15 p.m. when the whole presented an interesting and unusual sight. By 12.40 p.m. it had disappeared completely."

A corona is a series of coloured rings surrounding the sun or moon. Coronæ occur round both with equal frequency, but as the radius of a corona is generally much smaller than that of the halo of 22° the phenomenon is much nearer the luminary. It is therefore seen most frequently round the moon; the sun's light tends to obscure it unless the special methods of observation, referred to at the beginning of this chapter, are used. Coronæ:

Coronæ are of entirely different formation from halos. Halos are produced by refraction, whereas coronæ are diffraction phenomena due to water-drops. The positions and orders of the colours serve to distinguish the two sets of phenomena. Coronæ invariably show a brownish-red inner ring, which together with the bluish-white inner field between the ring and the luminary, forms the so-called aureole. Very frequently the aureole alone is visible. The brownish-red ring is characteristically different from the red ring of a halo; the former is distinctly brownish, especially when the aureole alone is visible, and of considerable width, whereas the latter is a definite red and much narrower. If other colours are distinguishable, they follow the brownish-red of the aureole outwards in the order from violet to red, whereas the red in a halo is followed by orange, yellow and green. The order of the colours is thus reversed. Aureole.

The size of the ring is not an infallible distinction between halos and coronæ, for coronæ vary in size; the smaller the water-drops producing it the larger the diameter of the corona. In exceptional circumstances a corona may be quite as big as a halo. In the year following the eruption of Krakatoa (1883) and again in 1903 after the eruption of Mount Pelée, a brownish-red ring of over 20° diameter was frequently seen with a clear sky. It was proved to be an unusually large corona, due to fine dust in suspension in the atmosphere, and received the name of "Bishop's ring." The criteria which the observer should apply to distinguish the two phenomena are not the diameters of the rings, but the sequence of colour and the presence of the brown-red of the aureole. Size of Coronæ.

As coronæ are diffraction phenomena they occasionally show the sequence of colour two, three or even four times over. This can never be the case with a halo.

In a foggy atmosphere (especially on mountains) an observer, standing with his back to the sun, will sometimes see coloured rings of light round the shadow cast upon the fog by his own head. The whole phenomenon is called the "Brocken spectre", and the coloured rings are usually known as a "glory". A large outer ring, known as "Ulloa's ring", Brocken Spectre.

which is really a white rainbow, is sometimes seen at the same time. The shadow of the observer on fog may sometimes be seen with a source of artificial light behind the observer.

Iridescent Cloud. Green and red patches are occasionally seen on cirrus and other clouds, at a distance from the sun or moon up to 25° or more. They have no apparent connexion with ordinary coronæ but are perhaps portions of coronæ due to the local occurrence of very small water-drops in the cloud. Frequently a number of these patches may be seen along a line passing through the sun. This phenomenon is known as "irisation." The most important point to note is the angular distance between the sun (or moon) and the patches showing irisation.

Rainbows. Primary and Supernumerary Bows. The normal appearance of a bright well-developed rainbow is as follows. The chief or primary bow shows the sequence of colours, violet, blue, green, yellow, orange and red, the red being on the outside or top of the bow. Closely inside this bow are one or two supernumerary bows with the colours in the same order, the first inner bow being much fainter than the primary bow and the second fainter still. Supernumerary bows do not, however, show the full range of spectrum colours; violet and pink, green and purple or blue and pale red are the most usual combinations. In cases of exceptionally brilliant rainbows more than two supernumerary bows may be seen.

Secondary Bows. Outside the primary bow and entirely detached from it is the secondary rainbow in which the full range of colours appear in the reverse order, red inside and violet at the top or outside. The primary bow is formed by means of one internal reflection in each raindrop, the secondary bow by two such reflections. In very exceptional cases more than one secondary bow has been seen. The sun, the observer's eye and the centre of the circle of which the primary rainbow forms an arc are always in a straight line, so that the azimuth of the highest part of the bow is 180° from the sun's azimuth. The normal radius of the arc of red light of the primary rainbow is 42°, of the violet arc 40¼°; in the secondary bow the radii are for red light 51° and for violet light 54°, all the values given being approximate. Hence it follows that the normal breadth of the primary bow is about 1¾° and that of the secondary bow about 3°. It also follows that with the sun at an altitude of 42° the uppermost point of the primary bow is on the horizon and hence no primary bow can be formed if the sun's altitude exceeds 42°. Consequently rainbows are mainly morning and evening phenomena; nearer mid-day if seen at all the arc of the bow is shorter and the altitude small.

Lunar Rainbows. Lunar rainbows are formed in precisely the same circumstances as solar ones, but are considerably rarer having regard to the comparatively short periods that a bright moon is above the horizon. A lunar rainbow is so much fainter than a solar one that it is not always possible to distinguish colour and the appearance is then whitish. Quite frequently, however, colour may be observed ; more rarely the whole sequence of colour can be seen, as in the solar rainbow. Secondary lunar rainbows are very rarely seen, on account of their faintness.

Fog-bows. White rainbows are sometimes formed by the sun ; for this to occur the raindrops composing the cloud must be very small and the observer must be near the cloud. Such a rainbow is called a " fog-bow " or " Ulloa's ring " and may form a complete circle. It is most commonly observed during fog.

Observation of Rainbows. An observer interested in rainbows should note that the colours, the angular width of each colour, and the brightest colour in the bow, are variable and depend on the size of the water-drops producing the bow. If it be desired to make observations of value on these differences the following points should be noted in the primary bow, (1) The sequence of colours, which are not always the same (2) the colour which shows the maximum luminosity (3) which colour band is the widest. The sequence of colours in the supernumerary bows, and whether these bows are continuous with the primary bow and with each other, should also be noted. The secondary bow is of less importance, but observations of any further bows or arcs of bows of abnormal character should always be given, with angular measurements to define their radii and positions as nearly as possible.

Coloration of the Sky. Blue Sky. A cloudless sky appears to be blue, but it may show all possible gradations between a deep blue and a whitish-blue shade, according to the state of purity of the air.

Sunrise and Sunset Phenomena. The coloration of the clouds at sunrise and sunset is often very beautiful and very striking, and is therefore frequently noted, although the phenomena observed when the sky is clear are of greater interest. When the sky is cloudless, the colour and form of the " first purple light " is worth attention. It is approximately parabolic in shape and appears soon after sunset at a considerable elevation above the point at which the sun has disappeared. It varies in colour between pink and violet. Observers are also invited to note the colouring of the western sky and the appearance of the " second purple light " which develops after the disappearance of the first. The times of appearance and disappearance of the second light are of interest. Other phenomena are also observed before and after sunset, including the " twilight arch," which in high latitudes in summer persists all night. At sunrise all the phenomena occur in reverse order. If " after glows " and other other colorations are associated with the sunset, the phenomena should be noted.

Earth-shadow. At the time of sunset the shadow of the earth, thrown by sunlight on the earth's atmosphere, rises up gradually from the horizon opposite to the point of sunset. The "earth-shadow" has a peculiar steely-blue colour differing from that of the rest of the sky, and the upper edge of the curved arc of the shadow is usually fringed with pinkish light. This shadow continues to rise and ultimately passes through the zenith but becomes more difficult to observe as the sky darkens and the distinction of colour lessens.

Duration of Twilight. Twilight lasts until the sun is 18° below the horizon, so that in tropical latitudes, where the sun sets perpendicularly or nearly so, the duration of twilight is shortest. At the pole there is about a couple of months twilight between the long summer day and the long winter night. The following table gives the duration of twilight for various latitudes.

Latitude N.	January 1st.	April 1st.	July 1st.	October 1st.
0°	1 hr. 16 min.	1 hr. 10 min.	1 hr. 16 min.	1 hr. 10 min.
20°	1 hr. 20 min.	1 hr. 15 min.	1 hr. 25 min.	1 hr. 14 min.
40°	1 hr. 39 min.	1 hr. 34 min.	2 hr. 4 min.	1 hr. 32 min.
60°	2 hr. 48 min.	2 hr. 41 min.	—	2 hr. 25 min.
Latitude S.	July 1st.	October 1st.	January 1st.	April 1st.

In midsummer, latitude 60°, twilight lasts all night, the sun never being 18° below the horizon.

Abnormal Refraction and Mirage. All rays of light passing through the atmosphere, except those from celestial objects in the zenith, become curved in greater or less degree, depending on the altitude of the source of light. This is due to refraction of the rays by successive layers of air of increasing density as the rays approach the observer, and is known as "normal refraction". The curvature of the rays is increased when the state of the atmosphere is such that density decreases more rapidly than usual with height, for example if the air is warmer higher up than near the surface. This is known as "abnormal refraction".

When there is abnormal refraction the horizon is raised by an amount dependent on the conditions at the time but always greater than is given in the tables of refraction. This additional raising of the horizon causes objects at suitable distances, but which are normally below the horizon, to come into view. Sometimes it is accompanied by an enlargement of the vertical height of an object on or near the horizon, with more or less blurring of the object; this is known as "looming". On the other hand there may be vertical contraction of objects, known as "stooping". The numerous observations of lights being seen at night far beyond their normal limit of visibility are examples of abnormal refraction.

Looming and Stooping.

Effect of Abnormal Refraction on Sights.

If the horizon is raised equally in all directions, and if there is no obvious looming of objects, there is no actual evidence of the occurrence of abnormal refraction at the time. Abnormal refraction may introduce considerable errors in the position of a ship obtained from sights and it is also a frequent source of disagreement between forenoon and afternoon sights. Two main sources of error are produced, the effect on the angle of dip and the effect on altitude. Of these the angle of dip is most affected. The dip of a shore horizon will also be in error. Hence the necessity for caution in the use of position lines obtained from sights if there be any suspicion of the presence of abnormal refraction. It is of course for this reason that three or more position lines obtained from altitudes of bodies on different bearings are used to fix position. The effect of abnormal refraction if not equal in all directions is thereby reduced.

Other Deceptions of Vision.

Deceptions of vision other than looming and stooping may accompany abnormal refraction. The horizon may appear double and objects may similarly be seen double, the image above the object being erect. The sun is often very distorted near the time of sunset, or less frequently at sunrise, and may assume different appearances in succession. A segment of the sun may appear above the real sun and a complete double sun may sometimes be seen. The sun has been seen to set twice in one evening. Similar phenomena may occur at the setting of bright planets, especially if viewed with glasses. Lights at night may be seen doubled and distorted.

Superior Mirage.

These phenomena are examples of mirage, but as already stated, abnormal refraction may occur without visible mirage. States of the atmosphere may exist other than that which produces simple abnormal refraction and these give other kinds of mirage. A form of mirage which is frequently observed at sea or in coastal waters, but seldom inland, is known as "superior mirage", in which, when fully developed, two images of an object are seen above it, the lower image inverted and the upper one erect. A distant light at night may thus appear as three in a vertical line. This mirage is not usually seen in low tropical latitudes and is most frequent in high latitudes. An inverted image is formed by the rays of light coming from the bottom of an object taking greater curvatures than those coming from the top. Superior mirage is produced by a warm layer of air, often of no great thickness, at a suitable height above the cooler air near the sea surface, that is by an inversion of temperature. It differs only from the condition necessary for simple abnormal refraction in that the change of temperature with height is more sudden.

Complex Mirages. Mirage may be very complex and may exhibit different forms either in succession or even at the same time in different directions. Erect or inverted images of objects may be seen while the object itself is below the visible horizon. Great distortion of images may occur. In certain localities multiple mirages occur, such as the Fata Morgana of the Straits of Messina. The condition necessary for the production of abnormal refraction and superior mirage, the presence of warm air over cooler air, is the same as that which gives rise to ordinary sea fog and hence the frequent occurrence of mirage either just before or after fog, or in the clear spaces between fog-banks.

Inferior Mirage and Sinking. Land mirage is of a different type, being produced by a layer of very warm air near the ground, and is called " inferior mirage ". This is often seen in desert regions and over hot surfaces, such as roads, in temperate latitudes. An inverted image of the object appears as if in conjunction with water. Mirage of this type may be seen on coasts on hot days as a strip of white light at the bottom of cliffs, islands, etc., causing them to appear cut off from the sea in front. This strip of white light, as well as the apparent water in the desert, is a reflection of the sky. Another manifestation of inferior mirage at sea is known as " sinking ". When there is cool air over warm sea, the conditions necessary for ordinary abnormal refraction and looming are reversed, so that the horizon may be lowered.

In observations of mirage the relative temperatures of air and sea should always be noted.

Scintillation. The atmosphere is far from uniform, containing pockets and layers of air of different temperatures and humidities, and therefore of different densities, adjacent to one another. These irregularities are usually constantly varying, owing to winds or vertical movements of the air at various heights, and produce the changes in apparent brightness of the stars known as scintillation or twinkling. Twinkling is thus due to minor fluctuations of the refractive power of the atmosphere. It may also be seen with distant terrestrial lights.

Twinkling is always greatest towards the horizon and in tropical latitudes does not usually occur much at altitudes exceeding 15°. In temperate latitudes bright stars near the horizon may exhibit marked changes of colour as well as of brightness.

Planets do not usually appear to twinkle as they present small discs. Each point of the disc twinkles independently of the others, so that on the average the light is steady.

When the sun sets under favourable conditions the last portion of the upper part of the disc may momentarily become green, bluish-green or sometimes cobalt-blue as it disappears, the colour being often very brilliant. This coloration is called the green flash or green ray. If brilliant, it may be observed without optical assistance. Favourable conditions are, the sun bright at time of setting, and setting taking place at the sea horizon or behind distant land showing an uninterrupted edge. Sometimes also green rays of light shoot upwards from the setting sun. Similar phenomena are observed at the appearance of the upper limb at sunrise ; they are attributed to the unequal refraction of light of different colours. The green flash is not always seen when conditions appear good and it is possible that states of abnormal refraction favour its appearance. **Green Flash.**

The green flash has occasionally been observed in connexion with other bodies, such as at the setting of the bright planet Venus, using optical aid.

Auroral displays are often seen in the higher north or south latitudes, being very rare in latitudes much under 40°. On account of the beauty and the interest of the phenomenon the following notes are given for those who wish to observe them in detail. In all cases azimuths should be given as true bearings. Auroral light is the visible manifestation of the passage of electrical discharges, possibly of solar origin, through the earth's atmosphere, but the precise mode of its occurrence is still unknown. **Aurora.**

Auroral forms are difficult to classify owing to their great variety and their rapid fluctuations and changes. The usual classification now adopted is :— **Forms of Auroræ.**

(1) Arcs of a more or less regular shape.
(2) Bands or ribbons.
(3) Rays or streaks.
(4) Floating curtains or draperies, often with folds.
(5) Corona.
(6) Patches or isolated cloud-shaped masses.
(7) Diffused light.

Arcs appear in many forms. The simplest consists of an approximately circular segment of uniform or nearly uniform light, whose lower ends may extend like those of a rainbow right down to the horizon. An arc may, however, be made up of narrow concentric arcs of various degrees of brilliancy in juxtaposition ; or it may consist of an innumerable number of short rays side by side, their lengths being in some cases **Arcs.**

approximately parallel to one another, in other cases radial, or nearly so, to the arc which they form. The arc is often elliptical or irregular in form, and several arcs of different shapes may be visible simultaneously. In regular-shaped arcs the highest point above the horizon is usually not far from the observers' magnetic meridian. It is, however, not uncommon for the summit to be considerably out of the magnetic meridian, and in high latitudes the summit has been observed in almost every possible magnetic azimuth. In measuring the altitude of the summit the lower or concave edge of the arc should be taken, as this is usually much the better defined. It is not unusual for arcs to be in visible motion, rising from the horizon towards the zenith or receding from it; and it may be impossible to do more than note approximately the greatest and least altitudes attained.

When an arc extends right down to the horizon it is worth recording the number of degrees between the ends measured along the horizon. The sky immediately under the concave border of an arc often appears dark. It is probable that this is merely an effect of contrast as stars are frequently observed in this " dark segment ". The existence or non-existence of the dark segment, and whether stars can be seen through it, should be noted.

Bands and Ribbons.

Bands and Ribbons are of innumerable shapes, nearly straight as if broken portions of an arc, or having the most complicated and serpentine of forms. They may appear more or less homogeneous, or may be visibly composed of rays. The length of a band seems usually to be perpendicular to the magnetic meridian, but the shapes are so various that it is difficult to define the position with accuracy.

Rays.

Rays often occur in close juxtaposition, the combination going to form an arc or a band. They also occur separately, often extending from the upper or convex border of an arc towards the zenith. The apparent length of rays may alter very rapidly, the ray suddenly darting towards the zenith and retiring from it. This characteristic has led to the description of auroral phenomena as " merry dancers ". Sometimes they are grouped into a single large fan, made up of rays which may point towards a common centre, or may be more or less parallel; in other cases there may be several apparently independent fan-shaped bundles of rays.

Draperies or Curtains.

Auroral Draperies or Curtains are one of the most impressive forms, but are seldom seen except in fairly high altitudes. The drapery may appear single or multiple, and the lower border may be nearly straight or very sinuous. These draperies seem often in rapid motion, and observers in high latitudes have described the appearance seen as they approach and pass overhead. When directly overhead they are said to narrow to a streak, just as a vertical sheet of light would seem to do as one passed immediately under it.

Auroral Corona, when fully developed, is, perhaps, the finest form of all. As the name denotes, it forms a more or less regular crown of light disposed about a centre. An imaginary line drawn from the apparent centre to the observer's eye is usually nearly parallel to the direction of the dipping magnetic needle. The centre of the corona is generally comparatively dark. Next to the darker centre there is usually bright illumination, which may appear fairly homogeneous or be obviously composed of rays. Further from the centre the ray structure is usually dominant. In some cases there is little general illumination, and the rays appear comparatively isolated from one another. Auroral Corona.

Patches of aurora often resemble the higher clouds, and it is sometimes difficult to distinguish aurora from illuminated cloud. Observers have asserted that what has been seen as cirrus before sunset, or in early twilight, has later been seen as a patch of aurora, and that what has appeared as a patch of aurora in the early morning has been seen as cirrus after dawn. Patches.

Diffused Auroral Light sometimes fills the whole or a large part of the sky, the illumination, though usually brighter in some parts than others, showing no distinct outlines. Diffused Auroral Light.

Auroral light is mainly white, with a yellow tint. When faint, it usually appears nearly pure white ; with increasing brightness there is a tendency to yellow. Sometimes there is a great deal of red in bright auroræ, especially when rays predominate and there is much apparent motion. In these circumstances it is not unusual to see green as well. The red is usually strongest towards the horizon, the green towards the zenith. Thus a ray may have its lower end red and its upper green ; or a corona may be green towards the centre and red below. It has been asserted that in some instances at least the green is a contrast colour, and is no longer seen when the observer excludes the light from the distinctly red parts of the aurora. Other colours are occasionally seen, including even violet. Colour of Auroræ.

Spectroscopic examination of auroral light shows that the brighter part is made up of rays of definite wave-length mainly produced by nitrogen. The characteristic green line is produced by oxygen.

The brightness varies within wide limits. An aurora may be so faint as to be visible only to the keenest eyesight, while in Arctic regions aurora is said to be sometimes very much Brightness of Auroræ.

brighter than the full moon. The estimate of brightness is often largely dependent on whether the moon is visible or not. It is thus important, when recording any degree of brightness, to describe the circumstances in which the observation was made.

Diurnal Variation of Auroræ.

The brightest aurora becomes invisible when the sun rises, and aurora is seldom seen until the sun is at least 5° below the horizon. We do not know, therefore, whether aurora is as prevalent during the day as at night. Aurora has been found at most stations in the northern hemisphere, with the possible exception of some in Greenland and Northern Canada, to have its greatest development from one to three hours before midnight. In the Antarctic several observers have found auroral displays to be most numerous in the early morning. Sometimes aurora has been visible during the same 24 hours over a large part of one, if not both, hemispheres, but in such a case the brilliancy of the display at any particular place seems largely dependent on the local time.

Frequency of Auroræ.

In the northern hemisphere the frequency increases northwards from the tropics until a latitude is reached which depends on the meridian. Information for very high latitudes is limited, but it is probable that a maximum is reached, after which the frequency of aurora falls off still further north. The latitude of maximum frequency is believed to vary from about 55° N. in longitude 60° W. to fully 75° N. in longitude 90° E. Aurora is at least five times as frequent in the North of Scotland as in the South of England. In Europe, in latitude 40° N., under one aurora is seen per annum on the average; in North America, in the same latitude, ten times as many are visible.

At places to the south of the zone of maximum frequency aurora is usually seen in the north, but in very high northern latitudes it is usually seen in the south. In intermediate latitudes aurora is seen sometimes in the north, sometimes in the south.

Information respecting auroræ in the southern hemisphere is much less copious than in the case of the northern hemisphere. Very fine displays of aurora have occasionally been seen in Australasia and on passages across the Southern Ocean, and a good many have been seen by members of Antarctic exploratory expeditions, but it is generally believed that aurora is less frequent in the southern hemisphere.

Seasonal Variation of Auroræ.

In most of Northern Europe, and in North America between latitudes 40° and 60° N., aurora is most frequent near the equinoxes. In higher latitudes these two maxima are replaced by a single one in mid-winter. It is, however, doubtful whether this apparent difference is not partly or wholly due to the different duration of sunlight in varying latitudes. Aurora is much more often seen in some years than others and in temperate latitudes there is a fairly well-marked 11-year periodicity, coincident, or nearly so, with the sun-spot period. In Arctic regions the relation between auroræ and sun-spots seems to differ from that of temperate latitudes.

Connexion with Magnetic Storms.

A big auroral display in temperate latitudes is nearly always accompanied by a big magnetic storm and large earth currents. Telegraph wires are sometimes traversed by such large currents that the despatch of messages is interrupted for several hours on end, or even rendered impossible. It is desirable during bright auroral displays to keep an eye on the compass, since deviations from the normal of more than 1° are sometimes experienced during magnetic storms, even in the latitudes of the South of England. When auroral draperies are observed in motion it is especially desirable to watch the compass needle. In high latitudes, where aurora and magnetic disturbances are both more common, there is often no apparent connexion between the two phenomena.

Height of Auroræ.

Of recent years many measurements of heights have been made in Norway, the earliest by Prof. STÖRMER, who devised satisfactory means of photographing auroræ. Simultaneous photographs are taken from two ends of a measured base, usually from 9 to 15 miles long, but sometimes a good deal longer. The observers at the two ends are connected by telephone and arrange to direct their cameras at certain stars, which appear in the photographs. The positions of the aurora relative to the stars differ in the two photographs and the auroral height can thus be calculated. The average height is about 60 miles but the recorded heights range from 40 miles to over 600 miles.

Observation of auroræ near the ground have been reported at times. These are not consistent with the measured heights but may be due to the illumination of mist by distant bright aurora.

Sound of Auroræ.

The audibility of auroræ, a sound resembling that of the discharge of electricity from points, is still in dispute. The great height of auroræ in the atmosphere seems to rule out the possibility of audible sound, but observers of repute have frequently stated that they have heard a crackling noise. This might, however, be caused by small local brush discharges from snow or bushes.

Zodiacal Light.

This is observed as the extremity of an elongated ellipse of soft whitish light which extends from the sun as centre, appearing above the westerly horizon after sunset or above the easterly horizon before sunrise. The best time for observation is just after the last traces of twilight have disappeared in the evening or just before the first traces appear in the morning, the greatest extent of the Light being then visible. The Light retains its apparent place among the stars and gradually sets in the evening or rises in the morning. It is sufficiently bright even in temperate latitudes not to be rendered invisible by faint twilight or partial moonlight.

The axis of the Light lies nearly in the plane of the ecliptic, approximating more closely to the plane of the sun's equator. The whole phenomenon is confined to the zodiacal constellations. In tropical latitudes, where the ecliptic makes a large angle with the horizon at all times of the year, the Light may be well seen on any clear night or morning in all months. In temperate latitudes the ecliptic is often inclined at such a small angle to the horizon that the Light is rendered invisible by the additional extent of the atmosphere traversed. In the latitudes of the British Isles it is best seen in the evenings of January to March and in the mornings of September to November; only about the time of the winter solstice is it possible to observe it on the morning and evening of the same day. In February the Light lies between the constellations of Pegasus and Cetus, the apex being near the Pleiades. Just after dark in the latitude of the British Isles the altitude of the apex of the Light is about 50° in this month, the cone lying obliquely with regard to the horizon; the breadth near the horizon is 25°–30°, the altitude of the part of greatest luminosity being 20°–30°.

The Light is pearly and homogeneous and differs markedly in quality from that of the Milky Way, the brightest part of which it may considerably exceed in luminosity. It is more brilliantly and readily seen in the tropics, but it is very conspicuous even in the latitude of the British Isles if observed away from large towns. The Zodiacal Light is generally believed to be a cosmic phenomenon, due to the reflection of the sun's light from innumerable minute bodies or dust which revolve about the sun, the mass extending outwards somewhat beyond the earth's orbit. The meteorological origin of the Light as the final stages of twilight in the earth's atmosphere is, however, still upheld by some.

Observation of the Zodiacal Light.

Observers interested should note whether the brightness varies in successive nights or successive years, comparing it with a specified portion of the Milky Way, preferably at the same altitude. The position of the axis and of the edges of the cone with respect to the stars should be given as well as they can be judged, and notes made of differences in colour, lack of homogeneity, etc. An appearance of "a cone within a cone" has sometimes been seen.

Associated with the Zodiacal Light are two other phenomena. Jointing the apices of the cones of the morning and evening Zodiacal Lights is an excessively faint band of Light, a few degrees wide, lying along or nearly along the ecliptic, called the Zodiacal Band. On this band, at a point very nearly or exactly 180° from the sun's position in the ecliptic, is a somewhat brighter and larger patch, 10° or more in diameter, known by the German name "Gegenschein" (literally "counterglow," but this term in English is applied to a meteorological phenomenon of twilight). The Zodiacal Band and the Gegenschein may be observed in temperate latitudes on the clearest moonless nights when at sufficient altitude, but are somewhat brighter in the tropics. Further observations of these very faint phenomena, in comparison with which the Zodiacal Light is a blaze of light, are much desired, especially from tropical localities. The track and width of the Band and the size, shape and exact position of the Gegenschein should be noted, together with variations of brilliancy and any special features seen, but the observation will be found difficult to the keenest eyesight. The Gegenschein is usually invisible for the few nights on which it is projected upon the Milky Way in its annual journey round the ecliptic. **Zodiacal Band and Gegenschein.**

An entirely distinct phenomenon, to which the name "lunar zodiacal light" has been given, is sometimes seen before moonrise or after moonset, after the ordinary lunar twilight begins or before it has gone. A faint yellowish cone of light extends vertically upwards from the horizon above the moon's place. It has no relation to the ecliptic and is a meteorological phenomenon probably of similar formation to the first purple light after sunset. **Lunar Zodiacal Light.**

During the night watches the seaman has many opportunities for obtaining useful observations of meteors. "Meteor" is a general term to include all those small bodies which, travelling through space, encounter the earth's atmosphere and become visible by reason of the state of incandescence produced by the friction of rapid passage through the attenuated air of the upper atmosphere. Millions of these objects enter the atmosphere daily, the vast majority of which are entirely disintegrated and subsequently settle down slowly to the earth's surface in the form of almost impalpable dust. A few, however, whose original bulk is greater, may partially survive the disintegrating effect and reach the earth's surface in solid form. These are called meteorites or aerolites. The earth's mass is therefore being constantly but slowly added to. The ordinary small meteors appearing as luminous streaks in the sky are popularly known as "shooting stars," but they have of course no connection with any star, being merely **Meteors or Shooting Stars.**

small fragments of matter varying in size from about a pin's head to a pea. Larger objects are known as fireballs. These may appear with the brilliancy of a first magnitude star or of the planets Jupiter or Venus, or, in the very finest examples, may greatly exceed the full moon in their temporary dazzling brilliancy. Many meteors, on the other hand, are so small and faint that they are invisible without optical aid. Unless actually seen to fall to the earth's surface an observer cannot say whether a large fireball reaches the earth as a meteorite or not. Many of the larger fireballs and meteorites are seen to burst and sometimes a detonation is heard. The meteorites which have been picked up rarely exceed a few pounds in weight and may be much less, but there have been some of very much greater size.

Speed of Meteors.

There is a considerable variation in the speed with which these bodies traverse the earth's atmosphere, this speed being the resultant of the meteor's original speed in space and the earth's velocities of rotation around its axis and revolution in its orbit. The resultant speeds usually lie between 10 and 45 miles per second. The average height above the earth's surface is 75 miles during the time of combustion and 50 miles at the time of disappearance.

Constitution of Meteorites.

The meteorites which have reached the earth's surface have been analysed and about one-third of the known chemical elements of which the earth is composed have been found in them. No new chemical element has been found. The elements, are however, frequently combined to form minerals not known in the earth, so that their origin must have taken place outside the earth. Small crude diamonds may occur. There are three classes of meteorites according to whether they are mainly formed of metallic iron, stone, or a mixture of the two.

Appearance of Meteors.

The appearance of meteors is as varied as their brightness. Some travel fast, others slowly. Some leave streaks or trains of sparks or luminous vapour while others do not. In many cases the train disappears immediately, but in others it remains visible for seconds or minutes. In extreme cases the duration has exceeded two hours. When the train remains visible for some time, curious changes may be observed in it following the action of the air currents of the high upper air, combined with the fall of the material due to gravity. Most of the larger meteors and fireballs are strongly coloured and the colours may change during the flight. The apparent path taken by the meteor is usually a straight line or arc, but it may assume serpentine or other forms.

Prolonged study of meteors over many years has shown that meteors belong to families or groups. Thus the well-known Perseid meteors which are very plentiful in August, especially from the 10th to the 13th, radiate from a point in the constellation of Perseus, after which they are named. In other words the tracks of all Perseids if produced backwards, whatever part of the sky they are actually visible in, meet in a point, showing that they belong to a cluster of small bodies travelling together in space in the same direction. The radiation of the tracks as seen from the earth's surface is merely a matter of perspective. The Leonids form another family which are most frequent about November 13th and radiate from a point in the constellation of Leo. From such well-marked groups there is every gradation down to very weak ones giving perhaps a few faint meteors on one or two nights in the year. It is estimated that about 100 radiant points, that is, separate showers, are active on every night of the year. Catalogues of radiant points have been published. The average rate of appearance of meteors is about 7 per hour in the first half of the year and 16 per hour in the second half, but meteors are always more numerous after midnight than before. On the occasion of special showers such as the Perseids or the Leonids the number observed is considerably greater. Occasionally meteors come in swarms as was the case with the Leonids in 1833 and 1866, when the fall was at the rate of many thousands per hour. All the meteors from radiant points which become active on the same night or succession of nights each year belong to the Solar System and move in definite orbits around the sun, and it has been shown that some of them move in the same orbits as certain comets that have been observed, so that these meteors form part of the matter or debris of the comet whose orbit they pursue. **Meteor Showers.**

It is not possible for the casual observer of meteors to deduce a radiant point except in the case of a bright well-marked shower such as the Perseids. There are, however, two ways in which an observer who is interested in these phenomena may make observations of value. **Observation of Meteors.**

In the case of single bright meteors the following should be noted as accurately as possible.

(1) The points of appearance and disappearance with respect to named stars.

(2) The duration of the flight.

(3) Magnitude of the meteor relative to a star or planet.

(4) Any notable colour, colour changes or other peculiarities.

(5) Whether seen through gaps in cloud or not.

If similar information is obtained for the same meteor from at least one observer in another place it is possible to calculate the heights of appearance and disappearance and the speed of the meteor. With regard to (1), the position if possible should be noted to the nearest half-degree, but it is often difficult owing to the suddenness of the appearance. Care should be taken not to overestimate the duration of the flight.

The appearance of meteors in unusual numbers on any night, especially if obviously directed from the same point in the heavens, should be put on record. It is not always realised that individual meteors are only seen over small areas of the earth's surface, and it may happen that the conditions are such that a meteor shower is visible only in restricted longitudes. The occurrence or non-occurrence of showers on a particular night is often of considerable astronomical interest.

Meteors and Weather.

There is no direct relation between the appearance of meteors and the weather, as was formerly believed. The clearer the night the more faint meteors will be seen. The data of meteor heights and speeds have been employed to discuss the temperature of the very attenuated atmosphere at great heights above the earth's surface, and any addition to the amount of information available will be welcomed by those interested in the subject.

Comets.

Observations of comets, to be of any value, should include angular distances, measured with a sextant, between the comet and at least two, but preferably three, named stars of the first or second magnitude. The position of the ship and the time of observation should be noted. An estimate of the brightness of the head of the comet, in comparison with a star or planet, should also be made, and information noted as to length of tail and general appearance.

Eclipses of the Sun and Moon.

Partial eclipses of the sun may be not infrequently observed, but are of little interest, save as spectacles. A total eclipse of the sun is the grandest phenomenon of nature. It is rare in any particular place and its visibility is confined to a very restricted area on any one occasion. The duration of the total phase rarely exceeds two minutes and may be only a second or two. The chief point of interest is the sun's corona, which can only be seen at these times. The form of the corona varies. It is pearly-white in colour and may extend some distance from the sun. It gives about half as much light as the full moon. Red prominences, composed of hydrogen gas, may also be seen with the unaided eye in some years, or with binoculars. The sky is dark enough to show the planets and brighter stars.

Only one point is of real interest in connexion with eclipses of the moon, the colour exhibited by the totally eclipsed moon. Complete disappearance of the moon when wholly within the earth's shadow is very rare. Usually some sunlight is refracted on to the moon by the earth's atmosphere. The moon therefore appears more or less reddish in hue, dependent on the cloudiness or state of that part of the earth's atmosphere through which sunlight reaches the moon. Considerable variations in colour are found to exist at different eclipses.

Corposants or St. Elmo's Fires.

The electrical phenomenon known as Corposants, or St. Elmo's Fires, frequently seen, not only on the extremities of masts and yards at sea, but also occasionally on the stays and other parts of the ship, appear when atmospheric electricity of low intensity induces electricity on the ship or other object that happens to be under its influence. This induced electricity concentrates at the extremities of structures either at sea or on shore and becomes visible as a luminous brush discharge. It affords an interesting illustration on a somewhat extensive scale of the elementary principle relating to the power of points in the dissipation of electricity. The phenomenon may also appear as luminous globes, for example on the wireless aerial. The amount of light given by the Fire varies considerably. Seamen of the several nations have allotted specific designations to these electrical manifestations. English-speaking nations refer to them indiscriminately as Corposants, or St. Elmo's Fires; in Portuguese they are known as Corpo Santo; in Italian, the Fires of St. Peter and St. Nicholas; whereas in French and in Spanish, they are the Fires of St. Elmo.

Waterspouts.

A waterspout is a funnel-shaped column extending from the lower surface of a cloud to the sea. The spout is formed by a point of cloud appearing at the base of nimbostratus cloud, descending as it grows. A small part of the sea surface becomes agitated, and a cloud of spray forms. In its descent the funnel cloud dips into the centre of the spray and the whole then appears as a column of water connecting cloud and sea. It is usually 20 or 30 feet in diameter, with a height of 200 feet or more, according to the cloud height. A waterspout lasts from a few minutes up to half an hour; in travelling over the sea surface it often becomes oblique or bent. It is in rapid rotation and the wind around it follows a circular path. Although very local, this wind is often violent, causing confused, but not high, sea. The waterspout finally gets thinner, breaks in two and quickly disappears. A number may be seen at the same time; on the other hand some waterspouts begin to form and are never completed. They are more frequent in lower latitudes and in the Mediterranean Sea; elsewhere they occasionally occur.

Air whirls.

Violent commotions in the lower clouds, without waterspouts forming, may be seen in low latitudes. These are called air whirls.

Line Squalls.

A line squall is a squall of wind, accompanied by rain or hail, associated with a sudden drop of temperature and the passing of a long line or arch of dark cloud which is a special type of nimbostratus or of cumulonimbus. This squall is caused by the meeting of warm and cold winds, the most favourable condition for which is the trough of a "V"-shaped depression in temperate latitudes. In the northern hemisphere the warmer wind generally comes from the south-west, so that the wind direction will veer during the passage of the squall. In the southern hemisphere the wind will normally back. During the passage of the squall the barometric pressure will rise with great suddenness about 2 mb., and the temperature will fall from 10° to 20° F. Line squalls are frequently precursors of thunderstorms, and owing to the violent convection and eddying of the atmosphere at the time of meeting of the cold and hot winds are often found to cause waterspouts. The Pamperos of the Argentine and Uruguay are line squalls.

Arched Squalls.

Other squalls may be met with at sea which are accompanied by the passage of a line or arch of cloud, but unless the characteristic change of wind, fall of thermometer and rise of barometer are observed these should not be called line squalls. They may be referred to as "arched squalls".

Phosphorescence.

The phosphorescence of the sea is one of the most remarkable of natural phenomena and various explanations of it have been attempted in the past. One theory held that sea water absorbed sunlight by day and emitted it by night. In 1749-50, however, a small animalcula giving a blue light was discovered by Vianuelli and Guixellani in the Mediterranean, and subsequent investigation has shown that animal life is the origin of marine phosphorescence. Light production is due to a great variety of organisms, from microscopic ones up to many forms of deep sea fish, and the peculiarity of the light is that it is generated without heat, a process never yet achieved by human agency. Light from different organisms has been analysed and the colour is also found to vary through white, silver, green, blue and lilac to red. The method of production has been shown to be some form of slow oxidization which is entirely automatic in the lower forms of life, but is in some measure under control in the higher forms.

Distribution and Seasonal Variation.

Recent research has shown that while phosphorescence may occur anywhere it is most frequent in the warmer tropical seas and in particular in the Arabian Sea, where it exhibits a definite maximum in August. In the North Atlantic Ocean some regions show summer maxima, while others have spring maxima. It also appears that phosphorescence is more frequent in coastal regions than in mid-ocean. One remarkable type of phosphorescence is the diffused " milky sea " which may give light enough to read by and to illuminate clouds. This type has often been reported as exerting a calming effect upon the sea surface. More elaborate phenomena occur which have not yet been satisfactorily explained, such as phosphorescent bands and the great rotating phosphorescent wheels.

CHAPTER VI

ICE AND OCEAN CURRENTS

Ice

Floating Ice and its danger to navigation is dealt with in a "Handbook of Weather, Currents, and Ice for Seamen" M.O. 379.

Terms Used to Describe Ice.

The following terms are used to distinguish the different kinds and conditions of ice.

Slush or Sludge.—The initial stages in the freezing of sea water when it is of gluey or soupy consistency. The term is also occasionally used for "brash ice" still further broken down.

Pancake Ice.—Small floes of new ice approximately circular and with raised rims.

Hummocking.—The results of pressure upon sea ice.

Hummocky Floes.—Floes composed wholly or partly of recemented pressure ice.

The Pack.—The term used to denote the main belt of derived ice which in the Antarctic girdles the continent south of the zone of the "westerlies" and in the Arctic fills the Polar sea and escapes southward from the outlets of the sea (French, "Banquise de derive").

The term "pack" is used more generally to mean any area of pack ice however small.

Close Pack.—Pack composed of floes mainly in contact.

Open Pack.—The floes for the most part do not touch.

Drift Ice.—Loose very open pack where water predominates over ice.

Brash.—Small fragments and rounded nodules, the wreck of other kinds of ice.

Berg.—A large mass of glacier ice.

Bergy Bits.—Medium sized pieces of glacier ice or of heavy floes or hummocky pack washed clear of snow (typical bergy bits have been described as about the size of a cottage).

Growlers.—Similar pieces of ice to the above, but so small as barely to show above sea level.

Rotten Ice.—Floes which have become much honeycombed in course of melting, or which appear black through saturation with water (thin sheets of new-formed very thin ice also appear black and may easily be confused with the last type when met in the pack).

Level Ice.—All unhummocked ice, no matter of what age or thickness, which has platy structure and fibrous appearance when broken.

Fast Ice.—Sea ice while remaining fast in the position of growth. True fast ice is only met along coasts where it is attached to the shore or over shoals where it may be held in position by islands or stranded icebergs.

Pack Ice.—Sea ice which has drifted from its original position.

A Floe.—An area of ice other than fast ice whose limits are within sight. Floes up to two feet in thickness may for convenience of description be termed "light floes"; floes thicker than this "heavy floes."

A Field.—An area of pack ice of such extent that its limits cannot be seen from a ship's masthead.

A Crack.—Any fracture or rift in sea ice.

A Lead or Lane.—A navigable passage through pack ice.

A Pool.—Any enclosed water area in the pack other than a crack or a lead or lane.

Water Sky.—Dark streaks on the sky due to the reflection of water spaces or the open sea in the neighbourhood of large areas of sea ice.

Ice Blink.—The white or yellowish white glare on the sky produced by the reflection of large areas of sea ice. (The antithesis of water sky.)

The time, date, latitude, and longitude of the ice seen, its nature and extent, should be logged; if possible, its height should be ascertained by angular measurement.

Attention is invited to Article 34 of the International Convention for Safety of Life at Sea, given in Appendix III.

Ocean Current Observation

Methods of Observation.

The set and drift of current experienced by a ship under way is the difference between the true fixed position and the position by Dead Reckoning, after a suitable interval.

The set and drift so found will only be true and for a depth of about half the ship's draught, if speed is accurately measured, steering good, judgment of leeway sound, and correction of compass for deviation and variation accurate.

This method of observation of set and drift of current has been the principal means of acquiring knowledge of ocean currents, and with the increasing accuracy of navigation, much is being learnt of the currents of the oceans.

By means of drift bottles, derelicts, and other drifting objects, the average velocity of the current over long distances has been estimated. Such estimations, however, do not give the true set and drift of the current over the whole of the drift of the bottle, derelict or object, since observation is not continuous, and generally the places of departure and arrival only are known. Hence the object may have drifted upon an indirect, winding or circuitous route.

Current Meter.

The current meter is the most accurate means of obtaining the direction and velocity of current both at the surface and in the depths, for it measures the rate at which the water passes it in much the same way as the patent log measures the rate at which it is being towed through the water by a ship. The direction is indicated by means of a compass attached to the meter, and thus positive measurements are obtained, but the use of this instrument is only practicable in surveying vessels and other special service ships. A ship should be anchored when the current meter is used.

PART II

CHAPTER VII

Organization of Voluntary Meteorological Observation at Sea

At the instigation of Commander M. F. MAURY, U.S.N., an International Conference was convened at Brussels in 1853, to consider the possibility of international co-operation and a uniform system of observation.

The oldest branch of the British Meteorological Office, the Marine Division, has been collecting observations of weather, currents and ice from ships at sea in all oceans since the year 1855, when it was established at the Board of Trade with Admiral FitzRoy as Superintendent, for the purpose of providing information to aid navigation and generally to promote knowledge.

In doing so, it has had a part in promoting the skill of seamen in observation and in establishing a system for the collection and dissemination of meteorological intelligence.

In 1932 the International Convention for Safety of Life at Sea, the outcome of the 1929 Conference, was embodied in the Merchant Shipping (Safety and Load Line Conventions) Act; and Article 35 of this Convention given in Appendix III specifies the services which are to be encouraged.

The organization of the Marine Division of the Meteorological Office, its branches and agencies, is intended to encourage the work at sea, to collect, collate and disseminate information.

Experience has shown that to be effective, collection must be limited, and observation regular, all requiring careful organization, encouragement and guidance.

British Corps of Voluntary Marine Observers.

The commanders and officers of ships who voluntarily do this work are known as the British Corps of Voluntary Marine Observers, and their ships comprise the British Voluntary Observing Fleet.

The number of this fleet is limited according to the requirements of the time. Regular observing ships not only return written observations, but a number of them, to accord with a specified total number of Selected Ships of all nations, act as British Selected Ships.

Selected Ships.

Selected Ships carry out a regular service of routine wireless weather telegraphy, by which means ships at sea and meteorological centres ashore are kept informed of the state of the weather at sea the world over.

"Marine Observer".

The principal medium of communication between the Marine Division and the corps of marine observers, is a periodical publication, the "Marine Observer", published quarterly by H.M. Stationery Office, with Monthly Supplements.

In the "Marine Observer", the fleet list is given, with the names of voluntary observing ships for the time being, their Commanders, observing officers, and W.T. operators.

Port Meteorological Officers and Merchant Navy Agents.

The names and addresses of the Port Meteorological Officers and Merchant Navy Agents, who at the ports form a personal link with the Marine Division, are given in the "Marine Observer"; and in this Journal and its Supplements, notices, advice and information are published as desirable; and the Commanders of British ships desiring information as to how to volunteer for this work, and so on, should refer to the current number of the "Marine Observer".

The principal branches of the work carried out by the British Voluntary Observing Fleet are :—

Meteorological Log.

(1) The keeping of the Meteorological Log, by which means knowledge of climate in all parts of the ocean is obtained, and meteorological charts of the oceans are made. The observations are made according to time of place, Ships' Apparent Time, and are taken six times daily at the relief of the watch.

In the past the majority of observing ships kept the Meteorological Log.

The amount of climatological data which has now been collected for the greater part of the navigable oceans is sufficient for the purpose at the present time.

There are still regions where more observations are desired, and a number of regular observing ships who navigate these regions keep the Meteorological Log upon which all the other work has been founded.

Meteorological Record of Synchronized Observations.

(2) The study of weather and weather forecasting as apart from climate, i.e. the day to day occurrence of weather, calls for other methods.

For timing wireless communication Greenwich Mean Time is desirable and in order to ensure synchronization of observation of weather, Greenwich Mean Time is also desirable. Accordingly times of observation at sea for the purpose of routine wireless weather telegraphy have been fixed by international agreement at 0000 0600 1200 and 1800 G.M.T.

For the purpose of recording weather, regular observing ships use Form 911, "Ship's Record of Synchronized Weather Observations".

For the purpose of coding weather reports, and keeping a record of the reports made in code, Selected Ships also keep Form 138, "Register for Selected Ships' Coded Wireless Weather Reports".

Ocean Current Observations. Observations of ocean current are made by observing ships, and are entered in either the Meteorological Log or Form 911.

Loan of Instruments. To ensure the accuracy of data collected for the purpose of research and for weather forecasting, ashore and afloat, and to provide a pattern which may be copied with advantage to all concerned for general use in merchant ships, the Meteorological Office lends instruments to the Captains of observing ships.

Only ships of British register are included in the fleet list.

These instruments are of standard pattern, and have been verified at the National Physical Laboratory.

Supply and Return of Instruments. Instruments are supplied to ships either by the Port Meteorological Officers or Merchant Navy Agents, and are delivered by hand. Instruments should be returned from a ship, when observations are being discontinued, to the appropriate Port Meteorological Officer or Agent by hand. When this is not possible, as for example at ports where there are no agents, application should be made to the Marine Superintendent of the Meteorological Office for instructions as to procedure, before instruments are sent by train. Similar remarks apply to the return of damaged instruments for repair or replacement.

Accidents to Instruments. Any accident to any instrument, even if no apparent damage is done to it, should be reported to the appropriate Port Meteorological Officer or Merchant Navy Agent; for names and addresses see current number of the "Marine Observer". The constants of the instrument may well have been altered without any apparent difference in its working. On no account should a barometer or any other instrument belonging to the Meteorological Office be sent to an instrument maker for repair, or an attempt be made to repair the instrument on board the ship.

Return of Instruments. When it is desired to return instruments lent by the Meteorological Office, the appropriate Port Meteorological Officer or Merchant Navy Agent should be advised.

If instruments are returned by a ship from a port where the Meteorological Office has not a branch or an agency, the following should be carefully observed.

A tally with the name of the ship should be attached to the instruments, which should be packed in the boxes in which they were supplied, enclosed in cotton wool or some soft elastic packing, and the boxes should be labelled "Glass—fragile instruments". The address to which instruments should be consigned is "Meteorological Office, Exhibition Road, South Kensington, London, S.W.7."

All instruments, except mercury barometers, should invariably be consigned by passenger train, at the railway company's risk, not by post. The company will charge their "glass" carriage rates, which are 50 per cent. higher than the ordinary rates. Railway companies will no longer accept mercury barometers for transmission by passenger train at company's risk, because of their fragile nature and the high cost of repairs when damage occurs.

A barometer of which the inner glass tube is broken, so that mercury is seen to escape from the instrument, should be sent by passenger train at owner's risk; it is very important that all loose mercury should be emptied from the instrument and from its wooden box before despatch, otherwise the mercury will attack the brasswork of the frame and silvering of the scales, causing much damage en route. The cistern should be unscrewed, the mercury poured out, and the cistern then replaced after making certain that no mercury is left in the barometer. The loose mercury should be placed in a strong glass or stone bottle, securely corked, and carefully packed inside the box. These precautions are particularly necessary when the barometer is fitted with a Gold correction slide.

If it is necessary to forward a mercury barometer of which the glass tube is unbroken, special arrangements will be required to avoid breakage during transit. For this purpose a "dooly", which is a specially designed crate with long handles, will be sent from the Meteorological Office upon request; instructions for packing are contained therein.

CHAPTER VIII

OBSERVING SCALES, INSTRUCTIONS FOR THEIR USE AND SPECIAL OBSERVATIONS FOR THE METEOROLOGICAL OFFICE

The Beaufort Wind Scale is given on pages 64 and 65. The appropriate scale number is assigned to the wind force at the time of observation by the judgment of the observer, the method used being described in CHAPTER I. **Beaufort Wind Scale.**

A German specification of visible effects of wind upon the sea has been proposed and is being tested in British ships with a view to adoption or modification. It is an attempt to define the appearance and sound of the sea for each of the Beaufort wind forces. It was published in the "Marine Observer", Volume XIII, 1936, page 54. This specification can only be regarded as a general description, since, as stated in CHAPTER I, the appearance of the sea depends to some extent on factors other than wind force.

The Douglas Sea and Swell Scale is given on page 66, and with the sea and swell scales separately on page 66. In the Meteorological Log and in Form 911 separate columns are provided for the entry of sea and swell according to this scale. **Douglas Sea and Swell Scale.**

High, very high and precipitous seas (6–8 of the scale) represent seas which occur with a swell or in the open ocean. The highest sea recorded in sheltered waters would usually be 5, but in exceptional circumstances, such as a hurricane, 6 or 7. Confused sea 9 may be occasioned by current, tide or sudden shift of wind, not necessarily by strong wind.

Methods of measurement of waves are given on pages 67 to 71.

Beaufort Wind Scale

Beaufort Number. International.	Meteorological Wind Scale. Determined at coast stations for a height of 33 ft. above sea level. Limits of Velocity nautical miles per hour. *knots.*	Average Velocity nautical miles per hour. *knots.*	Equivalent pressure in pounds upon a circular disc of one square foot.	The Seamen's Wind Scale. Beaufort's description of Wind. International.	Deep Sea Criterion, 1874. International.		Coastal Criterion.	Beaufort Number. International.
1	2	3	4	5	6		7	8
0	Less than 1	0	0	Calm	——		——	0
1	1 to 3	2	·01	Light air ..	Just sufficient to give steerage way* ..		Sufficient to give good steerage way to fishing smacks with the "wind free".†	1
2	4 to 6	5	·08	Light breeze ..	That in which a well-conditioned man-of-war, with all sail set, and clean full, would go in smooth water from—	1 to 2 knots	Fishing smacks with top-sails and light canvas "full and by" make up to 2 knots.	2
3	7 to 10	9	·28	Gentle breeze ..		3 to 4 knots	Smacks begin to heel over slightly under topsails and light canvas make up to 3 knots "full and by".	3
4	11 to 16	14	·67	Moderate breeze		5 to 6 knots	Good working breeze. Smacks heel over considerably on a wind under all sail.	4

5	17 to 21	19	1·31	**Fresh breeze** ..	**That to which she could just carry in chase, full and by—**	**Royals, &c.**	Smacks shorten sail ..	5
6	22 to 27	24	2·3	**Strong breeze** ..		**Topgallant sails.**	Smacks double-reef gaff mainsails.	6
7	28 to 33	30	3·6	**Moderate gale** ..	**That to which she could just carry in chase, full and by—**	**Topsails, jib, &c.**	Smacks remain in harbour and those at sea lie to.	7
8	34 to 40	37	5·4	**Fresh gale** ..		**Reefed upper topsails and courses.**	Smacks take shelter if possible.	8
9	41 to 47	44	7·7	**Strong gale** ..		**Lower topsails and courses.**	—	9
10	48 to 55	52	10·5	**Whole gale** ..	**That with which she could scarcely bear lower maintopsail and reefed foresail.**		—	10
11	56 to 65	60	14·0	**Storm**	**That which would reduce her to storm stay-sails.**		—	11
12	Above 65	—	Above 17·0	**Hurricane** ..	**That which no canvas could withstand**		—	12

For the purpose of showing the forces of winds by wind roses on Meteorological Charts, winds are grouped as follows :—

Scale Numbers

0	Calm.
1 to 3	Light winds.
4 to 7	Moderate winds.
8 and above	Gales.

The Gale Warning Signal in the British Isles is hoisted for winds which may reach force 8 or above. For this purpose force 7 is not considered a gale.

* A full-rigged ship of 1874.

† Cutter or Yawl-rigged average sized sailing trawler, loaded, with clean bottom.

Douglas Sea and Swell Scale (Combined)

SEA.	SWELL.									
		Low.		Moderate.			Heavy.			
	No swell. 0	Short or Average. 1	Long. 2	Short. 3	Average. 4	Long. 5	Short. 6	Average. 7	Long. 8	Confused. 9
0 Calm	00	01	02	03	04	05	06	07	08	09
1 Smooth ..	10	11	12	13	14	15	16	17	18	19
2 Slight	20	21	22	23	24	25	26	27	28	29
3 Moderate ..	30	31	32	33	34	35	36	37	38	39
4 Rough	40	41	42	43	44	45	46	47	48	49
5 Very rough ..	50	51	52	53	54	55	56	57	58	59
6 High	60	61	62	63	64	65	66	67	68	69
7 Very high ..	70	71	72	73	74	75	76	77	78	79
8 Precipitous ..	80	81	82	83	84	85	86	87	88	89
9 Confused ..	90	91	92	93	94	95	96	97	98	99

Douglas Sea and Swell Scales (separate)

State of Sea

Scale Number.	*Description.*
0	Calm
1	Smooth
2	Slight
3	Moderate
4	Rough
5	Very rough
6	High
7	Very high
8	Precipitous
9	Confused

Swell

Scale Number.	*Description.*
0	No swell.
1	Low swell, short or average length.
2	Low swell, long
3	Moderate swell, short
4	Moderate swell, average length
5	Moderate swell, long
6	Heavy swell, short
7	Heavy swell, average length
8	Heavy swell, long
9	Confused swell.

Measurement of Waves

Observations of wave dimensions are being collected so that reliable information may be added to the Douglas scale. Sufficient observations have not yet been received and marine observers will help by measuring waves and logging their measurements, whenever possible.

Recording Wave Measurements.

A form is supplied for this purpose. When making these measurements of sea and swell, marine observers should name the sea or swell by the term used in the Douglas scale, according to their own judgment, so that average dimensions may be computed from these observations, and attached to the terms as the result of this combined experience.

The information desired is as follows :

S.S...................... Captain......................
Observer....................
From .... To ....

Date .... Time of Observation.........
Latitude.................... Longitude..................
True Course .... Speed in Knots..............
If hove to, True Direction of Ship's Head..................
Wind at time of observation—True Direction ....
Force by Beaufort Scale..........................
Depth of Water in Fathoms (Approx.).....................
Element observed, Sea or Swell? ....Very important.
Height of Waves in Feet ....
Length of Waves in Feet ....
Period, *True* ....seconds.
Velocity, *True* ....
True Direction from which the waves come ....
General State of Sea—True Direction ....
Amount of Disturbance by Scale* ....
General State of Swell—True Direction...................
Amount of Disturbance* ....

Remarks (including methods of measurement adopted, degree of reliability, number of waves actually measured, variability of dimensions, etc.).

....
....
....

NOTE.—Only actual measured observations should be given, correction being made for ship's advance in all cases where applicable.

* Douglas Scale.

Methods of Measuring Waves.

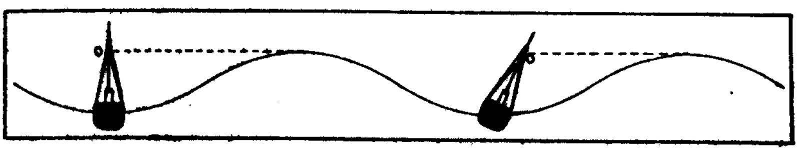
The length of a wave is the horizontal distance (usually expressed in feet) from crest to crest or hollow to hollow. The height is the vertical distance from hollow to crest (also in feet). The period of a wave is the time, in seconds, between the passage of two succeeding wave crests or hollows past a fixed point. The velocity of a wave is the rate at which its crest travels forward, and is of course obtained by dividing the length by the period, the result being the velocity in feet per second.

Precautions in Wave Measurement.

On board a moving ship, the measurement of the dimensions of waves frequently presents difficulty. The sea is often in a very confused state, owing to the crossing of waves from different directions and the combination of different series of waves travelling in similar direction; it is almost hopeless to attempt any measurement in these cases. Only those seas in which well-defined ridges of water follow one another with some approach to uniformity should be selected for measurement. Estimates, particularly those of wavelengths, are of little value for the purposes of investigation, for unless special precautions are taken, or the circumstances are specially favourable, even the practised eye of the seaman may be completely deceived in judging the distance between two wave crests as viewed from on board ship. The error is least when the height of eye above the waves is large, but even then, the estimates of independent observers may differ considerably.

Measurement of Height.

The most usual method for measuring the height of waves is for the observer to climb the rigging or otherwise place himself at a height sufficient for his eye to be just in line with the advancing wave crest and the horizon, when the ship is in the hollow. The height of eye above the ship's water line will then be the height of the oncoming wave. The nearer the observer is to an amidships position the less chance will there be of the measurement being vitiated by pitching. If the ship rolls heavily he should allow for this as accurately as possible by judging the amount of heel, or endeavour to make his observation at the moment when the ship is upright in the hollow.



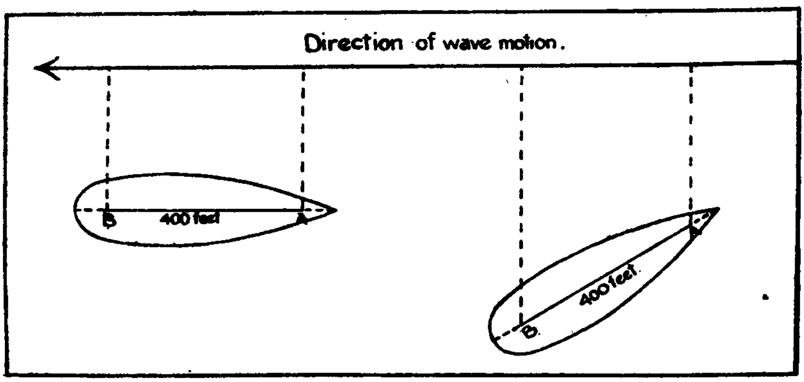
(*a*) FIG. 13. (*b*)

Exaggeration of estimates of wave heights is mostly attributable to the error caused by pitching and rolling. See FIGURE 13. When the ship is rolling (*b*) the observer O has to take up a higher position to get a line on the horizon than when she is upright (*a*). Another source of error may arise from the fact that the length of the ship may considerably exceed that of the wave, and not permit her to lie completely in the trough. In this case the ship may be buoyed up on two waves, and the height of the oncoming crest will consequently be under-estimated.

The above method is suitable for large waves, but the observer may not be able to take up a position low enough for the observation of the smaller waves, especially in modern liners; the heights of these may be estimated.

Measurement of Length, Period and Velocity.

It is evident that the simplest conditions for observing the lengths and periods of waves are when the ship is stem on to the waves, and is stationary. The true period and true speed of the waves can then be obtained by direct observation, and the length calculated. The following simple and effective methods of determining length, period and velocity of waves are those advocated by Captain J. F. RUTHVEN in his book "Take Care of the Ship".



(*a*) FIG. 14. (*b*)

Imagine a fore and aft base line AB (see FIGURE 14), say 400 ft. long, at each end of which a pair of battens is erected parallel to the wave crests (and at right angles to the ship's keel), to be used as sights. Observers at both stations note, by watches previously compared, the instant when a wave crest crosses their line of sight; they also note how long an interval elapses before the next wave crosses their observation station. Comparing their records, they determine the time, say 8 seconds, occupied by the waves in traversing the length AB, while the interval between successive waves is say 10 seconds; the speed of the waves is obviously then 50 ft. per second, and as they pass the observation points at 10-second intervals, this is the period and gives a wavelength of $50 \times 10 = 500$ ft.

If the ship's keel makes an angle with the waves as in (*b*) we can still use the same line, and train our battens parallel to the wave crests. The new or virtual base for our calculations will be the perpendicular distance between A and B, which will vary with the angle of the ship's fore and aft line and is obtained by multiplying the base AB, 400 ft., by the cosine of the angle between ship's keel and wave direction ; or with Traverse Table, distance between sights as distance, angle between wave direction and ship's course as course, then D. Lat. = distance travelled by wave crest.

When the ship is steaming, allowance has to be made for the ship's direction and speed in relation to that of the waves, and the following imaginary examples are worked out as simply as possible without the use of algebraic formulæ, for the guidance of observers.

(1) Suppose the ship steaming head to sea, she will meet the waves sooner than when at rest. Let the time occupied by the wave travelling along the base line of 400 ft. be 6·2 seconds (called the *speed interval*), and that between the passage of successive wave crests (called the *length interval*) be 7·7 seconds. The speed of the ship is 15 ft. per second.

In the first interval, the ship will have travelled 15 × 6·2 = 93 ft. and the *speed* of the wave will therefore be

$$\frac{400 - 93}{6 \cdot 2} = 50 \text{ ft. per second.}$$

Now as the wave is travelling 50 ft. per second, and the ship 15 ft. per second, they will be approaching one another at the rate of 65 ft. per second, and in the length interval, 7·7 seconds, will cover 65 × 7·7 = 500 ft. which is the length of the wave. The *true period* is *length* divided by *speed* = 500 ÷ 50 = 10 seconds.

(2) Suppose the ship to be travelling in *same direction as waves*, at a speed of 30 ft. per second. Let the *speed interval*, i.e., time occupied by wave traversing the base line, be 20 seconds, whilst the length interval was 25 seconds. In the first-named interval the ship would have travelled 30 × 20 = 600 ft., and the wave speed would therefore be

$$\frac{600 + 400}{20} = 50 \text{ ft. per second.}$$

As the wave is travelling 20 ft. per second faster than the ship, this multiplied by the length interval, 25 seconds, will be the length of the wave = 500 ft.

The period is, of course, the same as before.

(3) Suppose the ship steaming at 15 ft. per second *against the waves*, but making an angle of 26° with their direction.

The *virtual base* = 400 ft. × Cos. 26°
= 400 ft. × ·9 = 360 ft.

Component of ship's speed
(at right angle), *towards*
the waves = 15 × Cos. 26° = 15 × ·9 = 13·5 ft.

The observed *speed interval* was 5·67 seconds and *length interval* 7·9 seconds.

During the speed interval the ship will have travelled to meet the wave $13 \cdot 5 \times 5 \cdot 67 = 77$ ft., and the speed of the wave will therefore be $\frac{360 - 77}{5 \cdot 67} = 50$ ft. per second.

As the wave is travelling 50 ft. per second and the ship is approaching it at 13·5 ft. per second, they will be closing at 63·5 ft. per second, which when multiplied by the length interval, 7·9 gives 500 ft as the length of the wave.

(4) The last example is that of the ship *steaming with the waves* at 30 ft. per second but at an angle of 18° with their direction.

In this case the virtual base will be

400 ft. × Cos. 18° = 400 × ·95 =	380 ft.
Component of ship's speed *away from the wave* = 30 × Cos. 18° = 30 × ·95 =	28·5 ft.

The observed *speed* and *length* intervals were respectively 17·8 and 23·2 seconds. During the speed interval, the ship will run away from the wave $28 \cdot 5 \times 17 \cdot 8 = 507$ ft. This has to be added to the virtual base to get the distance the wave travels in that period, viz., $507 + 380 \div 17 \cdot 8$, which gives the wave speed of 50 ft. per second.

The wave is travelling at 50 ft. per second, that is 21·5 ft. per second (50 — 28·5) faster than the ship; this multiplied by the length interval, 23·2 gives the length of the wave, viz., $21 \cdot 5 \times 23 \cdot 2 = 500$ ft.

Another method of measuring wavelengths and one which will be preferred by many, is to tow astern a buoy or other mark, paying out sufficient line so that when a wave crest passes the stern, the buoy is on the crest of the next wave. The length of line run out gives the apparent wavelength; if waves and ship are travelling in the same or opposite direction, apparent length = true length; if ship's course makes an angle (B) with wave's course, the true length is simply obtained thus :—

True length = Apparent length × Cos. B.

Formation of Waves

The action of water when disturbed by waves is sometimes difficult to realise, because of the strong impression one gets, when watching waves approach, that the crests of the waves are themselves bodily moving forward. If however we watch a log of wood or other floating object, we shall notice that it makes little or no advance forward as the wave crest passes, but simply rises and falls and has a small movement to and fro.

The principle underlying the formation of deep sea waves therefore is that the observed motion is not the bodily advance of a mass of water, but merely the propagation of energy or movement created by the wind.

Profile of Waves.

The profile of an ocean wave is a curve known as a trochoid, which may be simply described as a curve which would be traced on a bulkhead by a marking point fixed to the spoke of a wheel, if we imagined the wheel to be rolled along under the deck head. In FIGURE 15, the large circle represents the wheel, and P the marking point on a spoke, OP (the distance from the axle) being called the tracing arm. The arrow shows the direction in which the circle rolls and the wave is supposed to

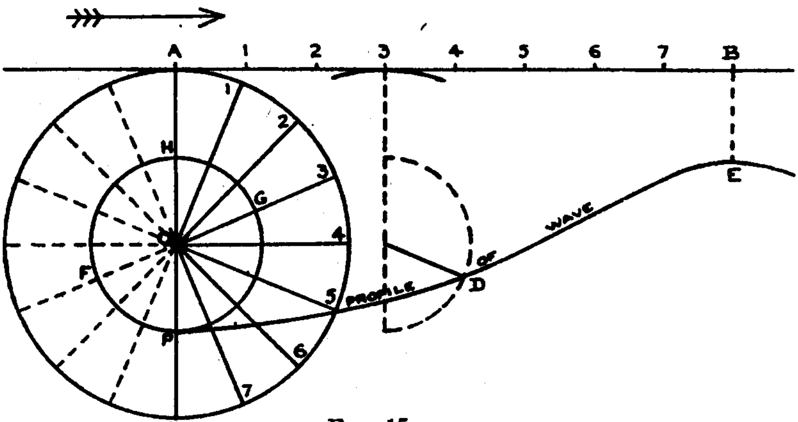


FIG. 15

be travelling. AB is the base, i.e., the straight line under which the circle is to roll, the length AB being equal to the half circumference of the wheel AR. Now as the circle rolls, when 3 of the circle reaches 3 of the base, the semi-circle FPG will be in the position shown by the dotted semi-circle ; and the marking point P will coincide with the point D, having described part of a trochoid PD. When the circle has completed half a revolution, the marking point P will coincide with E, having described the trochoid curve PDE, which is half a wave-length ; the diameter POH represents the height of the wave. The nearer the marking point is to the axle of the wheel, the flatter will be the trochoid.

The motion of the particles in a trochoid wave requires to be noticed. Each particle revolves with uniform speed in a circular orbit, perpendicular to the wave ridge (the diameter of the orbital circles being the height of the wave) and completes a revolution in the same time as the wave takes to advance its own length. At the wave crest the motion of the particles is wholly horizontal, advancing in the same direction as the wave ; at mid-height on the front slope, it is wholly upwards ; in the hollow it is again horizontal but in the opposite direction to the travel of the wave, and at mid-height on the back slope it is wholly downwards.

Waves below the sea surface.

The disturbance set up by wave motion must necessarily extend for some distance below the surface ; but its magnitude decreases very rapidly in accordance with a definite law, the trochoids becoming flatter and flatter as the depth increases. At a depth equal to one wavelength, it is less than a five-hundredth part of what it is at the surface, so that the water at that depth may be considered undisturbed ; and the motion associated with the largest ocean waves is inappreciable at even moderate depths.

Waves in shoal water.

Waves formed in deep sea are modified as they get into shoal water. When the depth is reduced to less than half the wavelength, the orbits of the particles commence to become flattened and more elliptical as the water shoals. The period of the wave remains unchanged, but the length and speed are reduced, while the height is increased. Finally when the depth is not sufficient for the complete formation of the undulation, the bottom of the wave is retarded by friction of the sea bottom, the top is thrown forward and the wave breaks into surf.

Where shoaling is very steep, the change in the appearance of the waves will be very rapid.

The foregoing explanation of the structure of trochoidal waves, with a smooth even profile, closely approximates to the actual observations of swell observed in the open ocean; but the fact that a ship rolling amongst waves is subjected to a certain amount of drift in the direction of the waves' advance, suggests that ocean waves do not conform entirely to this pattern. This subject, however, requires further investigation before a definite explanation can be given.

Relation between Length, Period and Velocity.

Certain relations have been established between the length and the period and velocity of trochoidal waves, the principal of which are as follows:—

$$\text{Length} = \text{Velocity} \times \text{Period}.$$
$$\text{Period} = \text{Velocity} \div 5\tfrac{1}{8}.$$
$$\text{Period} = \sqrt{\text{Length} \div 5\tfrac{1}{8}}.$$

By the use of these formulæ, if any one of the above wave elements is measured, the other two can be calculated, but for the convenience of observers the following table is given:—

Wave Length in Deep Sea.	Wave Period.	Velocity of Transmission of Individual Waves in Deep Sea.		Velocity of Transmission of the Groups of Waves in Deep Sea.	
Feet.	Seconds.	Feet per Second.	Nautical Miles per Hour.	Feet per Second.	Nautical Miles per Hour.
25	2·2	11·3	6·7	5·7	3·4
50	3·1	16·0	9·5	8·0	4·8
75	3·8	19·6	11·6	9·8	5·8
100	4·4	22·6	13·4	11·3	6·7
150	5·4	27·7	16·4	13·9	8·2
200	6·3	32·0	19·0	16·0	9·5
300	7·7	39·2	23·2	19·6	11·6
400	8·9	45·2	26·8	22·6	13·4
500	9·9	50·6	30·0	25·3	15·0
600	10·9	55·4	32·8	27·7	16·4
700	11·8	59·8	35·4	29·9	17·7
800	12·6	63·8	37·8	31·9	18·9
900	13·3	67·7	40·1	33·9	20·1
1,000	14·1	71·4	42·3	35·7	21·2

Groups of Waves. Waves at sea are observed to occur generally in series or groups, the region between successive groups consisting of comparatively calm water. If we follow the motion of the first wave of the group, we shall find that it dies out, and that the wave next behind takes the lead. If on the other hand we watch the last wave of the group we shall see that another one appears behind it. The new waves constantly arise in the rear as rapidly as those in front die out, so that the general appearance of a group of waves remains unchanged. The group as a whole has a definite velocity of propagation, which has been found to be half of that of the individual waves comprising the group, as shown in the table given above.

Swell. When wave motion is once set up in the ocean, it continues for a considerable time after the originating cause has ceased or passed away; persisting until the energy imparted to the wave is absorbed by the effect of gravity, friction, &c. Series of waves thus travelling away beyond the limits of the wind which raised them, retain their direction unchanged so long as they travel in deep water. The height will rapidly diminish, but the length and velocity will remain the same, and they assume the appearance of long low regular undulations of the water known as swell; and may ultimately appear as rollers or breakers on shores far distant from their place of origin.

Distance Swell has travelled. To find the distance which swell has travelled in a given time, half the velocity of the individual waves, as measured from the ship, should be used, this being, as above stated, the velocity of the group of waves as a whole. If, for example, waves 200 feet long are observed to be moving eastwards in mid-ocean, with a velocity of 19 knots, the disturbance would have been $9\frac{1}{2} \times 12 = 114$ miles west of the ship's position at a time 12 hours previously.

Need for further observations. Since Admiral Douglas drew up the Scale of Sea and Swell in 1922, a number of measurements have been made; but they are not sufficient. However, the measurements so far received indicate that the formula for the relationship of length, period, and velocity of waves, given on a previous page, may require modification.

Measurements of waves at sea are much required, and marine observers will greatly assist if they will obtain these wherever possible.

Specification of Cloud Form

The origin of cloud names is given in Chapter I. In 1891 a classification of ten main forms was adopted internationally and the International Cloud Atlas appeared in 1895. The names and definitions of cloud types given in previous editions of this Handbook were taken from this source.

Of recent years the question of cloud classification has again been considered by an International Commission and a new large atlas was published in 1932, together with a revised description of cloud forms. The classification into ten main forms, which is given below, is the same as before, but marine observers should note the following points :—

(1) The name " nimbus " is no longer used, being replaced by " nimbostratus ".

(2) The names and their abbreviations are written in a simpler form, without hyphens.

Upper Clouds.

(1) **Cirrus (Ci.).**—Detached clouds of delicate and fibrous appearance, without shading, generally white in colour, often of a silky appearance.

Cirrus appear in the most varied forms such as isolated tufts, lines drawn across a blue sky, branching featherlike plumes, curved lines ending in tufts, etc. ; they are often arranged in bands which cross the sky like meridian lines, and which, owing to the effect of perspective, converge to a point on the horizon, or to two opposite points (cirrostratus and cirrocumulus often take part in the formation of these bands).

(2) **Cirrocumulus (Cicu.).**—A cirriform layer or patch composed of small white flakes or of very small globular masses, without shadows, which are arranged in groups or lines, or more often in ripples resembling those of the sand on the sea shore.

In general, cirrocumulus represents a degraded state of cirrus and cirrostratus both of which may change into it. In this case the changing patches often retain some fibrous structure in places.

Real cirrocumulus is uncommon. It must not be confused with small altocumulus patches on the edges of altocumulus sheets.

3. **Cirrostratus (Cist.).**—A thin whitish veil, which does not blur the outlines of the sun or moon, but gives rise to halos. Sometimes it is quite diffuse and merely gives the sky a milky look; sometimes it more or less distinctly shows a fibrous structure with disordered filaments.

Middle Clouds.

4. **Altocumulus (Acu.).**—A layer, or patches composed of laminæ or rather flattened globular masses, the smallest elements of the regularly arranged layer being fairly small and thin, with or without shading. These elements are arranged in groups, in lines or waves, following one or two directions and are sometimes so close together that their edges join.

The thin and semi-transparent edges of the elements often show irisations which are rather characteristic of this class of cloud.

5. **Altostratus (Ast.).**—Striated or fibrous veil, more or less grey or bluish in colour. This cloud is like thick cirrostratus but without halo phenomena; the sun or moon shows vaguely, with a faint gleam, as though through ground glass. Sometimes the sheet is thin with forms intermediate with cirrostratus **(altostratus translucidus).** Sometimes it is very thick and dark **(altostratus opacus),** sometimes even completely hiding the sun or moon. In this case differences of thickness may cause relatively light patches between very dark parts; but the surface never shows real relief, and the striated or fibrous structure is always seen in places in the body of the cloud.

Lower Clouds.

6. **Stratocumulus (Stcu.).**—A layer or patches composed of laminæ or globular masses; the smallest of the regularly arranged elements are fairly large; they are soft and grey, with darker parts. These elements are arranged in groups, in lines, or in waves, aligned in one or in two directions. Very often the rolls are so close that their edges join together; when they cover the whole sky, as on the Continent, especially in winter, they have a wavy appearance.

7. **Stratus (St.).**—A uniform layer of cloud, resembling fog but not resting on the ground. When this very low layer is broken up into irregular shreds it is designated **fractostratus (Frst.).**

8. **Nimbostratus (Nbst.).**—A low, amorphous, and rainy layer of a dark grey colour and nearly uniform; feebly illuminated seemingly from inside. When it gives precipitation it is in the form of continuous rain or snow.

But precipitation alone is not a sufficient criterion to distinguish the cloud which should be called nimbostratus even when no rain or snow falls from it.

There is often precipitation which does not reach the ground; in this case the base of the cloud is always diffuse and looks " wet " on account of the general trailing precipitation, virga, so that it is not possible to determine the limit of its lower surface.

9. **Cumulus (Cu.).**—Thick clouds with vertical development; the upper surface is dome-shaped and exhibits protuberances, while the base is nearly horizontal.

When the cloud is opposite to the sun, the surfaces normal to the observer are brighter than the edges of the protuberances. When the light comes from the side, the clouds exhibit strong contrasts of light and shade; against the sun, on the other hand, they look dark with a bright edge.

True cumulus is definitely limited above and below, its surface often appears hard and clear cut. But one may also observe a cloud resembling ragged cumulus in which the different parts show constant change. This cloud is designated **fractocumulus (Frcu.)**.

10. **Cumulonimbus (Cunb.)**.—Heavy masses of cloud with great vertical development, whose cumuliform summits rise in the form of mountains or towers, the upper parts having a fibrous texture and often spreading out in the shape of an anvil.

The base resembles nimbostratus, and one generally notices virga. This base has often a layer of very low ragged clouds below it (fractostratus, fractocumulus).

Cumulonimbus clouds generally produce showers of rain or snow and sometimes of hail or soft hail, and often thunderstorms as well.

If the whole of the cloud cannot be seen the fall of a real shower is enough to characterize the cloud as a cumulonimbus.

Notes on Cloud Forms.

Many variations of the typical cloud forms, given above, can be recognized and have been given names. Notes on a few of the better known ones are given here.

When cirrostratus is diffuse and gives the sky a milky look, it is often called **cirronebula.**

Altocumulus castellatus is a distinct variety of altocumulus in which individual cloudlets are extended vertically upwards in little heads or towers.

Stratocumulus cloud sometimes takes a hard-edged oval or torpedo-shaped form. Such clouds are popularly known as " Whale-Back " clouds. Groups of cirrocumulus and altocumulus are sometimes massed together into a similar form. Such lenticular clouds generally occur with a very intense blue sky, a very unsteady barometer and a strong or high gusty wind. They are called **stratocumulus lenticularis.**

The lower surface of stratocumulus or cumulus cloud sometimes has an udder-like or mammillated appearance and is called **mammatocumulus.** Such clouds are popularly known as " Festoon " or " Pocky " clouds. This usually occurs in thundery weather. Sometimes higher clouds take a similar form.

Although the word nimbus is no longer used, the name **fractonimbus (Frnb.)** is still applied to the very low dark ragged clouds (" Scud ") which form in rainy weather below nimbostratus or altostratus cloud.

Various cloud types take at times the form of waves. These are called undulated clouds. Such clouds may show regular striae, parallel and equidistant, like waves on the surface of water. This mostly occurs with cirrocumulus, stratocumulus, and altocumulus. With stratocumulus the whole sky is sometimes covered with rolls of cloud, when it is called **roll-cumulus.** The direction of cloud striae may be observed. Two distinct systems are sometimes apparent, the clouds being separated into globular masses by striae in two directions; the directions of these two systems should be noted. As far as possible, these observations should be taken of striae near the zenith so as to avoid errors caused by perspective. The converging point or point of radiation of the upper clouds referred to above, under cirrus cloud, may be observed by estimating the bearing of this point on the horizon, to the nearest compass point (true).

Observation of Cloud

Cloud Amount. The proportion of the sky covered by cloud is judged on a numerical scale of tenths, 0 being cloudless and 10 completely overcast. The method of making this observation is described in Chapter I.

When the amount of cloud cannot be seen because of darkness, fog, dust storm or other surface phenomenon, the cloud amount should be indicated by a note of interrogation (?), to distinguish it from " no observation ", which is indicated by the column being kept blank. In this case an appropriate remark explaining the circumstances should be added.

In addition to estimating the total amount of sky covered by cloud of any form, " selected ships " estimate the amount of sky covered by the lower clouds. This is done by the same method, the entry being the estimated number of tenths of the sky covered by all forms of lower cloud.

Cloud Form. The observation of cloud form according to the ten kinds given above is not always easy; practice and experience are needed. Many skies are very complex in character, with various cloud forms at different levels, often superimposed upon one another. Moreover, as already stated, many variations of cloud form occur. In view of this diversity the observer must not expect to be able to assign all clouds to one or other of the types described, without hesitation. If he is unable to classify the clouds seen the fact should be noted.

Cloud Plate. A Cloud Plate accompanies this book. It is convenient to display this in the wheel house or chart house.

When the cloud form cannot be seen because of darkness, fog, dust storm or other phenomenon, the observation should be recorded by a note of interrogation (?). The same entry should be made for the upper and middle cloud in cases where it cannot be seen whether such clouds are present by reason of the obstruction of a complete lower layer of cloud. In all such cases a remark explaining the circumstances should be added.

The direction of motion of clouds should be noted, that is the direction from which the cloud is coming. At anchor this may be seen by sighting the cloud against a fixed point. At sea by day it is not so easy owing to the speed and motion of the ship; but at night time and when the cloud canopy is broken, stars near the zenith form very suitable fixed points. It should be remembered that the apparent motion of a cloud near the horizon will be distorted by the effect of perspective. This effect will decrease as the zenith is approached. Clouds at a greater zenith distance than 30° should not, therefore, be observed for motion unless no observation near the zenith is possible. Cloud Motion.

The speeds of clouds cannot be measured accurately at sea, but the following qualitative scale of velocities should be used:—0 to denote stationary, 1 to denote a slow movement, 2 moderate and 3 fast. Thus $\frac{\text{Ci}}{\text{N.W.}}$ 2 means cirrus cloud moving from northwest at moderate speed, while Acu. 0 denotes that altocumulus is stationary. Cloud Speed.

Several different cloud forms will frequently be present simultaneously. In such cases the direction of motion of "lower" clouds and "upper and middle" clouds should be separately observed. As far as possible each layer should be observed separately, and its appropriate direction and velocity noted. It is often very difficult to observe the motion of upper cloud without comparing it with the lower. This should never be done. The motion recorded must be the absolute motion of the cloud, not its motion relative to another moving object. The movement of upper cloud is by far the most useful of these observations.

The state of the weather is logged by letters of the Beaufort notation, which is as follows:— Beaufort Weather Notation.

Letters to indicate the State of the Weather

b = blue sky whether with clear or hazy atmosphere, or sky not more than one-quarter clouded.

bc = sky between one-quarter and three-quarters clouded.

c = mainly cloudy (not less than three-quarters covered).

d = drizzle or fine rain.

e = wet air without rain falling.

f = fog.

fe = wet fog.

g = gloomy.

h = hail.

kq = line squall.

l = lightning.

m = mist.

o = overcast sky (i.e., the whole sky covered with unbroken cloud).

p = passing showers.
q = squalls.
r = rain.
rs = sleet (i.e., rain and snow together).
s = snow.
t = thunder.
tl = thunderstorm.
u = ugly, threatening sky.
v = unusual visibility.
w = dew.
z. = dust haze; the turbid atmosphere of dry weather.

Remarks on the use of these letters are given below.

Appearance of the Sky.

The letters b, c, o, g and u are used to describe the general appearance of the sky. The use of the letters b, c and o is supplementary to the estimate of the amount of sky covered by cloud to the nearest tenth part of the whole sky, referred to in the section on Cloud.

Precipitation.

A distinction is drawn between steady rainfall (r), light drizzle (d), and passing showers (p). The indication of passing showers is useful, and the time of commencement and ending of heavy showers should always be noted. The letter e has been added to the Beaufort notation to indicate a state in which the air deposits water copiously on exposed surfaces without rain falling.

Unless otherwise stated, the letter p refers to showers of rain. Snow or hail showers may be entered as sp, hp; showers of mixed hail and rain, rhp.

Fog.

The words fog, f; mist, m; and haze, z, are used to indicate lessened transparency of the lower layers of the atmosphere caused by solid or liquid particles. Marine observers should endeavour to discriminate between them on the following lines. Mist and fog both refer to surface cloud, the distinction being one of degree; when either is experienced there will be little or no difference between the readings of the dry bulb and wet bulb thermometers. A slight fog is sometimes called a haze, but the word haze should properly be used only for obscurity due to smoke, dust or other cause; in this case the air is dry and there is considerable difference between the dry and wet bulb readings.

A "wet fog", in which water is deposited copiously on exposed surfaces, should be noted by means of the letters fe.

Visibility.

The letter v of the Beaufort scale denotes abnormal clearness and transparency of the atmosphere. With such exceptional visibility distant objects stand out from their background with great distinctness and show more sharply-defined detail than usual. It is generally recognisable by seamen. At such times it is so clear that stars may be seen to rise and set at night with the unaided eye, and the pole of a steamer's mast, hull down, may be seen on the horizon by day. This state of the atmosphere bears no relation to the distance at which objects can be seen, as defined in the scale given below. Thus if visibility were 9 (objects visible more than 30 miles) it might or might not be appropriate to enter the letter v in the weather column.

Fog and Visibility Scale.

In addition to using the Beaufort weather notation, when practicable the degree of visibility may be noted by the following scale. Entry is made of the number appropriate to the most distant object which can be seen. This observation may often be difficult or impossible at sea on account of the lack of objects at suitable distances ; at a shore station the measurement of visibility, by the daily observation of the same objects at fixed distances, is a comparatively simple matter.

Fog and Visibility Scale

(Specification for use at Sea)

0 Dense fog.	Objects not visible at 50 yards.
1 Thick fog.	Objects not visible at 1 cable.
2 Fog.	Objects not visible at 2 cables.
3 Moderate Fog.	Objects not visible at ½ mile.
4 Mist or haze, or very poor visibility.	Objects not visible at 1 mile.
5 Poor visibility.	Objects not visible at 2 miles.
6 Moderate visibility.	Objects not visible at 5 miles.
7 Good visibility.	Objects not visible at 10 miles.
8 Very good visibility.	Objects not visible at 30 miles.
9 Excellent visibility.	Objects visible more than 30 miles.

In a long vessel the lowest numbers of the scale, 0 and 1, can be determined by direct measurement. 2 and 3 indicate conditions of obscurity such that visibility extends beyond the length of the ship, but is not sufficient to proceed at speed on account of traffic. Accurate estimation of 2 and 3 may often be impossible. 4 and 5 indicate conditions when it may be possible to proceed at speed as regards traffic, but when coastal navigation by visual bearings may be difficult.

The only means of obtaining observations for the higher numbers of the scale are as follows. When coasting and when fixes can be obtained, the distance of points when first sighted, or last seen, may be measured from the chart. In the open sea, when ships meeting are sighted, visibility may be calculated if the time is taken when first and last seen, if the speed of the other ship is known.

The use of the horizon to estimate 6 or 7 is not to be relied on. If there is any obscurity or abnormal refraction, the visible horizon may be very misleading as a means of judging distance, particularly when the height of the eye is great, as in the case of an observer on the bridge of a large liner.

Hydrographic Observations.

In order to obviate duplication of work in ships of the Merchant Navy regularly observing for the Meteorological Office, and to obviate overlapping of Government Departments, hydrographic, marine biological, and other information may be included with the appropriate returns to the Meteorological Office.

Such information will be forwarded to the Hydrographer of the Navy, the Board of Trade, Ministry of Agriculture and Fisheries or other appropriate department.

The most important of these observations is the reporting of the positions of uncharted or inaccurately charted rocks, shoals, etc. When sending in such information the greatest care should be taken not only to give accurate positions and soundings, but also to provide the necessary data to check bearings, positions and soundings, including the data for the reduction of soundings to L.W.O.S.

Propagation of Sound and Weather Conditions.

The propagation of the air-waves which are received by the human ear as sound is a very complex matter and is liable on occasion to irregularities. These irregularities affect only the audibility of sound, not its pitch. Sound waves are reflected or refracted when they encounter strata or patches of air where there is a change of wind speed, temperature or humidity. If the observer and the source of sound are within a continuous stratum of fog, audibility is greater than normal, but if not, the presence of fog in patches may render sound inaudible even at short distances.

The propagation of sound through the air is of importance to navigation and comparatively little of practical value is known about it. Marine observers are therefore requested to log, when possible, the maximum distance at which sound signals or noises are heard at sea, also any peculiarity of the propagation of sound through the atmosphere at sea which may be experienced.

Every opportunity should be taken to ascertain the position at which the sound was made and to fix the position of the ship hearing the sound, also, when sound is apparently cut off, the positions at which this takes place and where the sound is reheard. The method and details of obtaining fixes and measurements should be given.

In cases of ships' sound signals the relative bearings and distance are sufficient, provided that the latitude and longitude of the ships observing are given. In all cases time and date are essential.

When such observations are obtained the following weather observations should also be carefully made and logged :—

Wind, true direction and force.
Weather by the Beaufort notation.
Types and amount of cloud and their apparent direction and velocity.
Temperature of the air, dry and wet bulb.
Temperature of the sea.
Visibility by scale.
General remarks.

Earthquake and Volcanic Phenomena.

Submarine earthquake shocks or tremors felt at sea should be logged. The effects of volcanic eruptions seen, such as the emergence of islands from the sea, change in appearance of volcanic islands as a result of eruption, or falls of volcanic dust on the ship, should be logged. A big volcanic eruption, whereby quantities of fine dust are projected into the atmosphere, may produce a variety of unusual meteorological effects, for days, weeks or even months afterwards. A special kind of corona following the eruption of Krakatoa is described in Chapter V. Among other effects that may occur are change in appearance of the blue sky, unusual vivid sky colouring at sunrise and sunset, the sun or moon appearing coloured, and unusual prolongation of twilight.

Magnetic Phenomena.

Magnetic phenomena of interest should be carefully logged. As examples may be given :— The effect of thunderstorms on ship's compasses, variation of the compass due to local causes, and differences between the variations observed and those indicated by the chart of magnetic variation in a given locality.

Observations for Fishery Research.

Arrangements are made on behalf of the Director of Fisheries Laboratory, Ministry of Agriculture and Fisheries, at Lowestoft, through the Port Meteorological Officers, for the collection of water samples on certain ocean routes, by a few ships. Special instructions with apparatus are supplied as necessary through the Port Meteorological Officers.

Since the density of sea water depends on its salinity, a more accurate method of determining the specific gravity of water than by using a hydrometer is to obtain its salinity from chemical analysis and then converting this salinity determination into specific gravity by means of a table. The samples are collected for this purpose and the chemical analysis is made by the Government chemist.

Marine Biological Observation.

By examining minute sea animals with the microscope marine observers may find an interesting occupation in their leisure.

Reliable observations and evidence of the speed of sea mammals and fishes may be useful, if logged.

CHAPTER IX

THE METEOROLOGICAL LOG, RECORD OF SYNCHRONIZED WEATHER OBSERVATIONS, AND OTHER FORMS FOR RECORDING OBSERVATIONS

Meteorological Log.

The Meteorological Log has been little altered, except in detail, since it was originally established after the first International Marine Meteorological Conference in 1853. The earlier editions were known as the "Weather Register", and with it Admiral FITZROY started the work of the Marine Division to determine precisely the climate of the different parts of the oceans.

In 1874 Captain HENRY TOYNBEE, who had then been Marine Superintendent at the Meteorological Office for seven years, and who had previously done most valuable meteorological work at sea, drew up a Meteorological Log, based on the original "Weather Register" but modified to accord with experience, together with instructions for observation. These were approved by the International Marine Meteorological Conference of that year, and brought into use by the Meteorological Office for British observing ships. They have formed the basis of all subsequent editions of the meteorological log and this book.

The Meteorological Log is a means whereby reliable information is collected to establish climate and for meteorological investigation.

Original Note Book.

In order that the observations may be deliberately entered, a rough book, called the "Original Note Book", is supplied.

In the Original Note Book, the observations should be entered as they are made; being copied after scrutiny into the Meteorological Log.

In writing up the Meteorological Log, it should always be remembered that the observations have to be coded in the Marine Division of the Meteorological Office, where the code figures are written in pencil in the columns over the observations.

Therefore write the routine observations in the columns of the Meteorological Log neatly, leaving space for code figures above them.

Hollerith System of Data Extraction.

A full description of the Hollerith system of mechanical extraction and compilation of marine meteorological data was given in Vol. XIV, No. 125, of the "Marine Observer".

The Meteorological Log is ruled after the fashion of a ship's log book, but adapted to logging precise details of all desirable meteorological elements; and is so arranged that it is self-explanatory. On the fly leaves are given some instructions and the scales to be used.

The observations of wind, weather, sea, etc. are entered by means of the figures or letters of the respective scales or notations in the columns provided for the purpose, and at the routine times of observation. They should not be repeated in the " Remarks " column. **Routine Observation.**

If the " Remarks " column is restricted for logging changes in the various elements, and for phenomena not included in the other columns, the value of these observations recorded by remarks is enhanced. **Remarks.**

At the end of the Meteorological Log (and the Original Note Book) several pages for " Additional Remarks " are provided. **Additional Remarks.**

Now the keeping of the Meteorological Log is necessarily stereotyped, because to deal with a vast number of observations in making investigations, unless the observations are made by one system and are recorded in a uniform manner, the task of the investigator becomes too burdensome and complicated. In " Additional Remarks " the observer while preserving accuracy can well show his originality in expression.

Description of experiences of all kinds at sea, in which the weather has a bearing, are most welcome. Observations of all the phenomena mentioned in the foregoing pages may be entered in these " Additional Remarks ".

A selection of these is published in the " Marine Observer ", and by this means a greater knowledge of the occurrences of natural phenomena which occur at sea is being acquired and spread.

It must ever be remembered in keeping the Meteorological Log that a blank space is preferable to a doubtful observation.

The Meteorological Log is only kept by ships with a complete set of tested Meteorological Office instruments, thus ensuring accuracy.

Form 911 " Ships Record of Synchronized Weather Observations " is a handy sheet, ruled in much the same way as the Meteorological Log, but times of observation are those fixed by international agreement at 0000, 0600, 1200 and 1800 G.M.T. **Record of Synchronized Weather Observations.**

Space is provided for logging the set and drift of the current observed, and the greater part of the back of the form is occupied by a space for " Additional Remarks ".

Form 138 " Register of Selected Ships' Coded Wireless Weather Reports " is used in coding the observations entered on Form 911. It is arranged in the order of the groups of the International Ships' Wireless Weather Telegraphy Code, and instructions for its use are printed upon it. **Register for Selected Ships.**

International Wireless Weather Telegraphy Code.

The Code is given on Form 138A, a handy card, varnished so that it may stand the wear and tear of constant use.

The decode is given in the Pamphlet M.O. 329, "Decode for use with the International Code for Wireless Weather Messages from Ships".

These registers, Form 138, not only provide a sheet for coding the weather reports, and returning confirmation of those sent, with particulars of communication, but being duplicates in code of the observations originally recorded in Form 911, they afford a means whereby the observations they contain can be passed on in writing to other meteorological services for the purpose of their investigations, and so on.

The foregoing are for the use of regular observing ships.

Ice Report.

The returning of information of drifting ice requires more general treatment; and Form 912 "Ice Report" is supplied through the Port Meteorological Officers and Merchant Navy Agents to the master of any British ship upon request.

This form provides a convenient means of confirming reports of ice made in conformity with Article 34 of the International Convention for Safety of Life at Sea, and for sending particulars, with date and position of all drifting ice seen at sea.

Miscellaneous Forms.

There are other forms used from time to time, which are available for use in British ships, both regular observing ships and others, which are distributed as necessary through the Port Meteorological Officers and Merchant Navy Agents.

Avoidance of overlapping of the work and International Supply of data.

Meteorological observations are all logged or recorded in British observing ships, with international scales.

Those in the Meteorological Log are extracted on to Hollerith cards, and by this means are made available to the meteorological services of the Dominions and foreign countries.

The synchronized observations recorded by Selected Ships on Form 911 are coded at sea in the Register, Form 138; and by this means are passed on to the appropriate meteorological services, the original observations being permanently retained in Form 911.

Thus, overlapping of work and duplication in British ships is unnecessary, their observations being available through the British Meteorological Office, to whom other State meteorological services desiring the co-operation of British ships should be referred.

APPENDICES

APPENDIX I

Meteorological Tables

TABLE I

THE ADJUSTMENT OF FIDUCIAL TEMPERATURE

Latitude N. or S.	Height in Feet of Barometer								
	0	5	10	15	20	25	30	35	40
°	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.
0	−15·2	−14·2	−13·1	−12·1	−11·0	−10·0	− 8·9	− 7·8	− 6·8
2	15·1	14·1	13·0	12·0	10·9	9·9	8·8	7·7	6·7
4	15·0	14·0	12·9	11·8	10·8	9·8	8·7	7·6	6·5
6	14·8	13·8	12·7	11·7	10·6	9·6	8·5	7·4	6·4
8	14·6	13·6	12·5	11·5	10·4	9·4	8·3	7·2	6·2
10	14·2	13·2	12·1	11·1	10·0	9·0	7·9	6·8	5·8
12	13·8	12·8	11·7	10·7	9·6	8·6	7·5	6·4	5·4
14	13·4	12·4	11·3	10·3	9·2	8·2	7·1	6·0	5·0
16	12·8	11·8	10·7	9·7	8·6	7·6	6·5	5·4	4·4
18	12·3	11·3	10·2	9·2	8·1	7·1	6·0	4·9	3·9
20	11·6	10·6	9·5	8·5	7·4	6·4	5·3	4·2	3·2
22	10·9	9·9	8·8	7·8	6·7	5·7	4·6	3·5	2·5
24	10·1	9·1	8·0	7·0	5·9	4·9	3·8	2·7	1·7
26	9·3	8·3	7·2	6·2	5·1	4·1	3·0	1·9	0·9
28	8·5	7·5	6·4	5·4	4·3	3·3	2·2	1·1	− 0·1
30	7·6	6·6	5·5	4·5	3·4	2·4	1·3	− 0·2	+ 0·8
32	6·6	5·6	4·5	3·5	2·4	1·4	− 0·3	+ 0·8	1·8
34	5·7	4·7	3·6	2·6	1·5	− 0·5	+ 0·6	1·7	2·7
36	4·7	3·7	2·6	1·6	− 0·5	+ 0·5	1·6	2·7	3·7
38	3·7	2·7	1·6	− 0·6	+ 0·5	1·5	2·6	3·7	4·7
40	2·6	1·6	− 0·5	+ 0·5	1·6	2·6	3·7	4·8	5·8
42	1·6	− 0·6	+ 0·5	1·5	2·6	3·6	4·7	5·8	6·8
44	− 0·5	+ 0·5	1·6	2·6	3·7	4·7	5·8	6·9	7·9
46	+ 0·5	1·5	2·6	3·6	4·7	5·7	6·8	7·9	8·9
48	1·6	2·6	3·7	4·7	5·8	6·8	7·9	9·0	10·0
50	2·6	3·6	4·7	5·7	6·8	7·8	8·9	10·0	11·0
52	3·7	4·7	5·8	6·8	7·9	8·9	10·0	11·1	12·1
54	4·7	5·7	6·8	7·8	8·9	9·9	11·0	12·1	13·1
56	5·7	6·7	7·8	8·8	9·9	10·9	12·0	13·1	14·1
58	6·6	7·6	8·7	9·7	10·8	11·8	12·9	14·0	15·0
60	+ 7·6	+ 8·6	+ 9·7	+10·7	+11·8	+12·8	+13·9	+15·0	+16·0

Based on a Temperature of 290°A.

TABLE I—*continued*

FOR LATITUDE AND HEIGHT ABOVE SEA LEVEL

Cistern Above Sea Level.								Latitude N. or S.
45	50	55	60	65	70	75	80	
°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°
− 5·7	− 4·7	− 3·6	− 2·6	− 1·5	− 0·5	+ 0·6	+ 1·6	0
5·6	4·6	3·5	2·5	1·4	0·4	0·7	1·7	2
5·5	4·5	3·4	2·4	1·3	0·3	0·8	1·8	4
5·3	4·3	3·2	2·2	1·1	− 0·1	1·0	2·0	6
5·1	4·1	3·0	2·0	0·9	+ 0·1	1·2	2·2	8
4·7	3·7	2·6	1·6	0·5	0·5	1·6	2·6	10
4·3	3·3	2·2	1·2	− 0·1	0·9	2·0	3·0	12
3·9	2·9	1·8	0·8	+ 0·3	1·3	2·4	3·4	14
3·3	2·3	1·2	− 0·2	0·9	1·9	3·0	4·0	16
2·8	1·8	− 0·7	+ 0·3	1·4	2·4	3·5	4·5	18
2·1	1·1	0·0	1·0	2·1	3·1	4·2	5·2	20
1·4	− 0·4	+ 0·7	1·7	2·8	3·6	4·9	5·9	22
− 0·6	+ 0·4	1·5	2·5	3·6	4·6	5·7	6·7	24
+ 0·2	1·2	2·3	3·3	4·4	5·4	6·5	7·5	26
1·0	2·0	3·1	4·1	5·2	6·2	7·3	8·3	28
1·9	2·9	4·0	5·0	6·1	7·1	8·2	9·2	30
2·9	3·9	5·0	6·0	7·1	8·1	9·2	10·2	32
3·8	4·8	5·9	6·9	8·0	9·0	10·1	11·1	34
4·8	5·8	6·9	7·9	9·0	10·0	11·1	12·1	36
5·8	6·8	7·9	8·9	10·0	11·0	12·1	13·1	38
6·9	7·9	9·0	10·0	11·1	12·1	13·2	14·2	40
7·9	8·9	10·0	11·0	12·1	13·1	14·2	15·2	42
9·0	10·0	11·1	12·1	13·2	14·2	15·3	16·3	44
10·0	11·0	12·1	13·1	14·2	15·2	16·3	17·3	46
11·1	12·1	13·2	14·2	15·3	16·3	17·4	18·4	48
12·1	13·1	14·2	15·2	16·3	17·3	18·4	19·4	50
13·2	14·2	15·3	16·3	17·4	18·4	19·5	20·5	52
14·2	15·2	16·3	17·3	18·4	19·4	20·5	21·5	54
15·2	16·2	17·3	18·3	19·4	20·4	21·5	22·5	56
16·1	17·1	18·2	19·2	20·3	21·3	22·4	23·4	58
+17·1	+18·1	+19·2	+20·2	+21·3	+22·3	+23·4	+24·4	60

and Barometer Pressure of 1000 mb.

TABLE II

CORRECTION OF BAROMETER FOR DIFFERENCE
ADJUSTED FIDUCIAL

Attached Thermometer.	Adjusted Fiducial Temperature.										Attached Thermometer.
	271°	272°	273°	274°	275°	276°	277°	278°	279°	280°	
°A.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	°A.
271	0·0	+0·2	+0·3	+0·5	+0·7	+0·9	+1·0	+1·2	+1·4	+1·5	271
272	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	272
273	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	273
274	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	274
275	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	275
276	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	276
277	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	277
278	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	278
279	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	279
280	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	280
281	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	281
282	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	282
283	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	283
284	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	284
285	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	285
286	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	286
287	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	287
288	2·9	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	288
289	3·1	2·9	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·6	289
290	3·2	3·1	2·9	2·7	2·6	2·4	2·2	2·0	1·9	1·7	290
291	3·4	3·2	3·1	2·9	2·7	2·6	2·4	2·2	2·0	1·9	291
292	3·6	3·4	3·2	3·1	2·9	2·7	2·6	2·4	2·2	2·0	292
293	3·8	3·6	3·4	3·2	3·1	2·9	2·7	2·6	2·4	2·2	293
294	3·9	3·8	3·6	3·4	3·2	3·1	2·9	2·7	2·6	2·4	294
295	4·1	3·9	3·8	3·6	3·4	3·2	3·1	2·9	2·7	2·6	295
296	4·3	4·1	3·9	3·8	3·6	3·4	3·2	3·1	2·9	2·7	296
297	4·4	4·3	4·1	3·9	3·8	3·6	3·4	3·2	3·1	2·9	297
298	4·6	4·4	4·3	4·1	3·9	3·8	3·6	3·4	3·2	3·1	298
299	4·8	4·6	4·4	4·3	4·1	3·9	3·8	3·6	3·4	3·2	299
300	5·0	4·8	4·6	4·4	4·3	4·1	3·9	3·8	3·6	3·4	300
301	5·1	5·0	4·8	4·6	4·4	4·3	4·1	3·9	3·8	3·6	301
302	5·3	5·1	5·0	4·8	4·6	4·4	4·3	4·1	3·9	3·8	302
303	5·5	5·3	5·1	5·0	4·8	4·6	4·4	4·3	4·1	3·9	303
304	5·6	5·5	5·3	5·1	5·0	4·8	4·6	4·4	4·3	4·1	304
305	5·8	5·6	5·5	5·3	5·1	5·0	4·8	4·6	4·4	4·3	305
306	6·0	5·8	5·6	5·5	5·3	5·1	5·0	4·8	4·6	4·4	306
307	6·2	6·0	5·8	5·6	5·5	5·3	5·1	5·0	4·8	4·6	307
308	6·3	6·2	6·0	5·8	5·6	5·5	5·3	5·1	5·0	4·8	308
309	6·5	6·3	6·2	6·0	5·8	5·6	5·5	5·3	5·1	5·0	309
310	−6·7	−6·5	−6·3	−6·2	−6·0	−5·8	−5·6	−5·5	−5·3	−5·1	310

NOTE.—This table is based on a Standard Pressure of 1,000 mb. For other
cent. of the correction for each 10 millibars above 1,000, and subtract one per

TABLE II—*continued*

BETWEEN "ATTACHED THERMOMETER" AND TEMPERATURE

Attached Thermometer.	Adjusted Fiducial Temperature.										Attached Thermometer.
	281°	282°	283°	284°	285°	286°	287°	288°	289°	290°	
°A.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	°A.
271	+1·7	+1·9	+2·0	+2·2	+2·4	+2·6	+2·7	+2·9	+3·1	+3·2	271
272	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	2·9	3·1	272
273	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	2·9	273
274	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	274
275	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	275
276	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	276
277	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	277
278	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	278
279	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	279
280	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	280
281	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	281
282	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	282
283	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	283
284	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	284
285	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	285
286	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	286
287	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	287
288	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	288
289	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	289
290	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	290
291	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	291
292	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	292
293	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	293
294	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	294
295	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	295
296	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	296
297	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	297
298	2·9	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	298
299	3·1	2·9	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·5	299
300	3·2	3·1	2·9	2·7	2·6	2·4	2·2	2·0	1·9	1·7	300
301	3·4	3·2	3·1	2·9	2·7	2·6	2·4	2·2	2·0	1·9	301
302	3·6	3·4	3·2	3·1	2·9	2·7	2·6	2·4	2·2	2·0	302
303	3·8	3·6	3·4	3·2	3·1	2·9	2·7	2·6	2·4	2·2	303
304	3·9	3·8	3·6	3·4	3·2	3·1	2·9	2·7	2·6	2·4	304
305	4·1	3·9	3·8	3·6	3·4	3·2	3·1	2·9	2·7	2·6	305
306	4·3	4·1	3·9	3·8	3·6	3·4	3·2	3·1	2·9	2·7	306
307	4·4	4·3	4·1	3·9	3·8	3·6	3·4	3·2	3·1	2·9	307
308	4·6	4·4	4·3	4·1	3·9	3·8	3·6	3·4	3·2	3·1	308
309	4·8	4·6	4·4	4·3	4·1	3·9	3·8	3·6	3·4	3·2	309
310	−5·0	−4·8	−4·6	−4·4	−4·3	−4·1	−3·9	−3·8	−3·6	−3·4	310

pressures an additional correction is necessary, the rule being, "Add one per cent. for each 10 millibars below."

TABLE II—*continued*

CORRECTION OF BAROMETER FOR DIFFERENCE
ADJUSTED FIDUCIAL

Attached Thermometer.	Adjusted Fiducial Temperature.										Attached Thermometer.
	291°	292°	293°	294°	295°	296°	297°	298°	299°	300°	
°A.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	°A.
271	+3·4	+3·6	+3·8	+3·9	+4·1	+4·3	+4·4	+4·6	+4·8	+5·0	271
272	3·2	3·4	3·6	3·8	3·9	4·1	4·3	4·4	4·6	4·8	272
273	3·1	3·2	3·4	3·6	3·8	3·9	4·1	4·3	4·4	4·6	273
274	2·9	3·1	3·2	3·4	3·6	3·8	3·9	4·1	4·3	4·4	274
275	2·7	2·9	3·1	3·2	3·4	3·6	3·8	3·9	4·1	4·3	275
276	2·6	2·7	2·9	3·1	3·2	3·4	3·6	3·8	3·9	4·1	276
277	2·4	2·6	2·7	2·9	3·1	3·2	3·4	3·6	3·8	3·9	277
278	2·2	2·4	2·6	2·7	2·9	3·1	3·2	3·4	3·6	3·8	278
279	2·0	2·2	2·4	2·6	2·7	2·9	3·1	3·2	3·4	3·6	279
280	1·9	2·0	2·2	2·4	2·6	2·7	2·9	3·1	3·2	3·4	280
281	1·7	1·9	2·0	2·2	2·4	2·6	2·7	2·9	3·1	3·2	281
282	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	2·9	3·1	282
283	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	2·9	283
284	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	284
285	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	285
286	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	286
287	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	287
288	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	288
289	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	289
290	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	290
291	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	291
292	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	292
293	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	293
294	0·5	0·3	−0·2	0·0	0·2	0·3	0·5	0·7	0·9	1·0	294
295	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	295
296	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	296
297	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	297
298	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	298
299	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	299
300	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	300
301	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	301
302	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	0·3	302
303	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	0·5	303
304	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	0·7	304
305	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	0·9	305
306	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	1·0	306
307	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	1·2	307
308	2·9	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·5	1·4	308
309	3·1	2·9	2·7	2·6	2·4	2·2	2·0	1·9	1·7	1·5	309
310	−3·2	−3·1	−2·9	−2·7	−2·6	−2·4	−2·2	−2·0	−1·9	−1·7	310

NOTE.—This table is based on a Standard Pressure of 1,000 mb. For other cent. of the correction for each 10 millibars above 1,000, and subtract one per

TABLE II—*continued*

BETWEEN "ATTACHED THERMOMETER" AND TEMPERATURE

Attached Thermometer.	Adjusted Fiducial Temperature.										Attached Thermometer.
	301°	302°	303°	304°	305°	306°	307°	308°	309°	310°	
°A.	mb.	mb.	mb.	mb.	mb.	mb	mb.	mb.	mb.	m.b	°A.
271	+5·1	+5·3	+5·5	+5·6	+5·8	+6·0	+6·2	+6·3	+6·5	+6·7	271
272	5·0	5·1	5·3	5·5	5·6	5·8	6·0	6·2	6·3	6·5	272
273	4·8	5·0	5·1	5·3	5·5	5·6	5·8	6·0	6·2	6·3	273
274	4·6	4·8	5·0	5·1	5·3	5·5	5·6	5·8	6·0	6·2	274
275	4·4	4·6	4·8	5·0	5·1	5·3	5·5	5·6	5·8	6·0	275
276	4·3	4·4	4·6	4·8	5·0	5·1	5·3	5·5	5·6	5·8	276
277	4·1	4·3	4·4	4·6	4·8	5·0	5·1	5·3	5·5	5·6	277
278	3·9	4·1	4·3	4·4	4·6	4·8	5·0	5·1	5·3	5·5	278
279	3·8	3·9	4·1	4·3	4·4	4·6	4·8	5·0	5·1	5·3	279
280	3·6	3·8	3·9	4·1	4·3	4·4	4·6	4·8	5·0	5·1	280
281	3·4	3·6	3·8	3·9	4·1	4·3	4·4	4·6	4·8	5·0	281
282	3·2	3·4	3·6	3·8	3·9	4·1	4·3	4·4	4·6	4·8	282
283	3·1	3·2	3·4	3·6	3·8	3·9	4·1	4·3	4·4	4·6	283
284	2·9	3·1	3·2	3·4	3·6	3·8	3·9	4·1	4·3	4·4	284
285	2·7	2·9	3·1	3·2	3·4	3·6	3·8	3·9	4·1	4·3	285
286	2·6	2·7	2·9	3·1	3·2	3·4	3·6	3·8	3·9	4·1	286
287	2·4	2·6	2·7	2·9	3·1	3·2	3·4	3·6	3·8	3·9	287
288	2·2	2·4	2·6	2·7	2·9	3·1	3·2	3·4	3·6	3·8	288
289	2·0	2·2	2·4	2·6	2·7	2·9	3·1	3·2	3·4	3·6	289
290	1·9	2·0	2·2	2·4	2·6	2·7	2·9	3·1	3·2	3·4	290
291	1·7	1·9	2·0	2·2	2·4	2·6	2·7	2·9	3·1	3·2	291
292	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	2·9	3·1	292
293	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	2·9	293
294	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	2·7	294
295	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	2·6	295
296	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	2·4	296
297	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	2·2	297
298	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	2·0	298
299	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	1·9	299
300	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	1·7	300
301	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	1·5	301
302	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	1·4	302
303	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	1·2	303
304	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	1·0	304
305	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	0·9	305
306	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	0·7	306
307	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	0·5	307
308	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	0·3	308
309	1·4	1·2	1·0	0·9	0·7	0·5	0·3	−0·2	0·0	+0·2	309
310	−1·5	−1·4	−1·2	−1·0	−0·9	−0·7	−0·5	−0·3	−0·2	−0·0	310

pressures an additional correction is necessary, the rule being, "Add one per cent. for each 10 millibars below."

TABLE III

TABLE OF CORRECTIONS TO BE APPLIED TO BAROMETERS WITH *Brass Scales* EXTENDING FROM THE CISTERN TO THE TOP OF THE MERCURIAL COLUMN, TO REDUCE THE OBSERVATION TO 32° FAHRENHEIT.

Temp.	INCHES.											Temp.
	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
°	+	+	+	+	+	+	+	+	+	+	+	°
0	·068	·069	·070	·072	·073	·074	·076	·077	·078	·080	·081	0
1	·065	·067	·068	·069	·070	·072	·073	·074	·076	·077	·078	1
2	·063	·064	·065	·067	·068	·069	·070	·072	·073	·074	·075	2
3	·061	·062	·063	·064	·065	·066	·068	·069	·070	·071	·072	3
4	·058	·060	·061	·062	·063	·064	·065	·066	·067	·069	·070	4
5	·056	·057	·058	·059	·060	·061	·062	·064	·065	·066	·067	5
6	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	·064	6
7	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	7
8	·049	·050	·051	·052	·053	·054	·054	·055	·056	·057	·058	8
9	·046	·047	·048	·049	·050	·051	·052	·053	·054	·054	·055	9
10	·044	·045	·046	·046	·047	·048	·049	·050	·051	·052	·053	10
11	·042	·043	·043	·044	·045	·046	·047	·047	·048	·049	·050	11
12	·039	·040	·041	·042	·042	·043	·044	·044	·045	·046	·047	12
13	·037	·038	·038	·039	·040	·040	·041	·042	·043	·043	·044	13
14	·035	·035	·036	·036	·037	·038	·039	·039	·040	·041	·041	14
15	·032	·033	·033	·034	·035	·035	·036	·036	·037	·038	·038	15
16	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035	·036	16
17	·027	·028	·029	·029	·030	·030	·031	·031	·032	·032	·033	17
18	·025	·026	·026	·027	·027	·028	·028	·029	·029	·030	·030	18
19	·023	·023	·024	·024	·025	·025	·025	·026	·026	·027	·028	19
20	·020	·021	·021	·022	·022	·022	·023	·023	·024	·024	·024	20
21	·018	·018	·019	·019	·019	·020	·020	·021	·021	·021	·022	21
22	·016	·016	·016	·017	·017	·017	·017	·018	·018	·018	·019	22
23	·013	·014	·014	·014	·014	·015	·015	·015	·015	·016	·016	23
24	·011	·011	·011	·012	·012	·012	·012	·012	·013	·013	·013	24
25	·009	·009	·009	·009	·009	·009	·010	·010	·010	·010	·010	25
26	·006	·006	·006	·007	·007	·007	·007	·007	·007	·007	·007	26
27	·004	·004	·004	·004	·004	·004	·004	·004	·004	·005	·005	27
28	·001	·002	·002	·002	·002	·002	·002	·002	·002	·002	·002	28
	—	—	—	—	—	—	—	—	—	—	—	
29	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	29
30	·003	·003	·003	·003	·003	·004	·004	·004	·004	·004	·004	30
31	·006	·006	·006	·006	·006	·006	·006	·006	·006	·007	·007	31
32	·008	·008	·008	·008	·009	·009	·009	·009	·009	·009	·009	32
33	·010	·011	·011	·011	·011	·011	·012	·012	·012	·012	·012	33
34	·013	·013	·013	·013	·014	·014	·014	·014	·015	·015	·015	34
35	·015	·015	·016	·016	·016	·017	·017	·017	·017	·018	·018	35
36	·017	·018	·018	·018	·019	·019	·019	·020	·020	·020	·021	36
37	·020	·020	·021	·021	·021	·022	·022	·022	·023	·023	·024	37
38	·022	·023	·023	·023	·024	·024	·025	·025	·026	·026	·026	38
39	·024	·025	·025	·026	·026	·027	·027	·028	·028	·029	·029	39
40	·027	·027	·028	·028	·029	·030	·030	·031	·031	·032	·032	40
41	·029	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035	41
42	·032	·032	·033	·033	·034	·035	·035	·036	·036	·037	·038	42
43	·034	·035	·035	·036	·036	·037	·038	·038	·039	·040	·040	43
44	·036	·037	·038	·038	·039	·040	·040	·041	·042	·043	·043	44
45	·039	·039	·040	·041	·042	·042	·043	·044	·045	·045	·046	45
46	·041	·042	·043	·043	·044	·045	·046	·047	·047	·048	·049	46
47	·043	·044	·045	·046	·047	·048	·048	·049	·050	·051	·052	47
48	·046	·047	·047	·048	·049	·050	·051	·052	·053	·054	·054	48
49	·048	·049	·050	·051	·052	·053	·054	·055	·055	·056	·057	49
50	·050	·052	·052	·053	·054	·055	·056	·057	·058	·059	·060	50

NOTE.—The temperature of the " ATTACHED THERMOMETER " should be used when applying these corrections.

TABLE III—*continued*

Temp.	INCHES.											Temp.
	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
°	—	—	—	—	—	—	—	—	—	—	—	°
51	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	51
52	·055	·056	·057	·058	·059	·060	·061	·062	·064	·065	·066	52
53	·057	·059	·060	·061	·062	·063	·064	·065	·066	·067	·068	53
54	·060	·061	·062	·063	·064	·065	·067	·068	·069	·070	·071	54
55	·062	·063	·064	·065	·067	·068	·069	·071	·072	·073	·074	55
56	·064	·066	·067	·068	·069	·070	·072	·073	·074	·076	·077	56
57	·067	·068	·069	·071	·072	·073	·075	·076	·077	·078	·080	57
58	·069	·071	·072	·073	·074	·076	·077	·078	·080	·081	·082	58
59	·072	·073	·074	·076	·077	·078	·080	·081	·083	·084	·085	59
60	·074	·075	·077	·078	·080	·081	·082	·084	·085	·087	·088	60
61	·076	·078	·079	·080	·082	·084	·085	·087	·088	·090	·091	61
62	·079	·080	·082	·083	·085	·086	·088	·089	·091	·092	·094	62
63	·081	·083	·084	·086	·087	·089	·090	·092	·093	·095	·096	63
64	·083	·085	·086	·088	·090	·092	·093	·095	·096	·097	·099	64
65	·086	·088	·089	·091	·092	·094	·095	·097	·099	·101	·102	65
66	·088	·090	·091	·093	·095	·097	·098	·100	·101	·103	·105	66
67	·090	·092	·094	·096	·097	·099	·101	·102	·104	·106	·108	67
68	·093	·095	·096	·098	·100	·102	·103	·105	·107	·109	·110	68
69	·095	·097	·099	·101	·102	·104	·106	·108	·110	·112	·113	69
70	·097	·099	·101	·103	·105	·107	·109	·111	·112	·114	·116	70
71	·100	·102	·103	·105	·107	·109	·111	·113	·115	·117	·119	71
72	·102	·104	·106	·108	·110	·112	·114	·116	·118	·120	·122	72
73	·104	·106	·108	·110	·112	·114	·116	·118	·120	·123	·124	73
74	·107	·109	·111	·113	·115	·117	·119	·121	·123	·125	·127	74
75	·109	·111	·113	·115	·117	·120	·122	·124	·126	·128	·130	75
76	·111	·113	·116	·118	·120	·122	·124	·126	·128	·131	·133	76
77	·114	·116	·118	·120	·122	·125	·127	·129	·131	·134	·136	77
78	·116	·118	·120	·123	·125	·127	·129	·132	·134	·136	·138	78
79	·118	·121	·123	·125	·127	·130	·132	·135	·137	·139	·141	79
80	·121	·123	·125	·128	·130	·133	·135	·137	·139	·142	·144	80
81	·123	·126	·128	·130	·132	·135	·137	·140	·142	·145	·147	81
82	·125	·128	·130	·133	·135	·138	·140	·143	·145	·148	·149	82
83	·128	·131	·133	·136	·138	·140	·142	·145	·147	·150	·152	83
84	·130	·133	·135	·138	·140	·143	·145	·148	·150	·153	·155	84
85	·132	·135	·137	·140	·143	·146	·148	·151	·153	·156	·158	85
86	·135	·138	·140	·143	·145	·148	·150	·153	·155	·159	·161	86
87	·137	·140	·142	·145	·148	·151	·153	·156	·158	·161	·163	87
88	·139	·143	·145	·148	·150	·153	·155	·159	·161	·164	·166	88
89	·142	·145	·147	·150	·153	·156	·158	·161	·164	·167	·169	89
90	·144	·147	·150	·153	·155	·158	·161	·164	·166	·169	·172	90
91	·146	·150	·152	·155	·158	·161	·163	·167	·169	·172	·175	91
92	·149	·152	·154	·158	·160	·163	·166	·169	·172	·175	·177	92
93	·151	·154	·157	·160	·163	·166	·168	·172	·174	·178	·180	93
94	·153	·157	·159	·163	·165	·169	·171	·174	·177	·180	·183	94
95	·156	·159	·162	·165	·168	·171	·174	·177	·180	·183	·186	95
96	·158	·161	·164	·168	·170	·174	·176	·180	·182	·186	·188	96
97	·160	·164	·167	·170	·173	·176	·179	·182	·185	·188	·191	97
98	·163	·166	·169	·172	·175	·179	·181	·185	·188	·191	·194	98
99	·165	·169	·171	·175	·178	·181	·184	·188	·190	·194	·197	99
100	·167	·171	·174	·177	·180	·184	·187	·190	·193	·197	·200	100

TABLE IV

Reduction of Barometric Readings to Mean Sea Level
Reading, 30 inches

Height in feet.	Temperature of Air. (Dry Bulb in Screen.) 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	Height in feet.
5	·006	·006	·006	·006	·006	·006	·006	·005	·005	·005	5
10	·012	·012	·012	·011	·011	·011	·011	·010	·010	·010	10
15	·019	·018	·018	·017	·017	·017	·017	·016	·016	·015	15
20	·025	·024	·023	·023	·023	·022	·022	·021	·021	·020	20
25	·031	·030	·029	·029	·029	·028	·027	·027	·026	·026	25
30	·037	·036	·035	·035	·034	·033	·032	·032	·031	·031	30
35	·043	·042	·041	·041	·040	·039	·038	·037	·037	·036	35
40	·049	·048	·047	·046	·045	·044	·043	·042	·042	·041	40
45	·056	·054	·053	·052	·051	·050	·049	·048	·047	·046	45
50	·062	·060	·059	·058	·056	·055	·054	·053	·052	·051	50
55	·068	·066	·065	·064	·062	·061	·060	·059	·057	·056	55
60	·074	·072	·071	·069	·068	·066	·065	·064	·062	·061	60
65	·080	·078	·077	·075	·074	·072	·071	·069	·068	·066	65
70	·086	·084	·083	·081	·079	·077	·076	·074	·073	·071	70
75	·092	·090	·089	·087	·085	·083	·082	·080	·078	·076	75
80	·098	·096	·094	·092	·091	·089	·087	·085	·083	·081	80
85	·105	·102	·100	·098	·097	·095	·093	·090	·089	·087	85
90	·111	·108	·106	·104	·102	·101	·098	·095	·094	·092	90
95	·117	·114	·112	·110	·108	·106	·103	·101	·099	·097	95
100	·123	·120	·118	·115	·113	·111	·108	·106	·104	·101	100

The correction is always ADDITIVE.

TABLE V

Corrections for Reducing Barometric Readings to Standard Gravity in Latitude 45°

Lat. N. or S.	Correction. At 27 in.	At 30 in.	Lat. N. or S.	Correction. At 27 in.	At 30 in.	Lat. N. or S.	Correction. At 27 in.	At 30 in.	Lat. N. or S.	Correction. At 27 in.	At 30 in.
°	in.	in.	°	in.	in.	°	in.	in.	°	in.	in.
0	−·070	−·078	23	−·049	−·054	46	+·002	+·003	69	+·052	+·058
1	·070	·078	24	·047	·052	47	·005	·005	70	·054	·060
2	·070	·078	25	·045	·050	48	·007	·008	71	·055	·061
3	·070	·077	26	·043	·048	49	·010	·011	72	·057	·063
4	·069	·077	27	·041	·046	50	·012	·013	73	·058	·064
5	·069	·077	28	·039	·043	51	·015	·016	74	·059	·066
6	·068	·076	29	·037	·041	52	·017	·019	75	·061	·067
7	·068	·075	30	·035	·039	53	·019	·021	76	·062	·069
8	·067	·075	31	·033	·036	54	·022	·024	77	·063	·070
9	·067	·074	32	·031	·034	55	·024	·027	78	·064	·071
10	·066	·073	33	·028	·032	56	·026	·029	79	·065	·072
11	·065	·072	34	·026	·029	57	·028	·032	80	·066	·073
12	·064	·071	35	·024	·027	58	·031	·034	81	·067	·074
13	·063	·070	36	·022	·024	59	·033	·036	82	·067	·075
14	·062	·069	37	·019	·021	60	·035	·039	83	·068	·075
15	·061	·067	38	·017	·019	61	·037	·041	84	·068	·076
16	·059	·066	39	·015	·016	62	·039	·043	85	·069	·077
17	·058	·064	40	·012	·013	63	·041	·046	86	·069	·077
18	·057	·063	41	·010	·011	64	·043	·048	87	·070	·077
19	·055	·061	42	·007	·008	65	·045	·050	88	·070	·078
20	·054	·060	43	·005	·005	66	·047	·052	89	·070	·078
21	·052	·058	44	−·002	−·003	67	·049	·054	90	+·070	+·078
22	−·050	−·056	45	± 0	± 0	68	+·050	+·056			

TABLE VI

Pressure Values

Equivalents in Millibars and Mercury Millimetres of Inches of Mercury at 32° F. in Latitude 45°

Mercury Inches.	Milli-bars.	Mercury Milli-metres.	Mercury Inches.	Milli-bars.	Mercury Milli-metres.	Mercury Inches.	Milli-bars.	Mercury Milli-metres.
27·02	915	686·3	28·35	960	720·1	29·68	1,005	753·8
27·05	916	687·1	28·38	961	720·8	29·71	1,006	754·6
27·08	917	687·8	28·41	962	721·6	29·74	1,007	755·3
27·11	918	688·6	28·44	963	722·3	29·77	1,008	756·1
27·14	919	689·3	28·47	964	723·1	29·80	1,009	756·8
27·17	920	690·1	28·50	965	723·8	29·83	1,010	757·6
27·20	921	690·8	28·53	966	724·6	29·86	1,011	758·3
27·23	922	691·6	28·56	967	725·3	29·89	1,012	759·1
27·26	923	692·3	28·59	968	726·1	29·92	1,013	759·8
27·29	924	693·1	28·62	969	726·8	29·94	1,014	760·6
27·32	925	693·8	28·65	970	727·6	29·97	1,015	761·3
27·35	926	694·6	28·67	971	728·3	30·00	1,016	762·1
27·38	927	695·3	28·70	972	729·1	30·03	1,017	762·8
27·41	928	696·1	28·73	973	729·8	30·06	1,018	763·6
27·44	929	696·8	28·76	974	730·6	30·09	1,019	764·3
27·46	930	697·6	28·79	975	731·3	30·12	1,020	765·1
27·49	931	698·3	28·82	976	732·1	30·15	1,021	765·8
27·52	932	699·1	28·85	977	732·8	30·18	1,022	766·6
27·55	933	699·8	28·88	978	733·6	30·21	1,023	767·3
27·58	934	700·6	28·91	979	734·3	30·24	1,024	768·1
27·61	935	701·3	28·94	980	735·1	30·27	1,025	768·8
27·64	936	702·1	28·97	981	735·8	30·30	1,026	769·6
27·67	937	702·8	29·00	982	736·6	30·33	1,027	770·3
27·70	938	703·6	29·03	983	737·3	30·36	1,028	771·1
27·73	939	704·3	29·06	984	738·1	30·39	1,029	771·8
27·76	940	705·1	29·09	985	738·8	30·42	1,030	772·6
27·79	941	705·8	29·12	986	739·6	30·45	1,031	773·3
27·82	942	706·6	29·15	987	740·3	30·48	1,032	774·1
27·85	943	707·3	29·18	988	741·1	30·51	1,033	774·8
27·88	944	708·1	29·21	989	741·8	30·53	1,034	775·6
27·91	945	708·8	29·24	990	742·6	30·56	1,035	776·3
27·94	946	709·6	29·26	991	743·3	30·59	1,036	777·1
27·97	947	710·3	29·29	992	744·1	30·62	1,037	777·8
28·00	948	711·1	29·32	993	744·8	30·65	1,038	778·6
28·03	949	711·8	29·35	994	745·6	30·68	1,039	779·3
28·05	950	712·6	29·38	995	746·3	30·71	1,040	780·1
28·08	951	713·3	29·41	996	747·1	30·74	1,041	780·8
28·11	952	714·1	29·44	997	747·8	30·77	1,042	781·6
28·14	953	714·8	29·47	998	748·6	30·80	1,043	782·3
28·17	954	715·6	29·50	999	749·3	30·83	1,044	783·1
28·20	955	716·3	29·53	1,000	750·1	30·86	1,045	783·8
28·23	956	717·1	29·56	1,001	750·8	30·89	1,046	784·6
28·26	957	717·8	29·59	1,002	751·6	30·92	1,047	785·3
28·29	958	718·6	29·62	1,003	752·3	30·95	1,048	786·1
28·32	959	719·3	29·65	1,004	753·1	30·98	1,049	786·8

TABLE VII

CHANGE OF BAROMETER IN LAST 2, 3 OR 4 HOURS

(Adapted for British Ships)

(The change in 3 hours should be given if possible)

	In 2 hours.	In 3 hours.	In 4 hours.	Code Fig.
Barometer steady.—Has not risen or fallen more than	0·3 mb. (·01 in.)	0·5 mb. (·01 in.)	0·7 mb. (·02 in.)	0
Barometer rising slowly.—Has risen	0·7–1·0 mb. (·02–·03 in.)	1·0–1·5 mb. (·03–·05 in.)	1·3–2·0 mb. (·04–·06 in.)	1
Barometer rising.—Has risen	1·4–2·4 mb. (·05–·07 in.)	2·0–3·5 mb. (·06–·10 in.)	2·8–4·8 mb. (·08–·14 in.)	2
Barometer rising quickly.—Has risen	2·6–4·0 mb. (·08–·12 in.)	4·0–6·0 mb. (·12–·18 in.)	5·2–8·0 mb. (·15–·24 in.)	3
Barometer rising very rapidly.—Has risen ..	over 4·0 mb. (·12 in.)	over 6·0 mb. (·18 in.)	over 8·0 mb. (·24 in.)	4
Barometer falling slowly.—Has fallen	0·7–1·0 mb. (·02–·03 in.)	1·0–1·5 mb. (·03–·05 in.)	1·3–2·0 mb. (·04–·06 in.)	5
Barometer falling.—Has fallen	1·4–2·4 mb. (·05–·07 in.)	2·0–3·5 mb. (·06–·10 in.)	2·8–4·8 mb. (·08–·14 in.)	6
Barometer falling quickly.—Has fallen	2·6–4·0 mb. (·08–·12 in.)	4·0–6·0 mb. (·12–·18 in.)	5·2–8·0 mb. (·15–·24 in.)	7
Barometer falling very rapidly.—Has fallen ..	over 4·0 mb. (·12 in.)	over 6·0 mb. (·18 in.)	over 8·0 mb. (·24 in.)	8

TABLE VIII

CHARACTERISTIC OF CHANGES OF THE BAROMETER IN THE LAST 3 HOURS

(Adapted for British Ships)

	Description of Changes.	*Code Figure.*
Net result, Barometer same or higher.	Barometer rising at first, then falling by a smaller or like amount	0
	Barometer rising at first, then steady or rising less quickly ..	1
	Barometer unsteady; but generally rising or stationary ..	2
	Barometer steady or rising	3
	Barometer falling or steady at first, then rising by the same or larger amount	4
	Barometer rising, at an increasing rate	4
Net result, Barometer lower.	Barometer falling at first, then rising by a smaller amount ..	5
	Barometer falling at first, then steady or falling less quickly ..	6
	Barometer unsteady, but falling	7
	Barometer falling	8
	Barometer steady or rising at first, then falling by a larger amount	9
	Barometer falling, at an increasing rate	9

NOTE.—These changes can generally only be given by ships which have barographs on board.

TABLE IX

Amount of Barometric Tendency (Rise or Fall of the Barometer in the last 3 hours)

(Adapted for British Ships)

Amount of Rise or Fall.		Code Figures.	Amount of Rise or Fall.		Code Figures.	Amount of Rise or Fall.		Code Figures.
Mb.	In.		Mb.	In.		Mb.	In.	
0·2	·01	01	6·0	·18	30	11·8	·35	59
0·4	·01	02	6·2	·19	31	12·0	·36	60
0·6	·02	03	6·4	·19	32	12·2	·37	61
0·8	·02	04	6·6	·20	33	12·4	·37	62
1·0	·03	05	6·8	·20	34	12·6	·38	63
1·2	·04	06	7·0	·21	35	12·8	·38	64
1·4	·04	07	7·2	·22	36	13·0	·39	65
1·6	·05	08	7·4	·22	37	13·2	·40	66
1·8	·05	09	7·6	·23	38	13·4	·40	67
2·0	·06	10	7·8	·23	39	13·6	·41	68
2·2	·07	11	8·0	·24	40	13·8	·41	69
2·4	·07	12	8·2	·25	41	14·0	·42	70
2·6	·08	13	8·4	·25	42	14·2	·43	71
2·8	·08	14	8·6	·26	43	14·4	·43	72
3·0	·09	15	8·8	·26	44	14·6	·44	73
3·2	·10	16	9·0	·27	45	14·8	·44	74
3·4	·10	17	9·2	·28	46	15·0	·45	75
3·6	·11	18	9·4	·28	47	15·2	·46	76
3·8	·11	19	9·6	·29	48	15·4	·46	77
4·0	·12	20	9·8	·29	49	15·6	·47	78
4·2	·13	21	10·0	·30	50	15·8	·47	79
4·4	·13	22	10·2	·31	51	16·0	·48	80
4·6	·14	23	10·4	·31	52	16·2	·49	81
4·8	·14	24	10·6	·32	53	16·4	·49	82
5·0	·15	25	10·8	·32	54	16·6	·50	83
5·2	·16	26	11·0	·33	55	16·8	·50	84
5·4	·16	27	11·2	·34	56	17·0	·51	85
5·6	·17	28	11·4	·34	57	17·2	·52	86
5·8	·17	29	11·6	·35	58	17·4	·52	87

TABLE X

Table for the Conversion of Temperature Readings on the Fahrenheit and Centigrade Scales to the Absolute Scale

Fahr.	Cent.	Abs.	Fahr.	Cent.	Abs.	Fahr.	Cent.	Abs.
0	−17·8	255·2	40	+ 4·4	277·4	80	+26·7	299·7
1	17·2	55·8	41	5·0	78·0	81	27·2	300·2
2	16·7	56·3	42	5·6	78·6	82	27·8	0·8
3	16·1	56·9	43	6·1	79·1	83	28·3	1·3
4	15·6	57·4	44	6·7	79·7	84	28·9	1·9
5	15·0	58·0	45	7·2	80·2	85	29·4	2·4
6	14·4	58·6	46	7·8	80·8	86	30·0	3·0
7	13·9	59·1	47	8·3	81·3	87	30·6	3·6
8	13·3	59·7	48	8·9	81·9	88	31·1	4·1
9	12·8	260·2	49	9·4	282·4	89	31·7	304·7
10	12·2	260·8	50	10·0	283·0	90	32·2	305·2
11	11·7	61·3	51	10·6	83·6	91	32·8	5·8
12	11·1	61·9	52	11·1	84·1	92	33·3	6·3
13	10·6	62·4	53	11·7	84·7	93	33·9	6·9
14	10·0	63·0	54	12·2	85·2	94	34·4	7·4
15	9·4	63·6	55	12·8	85·8	95	35·0	8·0
16	8·9	64·1	56	13·3	86·3	96	35·6	8·6
17	8·3	64·7	57	13·9	86·9	97	36·1	9·1
18	7·8	65·2	58	14·4	87·4	98	36·7	9·7
19	7·2	265·8	59	15·0	288·0	99	37·2	310·2
20	6·7	266·3	60	15·6	288·6	100	37·8	310·8
21	6·1	66·9	61	16·1	89·1	101	38·3	11·3
22	5·6	67·4	62	16·7	89·7	102	38·9	11·9
23	5·0	68·0	63	17·2	90·2	103	39·4	12·4
24	4·4	68·6	64	17·8	90·8	104	40·0	13·0
25	3·9	69·1	65	18·3	91·3	105	40·6	13·6
26	3·3	69·7	66	18·9	91·9	106	41·1	14·1
27	2·8	70·2	67	19·4	92·4	107	41·7	14·7
28	2·2	70·8	68	20·0	93·0	108	42·2	15·2
29	1·7	271·3	69	20·6	293·6	109	42·8	315·8
30	1·1	271·9	70	21·1	294·1	110	43·3	316·3
31	− 0·6	72·4	71	21·7	94·7	111	43·9	16·9
32	± 0·0	73·0	72	22·2	95·2	112	44·4	17·4
33	+ 0·6	73·6	73	22·8	95·8	113	45·0	18·0
34	1·1	74·1	74	23·3	96·3	114	45·6	18·6
35	1·7	74·7	75	23·9	96·9	115	46·1	19·1
36	2·2	75·2	76	24·4	97·4	116	46·7	19·7
37	2·8	75·8	77	25·0	98·0	117	47·2	20·2
38	3·3	76·3	78	25·6	98·6	118	47·8	20·8
39	+ 3·9	276·9	79	+26·1	299·1	119	+48·3	321·3

TABLE XI

For Finding the Relative Humidity (per cent.)

Dry Bulb.	Depression of Wet Bulb.												
°F.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°
90	100	96	92	88	84	81	77	74	70	67	63	60	57
88	100	96	92	88	84	80	77	73	69	66	63	59	56
86	100	96	92	88	84	80	76	72	69	65	62	58	55
84	100	96	92	87	83	79	76	72	68	64	61	57	54
82	100	96	91	87	83	79	75	71	67	64	60	57	53
80	100	96	91	87	83	79	74	70	66	63	59	55	52
78	100	95	91	86	82	78	74	70	66	62	58	54	50
76	100	95	91	86	82	78	73	69	65	61	57	53	49
74	100	95	90	86	81	77	72	68	64	60	56	52	48
72	100	95	90	85	80	76	71	67	63	58	54	50	46
70	100	95	90	85	80	75	71	66	62	57	53	49	44
68	100	95	90	84	79	75	70	65	60	56	51	47	43
66	100	95	89	84	79	74	69	64	59	54	50	45	41
64	100	94	89	83	78	73	68	63	58	53	48	43	39
62	100	94	88	83	77	72	67	61	56	51	46	41	37
60	100	94	88	82	77	71	65	60	55	50	44	39	34
58	100	94	88	82	76	70	64	59	53	48	42	37	31
56	100	94	87	81	75	69	63	57	51	46	40	35	29
54	100	93	87	80	74	68	61	55	49	43	38	32	26
52	100	93	86	79	73	66	60	54	47	41	35	29	23
50	100	93	86	79	72	65	59	52	45	38	32	26	20
48	100	92	85	77	70	63	56	49	42	36	29	22	16
46	100	92	84	77	69	62	54	47	40	33	26	19	—
44	100	92	84	75	68	60	52	45	37	29	22	—	—
42	100	91	83	74	66	58	50	42	34	26	18	16	—
40	100	91	82	73	65	56	47	39	30	27	—	—	—
38	100	91	81	72	63	54	44	39	31	22	—	—	—
36	100	90	80	70	60	54	44	35	26	18	—	—	—
34	100	90	79	70	60	50	41	31	21	—	—	—	—
32	100	89	79	68	57	47	36	27	17	—	—	—	—
30	100	88	76	65	53	43	33	22	—	—	—	—	—

TABLE XII

For Finding the Dew-Point (°F.)

Dry Bulb.	Depression of Wet Bulb.												
°F.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°
90	90	89	87	86	85	83	82	80	79	77	76	74	73
88	88	87	85	84	83	81	80	78	77	75	74	72	70
86	86	85	83	82	80	79	78	76	75	73	71	70	68
84	84	83	81	80	78	77	75	74	72	71	69	67	66
82	82	81	79	78	76	75	73	72	70	68	67	65	63
80	80	79	77	76	74	73	71	69	68	66	64	62	61
78	78	77	75	74	72	71	69	67	66	64	62	60	58
76	76	75	73	72	70	68	67	65	63	61	60	58	55
74	74	72	71	69	68	66	64	63	61	59	57	55	53
72	72	71	69	67	66	64	62	61	59	57	55	52	50
70	70	69	67	65	63	62	60	58	56	54	52	50	47
68	68	66	65	63	61	60	58	56	54	52	49	47	45
66	66	64	63	61	59	57	56	53	51	49	47	44	42
64	64	62	61	59	57	55	53	51	49	47	44	41	38
62	62	60	59	57	55	53	51	49	46	44	41	38	35
60	60	58	56	55	53	51	48	46	44	41	38	35	32
58	58	56	54	52	50	48	46	43	41	38	35	32	28
56	56	54	52	50	48	46	43	41	38	35	32	29	25
54	54	52	50	48	46	43	41	38	35	32	29	25	20
52	52	50	48	46	43	41	38	36	32	29	25	20	16
50	50	48	46	43	41	39	36	33	29	25	21	16	10
48	48	46	44	41	39	36	33	30	26	22	17	12	4
46	46	44	42	39	36	34	30	27	23	19	13	6	—
44	44	42	39	37	34	31	28	23	19	15	8	—	—
42	42	40	37	34	32	28	25	20	16	9	—	—	—
40	40	38	35	32	29	26	22	17	11	8	—	—	—
38	38	35	33	30	26	22	18	15	10	3	—	—	—
36	36	33	30	27	23	21	16	11	5	—	—	—	—
34	34	31	28	25	22	17	13	7	—	—	—	—	—
32	32	29	26	22	19	14	8	—	—	—	—	—	—
30	30	27	23	20	15	10	4	—	—	—	—	—	—

TABLE XIII

CONVERSION OF NAUTICAL MILES TO STATUTE MILES AND KILOMETRES

Nautical Miles.	Statute Miles.	Kilometres.	Nautical Miles.	Statute Miles.	Kilometres.
1	1·2	1·8	20	23·0	37
2	2·3	3·7	30	34·5	56
3	3·5	5·6	40	46·1	74
4	4·6	7·4	50	57·6	92
5	5·8	9·3	60	69·1	111
6	6·9	11·1	70	80·6	130
7	8·1	13·0	80	92·1	148
8	9·2	14·8	90	103·6	167
9	10·4	16·7	100	115·2	185
10	11·5	18·5			

Based on Nautical Mile of 6,080 feet.

TABLE XIV

To obtain approximately the True Force and Direction of the Wind from its Apparent Force and Direction, on the Deck of a Fast-Moving Vessel

Apparent direction of wind (in degrees off the bow).	Apparent force of wind (Beaufort scale).	1			2			3			4			5			6			7			8			9			10			11			12		
	Speed of vessel in knots.	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20	10	15	20
0	True direction, degrees off the bow.	180	180	180	180	180	180	180	180	180	0	180	180	0	0	180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	True force, Beaufort scale.	3	4	5	2	3	4	1	2	4	2	1	2	3	2	1	4	3	2	5	4	3	6	6	5	8	7	6	9	8	7	10	9	8	11	10	10
10	True direction, degrees off the bow.	178	179	179	171	175	177	126	167	172	32	116	159	21	43	112	17	25	49	15	20	28	14	17	21	13	15	18	12	14	16	12	13	15	12	13	14
	True force, Beaufort scale.	3	4	5	2	3	4	1	3	4	2	2	3	3	2	2	4	3	2	5	4	3	6	6	5	8	7	6	9	8	7	10	9	8	11	10	10
20	True direction, degrees off the bow.	176	177	178	163	171	174	116	156	166	56	110	145	40	68	108	33	46	71	29	38	51	27	33	41	25	30	35	24	28	32	24	27	29	23	25	28
	True force, Beaufort scale.	3	4	5	2	3	4	2	3	4	2	2	3	3	3	3	4	3	3	5	5	4	7	6	5	8	7	6	9	8	7	10	9	9	11	11	10
30	True direction, degrees off the bow.	174	176	177	157	168	171	116	150	161	73	112	138	56	82	110	48	63	85	43	54	68	40	47	57	38	44	51	37	41	47	36	39	43	35	38	41
	True force, Beaufort scale.	3	4	5	2	3	4	2	3	4	3	3	3	4	3	3	4	4	4	6	5	4	7	6	6	8	7	7	9	8	8	10	10	9	11	11	10
40	True direction, degrees off the bow.	172	175	177	154	165	169	118	146	157	85	115	138	70	93	115	61	77	95	56	68	80	53	61	71	50	57	65	49	53	60	47	52	56	46	50	54
	True force, Beaufort scale.	3	4	5	3	4	5	3	4	4	3	3	4	4	4	4	5	5	4	6	5	5	7	6	6	8	8	7	9	9	8	10	10	9	11	11	11
50	True direction, degrees off the bow.	171	175	176	152	163	168	121	145	155	97	121	138	82	102	119	73	88	103	68	79	91	64	73	82	62	69	76	60	66	72	58	63	68	57	61	65
	True force, Beaufort scale.	3	4	5	3	4	5	3	4	4	3	4	4	4	4	5	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	10	11	11	11
60	True direction, degrees off the bow.	171	174	176	151	162	167	125	145	154	104	125	139	92	109	123	84	98	110	79	90	100	75	84	93	73	80	87	71	77	83	69	74	79	68	72	76
	True force, Beaufort scale.	3	4	5	3	4	5	3	4	5	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	8	8	8	9	9	9	11	10	10	11	11	11
70	True direction, degrees off the bow.	170	174	175	152	161	166	129	144	154	113	129	141	102	116	128	94	106	117	89	99	108	86	94	102	83	90	97	81	87	93	80	84	89	78	82	87
	True force, Beaufort scale.	3	4	5	3	4	5	3	4	5	4	5	5	5	5	6	6	6	6	7	7	7	8	8	8	9	9	9	10	10	10	11	11	11	12	12	11
80	True direction, degrees off the bow.	170	173	175	153	162	166	133	146	155	120	134	143	110	122	132	104	114	123	99	108	116	96	103	110	93	100	106	91	97	102	90	94	99	88	92	96
	True force, Beaufort scale.	3	4	5	3	4	5	4	4	5	4	5	6	5	6	6	6	6	7	7	7	8	8	8	8	9	9	9	10	10	10	11	11	11	12	12	12
90	True direction, degrees off the bow.	170	173	175	154	162	167	139	150	157	126	138	146	118	129	137	112	122	129	108	116	123	105	112	118	102	109	114	101	106	111	99	104	108	98	102	106
	True force, Beaufort scale.	3	4	5	4	4	5	4	5	6	5	5	6	5	6	6	6	7	7	7	8	8	8	8	9	9	9	10	10	10	10	11	11	11	12	12	12
100	True direction, degrees off the bow.	171	174	175	156	163	167	143	153	158	132	143	149	126	135	142	121	129	135	117	124	130	114	120	126	112	117	122	110	115	119	109	113	117	107	111	115
	True force, Beaufort scale.	3	4	5	4	5	5	4	5	6	5	6	6	6	6	7	7	7	8	8	8	8	8	9	9	9	10	10	10	11	11	11	11	12	12	12	12
110	True direction, degrees off the bow.	171	174	175	159	164	168	148	156	160	139	147	153	133	141	146	129	136	141	126	132	136	123	128	133	121	126	130	119	124	128	118	122	125	117	120	124
	True force, Beaufort scale.	4	4	5	4	5	6	4	5	6	5	6	7	6	7	8	7	7	8	8	8	9	9	9	10	10	10	10	11	11	11	11	12	12	12	12	12
120	True direction, degrees off the bow.	172	175	176	162	166	170	152	159	163	145	152	156	140	146	151	136	142	147	134	139	143	132	136	140	129	134	138	128	132	135	127	130	133	126	129	132
	True force, Beaufort scale.	4	4	5	4	5	6	5	6	6	5	6	7	6	7	8	7	8	8	8	8	9	9	9	10	10	10	11	11	11	11	12	12	12	12	12	12
130	True direction, degrees off the bow.	173	175	176	164	169	171	157	162	165	151	156	160	146	152	156	144	149	152	142	146	150	140	144	147	138	142	145	137	141	143	136	139	142	135	138	140
	True force, Beaufort scale.	4	5	5	4	5	6	5	6	6	6	6	7	6	7	8	7	8	8	8	9	9	9	10	10	10	10	11	11	11	12	12	12	12	12	12	12
140	True direction, degrees off the bow.	174	176	177	167	171	173	161	166	168	157	161	164	154	158	161	151	155	158	150	153	156	148	151	154	147	150	152	146	149	151	145	147	150	144	147	149
	True force, Beaufort scale.	4	5	5	4	5	6	5	6	7	6	6	7	6	7	8	7	8	9	8	9	10	9	10	10	10	11	11	11	11	12	12	12	12	12	12	12
150	True direction, degrees off the bow.	176	177	178	170	173	174	166	169	171	163	166	168	160	163	166	159	161	163	157	160	162	156	159	160	155	157	159	155	156	158	154	156	157	154	155	157
	True force, Beaufort scale.	4	5	6	4	5	6	5	6	7	6	7	7	7	7	8	8	8	9	8	9	10	9	10	10	10	11	11	11	12	12	12	12	12	12	12	12
160	True direction, degrees off the bow.	177	178	178	174	175	176	171	173	174	169	171	172	167	169	170	166	168	169	165	167	168	164	166	167	164	165	166	163	164	165	163	164	165	163	164	165
	True force, Beaufort scale.	4	5	6	4	5	6	5	6	7	6	7	7	7	7	8	8	8	9	8	9	10	9	10	11	10	11	11	11	11	12	12	12	12	12	12	12
170	True direction, degrees off the bow.	179	179	179	177	178	178	175	176	177	174	175	176	173	174	175	173	174	175	172	174	174	172	173	174	172	173	173	172	173	173	172	172	172	172	172	172
	True force, Beaufort scale.	4	5	6	4	5	6	5	6	7	6	7	7	7	7	8	8	8	9	8	9	10	9	10	11	10	11	11	11	12	12	12	12	12	12	12	12
180	True direction, degrees off the bow.	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
	True force, Beaufort scale.	4	5	6	4	5	6	5	6	7	6	7	7	7	8	8	8	8	9	8	9	10	9	10	11	10	11	11	11	12	12	12	12	12	12	12	12

Beaufort Wind Scale	0	1	2	3	4	5	6	7	8	9	10	11	12
Limits of Velocities in Knots	Calm	1 to 3	4 to 6	7 to 10	11 to 16	17 to 21	22 to 27	28 to 33	34 to 40	41 to 47	48 to 55	56 to 65	65 and above

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APPENDIX II

Units of the C.G.S. (centimetre-gramme-second) System

The **Gramme** is the metric unit of mass. It is the thousandth part of the standard kilogramme of the International Bureau of Weights and Measures.

The **Metre** is the unit of length in the metric system, and the centimetre is one-hundredth of a metre. The metre was originally intended as a geographical unit and was taken as one ten-millionth of the earth's quadrant. One kilometre is 1,000 metres.

The **Second** is the universal unit of time.

The unit of **Velocity**, in the C.G.S. system, is the velocity of a centimetre per second.

The unit of **Acceleration**, in the C.G.S. system, is an acceleration of one unit of velocity per second.

The unit of **Force**, in the C.G.S. system, is the force which produces an acceleration of one centimetre per second in a mass of one gramme. It is called a dyne.

The unit of **Pressure**, in the C.G.S. system, is the dyne per square centimetre; but as this unit is exceedingly small a practical unit of atmospheric pressure is substituted, which is one million times as great, the megadyne per square centimetre. This unit has been given the name bar by meteorologists. The working pressure unit is one-thousandth of a bar, the millibar.

APPENDIX III

Extracts from Merchant Shipping (Safety and Load Line Conventions) Act, 1932

First Schedule

International Convention for the Safety of Life at Sea, 1929

Article 34

Danger Messages

The Master of every ship which meets with dangerous ice, a dangerous derelict, a dangerous tropical storm or any other direct danger to navigation is bound to communicate the information by all the means of communication at his disposal, to the ships in the vicinity, and also to the competent authorities at the first point of the coast with which he can communicate. It is desirable that the said information be sent in the manner set out in Regulation XLVI.*

Each Administration will take all steps which it thinks necessary to ensure that when intelligence of any of the dangers specified in the previous paragraph is received, it will be promptly brought to the knowledge of those concerned and communicated to other Administrations interested.

The transmission of messages respecting the dangers specified is free of cost to the ships concerned.

Article 35

Meteorological Services

The Contracting Governments undertake to encourage the collection of meteorological data by ships at sea, and to arrange for their examination, dissemination and exchange in the manner most suitable for the purpose of aiding navigation.

In particular, the Contracting Governments undertake to co-operate in carrying out, as far as practicable, the following meteorological arrangements :—

(*a*) To warn ships of gales, storms and tropical storms, both by the issue of wireless messages and by the display of appropriate signals at coastal points :

(*b*) To issue daily, by radio, weather bulletins suitable for shipping, containing data of existing weather conditions and forecasts :

(*c*) To arrange for certain selected ships to take meteorological observations at specified hours, and to transmit such observations by wireless telegraphy for the benefit of other ships and of the various official meteorological services ; and to provide coast stations for the reception of the messages transmitted :

(*d*) To encourage all ship-masters to inform surrounding ships whenever they experience wind force of 10 or above on the Beaufort scale (force 8 or above on the decimal scale).

The information provided for in paragraphs (*a*) and (*b*) of this Article will be furnished in form for transmission in accordance with Article 31, sections 1, 3 and 5, and Article 19, section 25, of the General Regulations annexed to the International Radiotelegraph Convention, Washington, 1927, and during transmission " to all stations " of meteorological information, forecasts and warnings, all ship stations must conform to the provisions of Article 31, section 2, of those General Regulations.

Weather observations from ships addressed to national meteorological services will be transmitted with the priority specified in Article 3, Additional Regulations, International Radiotelegraph Convention, Washington, 1927.

Forecasts, warnings, synoptic and other meteorological reports intended for ships shall be issued and disseminated by the national service in the best position to serve various zones and areas, in accordance with mutual arrangements made by the countries concerned.

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* See page 107.

Every endeavour will be made to obtain a uniform procedure in regard to the international meteorological services specified in this Article, and, as far as is practicable, to conform to the recommendations made by the International Meteorological Organization, to which organization the Contracting Governments may refer for study and advice any meteorological questions which may arise in carrying out the present Convention.

Regulation XLVI

Transmission of Information

The transmission of information regarding ice, derelicts, tropical storms or any other direct danger to navigation is obligatory. The form in which the information is sent is not obligatory. It may be transmitted either in plain language (preferably English) or by means of the International Code of Signals (Wireless Telegraphy Section). It should be issued **CQ** to all ships, and should also be sent to the first point of the coast to which communication can be made with a request that it be transmitted to the appropriate authority.

All messages issued under Article 34 of the present Convention will be preceded by the safety signal TTT followed by an indication of the nature of the danger, thus ; TTT Ice ; TTT Derelict ; TTT Storm ; TTT Navigation.

Information Required

The following information is desired, the time in all cases being Greenwich Mean Time :—

(*a*) *Ice, Derelicts and other Direct Dangers to Navigation.*

(1) the kind of ice, derelict or danger observed ;
(2) the position of the ice, derelict or danger when last observed ;
(3) the time and date when the observation was made.

(*b*) *Tropical Storms.* (Hurricanes in the West Indies, Typhoons in the China Seas, Cyclones in Indian waters, and storms of a similar nature in other regions.)

(1) *A Statement that a Tropical Storm has been Encountered.*

This obligation should be interpreted in a broad spirit, and information transmitted whenever the master has good reason to believe that a tropical storm exists in his neighbourhood.

(2) *Meteorological Information.*

In view of the great assistance given by accurate meteorological data in fixing the position and movement of storm centres, each shipmaster should add to his warning message as much of the following meteorological information as he finds practicable :—

(*a*) barometric pressure (millibars, inches or millimetres) ;
(*b*) change in barometric pressure (the change during the previous two to four hours) ;
(*c*) wind direction (true not magnetic) ;
(*d*) wind force (Beaufort or decimal scale) ;
(*e*) state of the sea (smooth, moderate, rough, high) ;
(*f*) swell (slight, medium, heavy) and the direction from which it comes.

When barometric pressure is given the word " Millibars ", " inches " or " millimetres ", as the case may be, should be added to the reading, and *it should always be stated whether the reading is corrected or uncorrected.*

When changes of the barometer are reported the course and speed of the ship should also be given.

All directions should be true, not magnetic.

(3) *Time and Date and Position of the Ship.*

These should be for the time and position when the meteorological observations reported were made and not when the message was prepared or despatched. The time used in all cases should be Greenwich Mean Time.

(4) *Subsequent Observations*

When a master has reported a tropical storm it is desirable, but not obligatory, that other observations be made and transmitted at intervals of three hours, so long as the ship remains under the influence of the storm.

Examples

Ice

TTT Ice. Large berg sighted in 4605 N., 4410 W., at 0800 G.M.T. May 15.

Derelict

TTT Derelict. Observed derelict almost submerged in 4006 N., 1243 W., at 1630 G.M.T. April 21.

Danger to Navigation

TTT Navigation. Alpha lightship not on station. 1800 G.M.T. January 3.

Tropical Storm

TTT Storm. Experiencing tropical storm. Barometer corrected 994 millibars, falling rapidly. Wind N.W., force 9, heavy squalls. Swell E. Course E.N.E., 5 knots. 2204 N., 11354 E. 0030 G.M.T. August 18.

TTT Storm. Appearances indicate approach of hurricane. Barometer corrected 29·64 inches falling. Wind N.E., force 8. Swell medium from N.E. Frequent rain squalls. Course 35°, 9 knots. 2200 N., 7236 W. 1300 G.M.T. September 14.

TTT Storm. Conditions indicate intense cyclone has formed. Wind S. by W., force 5. Barometer uncorrected 753 millimetres, fell 5 millimetres last three hours. Course N. 60 W., 8 knots. 1620 N., 9302 E. 0200 G.M.T. May 4.

TTT Storm. Typhoon to south-east. Wind increasing from N. and barometer falling rapidly. Position 1812 N., 12605 E. 0300 G.M.T. June 12.

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