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METEOROLOGICAL OFFICE

THE MARINE OBSERVER'S HANDBOOK

8th EDITION

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FOREWORD

The Marine Observer's Handbook is written for three purposes:

(1) To assist officers aboard vessels of the British Commonwealth, who voluntarily make observations at sea on behalf of Meteorological Services, to carry out this work in an efficient and uniform manner.

(2) To encourage all mariners to take an interest in meteorology and to assist them in their study of this important and interesting subject.

(3) To provide a book of reference for candidates for Masters' and Mates' examinations.

It will be noted that this book deals with meteorological instruments and the practical aspect of making observations. The companion volume, entitled *Meteorology for Mariners*, embraces the theory and the application of meteorology to the seaman's profession.

A study of the syllabus issued by the Ministry of Transport will suggest that candidates for the Second Mate's Certificate might usefully study Chapters 1 and 2. Candidates for the Mate's Certificate might study Chapters 1, 2, 4, 5, 6, 7. Candidates for the Master's and Extra Master's Certificate might read the same chapters and, in addition, Chapters 13 and 14.

The seaman is so dependent on the weather, not only for the safety of his ship but also for his personal comfort, that an interest in meteorology on his part is essential. It is undoubtedly true that in this modern age of large, fast, power-driven ships, just as in the ancient days of oared galleys and long-ships, and more recently of ocean-going sailing ships, no ship's officer can consider himself a complete sailorman unless he is "weather wise". Meteorological observing tends to quicken the eye of the observer, making him more alert and more ready for emergencies. The practiced observer is not only on the lookout for changes in weather and cloud and for interesting phenomena, but by his general alertness he will ensure that there are no "Irish pennants", loose tarpaulins, etc., when he is on deck.

Essentials to efficiency in meteorological observations are accuracy and attention to detail. The results are beneficial not only to Meteorological Services, and thence to mankind, but to the ship herself. By accurate reading and intelligent interpretation of humidity observations, for example, the master can decide whether ventilation of cargo is wise or not, or by a combination of sea and air temperature and humidity, the likelihood of fog can be forecast, aboard the ship. Timely notice of a shift of the wind or variation of its force or the sky becoming overcast or gradual deterioration of visibility may, on occasions, save a ship from getting into trouble. The largest and most powerful ship can be delayed or damaged by high winds, rough seas or because of fog. Valuable cargoes can be quickly ruined by unfavourable weather.

Anything that is worth doing is worth doing well and this is particularly so with regard to meteorological observations. A lone ship's observation from "somewhere in the ocean" may hold the key to an otherwise obscure meteorological situation, but it is better to have no observation than an inaccurate or erroneous one. An inaccurate observation may mislead the forecaster and, directly or indirectly as a result of that inaccuracy, a small ship or an aircraft may be lost.

Accuracy is just as important for climatological purposes. In the analysis of meteorological records for the compilation of atlases and for scientific investigation generally, a few inaccurate observations may so bias the results as to tend to falsify the picture. In deciding whether to reject an apparently erroneous observation, the investigator can only use his judgment and experience.

Observers at sea would perhaps be surprised at the many uses to which their observations are put, both commercially and scientifically. To mention only a few: frequencies of winds of gale force are required whenever the load line areas are reviewed; air temperatures and humidities have been useful in the testing of life jackets; meteorological data are needed by the respective research organisations in connection with the design of ships and with the efficiency of radar.

Thus, by taking an intelligent interest in meteorological observations, the seaman contributes to the cause of science and benefits the world in general and his fellow seamen in particular, by increasing our knowledge of meteorology and climatology.

Note to the eighth edition. Numerous revisions and additions have been made in this edition, to bring the book up to date. In particular, a new series of photographs has been added to Part II, depicting the appearance of the sea corresponding to each of the Beaufort forces. These photographs are also supplied on a card to voluntary observing ships of the U.K. Also, Part III (Phenomena) has been enlarged and re-arranged. In view of the changeover to the Celsius temperature scale (*see* page 21), Celsius dewpoint tables have been included at the end of the book.

MARINE DIVISION,
METEOROLOGICAL OFFICE.
December 1961.

Part I. Instrumental Observations

CHAPTER 1

The Barometer and the Barograph

Principle of the barometer. This 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 is made by completely filling with mercury a glass tube closed at one end and some 36 inches in length. The open end is then immersed in a cistern also containing mercury, and the tube is held upright. The mercury column falls, leaving a vacuum at the top of the tube, 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 (*see* Fig. 1).

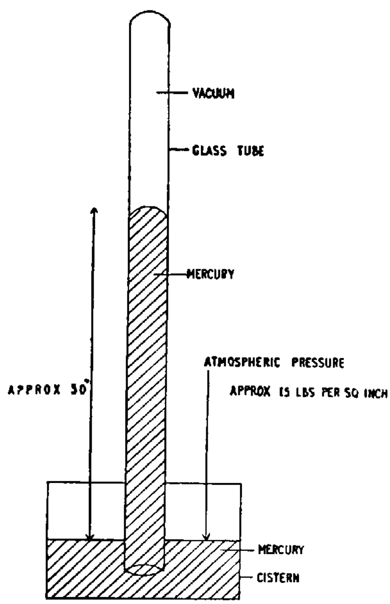
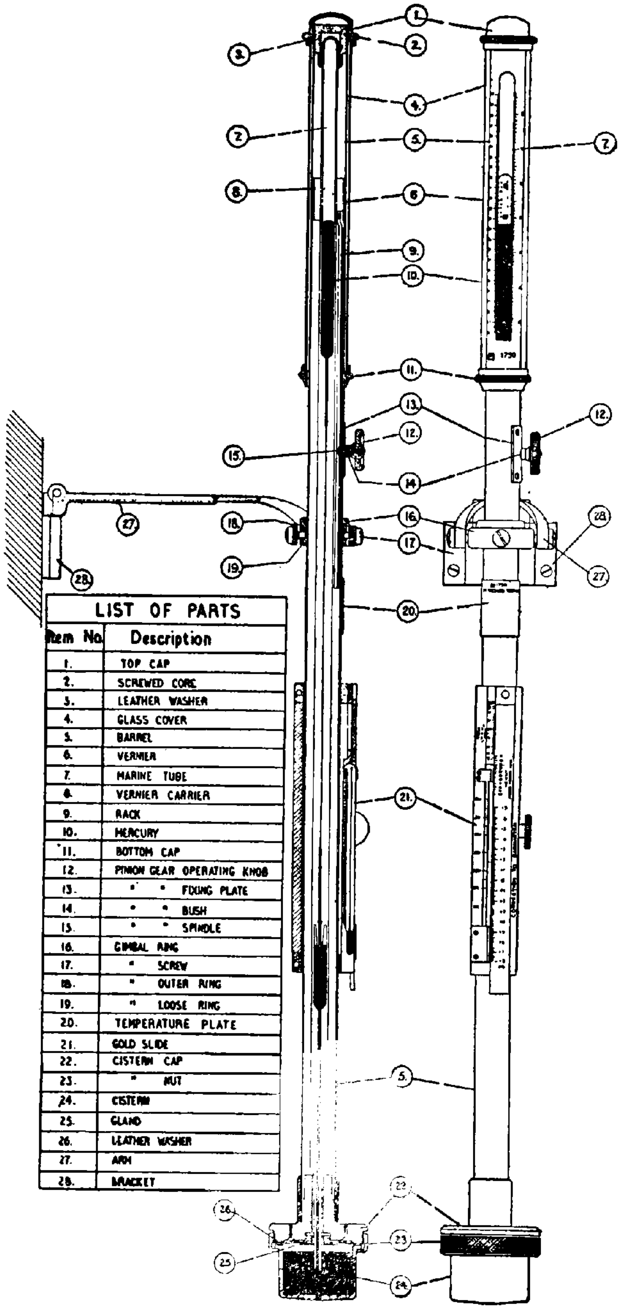


FIG. 1. A simple mercury barometer

The mercury barometer only gradually passed from this original simple form to that of a practical and portable instrument and was not used by seamen until a century had elapsed.

The Kew-pattern marine barometer. This consists of a glass tube and cistern enclosed in a metal protecting case (*see* Fig. 2). In the upper part of the cistern



Item No.	Description
1.	TOP CAP
2.	SCREWED CORE
3.	LEATHER WASHER
4.	GLASS COVER
5.	BARREL
6.	VERNIER
7.	MARINE TUBE
8.	VERNIER CARRIER
9.	RACK
10.	MERCURY
11.	BOTTOM CAP
12.	PINION GEAR OPERATING KNOB
13.	" " FIXING PLATE
14.	" " BUSH
15.	" " SPINDLE
16.	GIMBAL RING
17.	" SCREW
18.	" OUTER RING
19.	" LOOSE RING
20.	TEMPERATURE PLATE
21.	GOLD SLIDE
22.	CISTERN CAP
23.	" NUT
24.	CISTERN
25.	GLAND
26.	LEATHER WASHER
27.	ARM
28.	BRACKET

FIG. 2. The Kew-pattern marine barometer

are one or more small holes which admit the air, and a leather washer, permeable to air, which prevents the mercury from escaping, and also keeps out dust. The bore of the glass tube is considerably constricted for the greater part of its length, and, for part of this constriction, is reduced to a fine capillary. The object of these constrictions is to reduce the amount of "pumping", i.e., oscillations of the top of the mercury column, caused by the movements of the ship and by gusts of wind. At the top of the mercury column the bore of the tube is greater; this minimises the effect of "capillarity"* on the height of the centre of the mercury column, but leaves the upper surface of the column sufficiently convex to facilitate accurate reading. An air-trap in the tube prevents air from rising into the space above the mercury column, which should be an almost perfect vacuum. 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. On barometers graduated in millibars, the thermometer is graduated in degrees Absolute on older instruments, but in degrees Centigrade on those made after 1st January 1955; on inch barometers, it is usually graduated in degrees Fahrenheit.

Graduation of barometer scales.

INCHES AND MILLIMETRES. From the invention of the barometer until comparatively recent years the reading was invariably expressed as *the length of the mercury column necessary to balance the atmospheric pressure at that instant.* In the British Isles, atmospheric pressure was, therefore, expressed 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. The graduations are marked on a metal scale at the side of the instrument. Barometer scales graduated in inches are readable by vernier to a thousandth of an inch (·001). (*See* Fig. 16).

When we express the pressure in terms of inches or millimetres of mercury, we really mean that that pressure is the same as the weight of a given length of mercury column per unit area. If water were used as the liquid, the barometer would have to be over 30 feet long; mercury, which is used in practice on account of its high density, only needs a tube of a little over 30 inches.

MILLIBARS. The original procedure in measuring barometric pressure, which is still often used, was to measure the length of the mercury column and to give that length, in inches or millimetres, duly corrected, as a measure of the atmospheric pressure. It was later thought preferable that pressures should be expressed in units of pressure, not in units of length. In the C.G.S. system, used almost universally in other scientific work, the unit of force is the *dyne*, the force which, if applied to a mass of one gramme, will produce an acceleration

*Capillarity is the tendency of liquids in narrow tubes to rise above or fall below the hydrostatic level. This tendency depends on the relative attraction of the molecules of the liquid for one another and for the molecules of the material of the tube. The narrower the tube, the greater the tendency to rise or fall, so that the effect is particularly well marked in hair-like or capillary tubes, hence the name "capillarity". If the liquid wets the solid material, it will rise in the tube, but if not, it will be depressed. In the case of water in a glass tube, therefore, the water column is raised, particularly at the edge, while the reverse is the case with mercury in a glass tube, for mercury does not wet glass.

of one centimetre per second per second. A pressure of one *megadyne* (one million dynes) per square centimetre is almost equal to the average atmospheric pressure at sea level. It was proposed by V. Bjerknes that this C.G.S. pressure unit should be named a *bar* (from the Greek *baros*, weight) and should be adopted as the meteorological unit of atmospheric pressure. A bar, however, is too large a unit for convenience; in practice the millibar, the thousandth part of a bar, and therefore a pressure of 1,000 dynes per square centimetre is used as a working unit. Since May 1914, atmospheric pressures have been recorded by the Meteorological Office in millibars instead of in inches, and this is the generally accepted international method under arrangements made by the **World Meteorological Organization.**

Further information on the C.G.S. system will be found in the Appendix to the Tables, at the end of this book.

Barometers graduated in millibars have a longer line at each tenth millibar. By means of the vernier the pressure can be read to one-tenth of a millibar (*see* Fig. 17). One thousand millibars equal one bar. This is equivalent to a pressure of 29·53 inches, or 750·1 millimetres, of mercury at the standard value of gravity of 980.665 cm./sec.^{2}, and is thus very nearly equal to the average pressure of the atmosphere at sea level. An increase of one millibar (·0295 inch) in atmospheric pressure, therefore, indicates an increase of about a thousandth of the previous pressure.

BAROMETRIC CORRECTIONS

For a given pressure, the length of the mercury column of a barometer is not a constant but depends upon the density (and therefore on the temperature) of the mercury, the value of the acceleration due to gravity at the place of observation, and the height above sea level. Moreover, the indication on a barometer scale set up to measure the length of the column will depend upon the temperature of the scale itself. In order to make barometer readings comparable all over the world it is therefore necessary to specify "standard conditions"—temperature of mercury and of scale, and acceleration due to gravity—and to compute tables whereby corrections may be made for any departure from these conditions. In addition the readings have to be reduced to a standard altitude, which for altitudes of not more than a few hundred feet is mean sea level, and reduction tables have also been computed for this purpose.

The "standard conditions" referred to above were changed with effect from 1st January 1955, by a decision of the World Meteorological Organization at Geneva in 1953. The standard value of gravity was changed from 980·62 cm./sec.^{2} (which is very nearly equal to the gravity at mean sea level in latitude 45°) to 980·665 cm./sec.^{2} (which is a conventional standard). For barometers reading in inches the standard temperature was changed from 32°F. for the mercury and 62°F. for the scale to 0°C. for the whole instrument. For Meteorological Office barometers reading in millibars it was changed from 285°A.* (12°C.) to 0°C., for the whole instrument.

Because of these changes and because it will be many years before all the older barometers are converted or replaced it is now necessary to have two sets of correction tables available for mercurial barometers, whether they be

* See page 21.

graduated in inches or millibars, one for instruments adjusted to the old standard conditions and one for those adjusted to read correctly at gravity 980·665 cm./sec.^{2} and temperature 0°C.

All mercurial barometers have also to be corrected for capillarity*, which tends to depress the mercury in the tube; variation in the quantity of mercury in the cistern according to the length of the mercury column; defective vacuum, etc., but these are all made very small by suitable allowances in the process of construction and any residual errors and errors due to imperfections in construction or adjustment are included in the "index errors" of the instrument. These index errors are determined at the National Physical Laboratory for all M.O. mercury barometers and are given on a certificate supplied by that institution.

It is desirable that the index correction of a mercury barometer should be checked every three months, as this correction is liable to change slowly. All Port Meteorological Officers and Merchant Navy Agents have a standard barometer which is available for such comparisons, or a reading may be obtained by telephone from the nearest aerodrome. The ship's barometer should be corrected for temperature, altitude and gravity, before a comparison is made.

Corrections to inch barometers.

CORRECTION FOR TEMPERATURE. With increase of temperature, mercury expands, so that its weight per unit volume decreases; a column of greater length will therefore be required to balance a stated air pressure when the temperature is high than when it is low. The correction required to adjust the length to that at a standard temperature is therefore negative when the temperature is above the standard and positive when it is below. For an inch barometer adjusted to the old conventions, the standard temperature at which the mercury in the barometer would read correctly is 32°F. The metal scale on the instrument however, reads correctly at 62°F.; the reason for this is that the standard inch is legally defined as a certain length engraved on brass *at a temperature of* 62°F. Table I gives the temperature correction for such a barometer. The net effect of the different standard temperatures for the *brass scale* (62°F.) and the *mercury* (32°F.) is that the temperature at which the temperature correction in the table becomes zero is below 32°F. At any other temperature, the temperature correction is proportional to the length of the mercury column, that is, to the atmospheric pressure. Table I therefore gives the correction for ranges both of temperature and barometer readings. The temperature to be used with this table is that of the thermometer attached to the barometer, which, if the exposure of the barometer is correct, will give the temperature both of the mercury and of the brass scale.

For an inch barometer adjusted to the new conventions the standard temperature at which both mercury and scale would read correctly is 32°F. The appropriate corrections are given in Table II. Here also the temperature to be used is that of the attached thermometer.

* See footnote on page 3.

CORRECTION FOR GRAVITY. The barometer reading now has to be corrected for the variation of gravity from the standard value. Owing to the flattening of the earth at the poles, the distance of its surface from its centre of gravity is least in those regions, and greatest at the equator. In addition, the vertical component of the centrifugal force due to the earth's rotation is greatest at the equator and decreases to zero at the poles. The force of gravity, therefore, increases steadily from low to high latitudes. The greater the force of gravity, the greater will be the weight of a given mass of mercury and hence the smaller will be the length of the column required to counterbalance a given pressure of the air. For a barometer adjusted to the old conventions, standard gravity is 980·62 cm./sec.^{2}, which is very nearly the force of gravity at mean sea level in latitude 45°. The length of the mercury column is accordingly corrected to what it would be in that latitude, the correction being negative in low latitudes and positive in high latitudes.

At any given latitude differing from 45°, the correction to be applied is proportional to the mass of mercury forming the mercury column of the barometer. It is therefore proportional to the length of that column. Table III gives the correction at all latitudes and for two readings, 29 and 31 inches.

For a barometer adjusted to the new conventions standard gravity is 980·665 cm./sec.^{2} and Table IV gives the appropriate corrections for each degree of latitude and for the two pressures, 29 and 31 inches.

REDUCTION TO STANDARD LEVEL. When the barometer reading has been corrected for temperature, it must next be corrected for height above sea level. The pressure of the atmosphere at any level is equal to the total weight of all the air above a plate of unit area, held horizontally at that level. If such a plate were moved vertically upwards, the total weight above it must decrease by the weight of the column of air through which the plate had passed, and the pressure would fall accordingly. Thus, a barometer reading of 30 inches at sea level would fall to about 28·9 inches at 1,000 feet, and to about 21 inches at 10,000 feet. The barometer reading must therefore be reduced to a standard level, and for altitudes of not more than a few hundred feet above sea level, the standard adopted is mean sea level. As the weight of a given volume of air decreases as the temperature rises, this correction depends not only on the height above mean sea level, but also on the temperature of that air (*see* Table V). The temperature to be used for this table is that of the dry bulb in the screen, i.e., the temperature of the atmosphere at the time of measurement.

Besides these corrections there is also the *index correction* to be applied.

EXAMPLE.—In latitude 51° N., the barometer reads 30·240 inches at a height of 36 feet above sea level. The attached thermometer reads 60°F., the dry bulb in the screen reads 58°F., the index correction is + ·005, and the date of the N.P.L. certificate is 1.6.53.

		Inches
Uncorrected reading		30·240
Index correction	+	·005
		30·245
Temperature correction for 60°F. (Table I)	—	·085
		30·160
Gravity correction in lattitude 51°N. (Table III)	+	·016
		30·176
Height correction for 36 feet at air temperature of 58°F. (Table V)	+	·039
Corrected barometer reading		30·215

There are simple formulae by which approximate values of the temperature and height corrections can be obtained without tables. As these may sometimes be useful, they are shown in Table XI.

Corrections to Millibar Barometers.

CORRECTIONS FOR TEMPERATURE AND GRAVITY. As previously explained, the standard conditions for millibar barometers were changed from gravity 980·62 cm./sec.^{2} and temperature 285°A. to gravity 980·665 cm./sec.^{2} and temperature 0°C. (273°A.) with effect from 1st January 1955. The temperature corrections for barometers conforming to the old conventions, i.e., with N.P.L. certificates dated 31st December 1954 or earlier, are given in Table VI and those for new barometers, i.e. with N.P.L. certificates dated 1st January 1955 or later, in Table VII. The corresponding gravity corrections are given in Table VIII (old barometers) and Table IX (new barometers). These tables are all similar in form to the corresponding tables for inch barometers and require no further explanation.

REDUCTION TO STANDARD LEVEL. Corrections for reducing the barometer reading in millibars to mean sea level are given in Table X for various heights up to 100 feet and dry bulb temperatures between 0°F. and 90°F.

The index correction as given in the N.P.L. certificate must also be applied.

Example :—In latitude 27°N., the barometer reads 1017.3 mb. at a height of 53 feet above sea level. The attached thermometer reads 298°A., the dry bulb in the screen reads 78°F., the index correction of the barometer is + 0·3 mb. and the date of the N.P.L. certificate is 20.2.57.

		mb.
Uncorrected reading		1017·3
Index correction	+	0·3
		1017·6
Temperature correction for 298°A. (Table VII)	—	4·3
		1013·3
Gravity correction in latitude 27°N. (Table IX)	—	1·6
		1011·7
Height correction for 53 ft. at air temp. of 78°F. (Table X)	+	1·8
Corrected pressure at m.s.l.		1013·5

The Gold slide. Meteorological Office marine barometers are fitted with a Gold slide. This attachment makes the use of tables unnecessary for the reduction and correction of millibar barometer readings. (*See* Fig. 3.)

A sliding piece, movable by rack and pinion, and mounted beside the attached thermometer, carries two scales; the lower, alongside the mercury column of the thermometer, is marked "Correction to Barometer", and the upper, "Height above Water Line". Alongside the upper scale is mounted a strip of metal on which is engraved a "Latitude Scale". On the other side of the latitude scale, there is engraved, on the upper part of the "Attached Thermometer Scale", an "Index Scale". The Latitude Scale is fixed in such a position relative to the Index Scale as to allow for the index error of the instrument and should not, therefore, be moved. The whole slide is clamped to the barometer.

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

Before reading the barometer, adjust the Gold slide so that the height of the barometer above the water line, on the appropriate 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.

CONVERSION OF INCHES TO MILLIBARS

A table for the conversion of barometer readings in inches to millibars is given as Table XII. In certain instances abroad, barometric pressures given in millimetres may be encountered. No table is given for the conversion of millimetres to millibars as the conversion may be made very simply by increasing the pressure in millimetres by one third. For example, 750·0 mm. is very nearly equal to 1000·0 mb.

In barometers graduated with both millibars and inch scales, and made before 1st January 1955, the uncorrected readings taken at the same time will not be comparable. 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 somewhat below 32°F. at sea level in latitude 45°. (*See* explanation on page 5). 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.

In barometers conforming to the new conventions, however, the readings on the two scales will be directly related by 1000 mb. = 29·530 in., because the standard instrumental conditions of temperature and gravity are the same.

THE POSITION, SETTING UP, AND CARE OF THE MERCURY BAROMETER

Position of the barometer. In steamships, the mercury barometer is usually situated 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, this is usually impracticable.

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

(1) It must be out of the way of unauthorized persons.
(2) It must not be exposed to the direct rays of the sun.
(3) It must not be exposed to suddenly varying conditions of temperature due to causes within the ship, such as draughts of air from boilers, engine room, etc.
(4) The lighting should not be such as to cause a glare on the glass surface of the barometer tube. The light should come from behind or from the side of the observer.

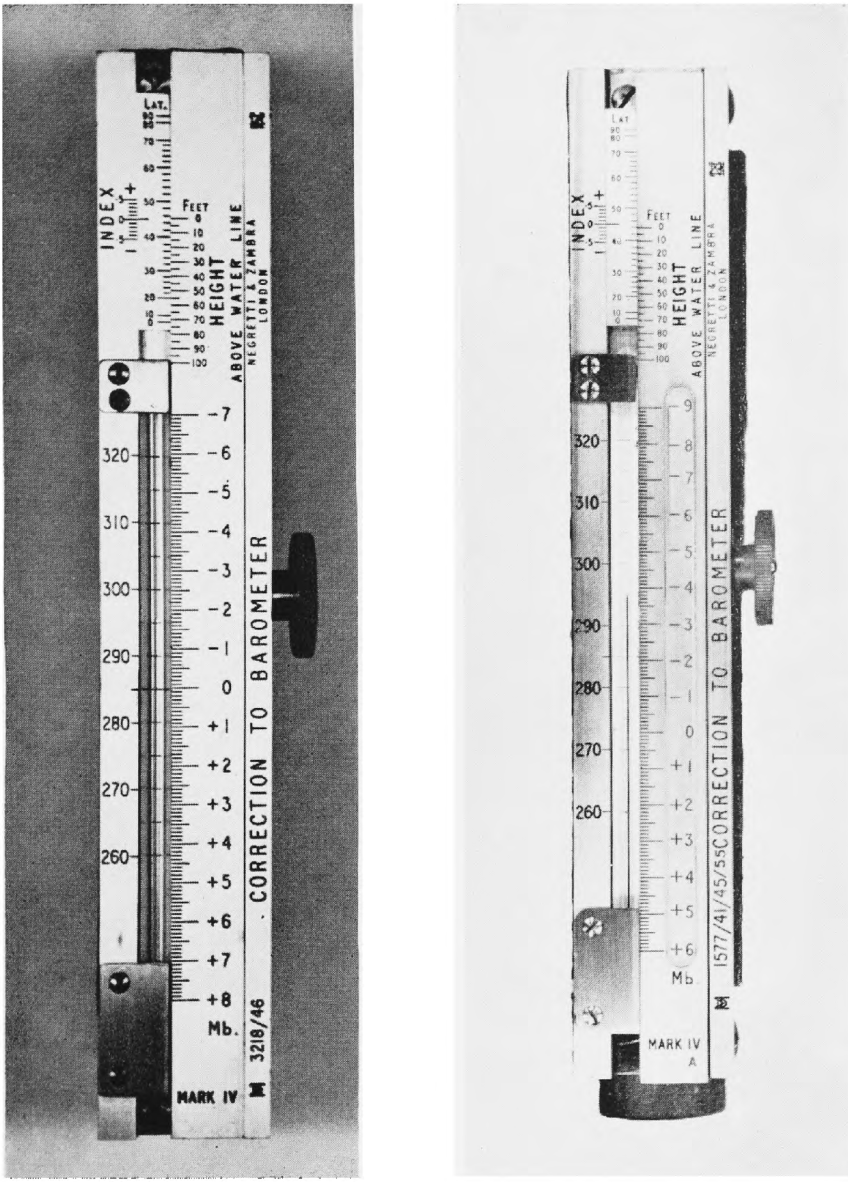
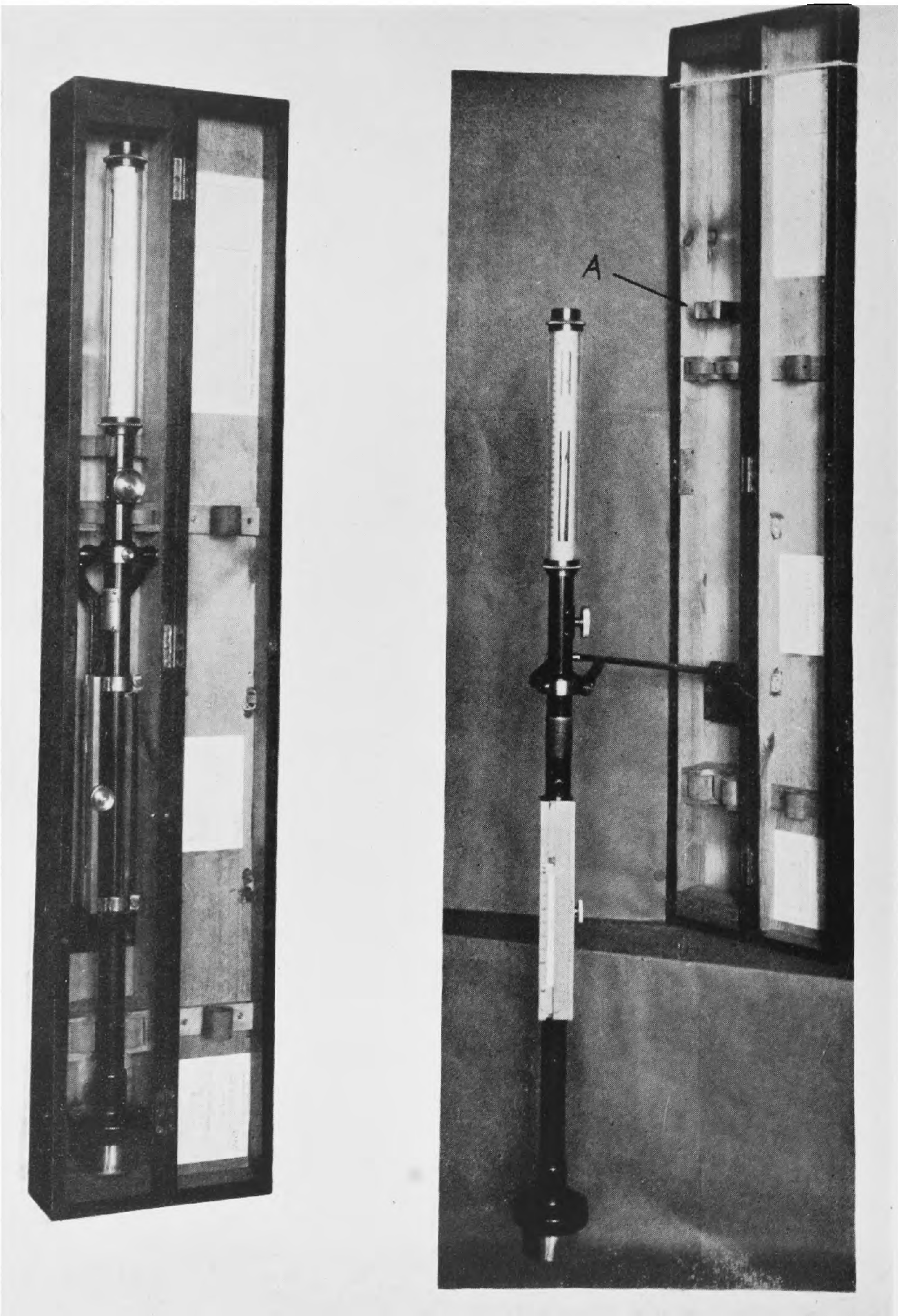


FIG. 3. The Gold Slide. Both these types are at present in use.



(*a*) (*b*)

FIG. 4. Stowage of the Kew-pattern marine barometer

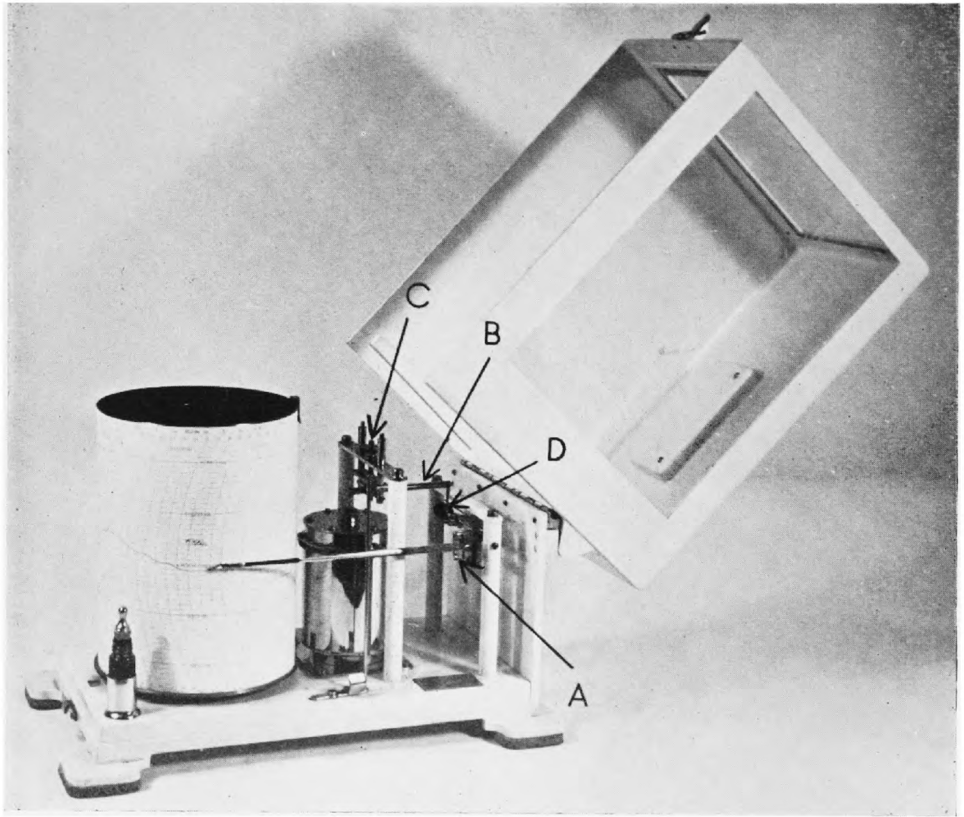
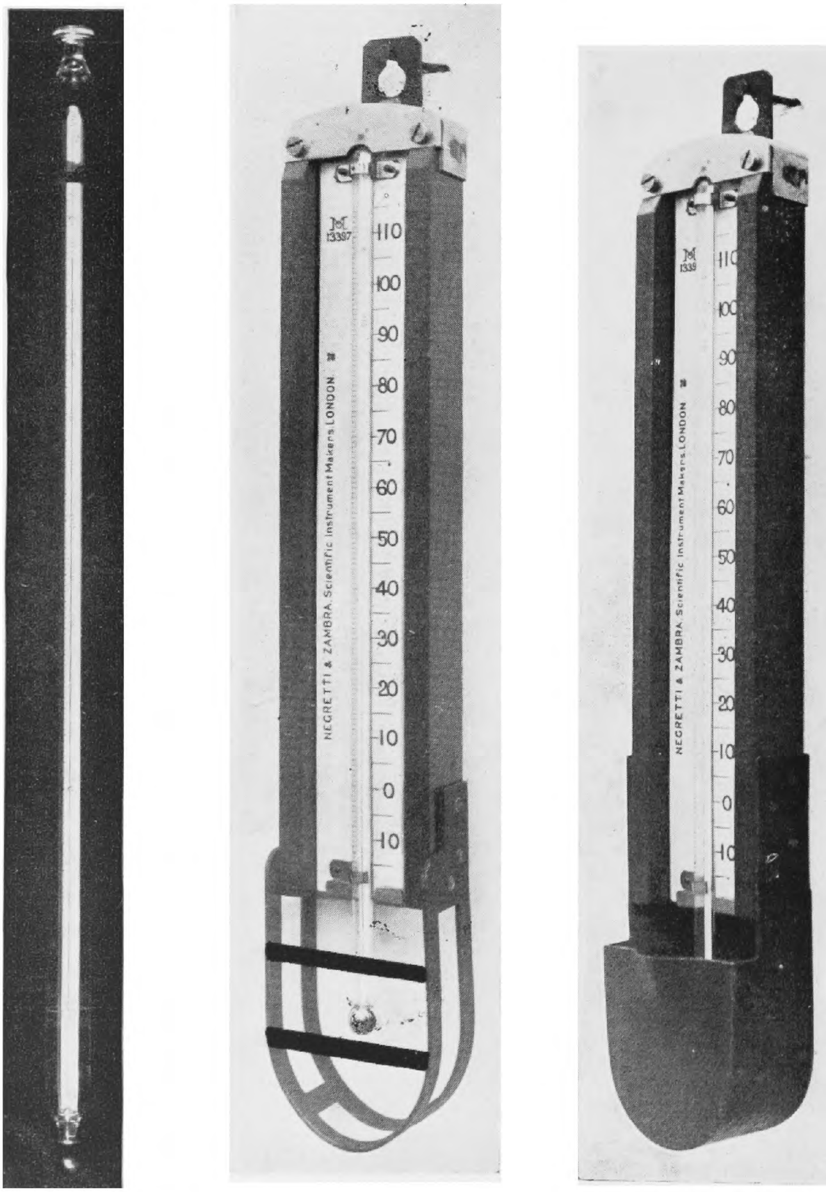


FIG. 5. The marine open-scale barograph



(a) *(b)* *(c)*

FIG. 6. Thermometer and air and sea thermometer protectors

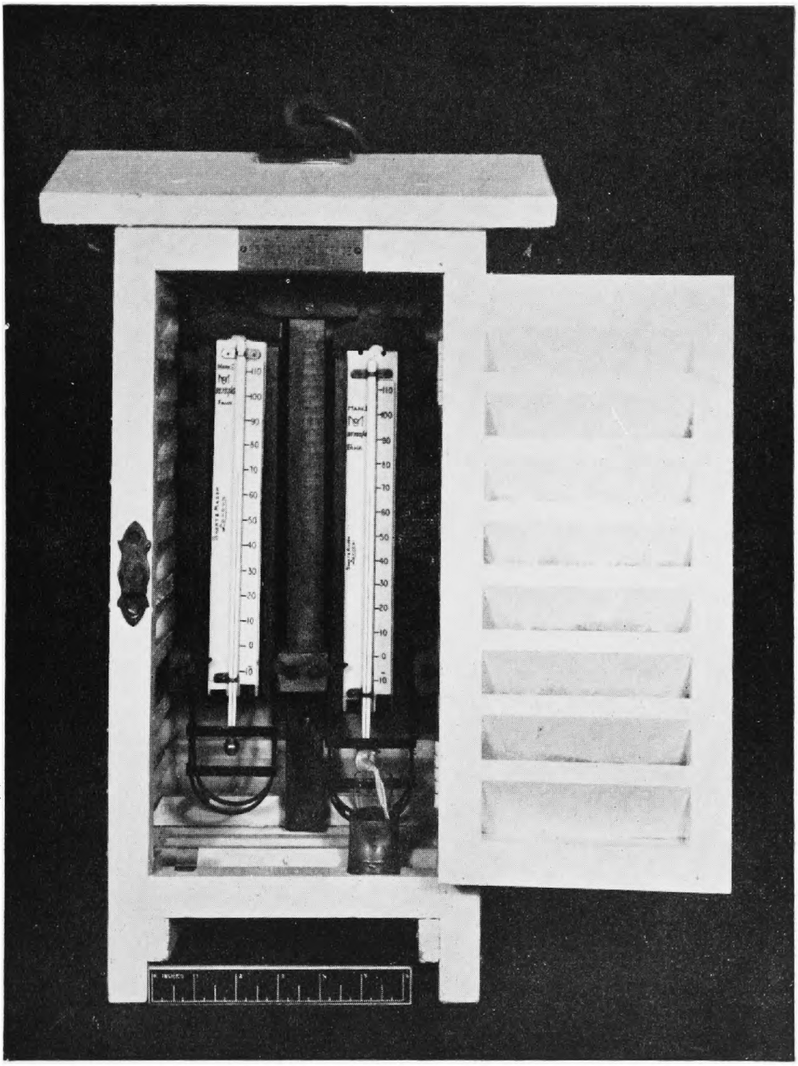


FIG. 7 (a). The portable Stevenson screen, with protected thermometers.

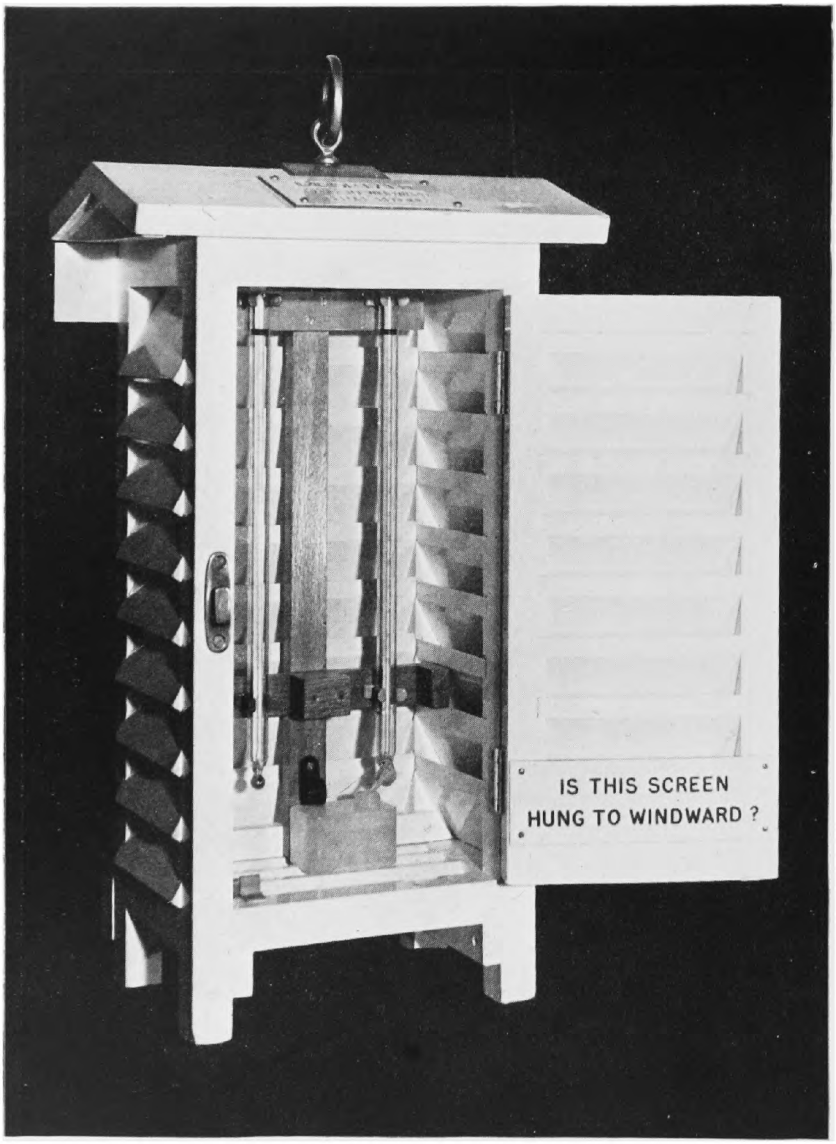
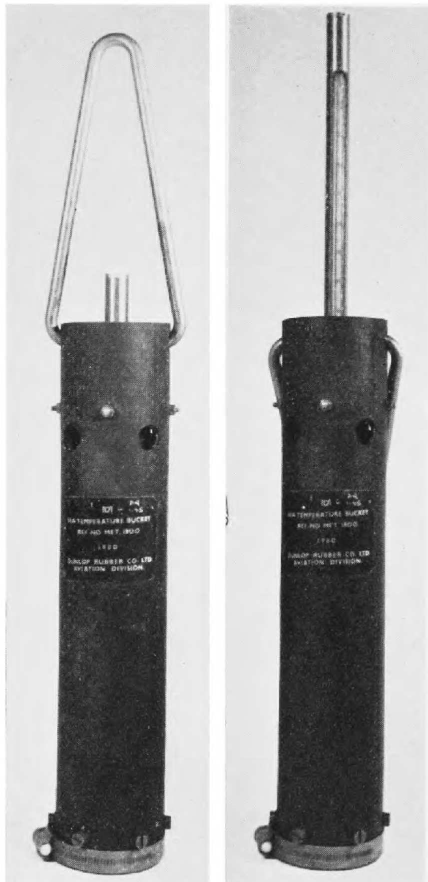


FIG. 7 (b). The portable Stevenson screen, with unprotected (but strengthened) thermometers



(*a*) (*b*)

FIG. 8

The canvas sea-temperature bucket

FIG. 9

The rubber sea-temperature bucket

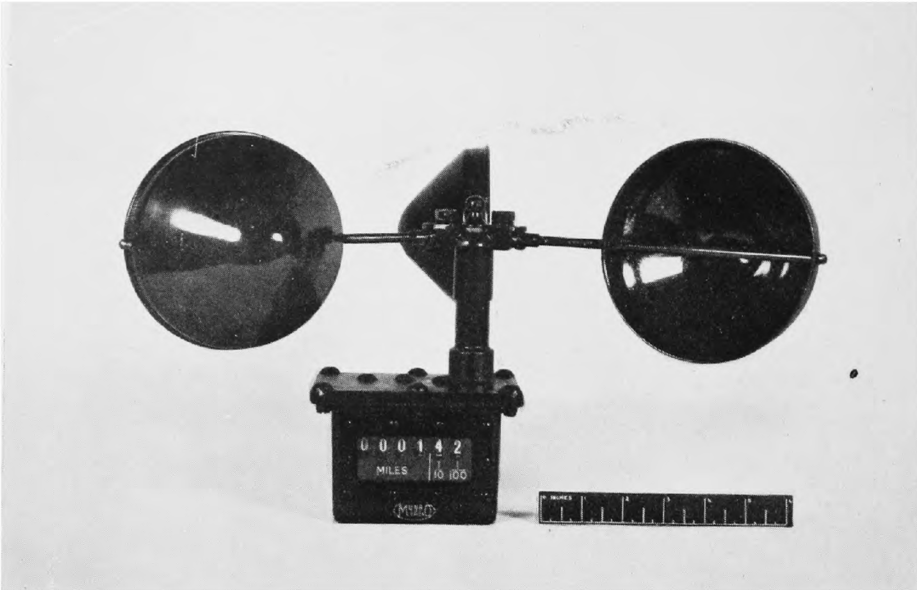


Fig. 10. The cup anemometer

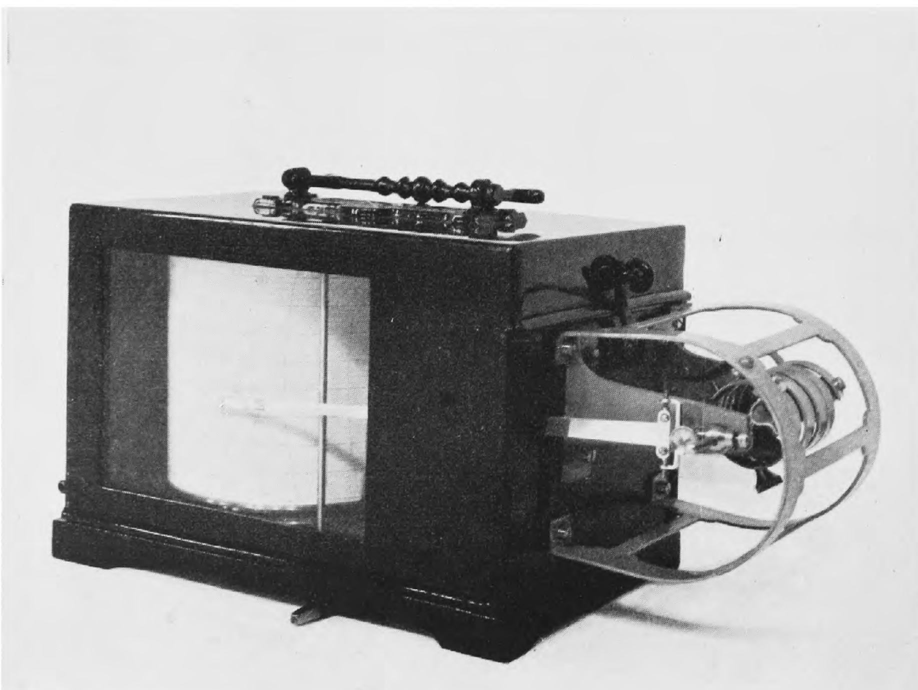


Fig. 11. The thermograph

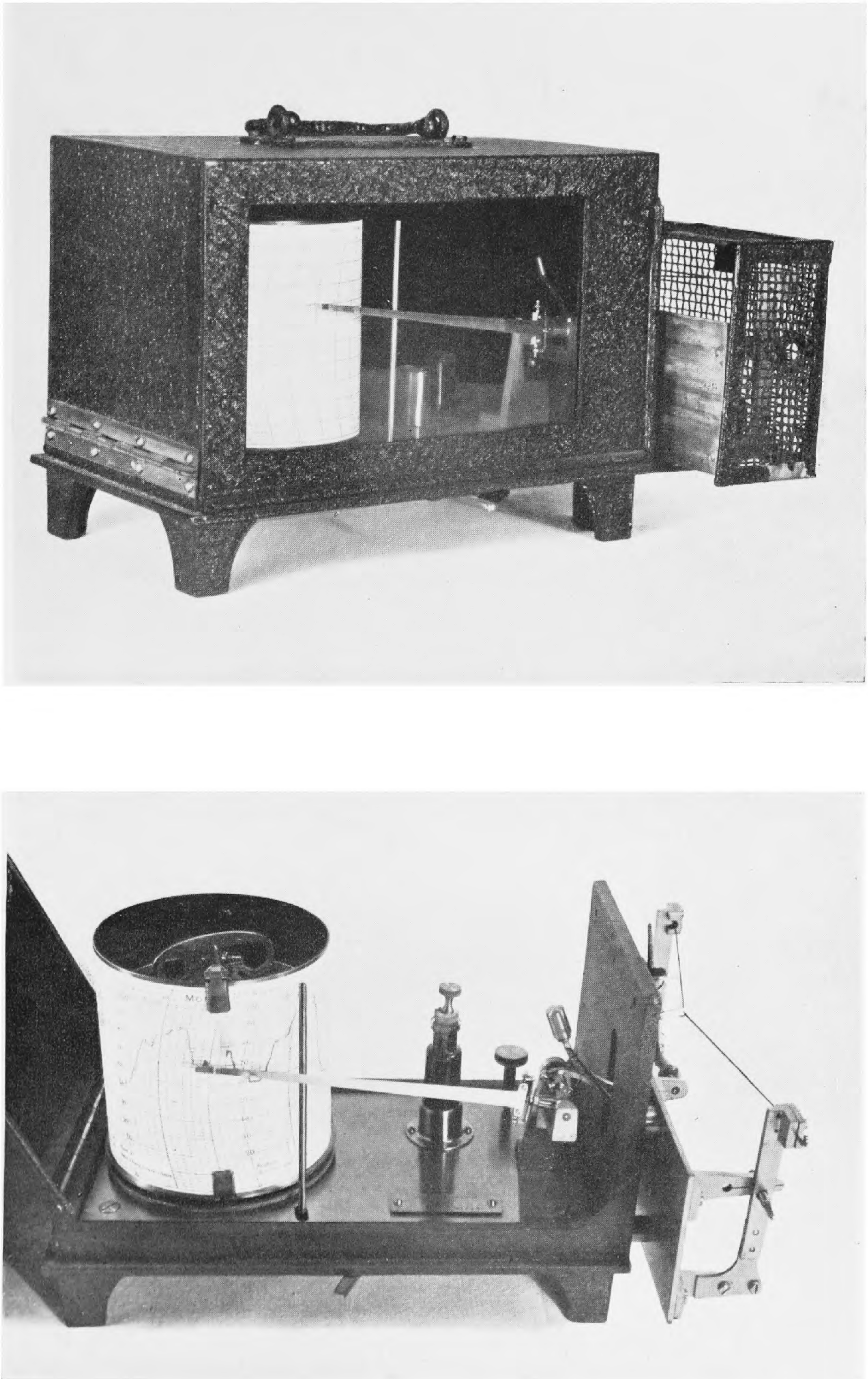


FIG. 12. The hair hygrograph. In the lower picture the wire cage has been removed to show the hair mechanism

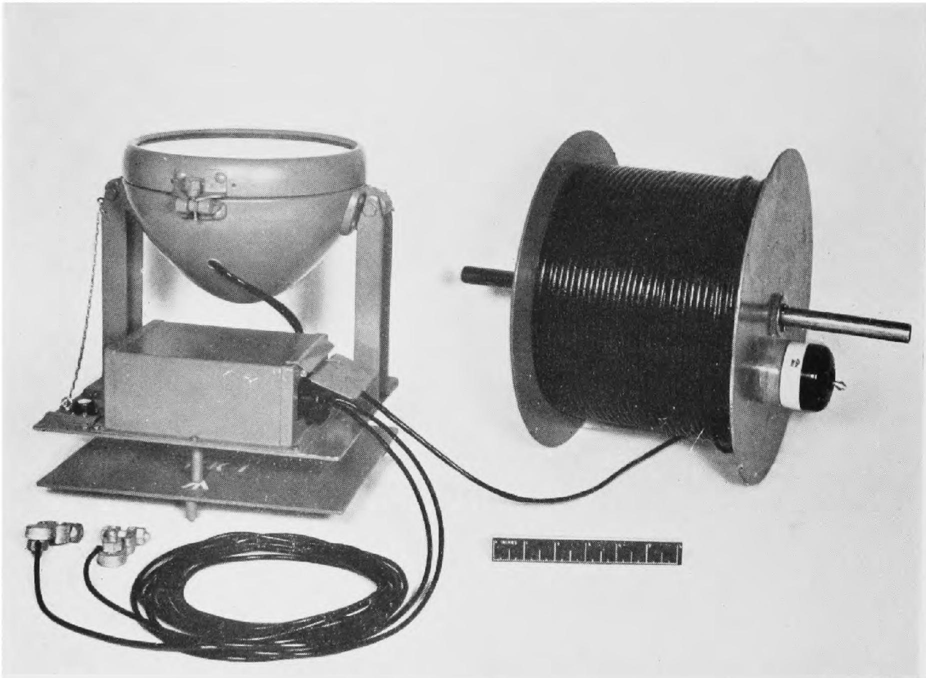


FIG. 13. The cloud searchlight

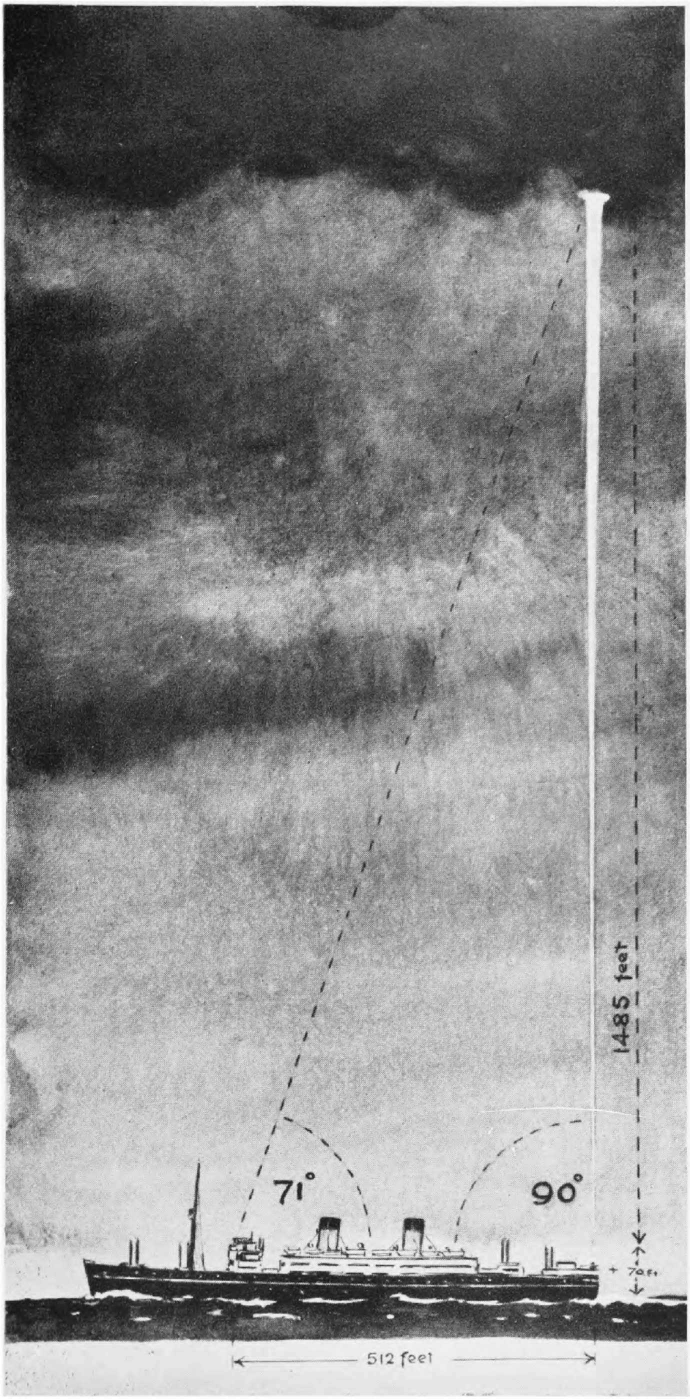
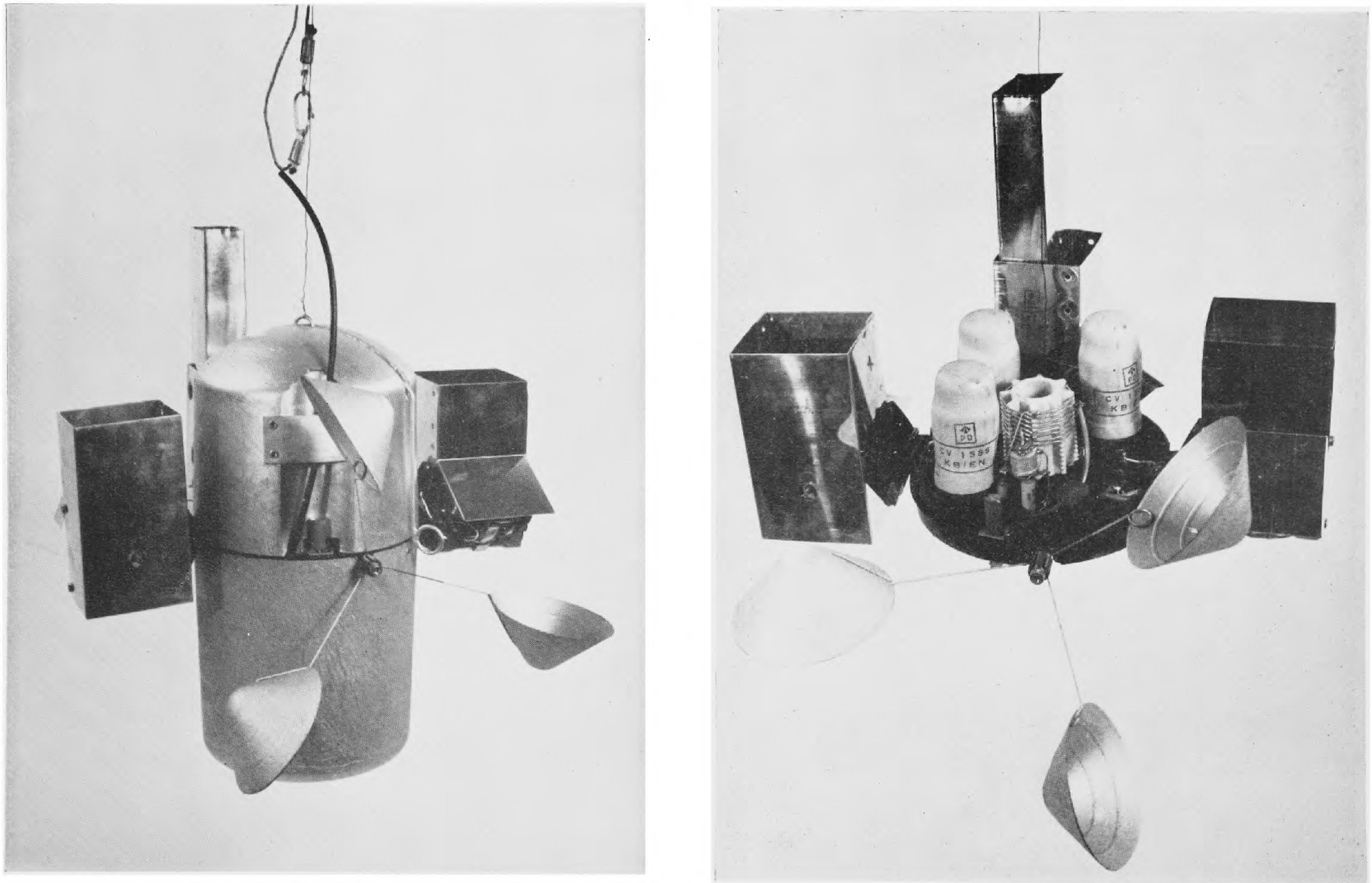


FIG. 14. A cloud searchlight in use at sea



(*a*) Assembled for flight

(*b*) View with covers removed

FIG. 15. The British radio-sonde

Setting up the barometer. The mercury barometer is supported so that it swings in gimbals and therefore tends to remain vertical when the ship is rolling. In order to give the instrument room to swing, it is supported by a suspension arm, hinged at one end. The hinged end can either be screwed to a bulkhead or shipped into a socket screwed to a bulkhead. The height of the suspension arm should be such that the top of the mercury at its highest probable position is just below the height of the eye of an average observer. A barometer that is too high is almost certain to cause errors of parallax. (*See* Fig. 18.)

The socket having been screwed to the bulkhead, the instrument should be carefully lifted, the hinged part of the suspension arm bent back at right angles and shipped into the socket so that the longer portion of the suspension arm is horizontal. The mercury should then fall gradually and the instrument will be ready for observation in about two hours; this also allows time for the instrument to take up the temperature of its surroundings. 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 undue violence must not be used.

Fig. 4 shows a marine barometer (*a*) housed in its case when in harbour and (*b*) in sea position. The case should be firmly secured to the bulkhead. The socket is screwed near the bottom of the case and a clip "A" is provided to hold the barometer in its housed position when in port. (*Note.*—the short screws holding the socket in the box are insufficient to hold the weight of the barometer when in the sea position. These short screws should be replaced by longer ones, at least $1\frac{1}{2}$-inch, screwed through the socket and box, and into the bulkhead.) A hook should be fitted to secure the lid open while at sea.

Taking down the barometer. Whenever a barometer has to be unshipped and placed in its box, first lift the instrument out of its socket 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, which might cause air to find its way into the upper end of the tube, even if they did not damage the instrument.

Care of the barometer. The barometer should be kept clean and dry. The gimbal screws should be examined occasionally, as they are usually made of brass and in the course of time may wear through, owing to the movement of the instrument at sea, particularly in small ships. Dust, particularly on the Gold slide, should be removed by gently brushing the instrument with a camel-hair brush or a soft cloth. Metal polish should *never* be applied. A very little clock oil or log oil may occasionally be used for lubrication.

If the rack and pinion of the Gold slide become very stiff they may be overhauled 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 the slider. Re-assemble, 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 scales should not be touched during this operation.

READING THE MERCURY BAROMETER

Temperature of the instrument. This is read to the nearest whole degree on the scale of the attached thermometer. The observation should be made immediately on reaching the instrument in order that the thermometer should be affected as little as possible by bodily heat radiated from the observer.

Height of the mercury column. 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, when in line, appear just to touch the uppermost part of the domed surface of the mercury. If a piece of white paper is placed behind the instrument

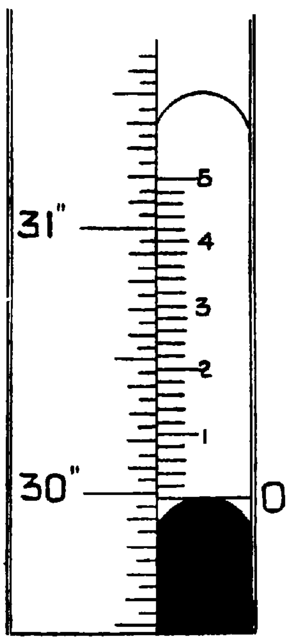


FIG. 16

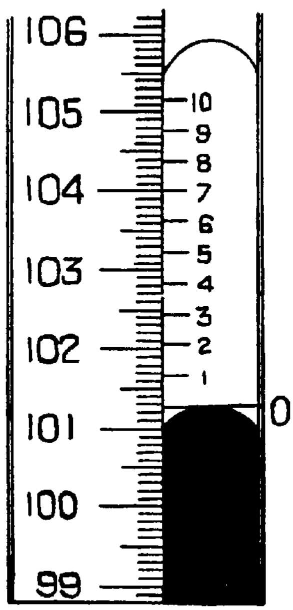


FIG. 17

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 mercury is not perfectly pure, it may happen that, when the barometer is falling, the top of the mercury column no longer shows a domed (convex) surface. The surface may be flat or even concave. The exact setting of the vernier is much more difficult under these conditions. The observer should move the vernier slowly downwards, keeping its lower edge and the lower edge of the sliding piece at the back in line as well as he can, till the white background just disappears at the centre of the tube. He should then move his eye a little up and down to make sure that the white background still remains invisible at the centre of the tube, before he takes the reading. In this case a bright white background, for example a piece of white paper held behind the top of the mercury column, is almost essential.

Figs. 16 and 17 illustrate the process of reading the vernier, which is done in the same way as that of a sextant. Fig. 16 shows an inch barometer, the reading being 29·990 inches, while Fig. 17 shows a millibar barometer, the reading being 1012·7 millibars.

Accuracy of reading. It is important that barometer readings for transmission by radio or for entry in a meteorological logbook be carefully made. An erroneous pressure reading may considerably mislead a forecaster, and the error may have serious consequences for ships at sea, particularly in tropical storm areas. Some possible sources of error are shown below.

ERROR DUE TO THE GOLD SLIDE BEING IMPROPERLY SET. In all cases the Gold slide (*see* page 8) should be reset before reading the barometer. This is particularly important where the ship is changing her latitude.

ERRORS DUE TO PARALLAX. 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. Whether the eye is too high or too low, the reading will be too high. If the eye is too high, only the front of the vernier can be seen and this will be in line 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 in line with the top of the mercury column and the eye, the lower front edge of the vernier being indistinguishable. (*See* Fig. 18.)

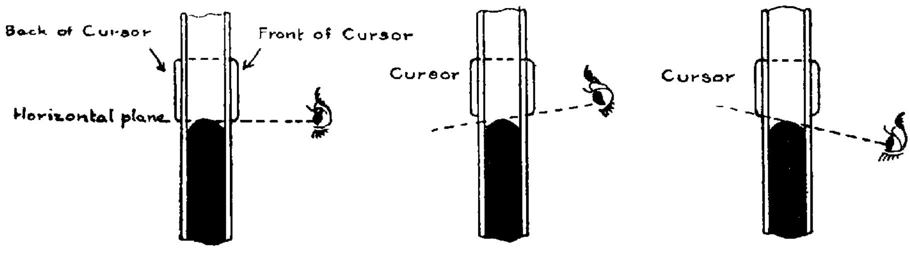


FIG. 18

Correct position of the observer
The eye of the observer and the lower edges of the front and back of the cursor are all in a horizontal plane tangent to the meniscus

Incorrect positions of the observer
In neither case is the eye of the observer in the horizontal plane tangent to the meniscus, and the result in both cases is too high a reading

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., ·05 inch or ·10 inch; such an error is usually due to making a mistake in counting the number of divisions on the fixed scale. The only means of guarding against such errors 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 last figure (tenths of a millibar or thousandths of an inch); in the check reading attention should be concentrated on the figures of higher value.

ERROR DUE TO WIND. It has been found that strong winds, blowing near the barometer, may affect the indicated pressure. When such winds are blowing during an observation, therefore, the doors of the charthouse in which the barometer is hung should be kept closed. This applies just 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*) Oscillations of the mercury caused by the pitching and rolling of the ship.

(*b*) Oscillations caused by the swinging of the instrument about its point of support.

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

(*d*) Variations of atmospheric pressure caused by the change of height of the ship due to her vertical motion on the waves.

The mean reading should be recorded, to obtain which the vernier should be set by eye midway between the highest and lowest positions of the mercury column. The pumping is often very irregular, and in order to get an accurate mean the observer is advised to 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 obtained were 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.

THE ANEROID BAROMETER

The aneroid barometer was invented in 1848. It 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 is more useful in showing changes in pressure than is a mercurial barometer, but in general it is less accurate. A precision type of aneroid, however, has an accuracy about equal to that of the Kew-pattern marine barometer (*see* page 1), provided that it is regularly checked against a standard mercurial barometer. Arrangements are now in hand in the U.K. for precision aneroids to be issued to voluntary observing ships.

Corrections to aneroid readings. Aneroid barometers of good quality are compensated, by the manufacturers, for such changes in temperature as they are likely to experience, either by leaving a calculated small amount of air in the vacuum chamber, or by the use of a bimetallic lever. Such aneroids, therefore, do not require correcting for temperature. No aneroids require correcting for latitude, as the principle on which they are based is the balancing of atmospheric pressure by the elasticity of metal, so that the force of gravity does not come into the picture.

The only corrections which should be applied to an aneroid reading are those for *index error* and for *altitude*. (*See* Tables V, X, XI.)

Precautions necessary with an aneroid. The instrument should be placed where it is not liable to sudden jars which may alter its index correction. It should be tapped gently before a reading is taken, as the pointer is liable to stick.

The aneroid requires frequent careful comparisons with barometers whose accuracy can be relied on, as changes in the elasticity of the metal of which the vacuum chamber is composed may cause quite appreciable variations in the index correction of the instrument. If the vessel does not carry a mercurial barometer with which the aneroid may be compared, every opportunity should be taken, when the vessel is in harbour, of making a comparison with a reliable mercurial barometer. If this is not possible, it may be possible to check the aneroid, when in harbour or near the land, by listening in to meteorological broadcasts, which frequently contain pressure readings taken at standard times

Date and Port	Temp. °F.	Range of Readings		Actual Reading	Error	P.M.O. or Agent
		ins.	mb.			
		28.00	948			
		28.50	965			
		29.00	982			
		29.50	999			
		30.00	1016			
		30.50	1033			
		31.00	1050			

FIG. 19. Record card for error of aneroid barometer (Form 908)

at a selection of meteorological stations. The correction for height must, of course, be applied to the reading of the aneroid before any comparison is made with broadcast data.

It may be mentioned here that all Port Meteorological Officers and Merchant Navy Agents and many harbour and mercantile marine offices have a standard barometer which is available for such comparisons, or a reading may be obtained by telephone from the nearest aerodrome. A record should be kept of such comparisons; this will be useful in assessing the reliability of the instrument and the correction to be applied when at sea. Fig. 19 shows the record card supplied by the Marine Division of the Meteorological Office to ships of the Observing Fleet, or to any other ship on request.

Adjustment of aneroid readings. The reading of an aneroid may be corrected, if desired, by means of the adjusting screw at the back. Whenever such an alteration of the index correction is made, the fact should be noted, with the date. Such adjustments should, however, only be made if the index correction becomes too great. Small changes in the index error of the instrument should be allowed for by altering the correction to be applied to the readings.

THE BAROGRAPH

The portable barograph is shown in Fig. 5. It is constructed on exactly the same principle as the aneroid barometer, but has a series of small metal vacuum boxes with corrugated surfaces instead of the single box of the aneroid. This series of boxes is connected through a series of levers with a pen arm 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.

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.

Small irregularities in the trace, known to the meteorologist as "embroidery", sometimes associated with showers and not infrequently with a transient increase of wind, are interesting features in barograms, showing the close connection existing between weather changes and variations in atmospheric pressure.

Care of the barograph. The barograph is a delicate instrument and must be handled carefully. 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.

Friction occurs between the pen and the paper on which it writes. The pressure of the pen on the paper should be reduced to the minimum consistent with a continuous trace; this pressure should be tested from time to time.

In the older type of instrument 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 the barograph now, 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. In Fig. 5, A denotes the gate suspension, which is suitably adjusted before issue.

Excess of ink in the pen should be avoided. Do not 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 become inked, it should be washed and slightly oiled. A thin, clear trace on the chart should be aimed at. The pen should be 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 be improved by drawing the point once or twice along an oil stone, but any oil should afterwards be removed.

The barograph, when used on board ship, should be located in a position where it will be least affected by concussion, vibration or movement of the ship.

Setting of the barograph. 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 at the end of this book.

In the type of barograph shown in Fig. 5, the setting is made by adjusting the height of the fulcrum of the principal lever B by means of the milled head screw C 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.

Standardizing the barograph. Like the aneroid barometer, and for the same reason (the possibility of changes in the elasticity of the metal of which the vacuum boxes are composed), the readings of the barograph should be compared at least once a week with those of a mercury barometer, duly corrected. The most suitable time is when the weekly chart is changed, and the reading of the barometer, together with the date and Greenwich Mean Time, should be entered up on the chart. If the ship does not carry a mercury barometer, every other opportunity of making such a comparison should be taken.

Adjustments to the barograph should not be made too frequently, but only if its readings become appreciably different from those of the barometer, and a note of the adjustment should be made on the chart, giving time and date.

The barograph clock and chart. The barograph is fitted with an 8-day clock which rotates a drum, round which the chart is fixed. The chart must therefore be changed weekly, the clock being wound at the same time. Before the chart is put on the drum, the date and time should be entered on it in pencil. Time marks should be made each day at 1200 Greenwich Mean Time, and just before the chart is removed, the times being entered on the chart, for the purpose of correcting the time scale should the barograph clock run fast or slow. The barograph should be kept to Greenwich Mean Time throughout the voyage. For the purpose of making time marks, barographs have a small button on the outer case which, when depressed, acts on a rubber roller (D in Fig. 5), which lsightly moves the pen arm vertically.

Before fixing the chart on the drum, the latter must first be lifted from the clock by removing the key and unscrewing the milled nut which holds the drum in place. The chart is then placed round the drum where it is held in position by two short spring clips that hold its bottom and top edges. When fixing on the drum, care must be taken that the horizontal lines printed on the chart are parallel to the flange at the base of the drum. If the chart is carefully cut, so that its lower edge is parallel to the horizontal lines, this will be the case when the edge of the chart is in contact with the flange all round the drum. If the chart is not accurately cut, allowance should be made for the fact by seeing that the horizontal lines are continuous where the two ends of the chart overlap while one end of the lower edge of the chart touches the flange. As the length of the chart is slightly greater than the circumference of the drum, there is some overlap when the chart is put on the drum. The last portion of the chart should come on top of the first portion, so that if the chart is not changed at the end of seven days, the pen will not catch on the edge of the chart and tear it, or damage itself.

The drum is then replaced on the clock and the whole is rotated till the pen records the correct Greenwich Mean Time. In order to avoid time errors that might be caused by backlash in the teeth of the clock gears, the final movement of the drum, when setting it, should be in the opposite direction to that in which it normally rotates.

Before the chart is taken off the drum, the pen must be moved away from the paper by means of the lever provided on the instrument. The pen must be filled with ink weekly, using the ink-bottle and filler supplied.

The open-scale barograph. To report barometric tendencies with the accuracy required for synoptic observations, it is desirable that open-scale barographs be used. These are barographs in which, for a given change of pressure, the pen moves over a considerably greater distance, up or down, than in the smaller barograph. Records from such barographs, when carried on board ships, have often been unsatisfactory, because the trace is not a fine line, but a ribbon of appreciable width. This is due to the greater sensitivity of the instrument and to vertical movements of the pen caused by transient factors such as vibration, temporary pressure changes due to gusts of wind, the rolling and pitching of the ship and its rise and fall among the waves.

An oil-damped open-scale barograph (Marine Mk. 2) is used aboard ships. In this instrument, the vacuum chamber is contained in a brass cylinder filled with oil and as it expands or contracts, forces oil out of this cylinder, or sucks it in, through a small hole. In this way small movements of the pen are damped out and only the major movements are shown on the chart. As a further precaution against vibration, the instrument is supported on rubber pads.

These barographs are used aboard most Selected Ships, but the smaller barograph is used in ships where there is insufficient space for the open-scale type.

THE CHANGE OR TENDENCY OF THE BAROMETER

The change or tendency of the barometer, always a valuable observation to seamen, is also of considerable value to the forecaster.

The barometric tendency, by international usage, is defined as the change in the barometric pressure in the last three hours. It is required in radio weather messages and is read off from the barograph. The position of the pen on the chart at the time of observation, and the reading of the trace three hours earlier, should be noted, if possible to the tenth of a millibar. The difference between these two readings will give the tendency. It should not be taken as the difference between two readings on the barometer, but should always be read off from the barograph, since the barograph method is less liable to error, and anyway the barometer is not customarily read every three hours at sea. Also, mistakes in reading a barograph are more likely to be detected, owing to the continuous availability of the trace.

It is essential that the barograph trace should be fine and sensitive, with the instrument free from mechanical faults such as sticking, and as far as possible not vitiated by the effects of vibration, or of unequal heating due to sunshine or nearby sources of heat.

Allowance for course and speed. To estimate the true tendency of the barometer reported from a ship under way, a meteorological service needs to allow for course and speed, and, therefore, in a ship's weather message provision is made for reporting the course and speed of the ship. This allowance for the course and speed of the ship should *not* be made by the observer on board ship when reporting tendency in a weather message; it is made as a matter of routine at the meteorological office ashore when the observations are plotted.

The characteristic of the barometric tendency. This is the name given to the coded description of the nature of the changes the pressure has undergone in the last three hours. It is generally required in ships' wireless reports, and is read off from the barograph trace. The diagrams in Fig. 20 show the various pressure changes that might have to be reported, together with the code figures to be used in reporting them.

The codes to be used in reporting the barometric tendency and characteristic are given, with other codes, in the *Ships' Code and Decode Book* (M.O.509) and in the *Admiralty List of Radio Signals, Vol. III.*

The diurnal variation in the pressure. Superposed upon its irregular variations due to changes in the weather, the barometric pressure has a regular rise and fall twice a day, the maximum values occurring at about 10 and 22 hours and the minimum values at about 4 and 16 hours, local time. In temperate regions the amplitude of these diurnal variations is comparatively small, so that they are usually lost in the much greater irregular variations of these regions, but nearer the tropics, the amplitude of the diurnal variation increases and the magnitude of other changes in general decreases, so that the diurnal variations become very marked and can be clearly seen, day after day, on a barograph chart. In these regions, therefore, barometric changes do not indicate changes in the weather, unless they remain considerable *after the diurnal variation has been allowed for.*

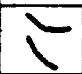
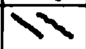
Code Figure	Trace	Description of Curve	Pressure *now*, compared with 3 hours ago
0		Rising, then falling Rising, then falling	The same Higher
1		Rising, then steady Rising, then rising more slowly	Higher
2		Rising, (steadily or unsteadily)	Higher
3		Falling, then rising Steady, then rising Rising, then rising more quickly	Higher
4		Steady	The same
5		Falling, then rising Falling, then rising	The same Lower
6		Falling, then steady Falling, then falling more slowly	Lower
7		Falling (steadily or unsteadily)	Lower
8		Steady, then falling Rising, then falling Falling, then falling more quickly	Lower

FIG. 20. Code numbers used to indicate the characteristic of barometric tendency

In the Monthly Meteorological Charts prepared by the Marine Division of the British Meteorological Office for the Atlantic (M.O. 483), the Western Pacific (M.O. 484), the Eastern Pacific (M.O. 518), the Indian Ocean (M.O. 519), and in the meteorological text of the appropriate Admiralty sailing directions, tables are given, showing, for these oceans, between latitudes 0° and 20°, N. or S., the corrections for diurnal variation to be applied to the observed pressure to reduce it to the mean for the day, and the average values of the barometric change in an hour, throughout the day, due to the diurnal variation. Corresponding figures do not differ greatly from one ocean to another or between north and south latitudes and have been averaged in this handbook to give values that will be approximately correct in any ocean for the two bands of latitude 0°–10°, N. or S., and 10°–20°, N. or S. These values are shown in Tables XIII and XIV (*see also* Fig. 21). In the tropics, should the barometer, after correction for diurnal variation (Table XIII) be as much as 3 millibars (approximately 0·1 inch) below the monthly normal for the locality, the mariner should be on the alert, as there is a distinct possibility that a tropical storm has formed, or is forming. A comparison of subsequent hourly changes in his barometer with the corresponding figures in Table XIV will show whether these changes indicate a real further fall in pressure, and if so, its amount.

When the observer on board ship is reporting barometric tendency, or entering it up in his log, he should not *correct it for changes due to normal diurnal variation.* This correction, like the correction for course and speed of the ship, is made, if necessary, as a matter of routine by the meteorological office receiving the observations.

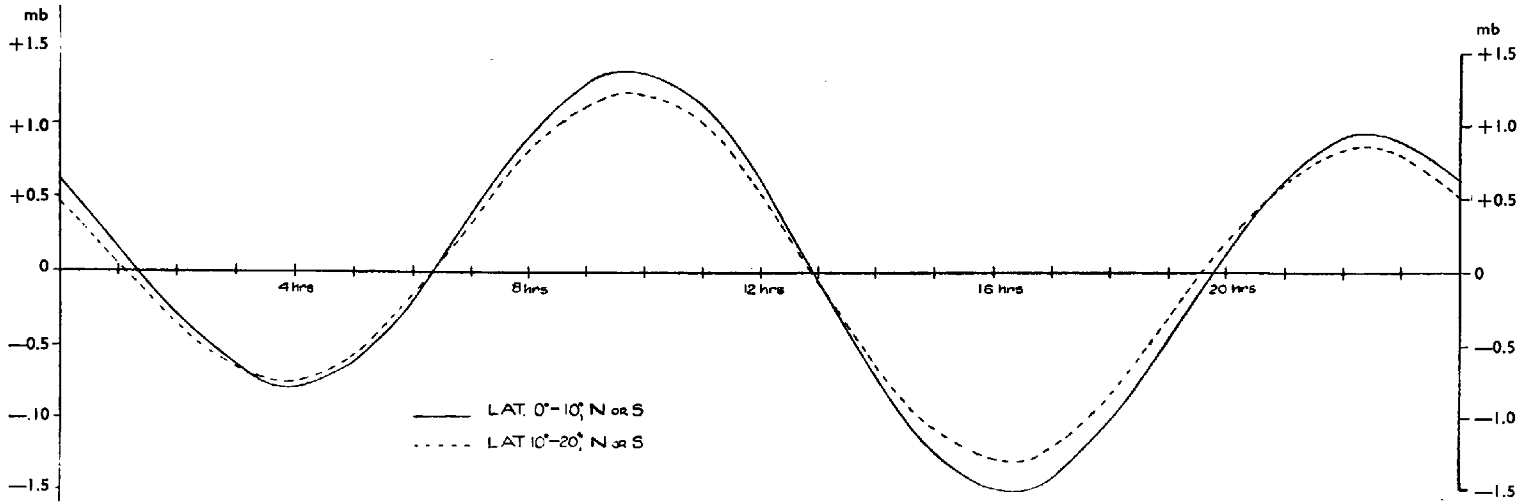


FIG. 21. Mean diurnal variation of pressure

CHAPTER 2

Dry and Wet Bulb Thermometers, Stevenson Screens. Aspirated and Sling Psychrometers. Sea Thermometers

A thermometer is an instrument for measuring the temperature of a substance. In the case of gases or liquids the mercury thermometer is a convenient instrument to use. It consists of a glass tube of very small bore, having a bulb at one end filled with mercury, while the other end of the tube is sealed. Almost all substances expand when they are heated and contract when they are cooled, but they do not all expand or contract at the same rate. 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 considerable expansion of the thread 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 observation of 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 and 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.

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 of 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 temperatures of the polar regions. Mercury freezes at about –39°C. (–38°F.) while alcohol freezes only at –130°C. (–202°F.), though it becomes a thick liquid and therefore useless for thermometric purposes, at –90°C. (–130°F.).

Graduation of thermometers. The earliest known graduation of a thermometer was that made in 1701 by Sir Isaac Newton, who divided the range of temperature between the freezing point of water and the temperature of the human body into twelve degrees.

The principle of thermometric graduation is as follows. The temperature at which pure ice melts is always the same and pure 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 1013 mb. or 29·92 inches of mercury. The four systems are as follows:—

(1) THE CELSIUS (FORMERLY "CENTIGRADE") SCALE. In 1742, Celsius, a professor in Upsala, suggested that the freezing point be called 100° and the boiling point 0°. The Celsius scale now is identical with this except that the figures are reversed, the freezing point being 0° and the boiling point 100°. The Celsius scale is in general use in most European countries. It is indicated by the letter C., thus "15°C."

The Director-General of the Meteorological Office agreed, in 1960, that U.K. Selected and Supplementary Ships should record and report temperatures in degrees Celsius as soon as new Celsius thermometers could be manufactured, tested, and issued to all of these ships. This changeover arose from a recommendation of the World Meteorological Organization that the Celsius scale be used instead of Fahrenheit in coded messages for international exchange.

(2) THE FAHRENHEIT SCALE. The melting point of ice is 32° and the boiling point of water 212°, the space between being divided into 180°. 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.". The zero of this scale, 0°F., represented the lowest temperature it was possible to produce artificially at the time the scale was devised.

(3) THE REAUMUR 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 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 Celsius scale must be written as —5°C. The Absolute scale of temperature is the Celsius 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 calculations of the pressure and density of air are facilitated. The zero of the Absolute scale (—273°C. or —459°F.) was not chosen at random. It represents approximately the temperature at which any substance has no heat at all. Temperature on the Absolute scale is proportional to the actual amount of heat contained in a body, independent of reference to such temperatures as the freezing and boiling points of water.

Conversion of thermometer scales. To convert Celsius readings to Fahrenheit use the following rule:—Multiply by 9/5 and add 32. Similarly, to convert from Fahrenheit to Celsius, subtract 32 and multiply by 5/9. From Fahrenheit to Absolute, proceed as for Celsius and add 273. Table XV gives the values on the Celsius and Absolute scales corresponding to each degree Fahrenheit, from 0°F. to 119°F.

Mounting the thermometer. In order to minimize the breakage of thermometers, mahogany protectors are supplied for marine use by the British Meteorological Office, as illustrated in Fig. 6b.

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, so that the ventilation of the bulb shall be reduced as little as possible by the guard.

Reading the thermometer. The thermometer should be read with care. Though the Fahrenheit scale is graduated only to whole degrees*, the reading on both Celsius and Fahrenheit thermometers should be given by estimation to the nearest tenth of a degree, or, if that is not practicable, to the nearest half degree. This is not only necessary for general accuracy but also for practical reasons, i.e., the computation of relative humidity and the dew point (*see* page 25), and the determination of the difference between air and sea surface temperatures. In a coded radio weather message, however, the temperature is required only to the nearest degree. When the actual reading comes half way between two degrees, i.e., at 0·5, the odd degree should be used for the radio weather message, e.g., 53·5° would be transmitted as 53.

When reading a thermometer, care should be taken to keep the eye at the same level as the end of the column, otherwise there will be an error due to parallax.

The mercury column of a thermometer occasionally separates in one or more places. The thermometers should therefore be examined before each observation to see if the column is continuous. If there is any break in the column, take the instrument down, swing it briskly at arm's length with the bulb end away from you till the column is again continuous, and replace it. After this, give the thermometers another 10 minutes to pick up the correct temperatures again, before taking the observation.

Thermometers should be kept clean. In damp weather any moisture should be removed from the dry bulb a little while before taking the reading. The graduations on the glass may in time become indistinct. Since the marks are cut in the glass, a rub with an ordinary lead pencil, or a wipe over with Indian ink, will make the graduations clear again.

THE DRY AND WET BULB THERMOMETERS

An instrument for measuring the humidity of the air is called a hygrometer. There are several kinds of hygrometers, but the form in common use, the dry and wet bulb thermometers, also known as Mason's hygrometer or a psychrometer, is the simplest. 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 firmly 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 other ends leading 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.

The principle of the dry and wet bulb thermometers is as follows: 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

*Ships' Celsius thermometers will be graduated in half degrees.

bulb and the mercury it contains; the thermometer consequently indicates a temperature lower than that of the air. If the air becomes drier, the rate of evaporation increases and the wet bulb temperature falls. The depression of the wet bulb can reach over 20°C. (36°F.) in a hot dry climate, such as that of Khartoum during part of the year. It sometimes amounts to 10°C. (18°F.) in England, but at sea the difference seldom reaches 5°C. (9°F.). When the humidity of the atmosphere is high, during or just before or after rain, when fog is prevalent, or when dew is forming, there is little or no evaporation and the two thermometers give the same, or very nearly the same, reading.

We may sum up the facts about humidity and the dry and wet bulb thermometers as under:—

Humidity.	*Evaporation.*	
High ..	Weak ..	Dry and wet bulbs read almost the same.
Low ..	Intense ..	Wet bulb reads much lower than dry.

Muslin and thread for wet bulbs. The wet bulb thermometer needs careful attention in order to get correct readings. The bulb of this thermometer should be covered with a single thickness of thin *clean* muslin or cambric, which is kept moist by attaching to it a few threads of darning cotton (No. 8) dipping into the small reservoir of water placed near it.

From the muslin provided, a small piece should be cut, sufficient to cover the bulb, and should be stretched smoothly over it, creases being avoided as far as possible. The muslin is kept in place by attaching the cotton wick in the

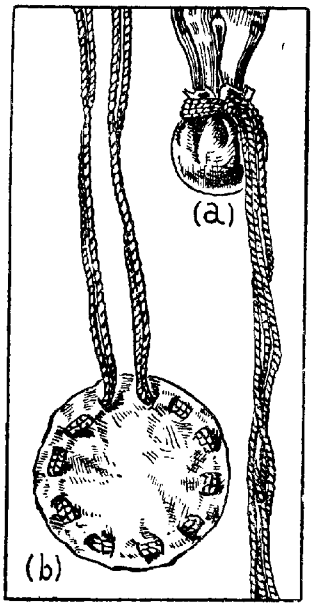


FIG. 22.
(*a*) Wet bulb with ordinary muslin and wick
(*b*) Muslin cap

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 (Fig. 22a).

Muslin caps ready threaded with cotton are sometimes supplied. These are slipped over the bulb, and the thread is then pulled tight and tied (Fig. 22b). 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 from the wick at the lowest point of the curve until the reservoir is emptied.

Precautions necessary in taking wet bulb observations. To get correct readings the muslin must be damp, but not dripping. If it is too wet, the reading of the thermometer will be too high. If it is not wet enough, the reading will again be too high. The former defect may be cured by cutting down the number of threads supplying moisture to the bulb. Take care, however, that this remedy does not make the muslin too dry.

It is important that the water should be pure. Ordinary water contains substances in solution and, if such water is used, as it evaporates it deposits these substances on the thread and muslin; the free flow of water to the muslin and its evaporation therefrom are checked, and the thermometer may read too high. Moreover, the rate of evaporation from impure water may differ appreciably from that for pure water. It is therefore desirable that distilled water should be used. This may be available from the ship's radio office, but is liable to become contaminated with acid in the course of a voyage. If, therefore, sufficient distilled water can be collected from the ship's radio office at the commencement of a voyage, this should be used. If distilled water is not available, condenser water from the engine-room may be used.

The muslin should be changed at least once a week and more often if it be dirty or contaminated by salt spray. 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 new ones. It is advisable to do this in any case after bad weather. If it is found that an encrustation of lime or other impurity has formed on the thermometer bulb, this should be scraped off. A note should be made in the "Remarks" column of the meteorological logbook whenever the muslin is changed.

Wet bulb temperature higher than dry bulb. If the reading of the wet bulb thermometer is above that of the dry bulb, make sure first that there is no error in reading. Then examine the muslin and thread. Make sure that they are clean and moist, but not too wet. See that the ventilation to which the thermometer bulbs are exposed is adequate. If no fault is found, book the temperatures as they have been read and note in the "Remarks" column that the reading has been checked, the muslin and thread examined, and that the ventilation is adequate.

Except as a result of a defect, it is impossible for the wet bulb to read higher than the dry if the temperature is steady, and if the wet bulb is above freezing point (see below). If the temperature is changing, however, one of the thermometers may be more sensitive than the other and follow the temperature changes with less lag. Under such circumstances it is possible that the wet bulb thermometer may sometimes be found to be reading higher than the dry bulb. In such a case the wet bulb should be taken as correct and the dry bulb reading adjusted to equality with the wet bulb. If this phenomenon occurs frequently and the fault cannot otherwise be traced, it may lie in one of the thermometers. These should be examined and if there is nothing obviously wrong, the spare thermometer should be brought into use to replace first one, and then (if necessary) the other thermometer, till satisfactory observations are again obtained.

Wet bulb readings 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 one of water. If the muslin is dry it must be given an ice coating by wetting it slightly with ice-cold water, using a camel-hair brush or by 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 0°C. (32°F.) until all the water has been converted to ice. It then begins to fall gradually to the true ice bulb reading. No reading must be recorded until the temperature of the ice 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 results as long as it lasts.

It must be pointed out that super-cooled water may exist on the wet bulb at temperatures well below freezing point and that, if this is not noticed by the observer, serious errors will occur. The freezing can be started by touching the wet bulb with a snow crystal, a pencil, or other object.

Measures of humidity. Dew-point and relative humidity can be obtained from the readings of the dry and wet bulb.

The *dew-point* is the temperature at which dew would begin to form on the bulb of the thermometer if the air were cooled down, the amount of water vapour in it remaining unchanged. Tables XVI to XIX give the dew-point for dry bulb temperatures and depressions of the wet bulb. The depression of the wet bulb is the difference between the dry and wet bulb readings. The amount of this depression depends on the ventilation to which the wet bulb thermometer is subjected and tables XVI and XVIII are to be used for observations in which the thermometers are exposed in the standard Stevenson screen. Since the amount of evaporation from ice and water surfaces is not the same, lines are ruled in the tables to call attention to the fact that above the line evaporation is going on from a water surface while below the line it is going on from an ice surface. Intermediate figures must therefore be obtained by extrapolation.

In order that values of the wet bulb depression of the necessary accuracy shall be available, it is especially desirable at low temperatures that the thermometers should be read to the tenth of a degree, or, at least, to the nearest half degree. This is because dew point changes rapidly at low temperatures with changes in wet bulb depression.

The *relative humidity* is the amount of water vapour actually present in the air, expressed as a percentage of the amount the air would contain at that temperature if it were saturated. In the British Meteorological Office a relative humidity of 95% is taken as a guide in determining whether to report mist or haze (*see* tables on page 45).

THE STEVENSON SCREEN

Dry and wet bulb thermometers are normally exposed, at sea, in a standard marine type "Stevenson screen". This is a box or compartment, the inside of which is protected from the sun and rain, on all four sides, by "jalousies" or louvres, which, however, let the air in freely. Various patterns of Stevenson screen are made ; the types used at sea (shown in Fig. 7), are known as portable Stevenson screens.

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 does the air. When the thermometer, however, is protected by a screen, the bulb only changes temperature through exchange of heat, by conduction or radiation, with the air in contact with it, so that the bulb and this air tend to attain the same temperature. If the ventilation is adequate, fresh supplies of air are constantly passing over the bulb and the temperature of the latter approximates closely to that of the outside air.

The thermometer screen is equally necessary at night. If the thermometer were in the open, the bulb would radiate away its heat until it fell to a temperature at which its loss of heat by radiation was just compensated by its gain of heat by conduction from the surrounding air, which would now be distinctly warmer than the bulb as air radiates away its heat only slowly. When the thermometer is in the screen, however, the heat radiated from its bulb falls mainly on the inside walls of the screen, which in their turn throw off heat, some of which falls on the bulb. The loss of heat due to radiation is thus minimized and, where the ventilation is adequate, is compensated by conduction from the fresh supplies of air constantly passing through the screen.

Position of Stevenson screen. The screen should be placed in the open air and, for convenience in reading the thermometers, about 5 feet 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. It should be out of the way of unauthorized persons; it must not be exposed to suddenly varying conditions due to causes within the ship, such as draughts of air from boilers, engine-room, etc. The lighting at night should be so arranged that it cannot affect the temperature of the thermometers. By day or by night the light should come from behind or from the side of the observer. The thermometer screen is usually placed on the bridge.

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 of that affected by heat from the ship, and therefore the weather side of the ship is most suitable. The most suitable location 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 relative wind is light. The choice of the bridge will avoid some of these sources of heating. (*See* Fig. 23.)

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

Setting up the thermometers. To set up the thermometers in the screen, the instruments in their protectors are secured into position and the wick from the wet bulb is well immersed in the water vessel. The water vessel is placed in the holder provided for it near the wet bulb.

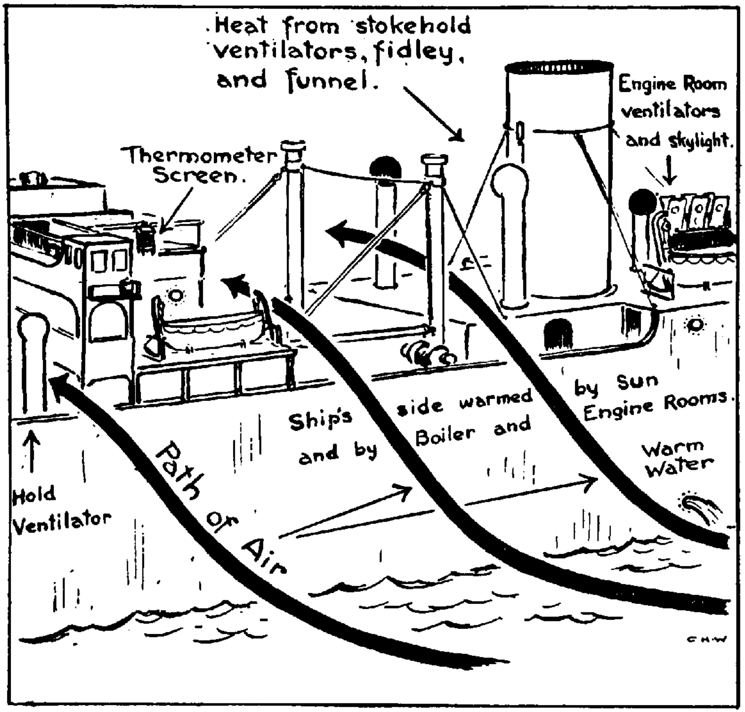


FIG. 23. Various sources of local heating in a merchant ship

ASPIRATED* AND SLING PSYCHROMETERS

The rate of evaporation from a wet bulb thermometer and hence the amount of its depression below the dry bulb thermometer depend on the rate at which air is passing over it. In a Stevenson screen, the ventilation depends on the strength and direction of the wind outside the screen and, as these are constantly varying, there is some uncertainty in the determination of humidity from such observations. For a given humidity, as the speed of the wind flowing past the wet bulb increases, the depression of the wet bulb also increases, till it reaches a

*Latin—*aspirare*, to blow upon.

maximum value when the wind is about 7 knots. Any increase of the wind above this value leaves the amount of depression practically unchanged. If, therefore, it can be arranged that the speed of the wind flowing past the wet bulb never falls below 7 knots, a much more precise measurement can be made of the humidity.

The fan-aspirated psychrometer. This instrument is designed to give accurate measurements both of temperature and humidity. A clockwork, electric, or hand-driven fan draws air past the dry and wet bulb thermometers at a rate greater than 7 knots. This operation is called "aspiration" of the bulbs. Each bulb is surrounded by highly polished metal tubes as shields which serve to minimise the errors due to solar and other radiation. Care should be taken that the instrument is not pointed towards a source of radiation as the shielding is not very effective for axial radiation.

The whirling or sling psychrometer. In this instrument the ventilation is provided by whirling or rotating the thermometers, which are mounted on a suitable frame for that purpose. This type of instrument is not very satisfactory for use on board ship as the readings must be taken in a place sheltered from direct radiation from the sun, and very rapidly, to avoid error due to indirect radiation, which may be considerable at sea. It may be difficult to find a place on board ship which is sheltered from direct radiation from the sun and at the same time sufficiently exposed to the air coming from windward of the ship.

Tables XVI and XVIII, at the end of this book, which are used for computing dew point from dry and wet bulb readings in a Stevenson screen, are based on the average ventilation inside such a screen, which is much less than that due to a wind of 7 knots. Special humidity tables are therefore required to compute dew point from the readings of an aspirated or sling psychrometer. These are printed as Tables XVII and XIX. As with Tables XVI and XVIII, lines are ruled to draw attention to the fact that above the line evaporation is going on from a water surface, while below the line it is going on from an ice surface, and that, therefore, interpolation must not be made between figures on different sides of the line.

THE APPLICATION OF HYGROMETRIC OBSERVATIONS IN THE CARE AND PROPER VENTILATION OF CARGO

Sweating, or the deposition of moisture, is a frequent cause of damage, both to cargo and to the internal structure of a ship, and it is desirable to keep a record, not only of the temperature and humidity of the outside air through which the ship is passing, but also of the temperature and humidity of the air in each hold, as far as this is practicable. Although deductions from such data will vary according to the nature of the cargo and the construction of the ship, experience of these observations should help the seaman to judge whether, at any particular time, his cargo and the structure of his ship are in danger of damage by moisture and whether conditions are likely to be improved, or the reverse, by ventilation.

SEA TEMPERATURE BUCKETS

For many years it was the standard practice, aboard British Voluntary Observing Ships, to use an ordinary canvas bucket to obtain a sample of sea water for taking the sea surface temperature. These canvas buckets were originally made aboard the ships but, since 1947, the Meteorological Office has supplied a special canvas bucket fitted with a spring lid opening inwards at the top of the bucket. This opens to admit water when the bucket is towed immersed, and closes again when the bucket is lifted from the water, thereby preventing spillage (Fig. 8). A further advantage is that evaporation from the surface of the water in the bucket, and the resultant cooling of the water, is somewhat reduced. Associated with the canvas bucket, an ordinary mounted thermometer, fitted with a sea thermometer protector (*see* Fig. 6c), is used to take the temperature. The protector has a guard round the bulb to minimise risk of breakage, and this guard is closed in and forms a reservoir for retaining a small quantity of sea water round the bulb, should it be necessary to remove the thermometer from the bucket to read it.

In 1958, an improved type of bucket, made of canvas-reinforced rubber, and incorporating a new sea thermometer protected by a sheath, was introduced for use aboard ships under way. The canvas bucket is still used aboard stationary or drifting vessels (i.e. light-vessels and ocean weather ships maintaining station). This new rubber bucket consists of two concentric lengths of canvas-reinforced rubber hose fastened at the top to a gunmetal mouth and sealed at the bottom with a solid teak plug (Fig. 9a). Contained within the bucket is a lens-fronted mercury-in-glass thermometer mounted in a brass tubular sheath which is fitted axially into the bucket. The brass sheath, which is cut away to allow the scale of the thermometer to be read and for the free circulation of the sea water around the bulb, can be partially withdrawn to take a reading (Fig. 9b). A polythene or rubber washer at the foot of the sheath acts as a stop to avoid the complete withdrawal of the sheath and thermometer from the bucket, and serves as a plunger, ensuring that the bulb of the thermometer remains immersed in the sea-water sample. The reinforced mouth of the bucket is fitted with a stout brass or galvanised wire sling to which a suitable rope lanyard (say a length of log-line or 15-thread pointline) should be attached for heaving. The bucket is also fitted with a retaining band or hose type clip around the outer case gripping the teak plug within.

The complete bucket is so designed that when it is dragged through the water circulations are set up, firstly through the annular spaces between the two lengths of hose and secondly between the inner hose and thermometer, which rapidly brings the temperature of the whole to that of the surrounding sea surface. The bucket is then brought inboard, and the sheath partially withdrawn to take the reading; this should be taken as soon as possible after the bucket is brought inboard, to avoid any change of temperature of the retained water sample due to sea-air temperature differences.

This bucket has been specifically designed to stand up to the severe treatment to which it is likely to be subjected in use in all types of weather aboard ship, and especially with the faster vessels in mind, where the wear and tear on the canvas bucket (and thermometer) led to a large replacement rate. The longitudinal area of cross section is very much reduced and the physical strength of the "walls" has been increased. The principle advantages of this construction compared with the conventional canvas bucket are: less likelihood of inaccurate temperatures being obtained, greater strength and longevity, considerable reduction in the "drag" whilst towing, and it takes up less room in storage.

The annular space between the two lengths of hose also tends to act as an insulator to lessen any tendency to change of temperature of the sample after it has been hove on deck.

The initial period in which this new bucket was used in Selected Ships was marked by an abnormal number of breakages of the thermometer. Most of these were traced to the fact that the cast had been made from the bridge instead of from the foredeck, as had been the custom with the older type of bucket, Improvements have since been made in the seating of the thermometer, but it should only be cast from the bridge when the ship is relatively steady and the bucket thus stands less risk of getting bumped on the ship's side while being lowered or hoisted.

Precautions necessary in taking observations. If there seems to be a great difference between sea and air temperature, keep the bucket in the sea long enough to ensure that it assumes the same temperature as the water. Take care that it is immersed forward of all discharge pipes.

(1) CANVAS BUCKET. Place the thermometer in the bucket immediately the water has been drawn. Keep the water in the bucket well stirred by moving the thermometer about. The thermometer should be moved up and down so as to change the water in the reservoir surrounding the bulb as much as possible. The thermometer should be read after it has been in the water about 30 seconds. It is preferable to lift the bucket to eye level, or to rest it on the rail, with one hand, steadying the thermometer with the other hand while taking a reading. In this case the thermometer will not be taken out of the bucket. If, however, it is found impracticable to read the thermometer without taking it out of the bucket, care should be taken to see that none of the water in the reservoir is spilt, so that the thermometer bulb remains immersed.

It is very important that the thermometer should be read as soon as possible after the water has been drawn from the sea. No more time should be allowed to elapse than is necessary to enable the thermometer to take up the temperature of the water, as exchange of heat between the bucket and the air around it, or evaporation from the wet canvas, may cause appreciable errors in a very few minutes. The interval of 30 seconds, specified above, between the immersion of the thermometer in the bucket and the observation of the temperature, should be sufficient if the water in the bucket is kept well stirred in the manner prescribed.

When the observation has been taken, the canvas bucket should be hung upside down to ensure its draining properly. Both the bucket and the sea thermometer should be kept in a shaded place when not in use.

(2) RUBBER BUCKET. While this newer bucket, due to its design, takes less time to assume the temperature of the sea water during drawing, and holds the temperature of the sample for a longer period, it is still important that as little time as practicable should elapse between the drawing and the reading of the thermometer.

After a reading has been taken with the sheathed thermometer partially withdrawn from the bucket, it should be fully replaced in the bucket, before stowage, for added protection. During this operation the water sample is inclined to flush from the holes in the bucket, and care is needed to avoid being splashed.

Engiue-room intake temperature. The temperature of the sea water is sometimes obtained by reading the temperature of the engine-room intake water. The thermometer is either inserted into a pocket in the main inlet pipe, or water is drawn off by means of a tap and the thermometer bulb is placed under the outflowing stream. This method is not normally recommended. What is wanted for meteorological purposes is the temperature of the surface water, not the temperature at the depth of several feet. The latter will probably be a close approximation if the sea is not smooth. In calm weather, however, there may be an appreciable change in water temperatures with depth.

When the sea is rough, or in large ships travelling at speed, it is not always practicable to use the bucket method and in such cases an engine-room intake temperature may be acceptable if carefully read with a thermometer whose index correction is accurately known. Care must also be taken that the temperature of the water has not had time to be affected by the heat of the engine-room, and, if the thermometer bulb is held under a water tap, that it is completely immersed so that it is not cooled by evaporation of water from its surface. If the thermometer is in such a position that it is difficult to read there may be an error due to parallax.

A note should always be made in the logbook of the method used in taking sea temperatures.

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

CHAPTER 3

Miscellaneous Instruments and Methods (for reference only)

The cup anemometer. This consists of either three or four cups, each attached to the end of a metal arm. The arms are pivoted so that they are free to rotate in a horizontal plane (*see* Fig. 10). When the wind blows against the anemometer, it exerts a greater pressure on the concave side of the cup than on the convex side with the result that the arms spin round. At the base of the instrument is an indicator, similar to the mileage indicator on a speedometer, which is geared to the cups. This is so calibrated that the difference between two readings indicates the number of land miles travelled by the wind in the interval. To determine the velocity of the wind, a reading is taken, the time noted, and another reading taken 3 minutes later (or at any other convenient interval). The difference between the two readings, multiplied by 20 (in the case of a 3 minute interval) gives the velocity in miles per hour. By taking the difference in the readings over 24 hours, the total mileage, and from it the average velocity over that day, can be obtained. Some anemometers indicate wind speed in knots direct.

The cup anemometer can also be used with electric transmission. The cups turn a contact maker which completes an electric circuit and rings a bell or buzzer after a wind run of 1/20 mile. Another switch is used to break the circuit when a reading is not required. To take a reading, the switch is closed. The interval from one bell ring to the next is timed. If the wind is strong, the time is taken for five or ten rings. The switch is opened when the reading has been obtained. The wind speed is found by dividing the wind run by the average interval between two successive rings.

The thermograph. This is an instrument which gives a continuous record of the temperature of the air. In most thermographs the thermometer consists of a bimetallic coil composed of two strips of different metals, welded together, and then coiled to form a spring. The metals have different coefficients of expansion, so that, as the temperature changes, the spring tends either to coil more tightly or to uncoil, and this motion is transmitted by means of levers to an arm carrying a pen, so that the pen moves up or down as the temperature rises or falls. The pen records on a chart which is placed round a drum. This drum, driven by clockwork, rotates once a day or once a week, according to the type. The chart is graduated in degrees and in hours (or days and hours), so that the temperature at any time can be read off (*see* Fig. 11).

When the thermograph is used on board ship, as in ocean weather ships, to give a continuous record of the temperature of the outside air, the instrument is exposed in a Stevenson screen, and the same precautions taken in fixing the position of this screen as are taken in the case of the Stevenson screen which contains the dry and wet bulb thermometers (*see* page 26).

The distant reading thermograph. Another type of thermograph, which is of considerable use when observations are desired from somewhat inaccessible places, is the "mercury-in-steel" or distant reading thermograph. The thermometer bulb is made of steel and contains mercury at high pressure. It is connected by capillary steel tubing, filled with mercury, to a "bourdon" tube, which is a hollow coiled tube, also filled with mercury. As the temperature changes, the mercury in the bulb expands or contracts. The change in volume is transmitted, through the mercury in the capillary tube, to the bourdon tube and causes an alteration in its curvature. The bourdon tube is connected to a pen arm which therefore moves up or down in accordance with changes in the temperature of the thermometer bulb. The capillary tube can be as long as 130 feet, but when it is very long, compensating devices are required to ensure that changes in the volume of the mercury in the capillary tube, due to changes of temperature, do not affect the reading. Some thermographs are constructed with two pens, operated by separate thermometer bulbs and tubes, so that both dry and wet bulb readings, or the dry bulb readings in two separate places, can be recorded. Electrically operated thermographs are used in ocean weather ships.

The hair hygrograph. This instrument gives a continuous record of the relative humidity of the air. It depends on the fact that a human hair, which has been freed from fat or grease by boiling in caustic soda or potash, varies considerably in length with the relative humidity, but only a little with other meteorological elements. As the humidity increases, the length of the hair increases, and vice versa. The changes, however, are not in proportion. A change of 5 per cent. in the relative humidity at the top of the scale, say from 90 to 95 per cent., gives a much smaller change in the length of the hair than an equal change lower in the scale, say from 40 to 45 per cent.

In the hygrograph, a small bundle of hairs is rigidly fastened at its ends and is pulled taut in the middle by a hook which is connected through a system of levers with an arm carrying a pen. As the length of the hair varies, the hook moves and the pen moves up or down. As in the case of the thermograph, the pen records on a chart wound round a drum which is revolved by clockwork (*see* Fig. 12).

If the hygrograph were used on board ship to give a continuous record of the relative humidity of the outside air, this instrument, too, would be exposed in a Stevenson screen and the same precautions taken in fixing the position of this screen as in the case of the screen containing dry and wet bulb thermometers or a screen containing a thermograph.

The rainguage. This is used on land to measure the actual depth of rain, snow, or hail, that has fallen in a given interval of time, usually 24 hours. The essential parts of a rain-guage are:—

(i) A circular metal funnel with a standard diameter, usually 5 or 8 inches.

(ii) A receiver, either a metal can or a glass bottle, in which the water that enters the funnel is collected.

(iii) A cylindrical metal outer cover, inside which the receiver is placed and over which the funnel fits. This prevents water entering the receiver except through the funnel and also helps to prevent loss of water by evaporation.

(iv) A measuring glass with which the amount of water collected in the gauge is measured. This is calibrated so as to show the actual depth of rain that has fallen in inches or millimetres.

To prevent deformation of the funnel, its rim is made of a stout brass ring, of which the upper edge is bevelled to diminish splashing. The sloping sides of the funnel are 4 to 6 inches below the rim in order to catch snow and also to diminish the effect of splashing.

The measurement of rainfall at sea is an observation that presents considerable difficulties. If the rim of the rain-guage is not level, the reading will be erroneous and the heaving of the ship makes it impossible, apart from mounting the guage in gimbals, to keep it level. Wind eddies tend to diminish the catch and the superstructure of the ship causes much eddying of the wind. Another source of error is sea spray. For these reasons, it has not been practicable, up to the present, to make the measurement of rainfall a routine observation at sea, but experiments are being made to this end.

Measurement of cloud height by balloon. A simple method of determining cloud height is by the observation of a small rubber balloon, filled with hydrogen so as to rise at a known rate. All that is necessary is to note the time that elapses between the release of the balloon and its disappearance in the lower surface of a cloud. Should the cloud be thin or the base ragged, the balloon may be visible for some time after it reaches the cloud; the time of entering the cloud is then taken as the time at which cloud or mist is first seen between the observer and the balloon. Binoculars are used to follow the balloon, in case it should rise too high to be followed by the naked eye. Care is taken to distinguish between cases in which the balloon is seen to enter a cloud and those in which the balloon is hidden by a cloud, at a lower level, drifting across the field of view.

The rate of rise of the balloon depends on its weight and dimensions, and on the free lift given to it by the hydrogen. The free lift is measured by the smallest weight that, attached to the balloon, will just keep it from rising. Given the weight, dimensions, and free lift, the rate of rise can be computed from a formula or obtained from a table or, alternatively, the free lift can be altered by varying the amount of hydrogen pumped into the balloon, so that it rises at a standard rate. In practice, for each size of balloon, a standard weight is provided and the balloon is given the free lift required to balance this weight, when it will rise at the standard rate required for that type of balloon.

At night, a small paper lantern containing a lighted candle can be attached to the balloon by means of fine thread and the observation carried out as before. In this case a different formula is used to compute the rate of rise of the balloon.

The cloud searchlight. The simplest and most satisfactory method of obtaining cloud heights at night is by means of the cloud searchlight (*see* Fig. 13). At one end of a measured base line is placed a searchlight of special design, the light of which is directed vertically upwards in a more or less parallel beam. This beam, on striking the under side of a cloud, produces a well-defined illuminated spot, or, in some cases of very low cloud, the beam may produce diffuse illumination over a part of its course. From the other end of the base line, the altitude of the light spot or of the lowest point of the diffuse illumination is measured by means of an alidade. This is a simple instrument for determining the angular altitude and consists of a sighting system rotating about a horizontal axis over a quadrant of a circle graduated in degrees. The base line, the line of sight of the observer and the beam of light constitute the three sides of a right-angled triangle, of which the base is known and one angle measureable; the height can therefore be computed or obtained from the Traverse Table, or, if the base line is fixed, read off directly from a calibration on the alidade.

To get good results and height up to, say, 8,000 feet, it is desirable that the base should be 1,000 feet long. On board ship the accuracy of the method is reduced because it is impossible to obtain a base of this length, but in such cases the searchlight and the alidade are set up as far apart as is practicable (*see* Fig. 14).

Measurement of upper wind by visual observations of balloons. Observations of wind velocity at various heights above the earth's surface are usually made by observing the paths followed by small rubber balloons, known as pilot balloons, which are filled with hydrogen. In proportion to its size, such a balloon is so light that it has very little momentum and hence it rapidly takes up the movements of the successive currents of air through which it passes.

On land the observation is carried out in this manner. At successive intervals of time, usually of a minute, the altitude and azimuth of the balloon are observed with a special type of theodolite, the pilot balloon theodolite. From these data the horizontal projection of the path of the balloon can be computed, if its height is known at each observation. The height is determined in one of two ways. (1) A tail of thread, of a standard length, is attached to the balloon, with a flag of light tissue paper at its lower end. As the balloon rises, this tail hangs vertically downwards and its apparent length, against a scale in the field of the telescope, is estimated at each observation. From the apparent length and the altitude, the height of the balloon at each observation can be computed. (2) A simpler method of determining the height of the balloon is to measure its free lift before setting it free. This, with the weight and dimensions of the balloon, will enable the rate of rise to be computed or read off from tables. The disadvantage of this method is that upward or downward currents may affect the altitude reached at any time and may cause errors of some magnitude in the computations.

At sea, where these observations are made aboard ocean weather ships, there is difficulty owing to the heaving of the ship, which makes it impossible to use the ordinary pilot balloon theodolite. Special theodolites have been devised for this purpose, but the simplest method is to use a sextant and a compass, from which the altitude and azimuth of the balloon can be observed. The tail method of determining the height of the balloon is impracticable at sea, but the use of a computed rate of rise for the balloon is generally less subject to errors over the sea than over the land, because of the smaller liability to upward or downward currents in the air. The accuracy of the sextant and compass method is not great, however, and, as the balloon has to be followed with the naked eye, observations cannot be taken to a great altitude.

The computation of the wind velocity at different heights is carried out either by plotting the horizontal projection of the path of the balloon or by the use of a special slide rule. Observations at sea are, of course, corrected for the speed and course of the ship.

Measurement of upper wind by radar. There are serious limitations in the method of determining upper winds by visual observations of balloons. Observations to any altitude can only be obtained if the atmosphere is at least moderately clear of cloud up to that altitude, while even in a clear sky strong winds may cause the balloon to be soon lost in distance. These reduce very considerably the value of the method, both for the construction of synoptic charts and for climatological purposes.

A method of observing upper winds has been developed in recent years which removes the first and considerably reduces the second of these limitations. A large rubber balloon carries a "three-cornered reflector" and its path is followed by means of radar. In this way its distance, azimuth and altitude can be observed, even through cloud, and at a much greater distance than visual observations can be made. The winds up to 60,000 feet or more can be computed by this method.

The radio-sonde. For meteorological purposes, it is desirable to obtain data as to pressure, temperature and humidity at various heights above the earth's surface. An early method of obtaining this information was to send aloft by balloon a light framework, containing self-recording instruments—a barograph, thermograph and hygrograph—specially constructed so as to have a minimum of weight. This apparatus, known as a meteorograph, carried a label offering a reward to the finder if he returned it to the meteorological office releasing the balloon. Useful information of upper air conditions was obtained in this way, but the information was only available days, or even weeks, after the balloon had been released and was therefore useless for forecasting purposes, while if the balloon, after bursting, fell into the sea, the information was all lost.

Nowadays, information is obtainable from instruments, self-recording or otherwise, carried in aeroplanes. Routine observations are obtained from the upper air by means of the radio-sonde (*see* Fig. 15). This is a miniature radio station, of extremely light weight, which is lifted into the upper air by a large rubber balloon filled with hydrogen and automatically transmits radio signals, from which pressure, temperature, and relative humidity may be deduced.

The British radio-sonde operates as follows. It carries a miniature aneroid, thermometer and hygrometer. Each instrument controls the position of a movable armature, with respect to an inductance; the barometer by changes in the volume of its vacuum chamber, the thermometer by the coiling or uncoiling of its bimetallic coil and the hygrometer by the change in length of a strip of gold beater's skin sensitive to relative humidity. Each inductance in turn is brought for a few seconds into an oscillating electrical circuit by means of a rotary switch, driven by a small windmill. The frequency of the oscillations is a function of the air-gap between the armature and inductance in use, and hence a function of the pressure, temperature, or relative humidity, as the case may be. This wave is used to modulate the frequency of a carrier wave sent out by another circuit. The frequency of the signal emitted by the radio-sonde is measured by tuning another oscillating circuit at the ground station till it is in tune with the incoming signal and by means of calibration curves these measurements are converted into readings of pressure, temperature, and relative humidity.

In practice, radio-sonde and radar wind observations are frequently carried out together, the radar target being carried between the balloon and the radio-sonde. Both these observations are made, as a routine, aboard ocean weather ships.

The detection of storms, precipitation, etc., by radio methods. In recent years many Meteorological Services have been regularly engaged in plotting the positions of thunderstorms, even at great distances, by a triangulation method. Cathode ray direction-finding sets, installed at several stations, determine the directions from which the atmospherics, which are associated with electric discharges in the atmosphere, reach these stations. The intersection of two rays, representing the directions from which an atmospheric reaches two stations, gives an estimate of the position at which this atmospheric originated, more or less accurate according to the angle at which the two rays cut one another. The use of three or more stations, suitably placed, avoids the necessity of using rays intersecting at too acute an angle and furnishes checks on the observations.

Reports of the positions of thunderstorms are known in the British Meteorological Service as "Sferic" reports, the word *sferic* being coined from *atmospheric*.

There are four stations in Britain making these observations, Hemsby (Norfolk), Camborne (Cornwall), Shanwell (Fife) and Longkesh (Northern Ireland).

Observations are generally made twelve times a day, the observers recording for 15 minutes at each time of observation. The observations are co-ordinated by the Central Forecasting Office of Great Britain at Bracknell (Berkshire).

Radar, too, can be used as a help in meteorological work. It has been found that radar pulses on short wave lengths are reflected by rain, clouds, hail and snow. Not only the positions in azimuth and distance but also the altitudes can be determined more or less accurately. Even the type of precipitation and the type and motion of the cloud can be estimated to some extent.

Part II Non-instrumental Observations

Introduction. Non-instrumental observations are very important and, being estimates, they are dependent upon the personal judgment of the observer. This judgment is the product of training and experience at sea, together with practice in making the observations. To acquire a technique of observation, adherence to the official instructions is essential. The aim of these instructions is not only to outline a satisfactory method of making observations, but to impose a standard procedure such that two observers, despite differences in training, will make approximately the same observation in similar circumstances. The assumption that observations are comparable, or made according to the same procedure, is the basis of synoptic meteorology.

Observations from ships are of special importance to the forecaster not only because they enable him to complete his charts over the oceans, but also because weather sequences at sea are simpler than those on land. They are therefore more characteristic of the air masses and hence more useful in the air-mass analysis that precedes the preparation of forecasts. Numerous instances occur in which the presence or absence of adequate ship reports has made all the difference between good and bad weather forecasts. An observer should never forget that his individual effort, his particular observations, may supply just the information required to resolve a forecasting problem hundreds or thousands of miles away.

The making of meteorological observations at sea is attended by many difficulties that are unknown to the shore observer. It is in overcoming them that the experience and training of the mariner are important. These difficulties largely result from the movement of the ship and the absence of landmarks.

CHAPTER 4

Wind, Weather and Visibility

Wind force and direction. Wind force is expressed numerically on a scale from 0 to 12.* This scale, which originally defined the wind force in terms of the canvas carried by a full-rigged frigate was devised by Captain, afterwards Admiral, Sir Francis Beaufort in the year 1808 for use on board ships of the Royal 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 with double topsails of that period. With the passing of sail, this specification meant very little to those who had no experience in square-rigged ships, and the practice arose of judging wind force from the state of the sea surface. In 1939 the International Meteorological Committee agreed to the use of a sea criterion by which the wind force was judged from the appearance of the sea-surface. This specification, brought

**See* Note to Table XXII

into use on 1st January 1941, and with subsequent minor amendments, is shown on pages 40 and 41. Photographs showing the appearance of the sea corresponding to each Beaufort force are given between pages 40 and 41.

In using this specification it is assumed that the observation is made in the open ocean and that the wind has been blowing long enough to raise the appropriate sea. The possibility of a lag between the wind getting up and the sea increasing cannot be ruled out. The appearance of the sea surface also depends on many other factors such as the fetch of the wind (i.e., distance from weather shore), the swell, the presence of tides, and whether or not precipitation is occurring. These effects should be allowed for before deciding the appropriate number on the scale. Experience is the only sure guide but the following remarks may be of some use:—

(*i*) A discrepancy between wind and sea occurs frequently close inshore where winds of a local character are likely.

(*ii*) An off-shore wind does not produce its appropriate sea close inshore but requires a certain fetch before its full effect is produced.

(*iii*) Swell is the name given to waves, generally of considerable length, raised by winds at a distance from the point of observation. Swell is not taken into account when estimating wind.

(*iv*) Tides or strong currents affect the appearance of the sea surface, a wind against tide or current causing more "lop"—a weather tide—and the wind in the same direction as a tide or current producing less disturbance of the sea surface—a lee tide.

(*v*) Precipitation, especially if heavy, produces a smoothing effect.

(*vi*) There is evidence that the height of the sea disturbance caused by a wind of a particular force is affected by the difference between sea and air temperatures, the sea being the warmer medium. If this difference increases, there is an appreciable increase in the sea disturbance, and vice versa.

Beaufort force can be transformed into wind speed by means of a table of equivalents. As the corresponding wind speed depends on the height, it is necessary to relate it to a standard height. This standard height is taken to be 33 feet. The speed equivalents at this standard height are included in the specification of Beaufort force given on pages 40 and 41.

The International Code (used for making meteorological reports by radio) makes provision for the reporting of wind speed in knots. The observer may derive this from the table of equivalents, taking the mid-point of the range corresponding with the observed Beaufort force; or, better still, he may interpolate according to his own judgment. For example, if the wind is estimated to be over Beaufort 5 but not quite Beaufort 6, it might be reported as having a mean speed of 21 knots.

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

Meteorologists as well as seamen use the term "veering" to indicate a change of wind in a clockwise direction and the term "backing" to denote a change in an anticlockwise direction.

BEAUFORT SCALE OF WIND FORCE

(*continued on page 41*)

Beaufort Scale Number	Mean Wind Speed in knots	Limits of Wind Speed in knots	Limits of Wind Speed in m./sec.	Descriptive Terms*	Sea Criterion	Probable Wave Height in feet†	Probable Maximum Wave Height in feet†
	Measured at a height of 33 feet above sea level						
0	0	Less than 1	0–0·2	Calm	Sea like a mirror	—	—
1	2	1– 3	0·3– 1·5	Light air	Ripples with the appearance of scales are formed but without foam crests.	¼	¼
2	5	4– 6	1·6– 3·3	Light breeze	Small wavelets, still short but more pronounced, crests have a glassy appearance and do not break.	½	1
3	9	7–10	3·4– 5·4	Gentle breeze	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	2	3
4	13	11–16	5·5– 7·9	Moderate breeze	Small waves, becoming longer; fairly frequent white horses.	3½	5
5	18	17–21	8·0–10·7	Fresh breeze	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray.)	6	8½
6	24	22–27	10·8–13·8	Strong breeze	Large waves begin to form: the white foam crests are more extensive everywhere. (Probably some spray.)	9½	13
7	30	28–33	13·9–17·1	Near gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.	13½	19
8	37	34–40	17·2–20·7	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift. The foam is blown in well-marked streaks along the direction of the wind.	18	25

STATE OF SEA PHOTOGRAPHS, FOR ESTIMATING WIND SPEED (SEE PAGE 39)

See footnotes on page 41

Photo by A. B. Neish (Crown Copyright)

FORCE 0

Wind speed less than 1 kt. (Sea like a mirror.)

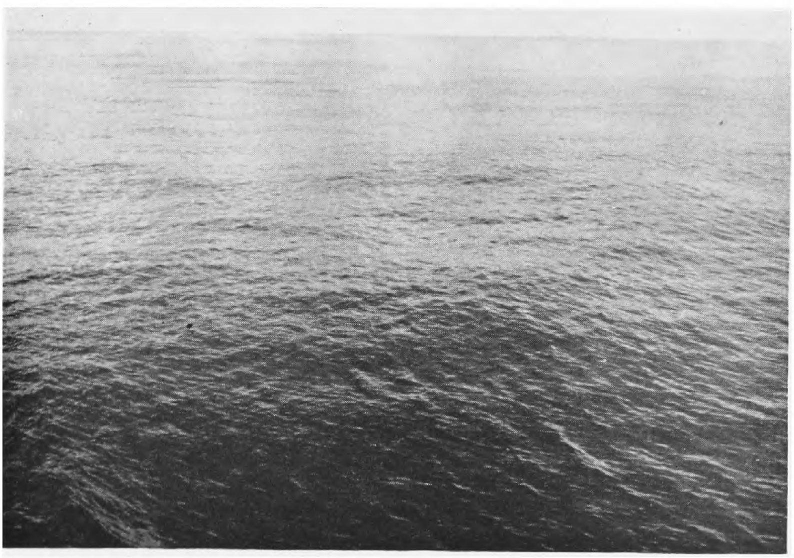


Photo by R. R. Baxter (Crown Copyright)

FORCE 1

Wind speed 1–3 kt.; mean, 2 kt.
(Ripples with the appearance of scales are formed, but without foam crests.)

SEA PLATE I

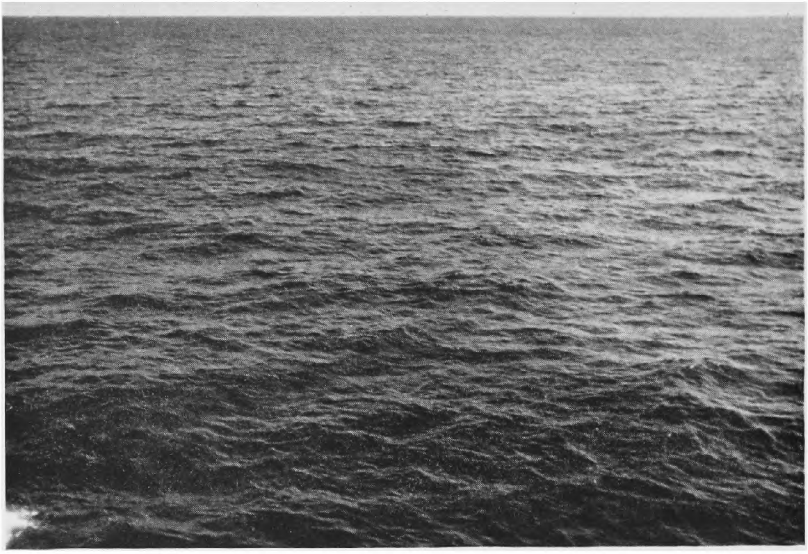


Photo by R. R. Baxter (Crown Copyright)

FORCE 2

Wind speed 4–6 kt.; mean, 5 kt.
(Small wavelets, still short but more pronounced—crests have a glassy appearance and do not break.)

Photo by R. Palmer

FORCE 3

Wind speed 7–10 kt.; mean, 9 kt.
(Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.)

SEA PLATE II

Photo by P. J. Weaver

FORCE 4
Wind speed 11–16 kt.; mean, 13 kt.
(Small waves, becoming longer; fairly frequent white horses.)

Photo by R. R. Baxter (Crown Copyright)

FORCE 5
Wind speed 17–21 kt.; mean, 18 kt.
(Moderate waves, taking a more pronounced long form; many white horses are formed. Chance of some spray.)

SEA PLATE III

Photo by R. R. Baxter (Crown Copyright)

FORCE 6

Wind speed 22–27 kt.; mean, 24 kt.
(Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray.)

Photo by R. R. Baxter (Crown Copyright)

FORCE 7

Wind speed 28–33 kt.; mean, 30 kt.
(Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.)

SEA PLATE IV

Photo by R. R. Baxter (Crown Copyright)

FORCE 8
Wind speed 34–40 kt.; mean, 37 kt.
(Moderately high waves of greater length; edges of crests begin to break into the spindrift. The foam is blown in well-marked streaks along the direction of the wind.)

Photo by P. J. Weaver

FORCE 9
Wind speed 41–47 kt.; mean, 44 kt.
(High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over. Spray may affect visibility.)

SEA PLATE V

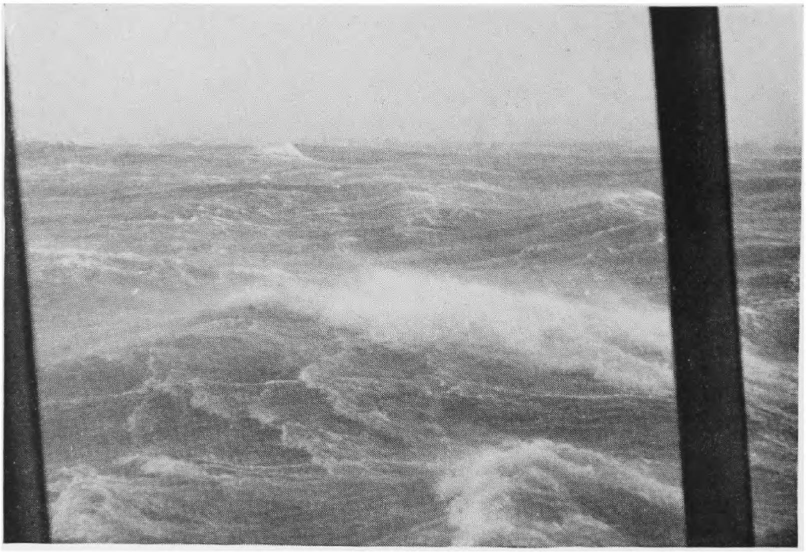


Photo by Kevin O'Keeffe (Crown Copyright)

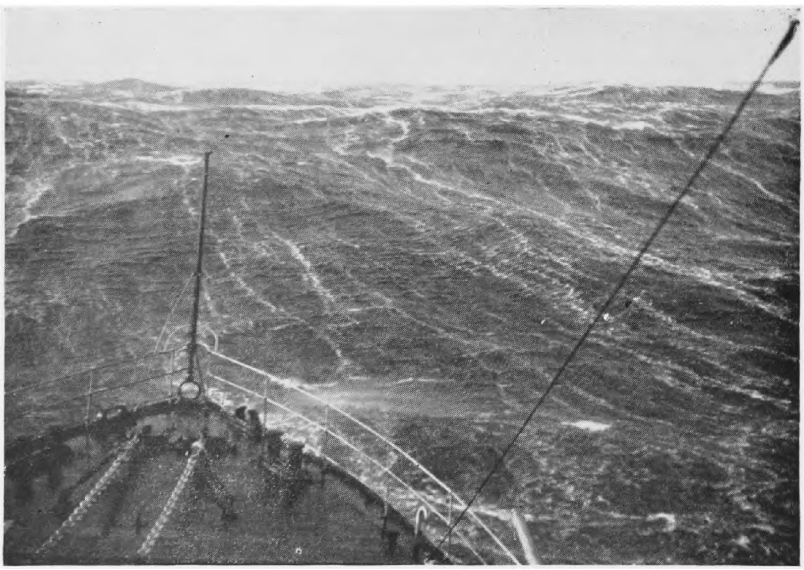


Photo by J. Hodkinson

FORCE 10

(The upper and lower photographs illustrate the difference in appearance between seas viewed along the trough and at right angles to the trough respectively).

Wind speed 48–55 kt.; mean, 52 kt.
(Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea takes a white appearance. The tumbling of the sea becomes heavy and shock-like. Visibility affected.)

SEA PLATE VI

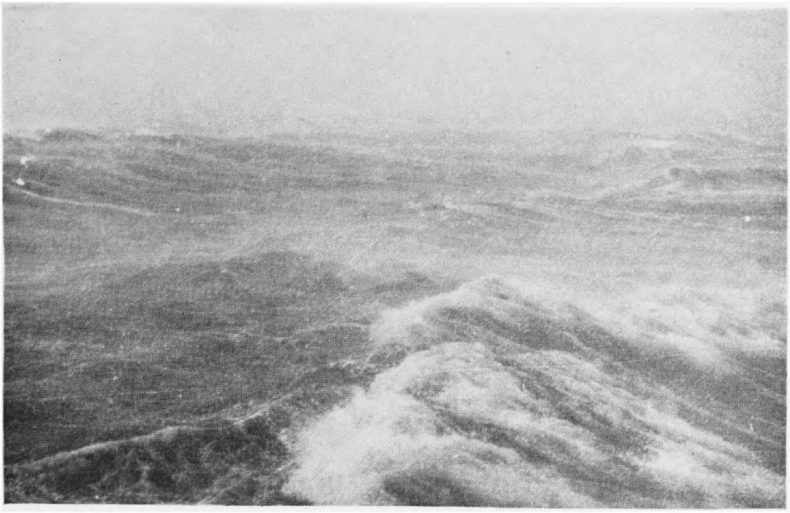


Photo by Kevin O'Keeffe (Crown Copyright)

Photo by G.P.O. (Crown Copyright)

FORCE 11

(The upper and lower photographs illustrate the difference in appearance between seas viewed along the trough and at right angles to the trough respectively).

Wind speed 56–63 kt.; mean, 60 kt.

[Exceptionally high waves. (Small and medium-sized ships might be for a time lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.]

SEA PLATE VII

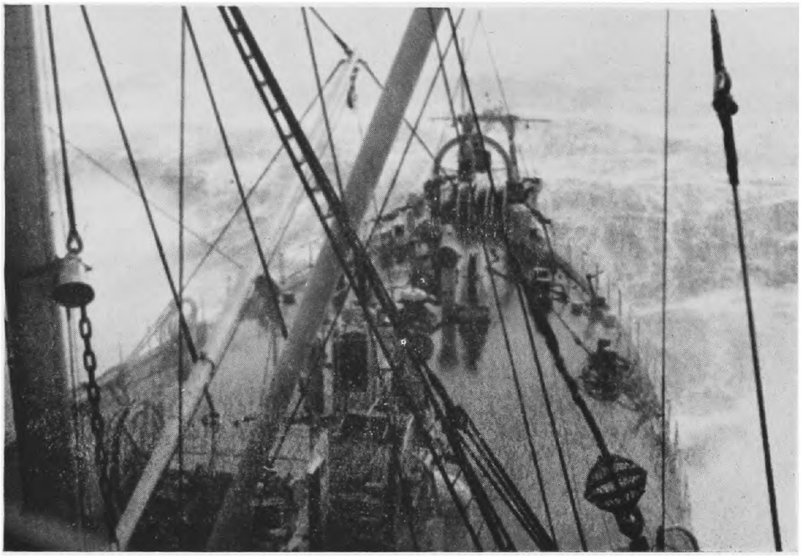


Photo by G.P.O (Crown Copyright)

Force 12

Wind speed 64–71 kt.; mean, 68 kt.: the Beaufort Scale actually extends to Force 17 (up to 118 kt.), but Force 12 is the highest which can be identified from the appearance of the sea.

(The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.)

BEAUFORT SCALE OF WIND FORCE—*continued*

Beaufort Scale Number	Mean Wind Speed in knots	Limits of Wind Speed in knots	Limits of Wind Speed in m./sec.	Descriptive Terms*	Sea Criterion	Probable Wave Height in feet†	Probable Maximum Wave Height in feet†
	Measured at a height of 33 feet above sea level						
9	44	41–47	20·8–24·4	Strong gale	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over. Spray may affect visibility.	23	32
10	52	48–55	24·5–28·4	Storm	Very high waves with long overhanging crests. The resulting foam in great patches is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The tumbling of the sea becomes heavy and shocklike. Visibility affected.	29	41
11	60	56–63	28·5–32·6	Violent storm	Exceptionally high waves. (Small and medium-sized ships might be for a time lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	37	52
12 and over	—	64+	32·7+	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	45	—

NOTES.—(1) It must be realised that it will be difficult at night to estimate wind force by the sea criterion.

(2) The lag effect between the wind getting up and the sea increasing should be borne in mind.

(3) Fetch, depth, swell, heavy rain and tide effects should be considered when estimating the wind force from the appearance of the sea.

*Some of these are different from those published previously: the changes were made by the World Meteorological Organization in January 1958.

†These columns are added as a guide to show roughly what may be expected in the open sea, remote from land. In enclosed waters, or when near land with an off-shore wind, wave heights will be smaller and the waves steeper.

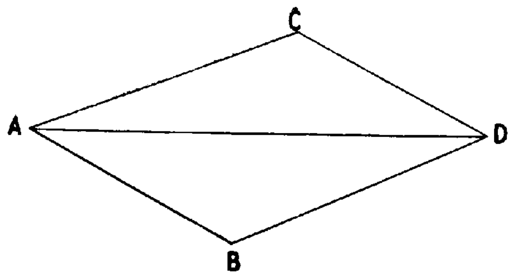


FIG. 24. Wind, parallelogram of velocities

Estimation of wind force and direction can often be made in the same way at night but sometimes on very dark nights it is impossible to see the effect of the lighter winds on the sea surface. In such cases the apparent or relative wind force and direction must be estimated by their effect on the observer, i.e., by the "feel" upon the face or upon a moistened finger, or by the direction in which the smoke is blowing. 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 astern and of the same velocity as the ship there is apparent calm on board the ship. In a calm, a ship steaming 10 knots will have an apparent head wind of velocity 10 knots, 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 will vary 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 velocities, or Table XXII, as explained below. In Fig. 24 if, for example, the ship is travelling along the line AB with speed 15 knots and the wind appears to be coming from the direction DA with speed 29 knots (Beaufort scale 7), the true direction of the wind is along CA and its speed 18 knots.

This result is easily obtained graphically by 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. The force and direction of the true wind may also be worked out by trigonometry, if preferred. To do this use the formula.

$$BD^2 = AB^2 + AD^2 - 2AB.AD \cos BAD$$

the angle BDA being then calculated from the rule of sines. Table XXII enables the conversion from apparent to true wind to be made by inspection.

In fast vessels the task of estimating accurately the true wind force and direction is no easy one and special care is required; this applies particularly to occasions when the wind is very light, and on dark nights.

Anemometers have as yet found only limited use at sea, the chief problem being to achieve an adequate exposure. The ship disturbs the airflow in its vicinity with the result that the wind measured by the instrument is not representative of the true airflow over the open sea. If a portable type of cup anemometer is used, the exposure may be varied at will and the best position chosen for any particular wind direction. The instrument measures "apparent" wind speed. To determine the true value, the wind direction must first be estimated and then allowance made for the speed of the ship.

Wind force and direction, taken alone, do not completely specify the character of the wind. It is well known that on occasions the wind is particularly gusty, as in showery weather. On rarer occasions, definite squalls may occur. The difference between a gust and a squall is essentially one of time-scale, a gust being momentary, whereas a squall may last several minutes. It is important when making the observations to note any unusual gustiness and the occurrence of squalls. When the latter occur it is of advantage if the time be noted together with any sudden change in wind direction. It is of interest to note that gusts have no appreciable effect in raising waves, whereas squalls may act for a sufficient length of time to raise a group of waves which travels with the squall.

WEATHER

For purposes of the meteorological logbook, the term "weather" embraces those elements covered by the ww and W codes, i.e., fog, precipitation, etc. (*See M.O.*509, *Ships' Code and Decode Book.*)

For a concise description of weather, Admiral Beaufort devised a system known as the Beaufort notation. Up to 1958, this method was used to record weather in the Present Weather column of the meteorological logbook. It is given below as it provides a handy way of amplifying the main synoptic report, or of recording the weather between observations, e.g. duration of precipitation, in the meteorological logbook for research purposes. It may also be found useful in the Deck Logbook and in the plotting of weather bulletins.

The present ww and W codes are sufficient to describe the weather for synoptic purposes, and have the added merit of being able to be punched on to cards.

The Beaufort notation.

b = Blue sky or sky not more than one-quarter clouded, whether with clear or hazy atmosphere.
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.
f = Fog.
g = Gale.*
h = Hail.
jp = Precipitation in sight of ship.
kq = Line squall.
l = Lightning.
m = Mist.
o = Overcast sky (i.e., the sky completely covered with a uniform layer of thick or heavy cloud).
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.
x = Hoar Frost.
y = Dry Air.
z = Dust haze; the turbid atmosphere of dry weather.

*The letter "g" is used for *gale* (Beaufort Force 8 or 9 maintained for at least 10 min.). "G" is used for *whole gale* (Beaufort force 10 or more maintained for at least 10 min.). The suffix "o", indicating *slight* is not used with "g", i.e. "g" will never be used to record winds less than Force 8.

The system has been extended since Beaufort's day to provide indication of intensity and continuity. Capital letters are now used to indicate occasions when the phenomenon noted is intense. On the other hand, occasions of slight intensity are distinguished by adding a small suffix "o".

Thus R = Heavy rain.
r = Rain (moderate).
r_o = Slight rain.

The prefix "i" indicates "intermittent", thus—
if = Fog patches.
ir_o = Intermittent slight rain.

The prefix "p" indicates "shower of", thus—
pR = Shower of heavy rain.
ps_o = Shower of slight snow.

A solidus "/" is used in "present weather" to distinguish present conditions from those in the past hour, thus—
c/r_o = Cloudy after slight rain in the past hour.

Continuity is indicated by repeating the letter, thus—
rr = Continuous moderate rain.

The following are further examples of the use of Beaufort notation—
cs_os_o = Cloudy with continuous slight snow.
oid_o = Overcast with intermittent slight drizzle.
bif = Blue sky with fog patches.
cqprh = Cloudy with squalls and shower of moderate rain and hail.
crrm = Cloudy with continuous moderate rain, and mist.

In past weather the letters are used in the same way but their order from left to right indicates sequence in time.

Thus "b, bc, cpr" indicates cloudless conditions, becoming partly cloudy, followed by cloudy conditions with shower(s) of rain.

Hints on observing weather

PRECIPITATION. A distinction is drawn in the ww and W codes between rain drizzle and showers. Showers are of short duration and the fair periods between them are characterized by clearances of the sky. Showers fall from clouds having great vertical extent and usually isolated. They do not often last more than half-an-hour. Showers are characteristic of an unstable polar air mass, usually flowing in the rear of a depression, but they are by no means confined to this situation.

Rain and drizzle fall from overcast or nearly overcast skies. The distinction between rain and drizzle depends not on the amount of the precipitation but on the size of the drops. Drizzle is "precipitation in which the drops are very small." Slight rain, on the other hand, is precipitation in which the drops are of appreciable size (they may even be large drops), but are relatively few in number. Observers should decide from the size of the drops whether the precipitation is drizzle or rain, and from the combined effect of the number and size of the drops whether the precipitation is slight, moderate, or heavy. The description "heavy" is relatively rare in temperate latitudes.

Precipitation is defined as intermittent if it has been discontinuous during the preceding hour, without presenting the character of a shower. Observers should cultivate the practice of recording the times of onset and cessation of precipitation.

Fog, mist and haze. Fog, mist and haze have in the past been used, rather loosely, to describe decreasing degrees of obscurity in the atmosphere. Modern practice reserves the description "haze" for occasions when the obscurity is caused by solid particles such as dust or sea salt. Fog and mist are akin in that they are both composed of minute water drops and may thus be distinguished from haze. In practice the distinction is usually made by means of the dry and wet bulb readings. The following table gives the approximate criterion for the reporting of mist and haze at various temperatures. Intermediate values may be obtained by interpolation. If the depression of the wet bulb is more than about that shown in the relevant column B, haze should be reported. If the depression is less, the obscurity should be reported as mist. (A relative humidity of 95% is used by the British Meteorological Office as a guide to the dividing line between mist and haze.)

Depression of the wet bulb corresponding to a relative humidity of 95%

Column "A"	Columns "B"		Column "A"	Columns "B"	
Dry Bulb, °C.	Depression, °C. Stevenson screen	Depression, °C. Aspirated psychrometer	Dry Bulb, °F.	Depression, °F. Stevenson screen	Depression, °F. Aspirated psychrometer
40	0.8	0.8	100	1.3	1.4
35	0.7	0.7	90	1.2	1.3
30	0.7	0.7	80	1.2	1.2
25	0.6	0.6	70	1.0	1.0
20	0.5	0.6	60	0.8	0.9
15	0.5	0.5	50	0.7	0.7
10	0.4	0.4	40	0.6	0.6
5	0.3	0.3	32	0.4	0.5
0	0.3	0.3			

The further distinction between mist and fog is only one of degree and is arbitrarily assigned. When the visibility is reduced to less than half-a-mile, the obscurity is described as fog; when greater than half-a-mile it is known as mist.

VISIBILITY. Although the use of such terms as fog, mist and haze is suitable for a general indication of the state of visibility in the ww code or in the text of a ship's logbook, a more precise method is needed in weather messages to indicate to the meteorologist the degree of obscurity of the atmosphere, irrespective of the reason that causes it. (The cause is given under the heading of "weather", e.g., ww = 05 indicates haze, ww = 10 indicates mist.) On land, observations are made of a number of selected objects at fixed distances, the distances increasing roughly in such a way that each distance is nearly double the next smaller distance. The determination of the most distant object of the series which is visible on any given occasion constitutes the observation of visibility. At sea such a detailed determination of visibility is not usually possible, but in making estimates of visibility a coarser scale is used, as shown below.

VISIBILITY SCALE FOR USE AT SEA

Code Figure		*Code Figure*	
90	Less than 55 yards.	95	2,200 yards.
91	55 yards.	96	2.2 nautical miles.
92	220 yards.	97	5.4 nautical miles.
93	550 yards.	98	10.8 nautical miles.
94	1,100 yards.	99	27 nautical miles or more.

Note 1. If the distance of visibility is between two of the distances given in the table, the code figure for the shorter distance is reported.

Note 2. The prefix "9" before each of the scale numbers appears here because this table is part of a code for reporting visibility in two figures by radio (*see Ship's Code and Decode Book* (*M.O.* 509) or *Admiralty List of Radio Signals, Vol. III.*)

In a long vessel the determination of the lowest numbers 90, 91 offers no difficulty as objects at known distances may be used. Visibility numbers 92 to 94 indicate conditions of obscurity such that the visibility is greater than the length of the ship but is not sufficient to allow full speed to be maintained. 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 other ships are sighted, visibility may be calculated if the time is taken when another ship is first and last seen and the relative velocity of the two ships is known (ships fitted with radar can, of course, obtain these distances directly). It is customary to use the horizon to estimate visibility numbers 96,97, although this cannot be relied upon. There are cases of abnormal refraction when the visible horizon may be very misleading as a means of judging distances, particularly when the height of the eye is great, as in the case of an observer on the bridge of a large liner.

The estimation of visibility at night is very difficult. What the meteorologist is interested in knowing is the degree of transparency of the atmosphere. But the distance seen at night depends on the amount of illumination; and the distance at which a light is seen depends on its intensity or candle-power. If there is no obvious change in meteorological conditions, the visibility just after dark will be the same as that recorded just before dark irrespective of the fact that one may not be able to see as far. A deterioration in visibility can sometimes be detected afterwards and the visibility figure adjusted accordingly. In doing this, care must be taken not to confuse the effect of a decrease in illumination, as for example when the moon sets, with a genuine decrease in visibility. The presence of a "loom" around the vessel's navigation lights is frequently a guide to deteriorating visibility.

CHAPTER 5

Clouds and Cloud Height by Estimation

A normal observation of cloud at sea involves:

(i) The identification of the cloud types present.

(ii) An estimation of the height of the base of the lowest layer reported under C_L (or under C_M, if no C_L).

(iii) An estimation of the amount of cloud reported under C_L (or under C_M, if no C_L).

The fundamental distinction in structure, which has great significance for forecasting, is between "layer" or "sheet" clouds, and "heap" clouds, i.e., clouds with marked vertical development. Examples of the latter are cumulus, sometimes known as the "wool pack" or "cauliflower" cloud, and cumulonimbus, the "thundercloud" or "anvil" cloud. In the further classification of sheet or layer clouds the consideration of height is taken into account, but the classification is not strictly one of height so much as of appearance. The main classification is into ten types as follows:—

Sheet clouds		*Approximate limits* (*see also page* 53)
Cirrus	(Ci)	Base above 18,000 feet
Cirrocumulus	(Cc)	
Cirrostratus	(Cs)	
Altocumulus	(Ac)	8,000 to 18,000 feet
Altostratus	(As)	
Nimbostratus*	(Ns)	Base below 6,500 feet
Stratus	(St)	
Stratocumulus	(Sc)	
Heap clouds (with vertical development)		
Cumulus	(Cu)	
Cumulonimbus	(Cb)	

Descriptions of the different types are given below.†

Cirrus (Ci). Detached clouds of delicate and fibrous appearance, without shading, generally white in colour, often of a silky appearance. Cirrus appears in the most varied forms, such as isolated tufts, lines drawn across a blue sky, branching feather-like plumes, and curved lines ending in tufts. These lines are often arranged in bands which cross the sky in lines and which, owing to the effect of perspective, appear to converge to a point on the horizon, or to two opposite points (i.e., polar bands). Cirrostratus and cirrocumulus often take part in the formation of these bands. Before sunrise and after sunset, cirrus is

*See footnote on page 52

†See after page 56 for cloud photographs. It will be noted that these are arranged in order of "Cloud type" according to the specifications of the code for reporting cloud. (Pages 51–53.)

sometimes coloured bright yellow or red. Owing to their great height cirriform clouds are illuminated long before other clouds and fade out much later. Observation of cirrus at night is difficult but, if thick and extensive, it may be noted by its dimming effect on stars.

Cirrocumulus (Cc). 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 structures in places. Real cirrocumulus is uncommon. It must not be confused with small altocumulus on the edges of altocumulus sheets. In the absence of any other criterion the term cirrocumulus should only be used when:—

(i) There is evident connection with cirrus or cirrostratus.

or (ii) The cloud observed results from a change in cirrus or cirrostratus.

Cirrostratus (Cs). A thin whitish veil, which does not blur the outlines of the sun or moon, but gives rise to haloes. 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. Cirrostratus may be observed at night by noting the slight diffusion of light around each star, whose brilliance is at the same time dimmed. It is almost impossible to differentiate between thick cirrus and cirrostratus at night in the absence of moonlight.

Altocumulus (Ac). A layer or patches, composed of laminae or rather flattened globular masses, the smallest elements of the regularly arranged layers 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.

When the edge or a thin translucent patch of altocumulus passes in front of the sun or moon a corona appears. This phenomenon may also occur with cirrocumulus and with the higher forms of stratocumulus. Irisation or iridescence is another possibility wiih altocumulus (*See also* page 102).

The limits within which altocumulus is met are very wide. At the greatest heights, when made up of small elements, it resembles cirrocumulus; altocumulus however is distinguished by not being either closely associated with cirrus or cirrostratus or evolved from one of these types. It is often associated with altostratus and either form may change into the other.

Two important varieties of altocumulus are "altocumulus castellanus" and "altocumulus lenticularis". Altocumulus castellanus is a variety peculiar to a thundery state of the atmosphere, and is sure evidence of high-level instability. In this form, individual cloudlets are extended vertically upwards in heads or towers, like small cumuli. The lenticular variety of altocumulus has clouds of an ovoid or lens shape, with clear-cut edges and sometimes showing irisations. It occurs frequently over mountainous country and in "fohn", "scirocco" and "mistral" winds. It may also often be seen after the passage of weak cold fronts.

Altostratus (As). Striated or fibrous veil, more or less grey or bluish in colour. This cloud is like thick cirrostratus, but does not show halo phenomena; the sun or moon shows vaguely, with a gleam, as though through ground glass. Sometimes the sheet is thin with forms intermediate with cirrostratus. Sometimes it is very thick and dark, perhaps even completely obscuring 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. Every gradation is observed between high altostratus and cirrostratus on the one hand and low altostratus and nimbostratus on the other. In practice it is important to distinguish between altostratus (thin) through which the sun or moon is visible and altostratus (thick) which completely obscures the sun or moon.

Nimbostratus (Ns). A low, amorphous (i.e., without form), and rainy layer, of a dark grey colour and nearly uniform; feebly illuminated seemingly from inside. Precipitation from nimbostratus is nearly always "continuous"; but precipitation is not a sufficient criterion. Cloud may be described as nimbostratus before precipitation has started. 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 precisely the limit of its lower surface.

Nimbostratus is usually the result of a progressive lowering and thickening of a layer of altostratus. Beneath nimbostratus there is generally a progressive development of very low ragged clouds (scud). These clouds are usually referred to as **pannus, fractocumulus (Fc)**, or **fractostratus (Fs)**.

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 (Fs). A veil of true stratus generally gives the sky a hazy appearance which is very characteristic, but which in certain cases may cause confusion with nimbostratus. When there is precipitation the difference is manifest; stratus cannot give the continuous precipitation usually associated with nimbostratus. When there is no precipitation a dark and uniform layer of stratus can easily be mistaken for nimbostratus. The lower surface of nimbostratus, however, has always a wet appearance (widespread trailing precipitation or virga); it is quite uniform and it is not possible to make out definite details. Stratus on the other hand has a "drier" appearance, and however uniform it may be, it shows some contrasts and some lighter transparent parts. Stratus is often a local cloud and, when it breaks up, the blue sky is often seen.

The name fractostratus is given to stratus which is broken up into patches and also to lifted fog, that is fog which has been lifted from the surface so as to become cloud.

Stratocumulus (Sc). A layer or patches composed of rounded masses or rolls; 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 two directions. Very often the rolls are

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*Latin; Virga—streak, bough or broom.

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. The difference between stratocumulus and altocumulus is essentially one of height. A cloud sheet called altocumulus by an observer at a small height may appear as stratocumulus to an observer at a sufficient height.

Stratocumulus may form by the spreading out of cumulus. This happens over land in the evening when the day-time cumulus clouds begin to spread out prior to dissolving. Another example is when developing cumulus meets a pronounced inversion layer. If unable to penetrate this layer the cloud spreads out horizontally in the form of stratocumulus.

Cumulus (Cu). Thick clouds with vertical development; the upper surface is dome-shaped and exhibits rounded 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, and 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 called **fractocumulus (Fc).** Cumulus, whose base is horizontal, clear-cut and generally of a grey colour, has a uniform structure, that is to say it is composed of rounded parts right up to its summit, with no fibrous structure. Even when highly developed, cumulus can only produce light precipitation.

Cumulus having but small vertical development and little individual extent is known as "fair weather cumulus" to distinguish it from the ordinary "large cumulus".

Cumulonimbus (Cb). 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 of the cloud resembles nimbostratus, and one generally notices "virga" (trailing precipitation). This base has often a layer of very low ragged clouds below it **(pannus).**

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 characterise the cloud as a cumulonimbus. A cumulonimbus cloud may cover the whole sky, in which case the base alone is visible and resembles nimbostratus from which it is difficult to distinguish. If the cloud mass does not cover all the sky and if even small portions of the upper parts of the cumulonimbus appear, the difference is evident. In other cases the distinction can only be made if the preceding evolution of the clouds has been followed or if precipitation occurs. Cumulonimbus gives showers whereas nimbostratus is associated with continuous precipitation.

The lower surface of cumulonimbus sometimes has an udder-like or mammillated appearance which is referred to as "mammatocumulus". When a layer of menacing cloud covers the sky and mammatus structure and trailing precipitation are both seen it is a sure sign that the cloud is the base of a cumulonimbus, even in the absence of all other signs.

Cumulonimbus is a real factory of clouds; it is responsible in great measure for the clouds in the rear of disturbances. By the spreading out of the more or less high parts and the melting away of the underlying parts, cumulonimbus can produce either altocumulus or stratocumulus (spreading out of the cumuliform parts) or dense cirrus (spreading out of the cirriform part).

Making the observations. The aspect of the sky is continually changing and the cloud formations in evidence at one particular time may not be typical, that is to say they may not be easily recognisable from the standard descriptions given above. If, however, the observer watches the sky over a period of time he will often find that doubtful cloud forms may be referred to a previous state of development that was typical. Hence the first rule in cloud observing— watch the sky as often as possible and not merely at the time of observation.

Coding the observations. The forecaster who eventually receives and uses the observer's reports does not merely want to know what clouds are present. It has been found that certain distributions or organisations of clouds in the sky, in other words certain "states of sky", are of particular significance. The observer is required to report these rather than the presence of a particular cloud form. These states of sky are as follows, separate specifications being used for low, middle and high cloud.

SPECIFICATION OF FORM OF LOW CLOUD (C_L) (Sc, St, Cu, Cb)

Code Figure	
0	No Stratocumulus, Stratus, Cumulus or Cumulonimbus.
1	Cumulus with little vertical extent and seemingly flattened, or ragged Cumulus other than of bad weather,* or both.
2	Cumulus of moderate or strong vertical extent, generally with protuberances in the form of domes or towers, either accompanied or not by other Cumulus or by Stratocumulus, all having their bases at the same level.
3	Cumulonimbus the summits of which, at least partially, lack sharp outlines, but are neither clearly fibrous (cirriform) nor in the form of an anvil; Cumulus, Stratocumulus or Stratus may also be present.
4	Stratocumulus formed by the spreading out of Cumulus; Cumulus may also be present.
5	Stratocumulus not resulting from the spreading out of Cumulus.
6	Stratus in a more or less continuous sheet or layer, or in ragged shreds, or both, but no Stratus fractus of bad weather*.
7	Stratus fractus of bad weather* or Cumulus fractus of bad weather, or both (pannus), usually below Altostratus or Nimbostratus.
8	Cumulus and Stratocumulus other than that formed from the spreading out of Cumulus; the base of the Cumulus is at a different level from that of the Stratocumulus.

*"Bad weather" denotes the conditions which generally exist during precipitation and a short time before and after.

9 Cumulonimbus, the upper part of which is clearly fibrous (cirriform), often in the form of an anvil; either accompanied or not by Cumulonimbus without anvil or fibrous upper part, by Cumulus, Stratocumulus, Stratus or pannus.

X Stratocumulus, Stratus, Cumulus and Cumulonimbus invisibile owing to darkness, fog, blowing dust or sand, or other similar phenomena.

SPECIFICATION OF FORM OF MIDDLE CLOUD (C_M) (Ac, As, Ns)

Code Figure

0 No Altocumulus, Altostratus or Nimbostratus.

1 Altostratus, the greater part of which is semi-transparent; through this part the sun or moon may be weakly visible, as through ground glass.

2 Altostratus, the greater part of which is sufficiently dense to hide the sun or moon, or Nimbostratus.*

3 Altocumulus, the greater part of which is semi-transparent; the various elements of the cloud change only slowly and are all at a single level.

4 Patches (often in the form of almonds or fishes) of Altocumulus, the greater part of which is semi-transparent; the clouds occur at one or more levels and the elements are continually changing in appearance.

5 Semi-transparent Altocumulus in bands, or Altocumulus in one or more fairly continuous layers (semi-transparent or opaque), progressively invading the sky; these Altocumulus clouds generally thicken as a whole.

6 Altocumulus resulting from the spreading out of Cumulus (or Cumulonimbus).

7 Altocumulus in two or more layers, usually opaque in places, and not progressively invading the sky; or opaque layer of Altocumulus, not progressively invading the sky; or Altocumulus together with Altostratus or Nimbostratus.*

8 Altocumulus with sproutings in the form of small towers or battlements, or Altocumulus having the appearance of cumuliform tufts.

9 Altocumulus of a chaotic sky, generally at several levels.

X Altocumulus, Altostratus and Nimbostratus invisible owing to darkness, fog, blowing dust or sand or other similar phenomena, or more often because of the presence of a continuous layer of lower clouds.

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*For synoptic purposes nimbostratus is included among the middle clouds in the code since it is continuous with the altostratus existing above it and has been formed as a result of a progressive lowering of altostratus from middle cloud level.

SPECIFICATION OF FORM OF HIGH CLOUD (C_H) (Ci, Cs, Cc)

Code Figure	
0	No Cirrus, Cirrocumulus or Cirrostratus.
1	Cirrus in the form of filaments, strands or hooks, not progressively invading the sky.
2	Dense Cirrus, in patches or entangled sheaves, which usually do not increase and sometimes seem to be the remains of the upper part of a Cumulonimbus; or Cirrus with sproutings in the form of small turrets or battlements, or Cirrus having the appearance of cumuliform tufts.
3	Dense Cirrus, often in the form of an anvil, being the remains of the upper parts of Cumulonimbus.
4	Cirrus in the form of hooks or of filaments, or both, progressively invading the sky; they generally become denser as a whole.
5	Cirrus (often in bands converging towards one point or two opposite points of the horizon) and Cirrostratus, or Cirrostratus alone; in either case, they are progressively invading the sky, and generally growing denser as a whole, but the continuous veil does not reach 45 degrees above the horizon.
6	Cirrus (often in bands converging towards one point or two opposite points of the horizon) and Cirrostratus, or Cirrostratus alone; in either case, they are progressively invading the sky, and generally growing denser as a whole; the continuous veil extends more than 45 degrees above the horizon, without the sky being totally covered.
7	Veil of Cirrostratus covering the celestial dome.
8	Cirrostratus not progressively invading the sky and not completely covering the celestial dome.
9	Cirrocumulus alone, or Cirrocumulus accompanied by Cirrus or Cirrostratus, or both, but Cirrocumulus is predominant.
X	Cirrus, Cirrocumulus and Cirrostratus invisible owing to darkness, fog, blowing dust or sand or other similar phenomena, or more often because of the presence of a continuous layer of lower clouds.

The use of these specifications, instead of reporting each individual cloud form, effects an economy and is also advantageous to the forecaster, who knows how to associate a state of sky with a particular weather situation.

The estimation of cloud height.

Apart from some ships of the Royal Navy and ocean weather ships, cloud height at sea is obtained by estimation. The first step in estimating cloud height consists of identifying the cloud as a type belonging to one of the three classes, low, middle or high. Low clouds have their bases below 6,500 feet. Medium cloud layers usually occur at levels between 8,000 and 18,000 feet, and high clouds are usually above 18,000 feet. As a rough guide, the heights of the bases of the various types of low cloud may be expected to be between the following limits:

Cumulus	2,000 to 5,000 feet.
Stratocumulus	1,500 to 5,000 feet.

Stratus	Usually below 1,000 feet and sometimes nearly down to the surface.
Nimbostratus	500 to 6,500 feet (usually below 2,000 feet in moderate rain or snow).
Cumulonimbus	1,000 to 5,000 feet.

These limits tend to be considerably higher in low latitudes; this applies particularly to high clouds.

It is difficult to estimate the height of middle or high cloud without much practice. The apparent size of the cloud elements is often an indication of height. For example, the lower the height of the individual cloudlets of an altocumulus layer, the larger they will normally appear. Layers having the appearance of altocumulus with large individual elements are often found at heights between 6,000 feet and 10,000 feet. The estimation of the height of stratified cloud, e.g., altostratus or nimbostratus, is particularly difficult. The lack of pronounced structure makes it easy to gain a false impression of height. Valuable experience can be gained on occasions when the observer knows that his ship is steaming towards a depression by watching the gradual lowering of the cloud base. The observer's impressions of the appearance of the sky in the successive stages of lowering will assist his judgment on future occasions. It is only by such experience that an observer can distinguish between a layer of nimbostratus in the lower middle band and a similar layer at, perhaps, only 2,000 to 3,000 feet.

Care must be taken before using the apparent speed of cloud as an index to its height. This apparent speed depends not only on the velocity of the wind at cloud level but also on the course and speed of the ship itself.

When coasting, cloud height may sometimes be estimated by comparison with the height of the mountains or hills in the background. In using this method, however, it should be remembered that cloud is usually lower over the hills than elsewhere and that it is the general level over the sea that is required.

At meteorological stations ashore, cloud height is usually measured by balloons, and at night by the "Ceiling Light Projector", or cloud searchlight. (*See* page 34.)

The estimation of cloud amount. The amount of cloud was in the past estimated as the number of tenths of sky covered. At a conference of the International Meteorological Organisation (Washington 1947) it was recommended that amount of cloud be estimated in eighths instead of tenths. This change of procedure was brought into force with the introduction of the new International Code (Washington) on 1st January 1949.

In making the observation it is necessary to stand in a position affording an uninterrupted view of the whole sky. To make an estimate for the whole sky at once requires practice and is rather difficult at first. It is convenient to imagine the sky divided into quadrants by two arcs drawn at right angles through the zenith.

Each quadrant represents two eighths of the total sky. If we choose the most appropriate of the figures—

0 = Clear or almost clear of cloud

1 = About half covered

2 = Completely or almost completely covered with cloud—

for each separate quadrant, than the total amount of cloud for the whole sky is obtained simply by adding the amounts in the separate quadrants.

At night the observation of total cloud amount is noted by observing which stars are showing and which are obscured. It is more difficult to differentiate between low, middle and high clouds and reliable observation depends upon the degree of illumination and the experience of the observer.

Photo by A. J. Aalders (Copyright: Royal Netherlands Meteorological Institute)

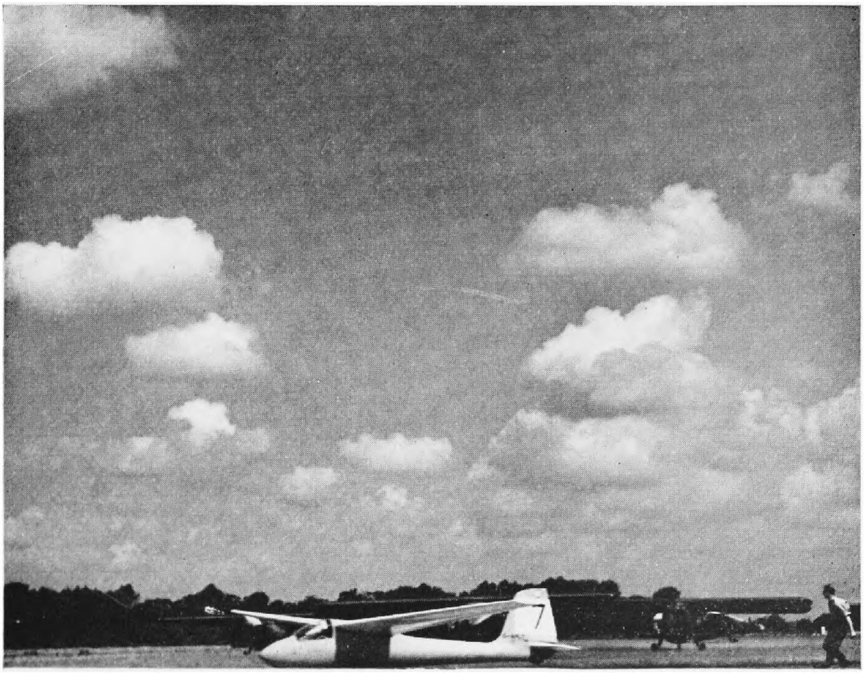


Photo by C. E. Wallington

C_L1 Fair weather cumulus. The cloud elements shown in the upper picture are in an early stage of development; they are small and shallow. In the lower picture they are in a slightly more advanced stage and, although still small, some show the characteristic domed tops.

The expression " fair weather " is in no sense a forecast. It is merely a description of the weather at the time at the place of observation.

Average height of cloud base: 2000 to 5000 feet.

CLOUD PLATE I

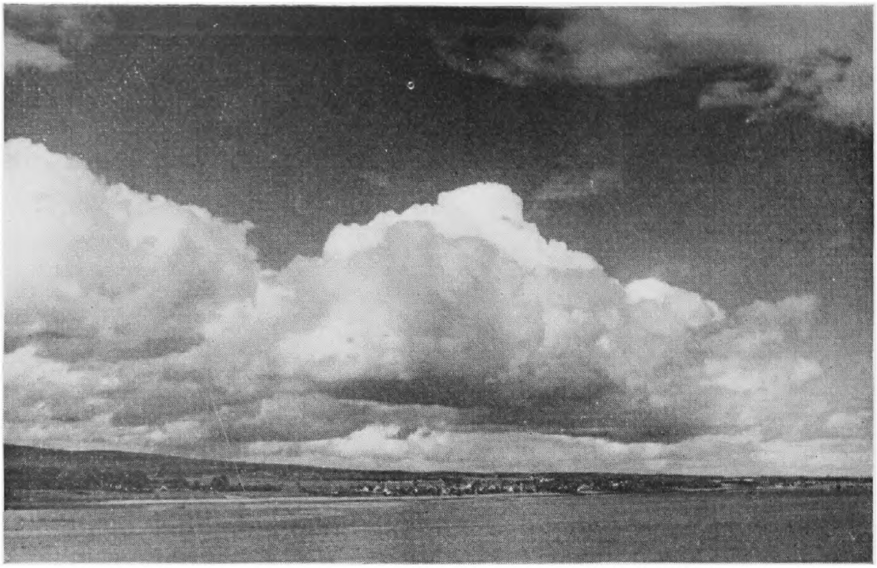


Photo by Cdr. E. R. Trendall, R.N.

C_L2 Towering cumulus. This is a further stage in the development of C_L1. The cloud has become much deeper and the tops are "cauliflower-shaped". The outlines are clear-cut and there is no tendency for the upper parts of the cloud mass to become blurred or fibrous in texture. When the cloud is well developed, rain showers may fall from it. Stratocumulus cloud may also be present but it must be at the same level as the base of the Cumulus.

Average height of cloud base: 2000 to 5000 feet.

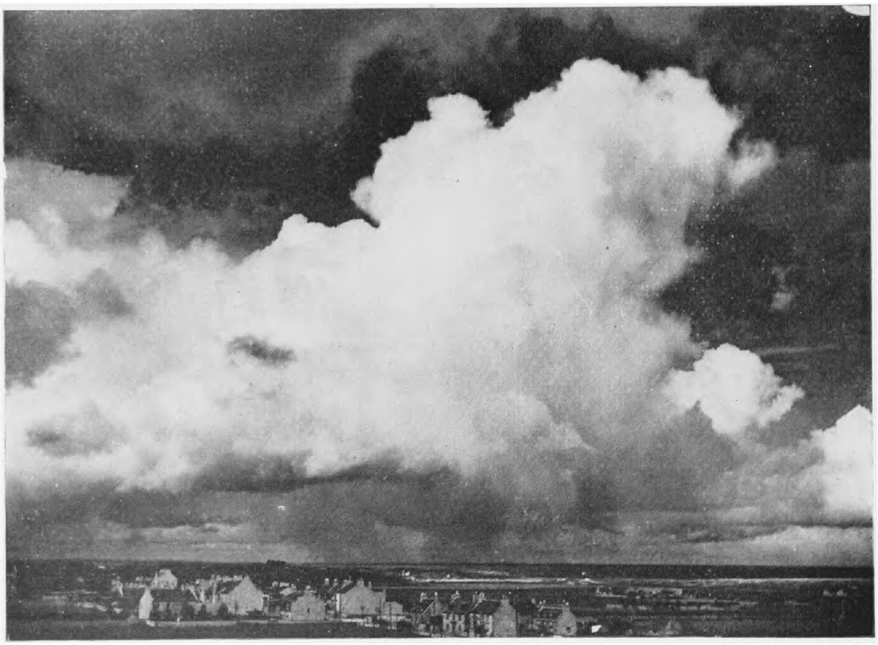


Photo by G. A. Clarke

C_L3 Cumulonimbus without anvil. Normally this is a further stage in the development of C_L2. The vertical depth of the cloud is now great and the outlines of the top of the cloud are becoming somewhat blurred and rather ragged, but the characteristic fibrous anvil has not yet developed. Showers are seen falling from the base of the cloud illustrated. When it is uncertain whether the cloud shall be called C_L2 or C_L3, the latter should be selected if the cloud gives rise to lightning, thunder or hail. Cumulus, Stratocumulus or Stratus may also be present.

Average height of cloud base: 1000–5000 feet.

Photo by A. J. Aalders (Copyright: Royal Netherlands Meteorological Institute)

C_L4 Stratocumulus formed by the spreading-out of Cumulus. Cloud of this type forms when the upper parts of Cumulus clouds, which had previously been gaining in height, can no longer do so and begin to spread out horizontally, forming a layer of Stratocumulus. (See Plate XIV describing the formation of C_M6.) Sometimes the spreading-out is only temporary and the Cumulus resume their growth above the stable layer.

Another type of C_L4 often occurs in the evening when the domed tops of the Cumulus begin to flatten: they then assume the appearance of patches of Stratocumulus.

Average height of cloud base: 4000 to 8000 feet.

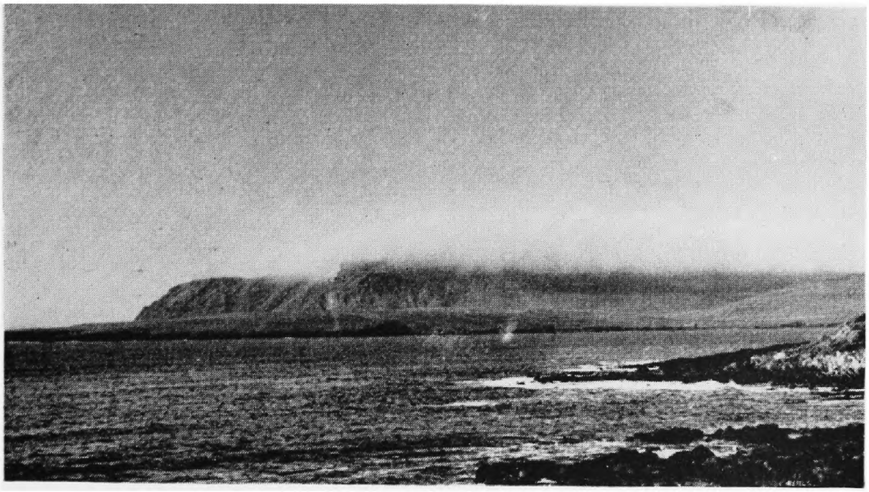
Photo by C. J. P. Cave.

Photo by R. K. Pilsbury

C_L5 Stratocumulus not formed by the spreading-out of Cumulus. The individual cloud masses may be separate and in the form of elongated bands or patches as shown in the upper picture, or they may be closed up into a continuous or nearly continuous layer as shown in the lower photograph. Often the cloud is dark and heavy looking, but it is frequently light in tone, usually when it is at a fairly high level, or when it is thin.

Average height of cloud base: 1500 to 5000 feet.

CLOUD PLATE IV



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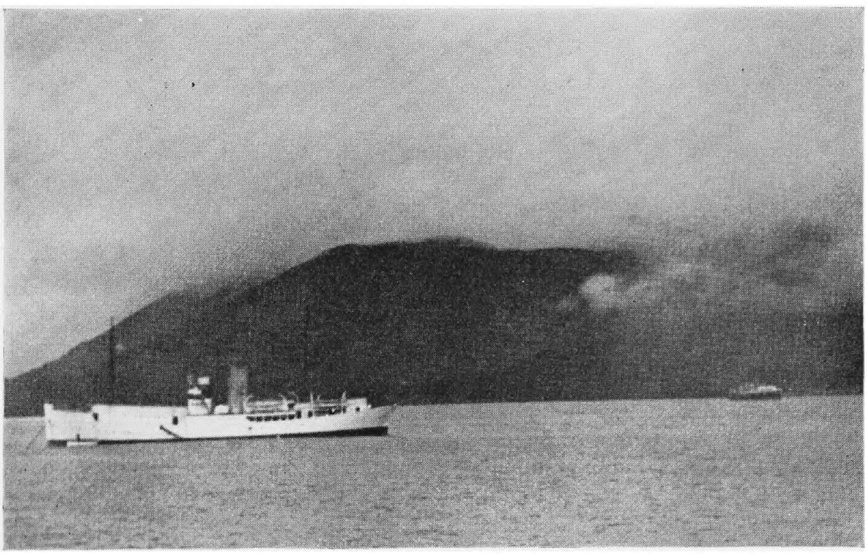

Photo by G. H. D. Evans

C_L6 Stratus. This commonly occurs as an unbroken layer of almost uniform, featureless grey cloud, but it is often seen in broken ragged fragments. When the layer is thin the shape of the disc of the sun or moon can be plainly seen through the cloud. Any precipitation from Stratus is in the form of slight drizzle or of snow grains. Orographic Stratus, formed over Fitful Head in the Shetland Islands, is shown in the upper picture; the lower picture shows Stratus formed from lifted fog.

Average height of cloud base: from near the surface to about 1000 feet.

CLOUD PLATE V

Photo by G. A. Clarke

Photo by A. J. Aalders (Copyright: Royal Netherlands Meteorological Institute)

C_L7 Ragged low clouds of bad weather.* These are well known to mariners as " scud ". (In the international cloud nomenclature the name for this cloud is " pannus "). The clouds are low-looking, ragged and shapeless; they are frequently dark. Through breaks in the cloud, a layer of Nimbustratus or Altostratus may be seen.

Average height of cloud base: between 300 and 1000 feet.

* i.e., precipitation imminent, actually falling, or very recently ceased.

CLOUD PLATE VI

Photo by R. K. Pilsbury

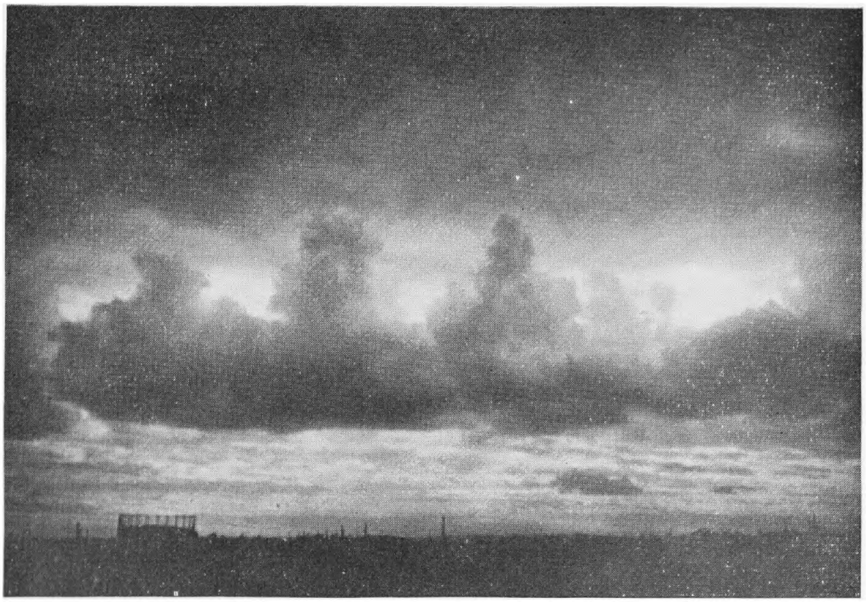

Photo by G. A. Clarke

C_L8 Cumulus amd Stratocumulus present at different levels. Stratocumulus formed from Cumulus is excluded. The amount of each type of cloud present is immaterial—the important thing is that the two kinds are at different levels, the Cumulus normally being at the lower level. Occasionally the tops of the Cumulus may reach or even penetrate the layer of Stratocumulus; the lower picture illustrates this.

Average height of cloud base: 1000–5000 feet.

CLOUD PLATE VII

Photo by G. A. Clarke

Photo by R. K. Pilsbury

C_L9 Cululonimbus with anvil. This is a massive cloud of great vertical depth and horizontal extent, having a frayed out, fibrous top in the shape of an anvil. It normally develops from C_L3 and commonly gives rise to thunderstorms and/or hail showers. Underneath the base of the cloud, which is often very dark, there are frequently low, ragged clouds, which in storms are only a few hundred feet above the surface. Occasionally the upper parts of the cloud merge with Altostratus or Nimbostratus. The lower picture shows the appearance which the base of a Cumulonimbus cloud presents when it is overhead. The downward hanging protuberances are due to turbulent down-draughts and are known as " mamma ".

Average height of cloud base: 1000–5000 feet.

CLOUD PLATE VIII

Photo by A. J. Aalders (Copyright: Royal Netherlands Meteorological Institute)

C_M1 Thin Altostratus. The background cloud seen in the picture is thin Altostratus, developed as a rule from the thickening Cirrostratus associated with an approaching warm front. At times, however, it results from the spreading out of the upper parts of a Cumulonimbus. Most of the cloud sheet is light grey and semi-transparent, the sun or moon shining weakly through it as through a sheet of ground glass. Any halo phenomena previously seen in Cirrostratus disappear as it thickens into Altostratus. The ragged patches of low cloud seen in the picture are associated with forthcoming bad weather and, although not yet entirely typical of C_L7, require to be coded as such.

Photo by A. J. Aalders (Copyright: Royal Netherlands Meteorological Institute)

Photo by French Meteorological Service

C_M2 Dense Altostratus or Nimbostratus. This develops from thickening C_M1, the greater part of the layer having become too dense for the sun or moon to be seen through it any longer. The grey colour of the cloud sheet becomes darker and a certain amount of shading may be seen, especially when there are several layers of medium-level cloud fused together: this is shown in the upper picture. The lower picture shows the appearance of the cloud sheet when it has thickened into Nimbostratus.

CLOUD PLATE X

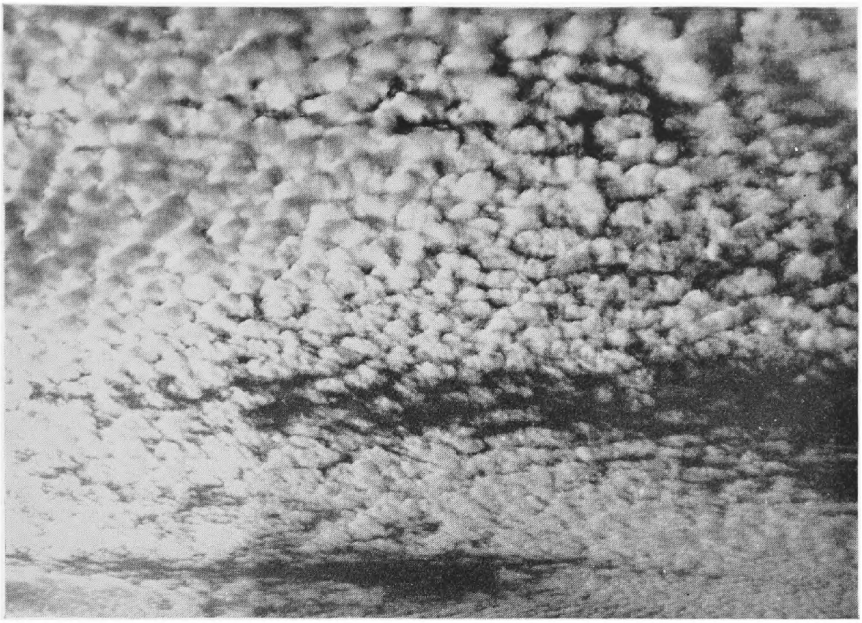

Photo by R. K. Pilsbury

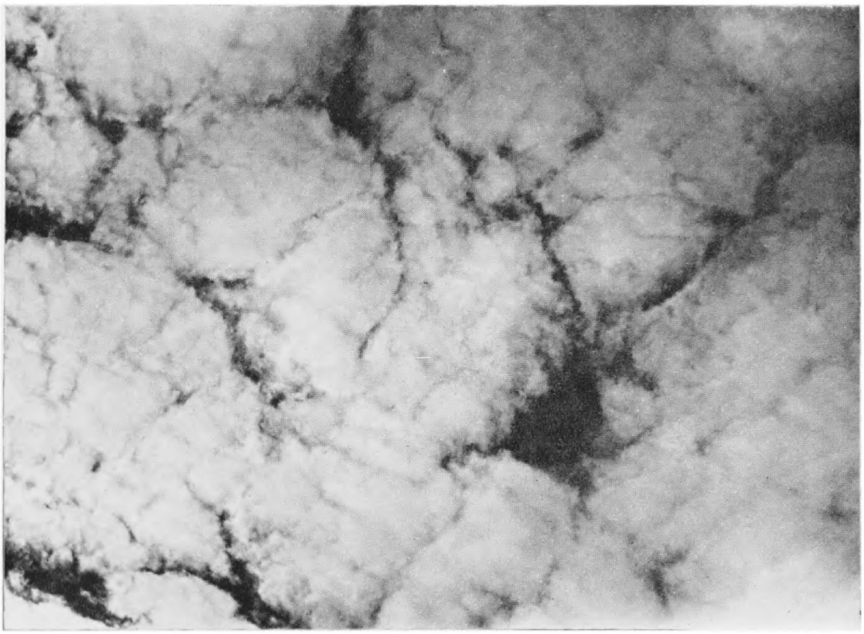

Photo by C. J. P. Cave

C_M3 Altocumulus at a single level, not progressively invading the sky. The elements in the cloud sheet shewn in the upper picture are small, more or less uniform, rounded and with no heavy shading; near the sun they are translucent. The cloud elements seen in the lower picture are large and flat and if they were more heavily shaded could be mistaken for Stratocumulus. However, being only lightly shaded and translucent, the layer has to be classified as Altocumulus.

Cloud Plate XI

Photo by G. A. Clarke

C_M4 Altocumulus in patches of lenticular form. The clouds shown in the picture are due to wave motion in the atmosphere and they are seen mainly over hilly country. At sea they are therefore likely to be seen only in certain coastal waters in the direction of the land. The cloud elements are smooth-looking and taper away towards the ends; they have bright translucent edges and show definite shading. In another variety of the cloud the elements are composed of fine granules and ripples lying in thin irregular patches, vaguely lenticular in shape and having fairly pronounced shading. Parts of the cloud near the sun often show the delicate colouring known as irisation.

Photo by L. Gain (Reproduction from World Meteorological Organisation's " International Cloud Atlas ")

C_M5 Altocumulus progressively invading the sky. The essential feature of this cloud type is that it spreads from some particular direction on the horizon and increases in amount, perhaps finally covering the whole sky. It may be in one or more layers of varying degrees of density, some parts being translucent and others heavily shaded. Sometimes it may resemble Stratocumulus at a high level.

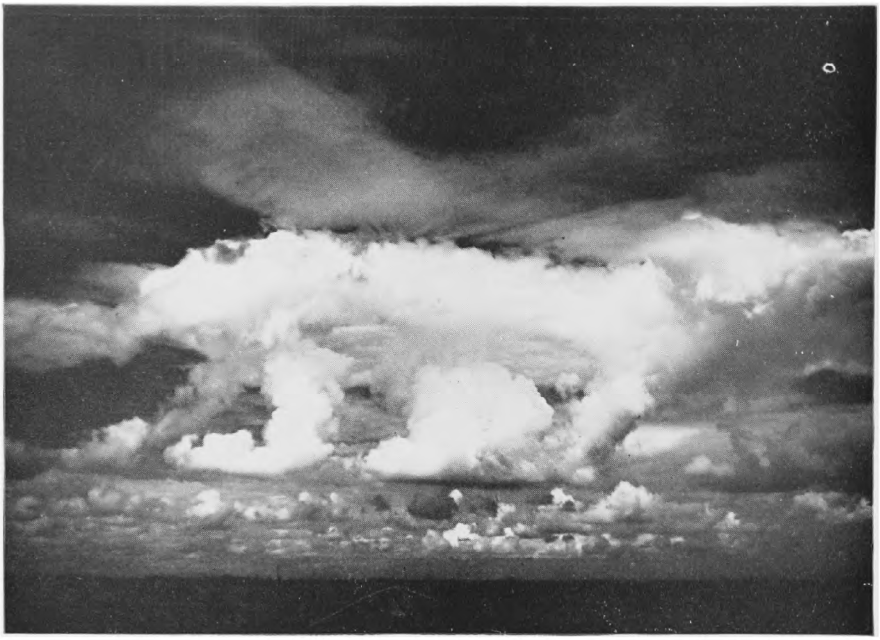

Photo by G. A. Clarke

C$_M$6 **Altocumulus formed by the spreading out of Cumulus or Cumulonimbus tops.** In certain atmospheric conditions,* the tops of these clouds reach a level above which they cannot rise, and they are compelled to flatten out horizontally, forming patches of Altocumulus of rather irregular thickness and shape, as shown in the picture. (Care should be taken not to confuse these with the anvil-shaped tops of Cumulonimbus.) If many large Cumulus-type clouds are present, the patches of Altocumulus, resulting from the spreading-out of their tops, may coalesce to form quite an extensive layer.

* *When there is a marked temperature inversion in the atmosphere it acts as a barrier to air rising by convection*

Photo by A. J. Aalders (Copyright: Royal Netherlands Meteorological Institute)

Photo by R. K. Pilsbury

C_M7 (*a*) **Altocumulus not increasing.** This type includes:

(i) Patches, sheets or layers of Altocumulus at different levels, either opaque or semi-transparent

(ii) Patches or sheets of Altocumulus at one level, or a single layer of Altocumulus. These are generally opaque.

(*b*) **Altocumulus together with Altostratus or Nimbostratus.** The Altocumulus normally occurs below the Altostratus or Nimbostratus and the question of whether the cloud amount is increasing or decreasing does not arise in this case. The lower picture shows the cloud layers which are partly merged, the Altocumulus being seen against the darker grey background of Altostratus.

Photo by R. K. Pilsbury

Photo by C. J. P. Cave

C_M8 Altocumulus castellanus and Altocumulus floccus. Both of these types are associated with developing thundery conditions over a wide area as opposed to thunderstorms arising from locally generated Cumulonimbus clouds. The upper picture shows a long line of typical Altocumlus castellanus in the distance; in the top half of the picture there are lines of Altocumulus in cumuliform tufts (Altocumulus floccus). The lower picture shows very ragged Altocumulus floccus in considerable quantity.

CLOUD PLATE XVI

Photo by French Meteorological Service

C_M9 Altocumulus of a chaotic sky. The main characteristic of the sky is its chaotic, heavy and stagnant appearance. It is complex with patches of medium cloud, more or less fragmentary and superposed, often badly defined and showing all the transitional forms below low Altocumulus and fibrous veils of Cirrus.

Photo by G. A. Clarke

C_H1 Cirrus in the form of strands or hooks, not progressively invading the sky. The picture shows clearly the fibrous structure of the Cirrus, which is composed of bundles of fine strands, many being hook-shaped at the ends. This type of Cirrus is quite often found with other types of Cirrus clouds, and the sky should be classified as C_H1 only when the combined amount of filaments, strands and hooks exceeds the total of other types of Cirrus present.

Photo by R. K. Pilsbury

Photo by R. K. Pilsbury

C_H2 Dense Cirrus in patches. The Cirrus occurs in dense patches or entangled sheaves whose amount does not usually increase with time. The patches sometimes resemble the remains of the upper part of a Cumulonimbus cloud, with which they may be thought, erroneously, to have some connection. Cirrus with sproutings in the shape of small turrets or battlements, or showing cumuliform tufts, is also included as C_H2.

CLOUD PLATE XIX

Photo by R. K. Pilsbury

C_H3 Dense Cirrus, the remains of the upper parts of Cumulonimbus. This commonly takes the form of an " anvil ", as shown in the picture, the lower part of the Cumulonimbus with which it is associated lying below the horizon. The Cirrus may be entirely separate from the Cumulonimbus of which it was a part. It may be assumed to have originated from Cumulonimbus if it has a general anvil-like shape, has frayed edges and appears dense.

Photo by R. K. Pilsbury

C_H4 Cirrus in the form of strands, often hook-shaped, progressively invading the sky. The Cirrus shown in the picture is moving from left to right, invading the sky and thickening, but there is, so far, no Cirrostratus present. The cloud appears densest in that part of the sky from which it is approaching.

CLOUD PLATE XX

Photo by R. K. Pilsbury

C_H5 Cirrus and/or Cirrostratus progressively invading the sky. The continuous veil is less than 45° above the horizon, in the direction from which the cloud is spreading. Cirrus of this type develops as a result of the continued spread of C_H4. The example shown in the picture has a tendency to lie in parallel bands, and in the distance it has thickened into Cirrostratus. The cloud often occurs in bands which appear to converge towards the horizon.

Photo by A. J. Aalders (Copyright: Royal Netherlands Meteorological Institute)

C_H6 Cirrus and/or Cirrostratus progressively invading the sky. The continuous veil extends more than 45° above the horizon, in the direction from which the cloud is spreading. The Cirrus in the top left-hand side of the picture is thickening rapidly into Cirrostratus. Halo phenomena may be expected when the veil has spread across the sun or moon.

Photo by G. A. Clarke

C_H7 Veil of Cirrostratus covering the whole sky. The cloud is usually light, uniform and nebulous, but it may be white and fibrous showing striations. It gives rise to halo phenomena round the sun or moon. Sometimes the veil is so thin that it is diffcult to distinguish it from the blue sky, and halo phenomena may provide the only reliable evidence of its presence.

Photo by G. A. Clarke

C_H8 (*a*) Cirrostratus not covering the whole sky, and either remaining constant in amount or decreasing. The picture shows a fairly dense sheet of Cirrostratus clearing away after the passage of a cold front.

(*b*) **Patches of Cirrostratus, whether increasing or not.** In this case the cloud occurs only in patches, which, although increasing, do so merely temporarily.

CLOUD PLATE XXIII

Photo by R. K. Pilsbury

Photo by D. S. Hancock (Reproduced from World Meteorological Organisation's " International Cloud Atlas ")

C_H9 Cirrocumulus alone or, when other cirriform cloud is also present, Cirrocumulus predominating. The upper picture is an example of typical Cirrocumulus, the individual elements of which are extremely fine and delicate; there is also a marked absence of shading. Sometimes cirrocumulus is associated with Cirrus or Cirrocumulus in composite patches which are usually in a state of continual internal transformation. The lower picture illustrates a type of Cirrocumulus which is rather rare. The wave-like structure is clearly visible in both pictures.

CLOUD PLATE XXIV

CHAPTER 6

Ocean Waves

The complex nature of wave-motion at sea. The action of wind in producing waves is not precisely understood. The effect of the wind varies from the tiny ripples ruffled on a pond by the merest breath of air to the mighty rollers of the North Atlantic and Roaring Forties. All ocean waves, other than those caused by movements of the sea floor, and tidal effects, owe their origin to the generating action of the wind. Wave-motion, however, may persist even after the generating force has disappeared, being then slowly dissipated by frictional forces.

An observer of the motion of the sea-surface at a particular place will, in general, notice a complicated wave form such as is shown in Fig. 28 (page 61), which may be regarded as the result of the superposition of a number of simple symmetrical wave-motions having different lengths and speeds.

The ideal observer is an instrument known as a wave-recorder which registers automatically the up and down motion of the water surface and enables a record such as Fig. 28 to be drawn. By mechanical means this record can be analysed or split up into its component simple waves. Wave-recorders can only be used on shore or from stationary ships and hence it is not possible to measure sea disturbance in general by this method although it would be most desirable to do so.

The distinction between sea and swell. The system of waves raised by the local wind blowing at the time of observation is usually referred to as "sea". Those waves not raised by the local wind blowing at the time of observation, but due either to winds blowing at a distance or to winds that have ceased to blow, are known collectively as "swell". Usually, one component of the swell dominates the rest, but occasionally two component wave-motions crossing at an angle may be observed. These are referred to as "cross swells".

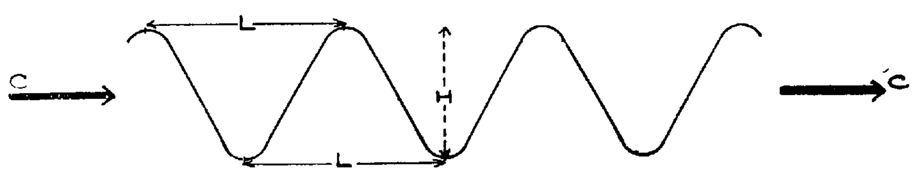

FIG. 25. Characteristics of a simple wave

The characteristics of a simple wave. The following definitions are used in describing a simple wave:—

(i) SPEED, C, usually expressed in knots, is the speed at which individual waves travel.

(ii) LENGTH, L, expressed in feet, is the horizontal distance between successive crests or successive troughs.

(iii) PERIOD, T, expressed in seconds, is the time interval required for the passage of successive crests (or successive troughs) past a given point.

(iv) HEIGHT, H, expressed in feet, is the vertical distance between the top of a crest and the bottom of a trough.

The following relations are found to hold for a simple wave:—

Speed = $3{\cdot}1 \times$ Period.
Length = $5{\cdot}1 \times (\text{Period})^2$.

By means of these formulae, measurements of one of the variables can be used to calculate the other two. The following table gives these relations numerically for different wave periods:—

Period (*secs.*)	*Length* (*feet*)	*Speed* (*knots*)
2	20·4	6·2
4	81·6	12·4
6	183·6	18·6
8	326·4	24·8
10	510·0	31·0
12	734·4	37·2
14	999·6	43·4
16	1305·6	49·6
18	1652·4	55·8
20	2040·0	62·0

There is no inherent theoretical relation between the height and period of a simple wave. We can imagine the height to be varied at will, the period (and hence length and speed) remaining constant. In real wave motion, however, in which many simple waves are superposed there is a further consideration that enables us to see how the height is limited. If we call the quotient H/L the "steepness" of the wave, it is found that the mean steepness does not increase beyond 7·6 per cent. (1/13). If the mean steepness is less than this figure then the waves are capable of absorbing more energy from the wind, thus increasing their height relative to their length. When the limiting steepness is reached, surplus energy received from the wind is dissipated by the breaking of the waves at the crests (white horses). This limiting value of the steepness explains why the mean maximum height of the sea waves is roughly in proportion to their length; for example, wind driven waves of length 400 feet (period 9 seconds) would not be expected to have a mean maximum height greater than 30 feet. If the wavelength were about 500 feet (period 10 seconds) this limiting value of the mean maximum height would be increased to 40 feet. On the other hand, long swells, perhaps 1,000–2,000 feet in length, may have heights of less than a foot.

When the height of the wave is small compared with its length, the wave profile can be adequately represented by a simple sine curve. As the height becomes relatively greater, however, it is seen that the crests become sharper and the troughs much more rounded, the precise profile being a curve known as a "trochoid". This is the curve that 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 deckhead.

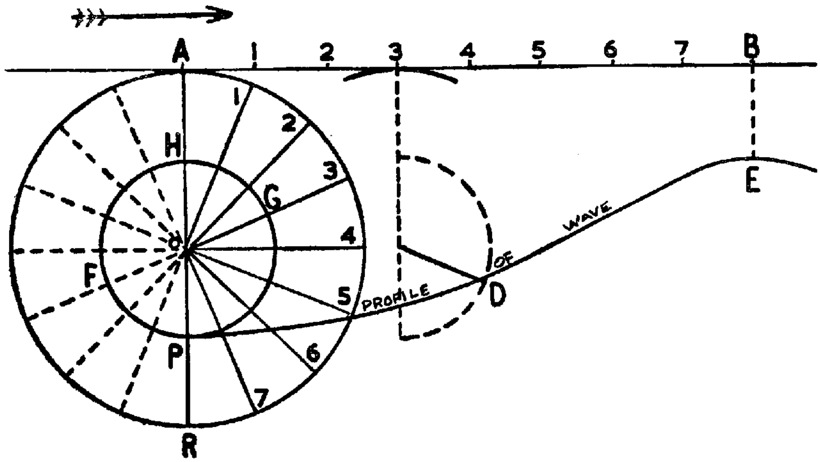

FIG. 26. Representation of a trochoidal wave form

In Fig. 26, 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 in which the wave is supposed to 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 position 3 of the circle reaches position 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 wavelength; 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.

In an ideal wave each water 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 a 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 trough 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. This motion may be seen by watching a floating object at the passage of a wave. The object describes a circle but is not carried bodily forward by the wave.

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, and the water particles revolving in ever-decreasing circles. At a depth of one wave-length the disturbance 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. The motion associated with the largest ocean waves is inappreciable at even moderate depths, as is demonstrated by experience in submarines.

Wave groups. Experience shows that waves generally travel in groups with patches of dead water in between, the wave height being a maximum at the centre of each group. We have said earlier that any observed wave motion can be regarded as built up from a number of simple wave forms. Let us consider, for example, the superposition of two simple wave motions having the same height but slightly different periods. If the crests of the two wave motions are made to coincide at the initial point of observation the height of the resultant wave will be twice that of each component wave. To each side of this point, however, owing to the difference of period, the additive effect becomes less until a point is reached where the heights of the component waves, being of different sign, completely annul each other's effect. Beyond this point the heights again become additive until the troughs of the component waves coincide. In other words, there is a variation of height superposed on the ordinary wave motion. It can also be shown that two simple wave trains moving in slightly different directions give a resultant pattern composed of "short-crested" waves as distinct from the "long-crested" waves of simple wave motions.

The speed of a wave group is not the same as that of the individual waves comprising it. Each individual wave in its turn emerges from the dead water in the rear of the group, travels through the group and subsides in the dead water ahead of it. The speed of the wave group must therefore be less than the speed of an individual wave. Both theoretical considerations and experience show that the wave group travels at one half the speed of the individual waves.

The origin and travel of swell. Swell waves originate in the heavy seas created in a storm area. Short waves have an insufficient store of energy to enable them to travel long distances against the dissipating action of friction. Hence, in general, it follows that swell waves are long waves in comparison with the wind-driven waves at the place of observation.

In calculating the distance travelled by swell, care must be taken to distinguish between the speed of the individual waves and the speed of the wave groups. If, for example, a ship reports the sudden onset of waves whose speed, calculated from the period, is 30 knots, then another ship in the line of advance of these waves will experience their onset at a time obtained by allowing a speed of $\frac{1}{2} \times 30 = 15$ knots for the disturbance.

As swell travels its height decreases. Investigations by the National Institute of Oceanography show that if R is the distance from the point of generation in nautical miles then the amplitude at distance R is $(\frac{300}{R})^{\frac{1}{2}}$ of that at the point of generation by the wind. Thus, a swell would lose one half of its height in travelling a distance of 1,200 nautical miles. The long swells are the greatest travellers.

Waves in shallow water. All the previous remarks refer to waves in deep water. When a deep-water wave enters shallow waters it undergoes profound modification. Its speed is reduced, its direction of motion may be changed and, finally, its height increases until, on reaching a certain limiting depth, the wave breaks on the shore. Water may be regarded as shallow when the depth is less than half the length of the wave.

The decrease in speed when a wave approaches the shore accounts for the fact that the wave fronts become, in general, parallel to the shore prior to breaking. Fig. 27 shows a wave, approaching the shore at an angle, being refracted until it becomes parallel to the shore.

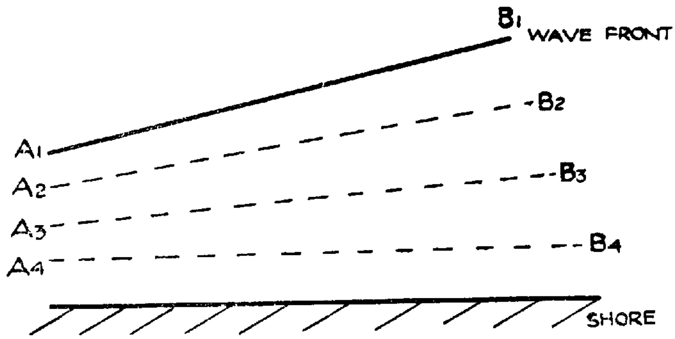

FIG. 27. Refraction of a wave approaching the shore at an angle

The same reasoning may be applied to explain how waves are enabled to bend round headlands and to progress into sheltered bays.

OBSERVING OCEAN WAVES

The inherent difficulties of observation. It has been remarked earlier that the ideal observer is a wave-recorder which can register automatically the up and down motion of the sea surface at a fixed point. A typical record is shown in Fig. 28.

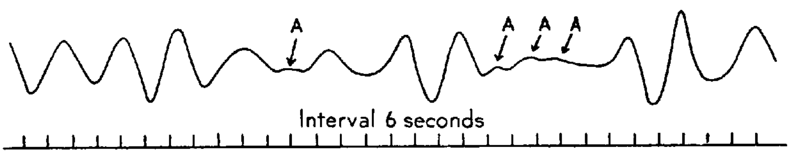

FIG. 28. Wave form of the sea-surface

The record is, in general, complex and shows immediately all the difficulties inherent in eye observation. For example, are all the waves to be considered on an equal footing or are only the big waves to be counted? Since the wave characteristics vary so much, what average values shall be taken? It is obvious that if comparable results are to be obtained the observer must follow a definite procedure. The flat and badly formed waves ("A" in Fig. 28) between the wave groups cannot be observed accurately by eye and different observers would undoubtedly get different results if an attempt were made to include them in the record. The method to be adopted, therefore, is to observe only the well-formed waves in the centre of the wave groups. The observation of waves entails the measurement or estimation of the following characteristics:

Direction Period Height

Reliable average values of period and height can only be obtained by observing at least twenty waves. Of course these cannot be consecutive; a few must be selected from each succeeding wave group until the required number has been obtained. Only measurements or quite good estimates are required. Rough guesses have little value and should not be recorded.

It will often be found that there are waves coming from more than one direction. For example, there may be a sea caused by the wind then blowing and a swell caused by a wind that has either passed over or is blowing in a distant area. Or there may be two swells (i.e., cross swells) caused by winds blowing from different directions in distant areas. In such cases the observer should distinguish between sea and swell, and report them separately, giving two groups for swell when appropriate.

Observing waves from a moving ship

(i) DIRECTION FROM WHICH THE WAVES COME. This is easily obtained either by sighting directly across the wave front or by sighting along the crests of the waves and remembering that the required direction differs from this by 90 degrees. Direction is always recorded true, not magnetic.

(ii) PERIOD. For measurements of period a stopwatch is desirable. If this is not available an ordinary watch with a seconds hand may be used or, alternatively, a practised observer may count seconds.

The observer selects a distinctive patch of foam or a small object floating on the water at some distance from the ship, and notes the time at which it is on the crest of each successive wave. The procedure is repeated for the larger waves of each successive group until at least twenty observations are available. The period is then taken as the average time for a complete oscillation from crest to crest. In a fast ship it will be found that the "patch of foam" method will rarely last for more than one complete oscillation and that many waves have to be observed separately. With practice, suitable waves can easily be picked out and the timing from crest to crest becomes quite simple. When it is desired to use an object, such as a bottle, it should be thrown initially as far forward on the bow as possible.

Another method available to the observer with a stopwatch is to observe two or more consecutive "central" waves of a wave group while the watch is running continuously, then to stop the watch until the central waves of the next wave group appear, the watch being then restarted. This procedure is repeated until at least twenty complete oscillations have been observed. The period is then obtained by dividing the total time by the number of oscillations.

(iii) HEIGHT. Although wave-recorders are fitted to a few research ships, there is at present no method of measuring the height of waves from a merchant ship, but a practised observer can make useful estimates. The procedure to be adopted depends on the length of the waves relative to the length of the ship. If the length of the waves is short in comparison with the ship's length, i.e., if the ship spans two or more wave crests, then the observer should take up a position as low down in the ship as possible, preferably amidships, where the effect of pitching is least and on the side of the ship from which the waves are coming. The height should then be estimated from the appearance of the waves on the side of the ship, at times when the pitching and rolling of the ship is least.

This method fails when the length of the waves exceeds the length of the ship, for then the ship rises bodily with the passage of each wave crest. The observer should take up a position in the ship so that his eye is just in line with the advancing wave crest and the horizon, when the ship is vertical in the trough. The height of eye above the ship's water line is then the height of the 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 it is particularly important to make the observation at the moment when she is upright in the trough. Exaggeration of estimates of wave height is mostly due to errors caused by rolling. (*See* Fig. 29. When the ship is rolling (b), the observer at "o" has to take up a higher position to get a line on the horizon than when she is upright (a).)

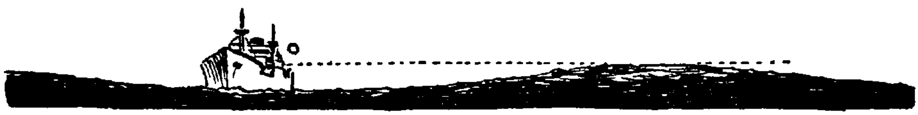

FIG. 29 (*a*)

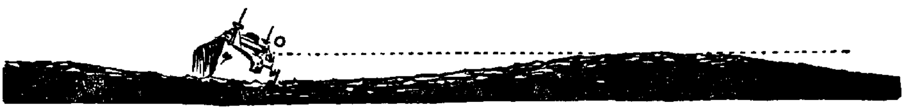

FIG. 29 (*b*)

The observation of height of waves is most difficult when the length of the waves exceeds the length of the ship and their height is small. The best estimate of height can be obtained by going as near the water as possible, but even then the observation can only be rough.

The inherent difficulties already mentioned together with the practical difficulties of estimation make it essential that the recorded height be the average value of about twenty distinct observations. These observations should be made on the central waves of the more prominent wave groups.

Wave observations at night or in low visibility. Under these conditions the most that the observer can normally hope to record is direction and an estimate of height, or perhaps direction only, which would at least indicate the presence of waves. Such observations might be of considerable value in tropical waters in the hurricane season. It is only on very bright nights that the observation of period would be practicable.

Observing waves from weather ships. A wave-recorder, which can record the period and height of the waves, has been installed in one of the British ocean weather ships. But even when no special instruments are carried, weather ships have the advantage of being able to "heave to" at will, thus securing the best conditions for wave observation. The methods outlined in (ii) may be used to better advantage than by ordinary merchant ships. For example, a floating object may be observed for a considerable time; it is not lost in the distance as occurs when the ship is moving.

In addition to these observations the length and period of waves can be determined from a stationary ship as follows:

(*a*) Length can be observed by streaming a buoy for such a distance astern that the crests of successive waves are simultaneously passing the buoy and the observer. The distance between the two is the wavelength.

(*b*) Period can be obtained by noting the time taken for the wave to travel the distance between the buoy and the observer.

By simple division the speed of the individual waves can be deduced.

The importance of wave observations. The study of ocean waves has only recently been put on a scientific basis by the utilisation of an automatic method of recording and the subsequent analysis of the record into component simple waves. The establishment of a network of specially equipped observing stations would probably add much to our present knowledge of the generation, transmission and decay of ocean waves. The new method of recording has made evident the limitations of former methods of observation, including the use of sea and swell scales, and has indicated the necessity of obtaining quantitative observations of wave characteristics.

Of practical importance is the fact that quantitative wave observations may be used for identifying the approximate position of a storm centre when suitable weather observations are lacking. The use of swell as an indication of the approach of a tropical storm is well known. The forecasting of swell on exposed coasts, such as those of Morocco and Portugal, is of considerable value for the protection of coastal shipping and port installations. The accuracy of these forecasts depends largely on an adequate supply of reliable ships' observations. Statistics of the period and height of waves would be of value to naval architects particularly in respect of stability, rolling and behaviour of the ship structure in a seaway.

CHAPTER 7

Observations of Ocean Currents and Ice

OCEAN CURRENT OBSERVATIONS

The method of obtaining current observations is to calculate the difference between the dead reckoning position of the vessel, after making due allowance for leeway, and the position by a reliable astronomical, land or radio fix. The result is the set and drift experienced by the vessel during the interval since the previous astronomical or land fix.

This method of observing set and drift of current has been the principal means of acquiring knowledge of the surface currents of the ocean, and with the increasing accuracy of navigation and the accumulation of observations, much is being learnt about the subject. The list of atlases so far prepared is given on pages 117-8. Very many more observations of current are required, because in large regions of all the oceans, the number of observations used in these atlases is so small. Furthermore, on account of the seasonal variation to which currents are subject, it is most desirable that monthly charts should be published; this will only be possible when the number of available observations is considerably increased.

The set and drift found by the above method is that for a mean depth of about half the ship's draught. It will only be correct if the ship's speed through the water is accurately known, the steering good, the judgment of leeway sound, and the compass error accurately known. In estimating a ship's dead reckoning position, the speed, or distance run through the water, is always difficult to estimate; a compromise between log distance and distance by engine revolutions after due allowance for slip, gives perhaps the best results. For the purposes of computation of current roses, predominant and vector mean currents, information of current of all strengths, including weak ones and "nil" current, are equally important and, in fact, essential to give a true picture of the general current circulation.

The attention of marine observers is drawn to the pages at the end of the meteorological log, for the recording of the set and drift of all currents observed during a voyage. Observations of ocean current will be very welcome from any ship, whether reporting meteorological observations or not.

The surface current observations from the open ocean which are the most useful are those computed between two star fixes at twilight. This is because the fixes are accurate, the period between them short enough to make it probable that the ship has only experienced one current in the elapsed time, and also short enough to reduce any errors in the dead reckoning course and distance to a minimum. Reliable radio, radar, and electronic fixes are also acceptable. Careful notes should be made of the method of obtaining each fix.

Noon to noon currents are generally acceptable though never quite so good as those from stars to stars. For one thing, the noon position, though it is normally taken by several officers, can only be regarded as a running fix, the accuracy of which may be dependent on a due appreciation of a current experienced between the morning sun sight and noon, the very element which we are trying to find. However, for practical purposes, when spread over 24 hours, this error is probably negligible in the majority of cases, and the chief thing which spoils the accuracy of a current so computed is that the ship may have experienced two or more currents during the 24 hours. These may give a resultant quite different from its constituents. This is particularly so in a fast ship. Current observations from noon on one day to morning stars on the next or from evening stars on one day to noon on the next are, in general, acceptable. Currents worked between morning stars on two successive days or between evening stars on two successive days are acceptable and are preferred to noon to noon currents, but no current for a longer period than a "ship day", which may be 24½ or even 25 hours, need be entered.

The inherent inaccuracies of the normal noon position, however carefully it is compiled, will have a disproportionate effect on a current compiled from morning stars to noon or from noon to evening stars, and any such currents are not accepted for the atlases and should not therefore be entered. Officers will, however, be aware that there are many occasions when a true fix is possible in daylight and the sun may be crossed with Venus, the moon or even Jupiter. Such a fix gives the enthusiastic observer of ocean currents a golden opportunity, especially when stars have been missed, and the presence of one or other of these bodies on a suitable bearing at noon will ensure the accuracy of the noon position, in which case a morning star to noon current would be acceptable.

It is necessary, however, to caution the over-enthusiastic officer against putting himself to needless trouble by working out currents which overlap or duplicate each other and which will consequently have to be discarded. For instance, suppose a ship gets the following positions:

(1) Noon (a.m. sun, run up to meridian altitude)
(2) Venus and sun in the afternoon
(3) Stars about 7 p.m.
(4) Stars about 5 a.m.
(5) Sun and moon in the forenoon
(6) Noon (a.m. sun, run up to meridian altitude)

There is a variety of currents which could be worked but many of these would overlap. The ones most acceptable to us would be those between 2 and 3, 3 and 4, and 4 and 5, i.e. short periods between true fixes none of which fall in the period of a current already worked.

When selecting currents for incorporation into the atlases we have to take into consideration the wind and weather. The dead reckoning required for these observations depends simply on the true course steered and the distance steamed through the water *since the observation from which the current is being computed*, making due allowance for leeway only. Some ships, such as loaded tankers, will make little leeway in any but the strongest wind, others, such as high sided ships flying light, will make a lot, and because of the uncertainty of the amount of leeway made by ships in winds of *force* 6 *and above* it has been our custom to give less weight to currents computed in such circumstances.

The state of loading of the ship and the means of measuring her speed are also taken into consideration. Ships which measure their distance by engine revolutions only are bound to give an uneven performance when the propeller is not reasonably well immersed, i.e. when the ship is in light condition, and currents should not therefore be recorded in these circumstances.

When coasting and in sight of land, currents computed between shore fixes are most desirable. It should be ensured, however, that the ship is not being influenced by tides.

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 needs to be anchored when the current meter is used.

ICE OBSERVATION

Attention is invited to the International Convention for the Safety of Life at Sea, 1960, Safety of Navigation, Regulations 2, 3 and 4 (*see* Chapter 14).

Provision for reporting ice is made in the International Synoptic Code (Washington, 1947). The reporting of sea ice in the synoptic weather report does not, however, supersede its reporting according to the International Convention for Safety of Life at Sea. Captains will give great assistance if they report observations of all ice sighted, by completing the appropriate form. Observing ships using the Trans-North Atlantic tracks are requested to complete this form, not only when ice is encountered, but also when they have passed through the ice region during the ice season without encountering ice. Such a "nil" report is valuable, since it is desirable to determine, as far as possible, when tracks have been clear of ice. It will be useful if the dimensions of ice, including the height of bergs seen, can be given.

The following are the descriptive terms of the International Ice Nomenclature which was officially adopted by the World Meteorological Organisation in December 1955. A list of other terms associated with ice and ice navigation follows (page 73).

Where double terms are given, e.g. ice floe/floe, either of the two terms may be used. When qualifying words precede the double term they apply to whichever term is used, e.g., close pack-ice/drift-ice may be used in either of the forms, close pack-ice or close drift-ice.

ANCHOR ICE/GROUND ICE. Ice found attached or anchored to the bottom, irrespective of nature of its formation.

ARCTIC PACK. Almost salt-free ice, having existed over two years. Thickness up from 2.5 metres (8 feet). The ice surface is undulating. Its hummocks having melted more than once are therefore smoothed. In case of absence or insignificant thickness of snow cover, this ice is coloured in different tints of blue.

BARE ICE. Ice without snow cover.

BARRIER BERG. See Tabular berg.

BAY/BIGHT. An inward bend of the ice-edge, formed either by wind or current.

BAY-ICE. Level ice of more than one winter's growth, which has remained unhummocked and also becomes nourished by surface layers of snow. Thickness of ice and snow up to about 2 metres (6½ feet) above sea level.

BELT. Long area of pack-ice/drift-ice from a few kilometres (miles) to more than 100 kilometres (50 miles) in width.

BERGY-BIT. A medium sized piece of ice, generally less than 5 metres (about 16 feet) above sea level and about the size of a small cottage, mainly originating from glacier-ice, but occasionally a massive piece of sea-ice or disrupted hummocked ice. When the sea-ice origin is not in doubt the term Floeberg may be used.

BIG ICE-FLOE. See Ice-floe.

BIGHT. See Bay.

BRASH-ICE. Accumulation of small fragments not more than 2 metres (6½ feet) across, the wreckage of other forms of ice.

CLOSE PACK-ICE/DRIFT-ICE. Composed of floes mostly in contact. Ice cover 7/10–9/10 or 6/8–7/8.

CRACK. Any fracture or rift in sea-ice not sufficiently wide to be described as a lead/lane. It is usually possible to jump across a crack.

DRIED ICE. Ice surface, from which the water has disappeared after the formation of cracks and holes. During the period of drying, the surface is whitening.

DRIFT ICE. See Pack-ice.

FAST-ICE. Sea-ice which remains fast, generally in the position where originally formed, and which may attain a considerable thickness. It is found along coasts, where it is attached to the shore, or over shoals, where it may be held in position by islands, grounded icebergs or grounded polar ice.

FIRN SNOW/NÉVÉ. Snow which has become coarse-grained and compact through temperature changes, forming the transition stage to glacier-ice.

FLOE. See Ice-floe.

FLOEBERG. See Bergy-bit.

FRAZIL CRYSTALS. See Ice crystals.

FROST SMOKE. Fog-like clouds, due to the contact of cold air with relatively warm sea water, which appear over newly-formed leads/lanes and pools, or leeward of the ice-edge, and which may persist while slush or sludge and young ice are forming.

GLACIER BERG. Mass of glacier-ice which has broken away from its parent formation on the coast, and either floats, generally at least 5 metres (about 16 feet) above sea level, or is stranded on a shoal.

GLACIER-ICE. Any ice floating on the sea as a berg, which originates from a land glacier.

GLACIER TONGUE. Projecting seaward extension of glacier, usually afloat. In the Antarctic the extension may be up to many tens of kilometres (50 miles or more).

GROUNDED HUMMOCK. Hummocked grounded ice formation. There are single grounded hummocks and lines (or chains) of grounded hummocks.

GROUND ICE. See Anchor ice/Ground ice.

GROWLER. Smaller piece of ice than a bergy-bit, frequently appearing greenish in colour and barely showing above water. May originate both from sea-ice and from glacier-ice.

HUMMOCK. Ice pieces piled one over another on a rather smooth ice surface.

HUMMOCKED ICE. Ice piled haphazardly one piece over another.

ICE-BAR. Ice-edge consisting of floes compacted by wind, sea and swell, and difficult to penetrate.

ICEBERG. Large mass of floating or stranded ice, more than 5 metres (about 16 feet) above sea level, which has broken away either from a glacier or from an ice-shelf formation. Sub-divisions are Glacier berg and Tabular berg/Barrier berg.

ICE-BLINK. A typical whitish glare on low clouds above an accumulation of distant ice. It is especially glowing when observed on the horizon.

ICE BRECCIA/ICE MOSAIC. Ice pieces of different age frozen together.

ICE-CAKE. A floe smaller than 10 metres (33 feet) across. One less than 2 metres ($6\frac{1}{2}$ feet) across may be termed a small cake. (See Brash-ice).

ICE CRYSTALS/FRAZIL CRYSTALS. Fine spicules or plates of ice, suspended in water.

ICE-EDGE. The boundary at any given time between the open sea and sea-ice of any kind, whether floating or fast.

ICE-FIELD/FIELD OF ICE. Area of pack-ice/drift-ice, consisting of any size of floes, of such extent that its limits cannot be seen from the crow's nest.

ICE-FLOE/FLOE. A single piece of sea-ice, other than fast-ice, large or small, described if possible as "Light" or "Heavy" according to thickness.

Vast	—	over 10 kilometres ($5\frac{1}{2}$ miles) across
Big	—	1–10 kilometres ($\frac{1}{2}$–$5\frac{1}{2}$ miles) across
Medium	—	200–1,000 metres (660 feet–$\frac{1}{2}$ mile) across
Small	—	10–200 metres (33–660 feet) across

ICEFOOT. Ice step attached to the coast, unmoved by tides and remaining after the fast-ice has moved away. Several varieties of icefoot can be distinguished.

ICE ISLAND. Drifting portion which has separated off from an ice-shelf.

ICE LIMIT. Average position of the ice-edge in any given month or period based on observations over a number of years.

ICE MOSAIC. See Ice breccia/Ice mosaic.

ICE-RIND. A thin, elastic, shining crust of ice, formed by the freezing of slush or sludge on a quiet sea surface. Thickness less than 5 centimetres (2 inches). It is easily broken by wind or swell, and makes a tinkling noise when passed through by a ship.

ICE-SHELF. Ice formation over 2 metres ($6\frac{1}{2}$ feet) above sea level with level surface, which originates from annual accumulations of firn-snow/névé layers on bay-ice (or on the seaward extension of a glacier).

ICE-SLUSH. An accumulation on the surface of the water of ice needles frozen together; it forms patches or a thin compact layer of a greyish or leaden-tinted colour. The surface of the sea covered with ice-slush has a dim tint.

LANE. See Lead.

LARGE ICE-FIELD/FIELD OF ICE. An ice-field over 20 kilometres (11 miles) across.

LEAD/LANE. A navigable passage through pack-ice/drift-ice.

LEVEL ICE. Ice with a flat surface, which has never been hummocked; typical with regard to bays, gulfs, straits, archipelagoes and shallow waters, where the ice formation occurs in undisturbed conditions.

MEDIUM ICE-FIELD/FIELD OF ICE. An ice-field 15–20 kilometres (8–11 miles) across.

MEDIUM ICE-FLOE. See Ice-floe.

MEDIUM WINTER-ICE. Winter-ice of thickness 15–30 centimetres (6–12 inches).

NÉVÉ. See Firn-snow.

NEW ICE. A general term which includes Ice crystals/Frazil crystals, Slush, Sludge, Pancake ice and Ice-rind.

OPEN ICE-EDGE. Unsteady and not sharply outlined ice-edge, limiting an area of open ice; in most cases it is to leeward.

OPEN PACK-ICE/DRIFT-ICE. Floes seldom in contact, with many leads and pools. Ice cover 4/10–6/10 or 3/8–5/8.

OPEN WATER. A relatively large area of free navigable water in an ice-encumbered sea.

PACK-ICE/DRIFT-ICE. Term used in a wide sense to include any area of sea-ice, other than fast-ice, no matter what form it takes or how disposed.

PANCAKE ICE. Pieces of newly-formed ice, usually approximately circular, about 30 centimetres to 3 metres (1–10 feet) across, and with raised rims, due to the pieces striking against each other, as the result of wind and swell.

PATCH. A collection of pack-ice/drift-ice, less than 10 kilometres ($5\frac{1}{2}$ miles) across, the limits of which are visible from the crow's nest.

POLAR FAST-ICE. Fast-ice formed by the grounding and cementing together of polar ice. By the end of the winter it may reach some tens of kilometres (20 miles or more) from the coast.

POLAR ICE. Extremely heavy sea-ice, up to 3 metres (10 feet) or more in thickness of more than one winter's growth. Heavily hummocked and may ultimately be reduced by weathering to a more or less even surface. Polar ice may be subdivided into Young polar ice and Arctic pack.

POLYNYA. Water area enclosed in ice, generally fast; this water area remains constant and has usually an oblong form. Sometimes the "polynya" is limited on one side by the coast.

POLYNYA OFF EDGE OF SHORE ICE. Polynya between shore ice and drift-ice, formed by squeezing winds and currents.

POOL. Any enclosed relatively small sea area in pack-ice/drift-ice other than a lead/lane.

PRESSURE-ICE/SCREW-ICE. A general term for ice which has been squeezed together and in places forced upwards. Subdivisions are Rafted ice, Hummocked ice, and Pressure ridge.

PRESSURE RIDGE. Ridge or wall of hummocked ice where floes have been pressed against each other.

PUDDLE. See Snow water on the ice/Puddle.

RAFTED ICE. Type of pressure-ice/screw-ice formed by one floe over-riding another.

RAM. An underwater ice projection from an iceberg or a hummocked ice-floe. Its formation is usually due to a more intensive melting of the unsubmerged part of the floe.

ROTTEN ICE. Ice which has become honeycombed in the course of melting and which is in an advanced state of disintegration.

SCREW-ICE. See Pressure-ice.

SHORE ICE. Basic form of fast-ice, representing a compact ice cover attached to the shore and, in shallow waters, also grounded; during changes of sea level vertical fluctuations can be observed. Shore ice can spread in breadth up to several hundreds of kilometres (200 miles or more).

SHORE LEAD. A lead between pack-ice/drift-ice and the shore, or between pack-ice/drift-ice and a narrow fringe of fast-ice.

SHORE POLYNYA. Polynya along the coast, formed either by current or wind.

SLUDGE. Spongy whitish ice lumps, a few centimetres (one or two inches) across; they are formed of slush, of snow slush and sometimes of spongy ice lumps formed on the bottom of the sea and emerging on the surface.

SLUSH OR SLUDGE. An accumulation of ice crystals which remain separate or only slightly frozen together. It forms a thin layer and gives the sea surface a greyish or leaden-tinted colour. With light winds no ripples appear.

SMALL ICE-CAKE. An ice-cake less than 2 metres (6½ feet) across.

SMALL ICE-FIELD/FIELD OF ICE. An ice-field 10–15 kilometres (5½–8 miles) across.

SMALL ICE-FLOE. See Ice-floe.

SNOW-COVERED ICE. Ice covered with snow.

SNOW SLUSH. Viscous mass formed as a result of a thick snow fall into cooled water.

SNOW WATER ON THE ICE/PUDDLE. Ice, the surface of which is covered with snow water, i.e. an accumulation on the ice of melt-water, mainly due to snow melting. The stages of development of snow water are as follows: patches of melting snow, puddles on the ice—small and shallow accumulations of melt-water on the ice, larger amounts of water, which have deepened on account of ice melting and which have sharply-defined outlines.

STANDING FLOE. A separate floe standing vertically or inclined and enclosed by rather smooth ice.

STREAM/STRIP/STRING. Long narrow area of pack-ice/drift-ice, about 1 kilometre ($\frac{1}{2}$ mile) or less in width, usually composed of small fragments detached from the main mass of ice, and run together under the influence of wind, swell, or current.

STRING. See Stream.

STRIP. See Stream.

TABULAR BERG/BARRIER BERG. A flat-topped berg, showing horizontal firn-snow/névé layers, usually broken off from an ice-shelf formation.

THAWING HOLES IN THE ICE. Ice with open holes in it, usually of a circular form; these holes are a further stage of development of snow waters by ice melting.

THICK WINTER-ICE. Winter-ice more than 30 centimetres (1 foot) thick.

TIDE CRACK. Crack formed between shore ice and the icefoot under the action of the fluctuation of the sea level. Typical only for shore ice areas.

TONGUE. A projection of the ice-edge up to several kilometres (miles) in length, caused by wind or current.

VAST ICE-FLOE. See Ice-floe.

VERY CLOSE PACK-ICE/DRIFT-ICE. Ice cover practically 10/10 or 8/8 and little if any water present.

VERY OPEN PACK-ICE/DRIFT-ICE. Water preponderates over ice. Ice cover 1/10–3/10 or 1/8–2/8. (Formerly known in Britain as "drift-ice".)

WATER-SKY. Typical dark patches and strips on low clouds over a water area enclosed in ice or behind its edge. It is due sometimes to an open water area out of the limits of visibility.

WEATHERED ICE. Hummocked polar ice subjected to weathering which has given the hummocks and pressure ridges a rounded form. If the weathering continues, the surface may become more or less even.

WINTER FAST-ICE. Fast-ice in fjords, gulfs and straits, mainly formed by growth from the shore, but also by cementing of pack-ice/drift-ice. Winter fast-ice rises and falls according to the tide.

WINTER-ICE. More or less unbroken level ice of not more than one winter's growth, originating from young ice. Thickness from 15 centimetres to 2 metres (6 inches to $6\frac{1}{2}$ feet). Completely safe for travelling purposes. Winter-ice may be subdivided into Medium winter-ice and Thick winter-ice, q.v.

YOUNG ICE.* Newly-formed level ice generally in the transition stage of development from ice-rind, or pancake ice, to winter-ice; thickness from 5–15 centimetres (2–6 inches), as a rule impassable and unsafe for travel either by men or dogs, or in the case of aircraft for ski or wheel landings.

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*Young ice was frequently referred to as "bay ice" by British whalers in the early 19th century.

YOUNG POLAR ICE. Polar ice which has not melted during the first summer of its existence and which has passed over to the second phase of increase. At the end of the second winter, it attains a thickness up to 2 metres ($6\frac{1}{2}$ feet) and more. It differs from ice one year old by a greater portion showing above the surface of the water and also by the hummocks on it being smoother.

YOUNG SHORE ICE. Primary stage of formation of shore ice; it is of local formation (at shore) and usually consists of ice-rind or thin young ice; usually some 10 metres (30–35 feet) in width, but sometimes even more (100–200 metres (330–660 feet)).

Other terms associated with ice and navigation are:—

BESET. Situation of a vessel when closely surrounded by ice and unable to move. See also Nip, below.

BLINK. Same as Ice-blink, see Descriptive Terms.

BORING. Pressing the ship through small ice or young ice, under power or sail.

CALVING. The breaking away of a mass of ice from a glacier or iceberg.

DÉBACLE. The break-up of the ice in rivers in spring (see ice-gang, below).

FIELD OF ICE. Same as Ice-field, see Descriptive Terms.

FJORD ICE. Term used by Scandinavians for Level ice (see Descriptive Terms) originating in fjords.

FLAW. Term sometimes applied to the edge of fast-ice, adjacent to a Shore lead, see Descriptive Terms.

ICE-ANCHOR. Hook or grapnel, adapted to take hold upon ice.

ICE-CHISEL. A long chisel of stout construction for cutting holes in ice.

ICE-FRONT. The position of the floating seaward-facing cliffs of an Ice-shelf (see Descriptive Terms) on any given date, e.g. "Ross ice-front (1911)".

ICE-GANG. Term used to denote the movement, in rivers, etc., of a field of hurrying masses of thick heavy ice; ice conditions after the débâcle, see above.

ICE-SPEAR. A light wooden staff with a metal point, used for testing whether it is safe to walk on thin sea-ice.

MORAINE. Rock debris associated with a glacier.

NIP. Ice is said to nip when it closes up so as to prevent the passage of a vessel. A vessel so caught, though undamaged, is said to be nipped. See also Beset, above.

NUNATAK. An isolated rocky peak rising from a sheet of inland ice.

PRESSURE AREA. An area of Pressure-ice/Screw-ice, see Descriptive Terms.

SALLYING. Rolling vessel by means of crew running from side to side, in order to loosen ice around the ship and allow her to make headway.

SCREWING. When ice floes rotate in the formation of Pressure-ice/Screw-ice (see Descriptive Terms) the process is known as screwing.

SEA BAR. Same as Ice-bar, see Descriptive Terms.

SEA SMOKE. Same as Frost smoke, see Descriptive Terms. Also known as "Arctic sea smoke", "water smoke" and sometimes as "the Barber".

WORKING. Making headway through Pack-ice/Drift-ice, see Descriptive Terms.

Part III Phenomena

CHAPTER 8

THE OBSERVATION OF PHENOMENA

GENERAL REMARKS

The seaman has unusual opportunities for observing natural phenomena of all kinds. This can be made an interesting hobby, and the observer may be lucky enough, sooner or later, to make a rare, or even unique, observation, which if carefully observed and recorded, will contribute to scientific knowledge. The comparative frequency or rarity of certain phenomena is indicated in this and the four following chapters, as far as our present knowledge goes. Phenomena of unknown origin are occasionally seen at sea and these should be carefully observed and recorded.

It is however not only the rare observations which are of value. All meteorological phenomena, whether optical or general, are directly related to the state of the atmosphere and weather prevailing at the time, and their recording in the Remarks Column of the Meteorological Log or in the space provided for Additional Remarks, helps to complete the information given by routine observations. Also there is probably a good deal to be learnt yet about many of the more common phenomena, including their frequency and geographical distribution, for which it is obvious that all observations made in any part of the world should be put on record.

Hints are given in these chapters on the observations or measurements which are necessary if the phenomenon is to be correctly identified. Observations are much more valuable if accompanied by drawings or sketches, in black and white or colour, or by photographs. If there is not room in the log, the observations and sketches can be attached to it.

The more interesting and unusual observations and illustrations will be published in *The Marine Observer.* Notes on phenomena which are outside the scope of the Meteorological Office are always sent on to the relevant authority for examination and comment.

METHODS OF OBSERVATION

Some optical phenomena such as coronae and iridescent cloud, are formed very near the sun or moon. Those near the sun may not be seen at all unless the eyes are shaded from direct sunlight. Apart from this, optical phenomena such as halos, coronae, etc., viewed in the daytime, when the sky is often very bright, are more easily seen if the amount of light entering the eye is reduced, and sometimes a very faint halo, etc., can only be seen if this is done. The sky may be viewed through neutral-tinted glass of a light tone, such as the lightest of the series belonging to a sextant, or the reflection from black glass may be used, if available, or from a piece of ordinary glass painted on one side with black enamel or backed with black paper. If a pair of ordinary sun-glasses of suitable colour is available, this is the best method of all. Yellow-brown, not too deep, has been found to be very satisfactory. Glasses of this colour have the power of slightly increasing contrast, so as to show distant land more distinctly on a misty day. The natural colour of any phenomenon is, of course, modified by these. The same methods also give a better view of clouds, of the details in a bright cloud mass, or of the very faint extensions, near the limit of visibility, of cloud in a blue sky.

There is a useful tip for seeing any very faint light at night, which is near or just beyond the limit of direct visibility. Do not look directly at the object, or where you suspect it to be, but fix the attention on a point a little way above, below, or to the side of it. Then view the spot " out of the corner of the eye ". Light will thus be seen that would be otherwise invisible, or if it is directly visible, it will appear brighter by this process of " averted " or " oblique " vision. This applies to very faint light of every sort, whether concentrated in a point or diffused, such as faint terrestrial lights, faint stars, comet's tails, all zodiacal light phenomena and the fainter parts of aurorae.

In the case of phenomena of considerable duration, it is best to make notes of the various appearances as they are seen to come into view, or of other changes, carefully recording the times throughout the progress of the phenomenon. This is preferable to trusting to the memory afterwards. Rough sketches can also be made at the time and subsequently worked up into finished drawings or sketches. If colour is to be used, notes of the various colours should be made at the time. For making notes or sketches at night, the minimum amount of artificial light should be used.

It is desirable that observations be accompanied by sketches and/or photographs, whenever possible. These will often show detail that cannot be put into words. Sketches should be made on plain white paper, inserted in the logbook, so that if they are to be reproduced in *The Marine Observer* this can be done without having them redrawn, whereby some of the character of the original ones may be lost. Drawings made on a logbook page cannot be reproduced directly, as the quality of the paper is unsuitable. Sketches may be made either in black Indian ink or in pencil; in some cases delicacy of shading or fine detail is better rendered in pencil. Sketches made in white ink on black paper are also very suitable for reproduction and are especially appropriate for observations made at night. Although sketches in colour cannot be so reproduced in *The Marine Observer* they may be of value in amplifying the detail given in the written observation.

Accuracy of the size and relative position of the main features of what is seen are the prime requirements. Angular measurements are necessary in many cases for the identification of the phenomenon, as explained in the subsequent chapters. These are best incorporated in the written observation, unless the accompanying sketch is purely a diagrammatic one.

Phenomena such as halos, rainbows and waterspouts may be photographed, giving a sufficiently short exposure, such as would best show cloud detail. The best results, particularly in the case of coloured objects, can only be got by the use of panchromatic film and a suitable colour filter over the lens. The same remarks apply to mirage, which has very rarely been photographed, though there appears to be no reason why satisfactory results should not be obtained.

OBSERVATIONS BY RADAR

With radar sets working on 3 cm. or 10 cm., having a suitable form of presentation (e.g., P.P.I.), echoes are obtained from rain up to distances of 50 miles or more. In this way showers, fronts and thunderstorms may be located and warning given of their approach. Echoes from cloud have been reported, but these are probably due to rain or drizzle within the cloud and not to the cloud particles themselves.

Objects at ground level or sea level are normally visible on the radar screen at distances a little beyond the geometrical horizon, owing to refraction. In certain conditions, however, much greater ranges are obtained. This occurs most frequently over the sea, and is due to a temperature inversion near the surface and/or a fall of humidity with height which causes reflection or abnormal refraction of the rays.

The reverse effect, i.e., a smaller degree of refraction than is usual—or sub-refraction—can occur owing to a very pronounced temperature lapse rate and/or an increase of humidity with height. Sub-refraction however is neither a very marked nor frequent phenomenon.

Ordinary meteorological fronts are not a major cause of abnormal radar ranges. Due to absorption of the radio energy, very heavy rain may tend to mask a radar target behind the rain area; this effect is unlikely to be significant on a wave length of 10 cm. but it may become important at shorter wavelengths.

The use of radar as a means of detection of ice should be borne in mind. In normal meteorological conditions, echoes from most bergs should be detected at a useful range, but in certain meteorological conditions sub-refraction may occur and normal detection ranges be appreciably reduced. It has also been found that at times, even under favourable conditions, a very poor echo has been obtained from quite a large berg, the inclination of the slope presented to the observer apparently having an effect upon its reflecting properties, which is of as much account as the length or height of the berg. Bergy-bits, growlers or pieces of pack-ice, especially if smoothed by weathering, may pass undetected in strong sea clutter, even if they are large enough to sink or damage ships. On the other hand, in conditions where sea clutter is well marked, the cessation of such echoes may indicate the presence of pack-ice.

Radar can therefore only be considered as a valuable additional aid to the navigator in the detection of ice and it must be clearly understood that an absence of indication on the screen does not necessarily mean the absence of dangerous ice in the neighbourhood of the vessel.

CHAPTER 9

Astronomical Phenomena

ECLIPSES

Partial eclipses of the sun or moon provide interesting spectacles but afford no opportunity for the seaman to make observations of particular value. Little diminution in sunlight is perceived until more than half the sun's disc is covered by the moon. An appreciable fall of temperature occurs during a large partial eclipse of the sun.

A *total* eclipse of the *sun* is perhaps the grandest of all natural phenomena. While almost of annual occurrence, its visibility on any occasion is confined to a very small area, along a line usually less than 100 miles wide, so that in any fixed place it is in general very rare. The duration of the total phase is very short, usually from a few seconds up to about two minutes, though in very exceptional circumstances it may be considerably more, the possible maxima being nearly eight minutes. During totality the fall of temperature is marked; often the wind changes or springs up, if previously calm. The sky darkens and has a peculiar appearance, often with lurid cloud colours. During totality the bright planets and the brighter stars may be seen.

Very occasionally a ship at sea or in harbour may be on the line of totality and several of such observations have been received in the last 25 years. The seaman fortunate enough to witness such an eclipse should endeavour to record all that he sees in as full detail as possible. There is so much to see in such a short time that it is desirable for several persons to observe in company. At the instant the moon finally covers the round body of the sun normally seen, the solar corona will spring into view. This is an irregularly-extended atmosphere of the sun, pearly-white in colour, giving about half as much light as the full moon. It has a definite shape which varies according to the position of the year of observation in the 11-year cycle of solar activity (*see* under Sunspots). Near the time of maximum activity the corona is disposed fairly equally round the sun, with a definite structure of rays and bands, and sometimes curved forms like flower petals. Near the time of minimum activity the corona shows much less structural detail and the form is quite different. A wide band, more or less parallel sided, stretches outward from the equatorial region of the sun, one on each side of the sun, and these bands may extend a long distance, up to two or more solar diameters. At this time the polar regions usually show only a few short rays of coronal light. In the intermediate years of the solar cycle, the corona assumes forms intermediate between those described above.

Owing to the short duration of total solar eclipses and their comparative rarity, the total time for which the corona has been seen in the last 150 years is probably about two hours. Its exact form on any particular occasion is unpredictable. Marine observers can therefore make observations of real scientific value if the form, extent and detail of the corona is carefully noted and sketched. As the fainter extensions of the corona are best seen with the unaided eye and the structural detail is best seen with binoculars or a small telescope, it is best, especially when the duration of totality is short, to have two observers, each working in one of these different ways.

One or more of the great rose-red eruptions of hydrogen and calcium gas from the sun, known as prominences, may be seen adjacent to the moon's limb without optical assistance, especially if the sun is near its state of maximum activity. Unlike the corona, these may be seen in full sunlight on any day, by astronomers using special apparatus. Other features of a total eclipse on which attention may be concentrated are (i) meteorological effects, (ii) the changing colour effects of sky and cloud and the rapid onrush of the moon's shadow through the air as the total phase begins, (iii) the visibility of planets and stars.

The total phase of a *lunar* eclipse generally lasts a considerable time, sometimes for nearly two hours; the exact duration depends on how centrally the moon passes through the earth's shadow. The totally eclipsed moon usually remains visible, appearing of some shade of red or copper. Careful observation of this colour, and its changes, if any, during the total phase are of value. A general statement of the degree of brightness of the totally eclipsed moon should also be given, noting how far its surface markings remain visible. The totally eclipsed moon receives reddish sunlight by refraction through the section of the earth's atmosphere in profile to the moon at the time, and the amount and colour of the refracted light vary according to the cloudiness and other meteorological conditions in this part of the atmosphere. When fine dust in sufficient quantity is suspended in the air after a big volcanic eruption, the moon may almost, or even completely, disappear from sight during total eclipse. Such an observation should be carefully recorded, with all relevant detail.

COMETS

Comets are members of the Solar System, moving in elliptical orbits, in most cases so enormously elongated that the period of revolution round the sun may be hundreds or even thousands of years. A few return in a comparatively short time, one of these being the well-known Halley's Comet, with a period of about 77 years, last seen in 1910.

Comets are much less dense than planets, and consist of a loose aggregation of widely separated small solid bodies, ranging from the size of a grain of sand to that of small stones, probably with an admixture of larger pieces. The diameter of this collection is usually only a few hundred miles, but may be several thousand. Comets are only seen in that part of their orbit near the sun, when they shine partly by reflected light but mainly by the vaporising of the material of the comet by the sun's heat. An interesting feature of a comet is its tail, which is only formed when the comet is relatively near the sun. This consists of dust and gases ejected from the head, probably by light pressure and electrical repulsion. The tail of a large comet may be many millions of miles in actual length. The apparent length may be anything from a degree or two to 60° or 80° or more. The direction of the tail is from the comet's head away from the sun. This direction bears no relation to the direction of the movement of the head of the comet in its orbit. The tail of a comet, unlike the transitory trail of a meteor, therefore does not show the direction in which the comet has travelled.

Most comets never become bright enough to be seen without telescopic aid and some never develop tails, but a bright comet is a magnificent naked-eye spectacle. There should be no confusion between the appearance of a comet and a meteor. A meteor is only seen for a few seconds as it travels more or less rapidly over its apparent path in the sky. A comet remains apparently fixed among the stars and sets with them in due course. It has a continuous movement relative to the stars, but in most cases this can only be seen in a naked-eye or binocular observation by comparing its position on successive nights. The period of naked-eye visibility of a comet may be anything from a few days to a number of weeks. It finally becomes invisible by either getting too faint, or passing into the daylight region of the sky or changing in declination so as to sink below the horizon.

Astronomers measure the position of the head of a comet relative to stars near it in the field of view of a telescope, or large scale photographs may be taken. From a minimum of three such observations on successive nights, the comet's orbit in space and its subsequent apparent track in the sky can be computed. Angular distances of the comet from two or three bright stars, measured by sextant, are not sufficiently accurate for this purpose, but serve to identify the object and help in making an accurate sketch of the comet and its tail in relation to the stars. It may occasionally happen that more than one naked-eye comet is visible at the same time.

Valuable observations of a naked-eye comet may be made at sea, and it may happen that some interesting feature is seen which would not otherwise be put on record, if conditions of daylight or cloud make observations impossible in other parts of the world at that particular time. The brightness of the head and the form and length of the tail may sometimes change appreciably from night to night. The brightness of the head is estimated by comparison with that of neighbouring stars or planets, as described under Novae, below. The altitude of the comet's head should be given, as part of this observation, also notes on the state of the sky, such as whether thin cloud, haze, twilight or moonlight is present. Careful sketches of the form and length of the tail are valuable and should include details of the structure of the tail, if any are seen, stating whether the observation was made with the unaided eye, or with binoculars. The end of the tail usually fades very gradually into the dark sky and the method of averted vision (see page 75) can be used to see it as far as possible; binoculars will not show the fainter extension. It is of special importance to record any tails, other than the main one, which may be visible; these are normally on the same side of the head as the main tail, making various angles with it, and they are usually narrower and fainter than the main tail. On rare occasions a short tail pointing towards the sun may be seen, i.e., in a direction opposite to that of the main tail. If the comet shows any peculiarity of colour this should be noted.

THE ZODIACAL LIGHT AND ASSOCIATED PHENOMENA

The Zodiacal light. This is observed as the cone-shaped extremity of an elongated ellipse of soft whitish light which extends from the sun as centre, extending above the westerly horizon in the evening or the easterly horizon in the morning. 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 light retains its apparent place among the stars and gradually sets or rises with them. It is more brilliant in the tropics, but is very conspicuous even in temperate latitudes, if observed away from the glare of large towns.

The axis of the light lies in the zodiac, very nearly but not quite in the plane of the ecliptic. 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 the temperate latitudes of the northern hemisphere it is best seen in the evenings of January to March and in the mornings of September to November.

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. Its luminosity decreases with altitude above the horizon, since its brightness is greater the nearer the observed point is to the sun's position below the horizon. It appears, however, to fall off in brightness near the horizon on account of the greater thickness of the atmosphere its light has to traverse. At any altitude the axis of the light is brighter than its lateral parts. In northern temperate latitudes the edge of the cone towards the north in azimuth is less well-defined than that towards the south and tends to spread northwards near the horizon.

The Zodiacal light is believed to be a cosmic phenomenon, due to the reflection of the sun's light from dust or gaseous matter, extending outwards to a point somewhat beyond the earth's orbit. There is much that is not known about this phenomenon and new observations from all latitudes will be of real value. Any features of interest should be noted, such as the colour of the light and any irregularity of form or light distribution. Observations of its brightness will be of value, as it is not yet known whether this is constant on successive nights or in different years. Apparent changes of brightness often occur since the night sky is not always equally transparent. The presence of a bright planet, especially Venus, in the region of the light dims it considerably. Estimates of brightness should be made on moonless nights, after all twilight has disappeared, by comparing the light with that of the Milky Way, preferably at about the same altitude. The position of the Milky Way should be specified, as this varies markedly in brightness in different parts of the sky. Thus the light on a given night might be estimated to be twice as bright as the Milky Way in Cygnus.

Observations of the precise position of the light, about which there is still some uncertainty, may be made by a careful sketch of the cone showing the position of specified stars, either within, on the edge of, or outside the cone.

Zodiacal band and Gegenschein. Joining the apices of the cones of the morning and evening Zodiacal lights is an extremely faint luminous band, 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, but ill-defined patch, 10° or more in diameter, known by the German name " Gegenschein ". This therefore is due south (in the northern hemisphere) at midnight, local time. These phenomena may be observed in temperate latitudes on the clearest moonless nights when at sufficient altitude; they are somewhat brighter in the tropics, on account of the greater altitude of the ecliptic. Further observations of these phenomena are much desired, especially from tropical localities. The track and width of the band, and the size, shape and position of the Gegenschein should be noted, together with variations of brilliancy and any special features seen, but the observation will be found difficult even to keen 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.

NOVÆ

Sometimes, quite unpredictably, a small star, usually a faint telescopic one, brightens up very much, within a few hours or a day or two at the most. This is, somewhat loosely, called a " nova " or " new star ". While many of these never become visible to the naked eye, occasionally one does so and may even reach the first magnitude, or brighter, thus completely changing the aspect of the constellation in which it appears. If conspicuous, a nova is generally mentioned in the newspapers. Should the marine observer hear of one, or discover one (in which case he will usually find he is not the first discoverer) he may be interested in following its changes of brightness. The normal history of a nova is that it remains at full brightness for a short time, probably a day or two at the most, and then very gradually decreases, the reduction in brightness being interrupted by slight temporary increases. If the star has attained the third magnitude or more it may remain visible to the naked eye for several weeks.

If the observer wishes to record the exact brightness of a nova (or other star) at any time, he may select a star of about the same altitude judged to be exactly of the same brightness. If no such star is available, he should select two stars of about the same altitude as the nova, one a little brighter and one a little fainter than the nova. He can then express the brightness of the nova in terms of the small interval of brightness between the two comparison stars. For example, it might be halfway between them in brightness, or one-third of the interval, counting from the brighter to the fainter, or one-quarter of the interval, counting from the fainter to the brighter. If such an observation is received, it can be easily converted into actual magnitudes, since the magnitudes of all naked-eye stars have been accurately determined. Both these methods break down if the star is much above the first magnitude, as suitable comparison stars would probably not be available. One or more of the bright planets, if visible, might, however, serve for this purpose.

An accurate observation of the magnitude of a nova, especially in its early stages when the brightness is changing quickly, may be of great value to astronomers, since no other observation might have been made anywhere else at the same time.

SUNSPOTS

It is very dangerous to the sight to look at the sun, either with or without optical aid, without using smoked or deeply-tinted glass to reduce the light. This applies even when the sun is in partial eclipse. The only exception is when the sunlight is greatly weakened by passage through fairly thick fog, especially when the sun is at low altitude.

The number and size of sunspots varies in different years. Over a period of years solar activity, of which the occurrence of large sunspots is one manifestation, rises to a maximum and subsequently falls to a minimum. The time between successive maxima varies considerably, but averages about 11 years. For several years around the time of maximum activity, spots are frequently large enough to be seen without optical aid; sometimes two or more are so visible at the same time. Around the time of minimum activity, spots are either very small or completely absent. The life of an individual spot may be anything from a few days to several weeks.

Owing to the sun's rotation on its axis, a spot previously formed, and coming into view at the sun's eastern limb, will appear to cross the disc in about 14 days, if it last so long. Apparent changes of position of the spots on the sun's disc take place during the day, but are merely due to the observer's changing angle of view. The imaginary line forming the horizontal diameter of the sun at noon appears to be tilted upward between sunrise and noon and downward between noon and sunset, the most extreme tilting occurring at sunrise and sunset.

Daily photographs of the sun through telescopes are taken at one or other of the astronomical observatories throughout the world. While marine observers may find it interesting to see the spots and note their changes of form and position on successive days, especially in years of maximum solar activity, it is not necessary to make sketches of them in the logbook as these can never be accurate enough to have any scientific value.

SOLAR FLARES. Near certain sunspots there occur areas which undergo sudden increases in brightness; these are called flares. They are best seen by means of special instruments which give a picture of the sun's surface in red hydrogen light. Some of the greatest solar flares have, however, been observed as increases in the total white light of the sun; seen in this way, a flare lasts for a few minutes and has about the same area as a large sunspot. The first such observation of a bright patch on the sun's surface was made in 1859 and several flares have been similarly observed since then. The appearance of flares cannot be predicted, but they are more numerous at times of maximum solar activity (as measured by the numbers of sunspots).

The increase in light intensity during a flare is particularly strong in the ultra-violet part of the spectrum (the part beyond the visible violet light to which our eyes are not sensitive). The blast of ultra-violet light emitted from a solar flare produces several detectable effects in the high atmosphere of the earth.

Associated with the increase in light intensity during a flare, there is ejection of material particles from the region of the flare out into space. This material shoots out at speeds of about 200 to 400 miles per second, which probably increases as the material gets further from the sun. If moving in the appropriate direction, this material causes interesting effects in the high atmosphere. Some of the high atmospheric effects of solar flares are described in the next chapter.

CHAPTER 10

Phenomena of the High Atmosphere

Regions of the high atmosphere. The high atmosphere of the earth is classified into regions according to the degree of ionization of the atoms of the atmospheric gases at the level concerned, that is, according to the electrical conductivity. In the lower atmosphere, air is a very good electrical insulator, i.e., its conductivity is very low. In the high atmosphere, however, many of the atoms are ionized so that the air is electrically conducting. The classification into regions depends on the different degrees of conductivity and other electrical properties at the different levels. In temperate latitudes there are three regions, at the following heights: the *D* region, between 40 and 60 miles up; the *E* region, between 60 and 80 miles; and the *F* region, between 80 and 250 miles.

Short wave radio fadeouts. Long distance radio transmission in the short wave band (in the frequency range of 1.5 to 30 megacycles per second) is achieved by reflection of the radiation from the *F* region, the *D* and *E* regions normally having very little effect on short wave signals. When the blast of ultraviolet light from a solar flare reaches the earth, it increases the ionization in the *D* region, however, and this increased ionization causes absorption of short wave signals and produces a fadeout in transmission, reducing the signal strength to perhaps as little as one-tenth of its previous value. Such a short wave radio fadeout can occur only on the daylight hemisphere of the earth; it usually lasts for about twenty minutes.

Sudden enhancements of atmospherics. Lightning flashes in the lower atmosphere are a source of radio noise, detected over a wide range of frequencies as the crackles called atmospherics. Thunderstorms, and so lightning flashes, are most numerous in the tropics, and transmission round the earth to higher latitudes of the resultant radio noise is by means of reflection from the various conducting regions of the high atmosphere. For the long wave part of atmospherics (in the frequency range below 100 kilocycles per second) it is the *D* region which acts as the reflector. Following a solar flare and the consequent increased ionization in the *D* region, the reflection of long wave atmospherics is suddenly improved and the noise level of atmospherics may rise to as much as double its normal value. The rise takes place in a few minutes and the level remains high for an hour or two.

Short wave radio blackouts. When the material ejected from the sun during solar flares, and at other times, reaches the earth, it affects the electrical properties of the *F* region in such a way that it ceases to act as a reflector for short wave radio. This effect is called an ionospheric storm. It is most severe in high latitudes because the material particles coming from the sun are electrically charged and are guided to the polar regions by the earth's magnetic field. Being often, though not always, connected with solar flares, ionospheric storms are more frequent during solar activity maximum. The short wave radio blackout associated with a severe ionospheric storm may last for several days.

Magnetic disturbances. The earth's magnetic field is almost entirely of internal origin, being most probably produced by electric currents flowing in the molten material of the core, but there is a small part of it (less than one-hundredth) which can be attributed to electric currents flowing in the high atmosphere. It is believed that these currents flow mainly in the *E* region. The daily heating of the atmosphere by the sun causes the currents to go through a regular daily cycle of change. These regular changes are very small in most places and cannot be detected by an ordinary compass needle, the maximum change of direction of the needle during a day being about one-fifth of a degree of arc.

Quicker changes occur at the times of short wave radio fadeouts, but they also are too small to be detected by a compass needle. They are known as magnetic crochets or as solar flare effects.

Much larger deviations can occur, however. They are the result of large, irregular changes in the *E* layer currents, called magnetic storms, which occur in conjunction with ionospheric storms and short wave radio blackouts in high latitudes. Like the ionospheric storms of the *F* region, these *E* region magnetic storms are caused by the arrival of the material particles ejected from the sun during solar flares and at other times.

If the magnetic storm be severe, the compass needle may be deflected continuously in one direction, to the extent of about half a degree, for some hours. In more intense storms the needle may oscillate one degree or more on either side of its normal position, and such oscillation may continue for as long as ten or twenty minutes before dying out. Further oscillation may occur after a period of quiescence. Deviations of 2° or more have been known, but are rare. During the great magnetic storm of 25th January 1938, a deviation of 4° eastward was observed off the Portuguese coast.

NOCTILUCENT CLOUD

This rare phenomenon is not true cloud. The presence of what appears to be luminous cloud at night has been occasionally reported from latitudes between 45°N. and 65°N., during the long twilight of summer, from mid-May to mid-August. So far no such observation has been made in the southern hemisphere. When present, the clouds become slowly visible in the darkening twilight sky, from one-half to one hour after sunset. They usually appear along the northern horizon as a delicate pattern of parallel silvery or bluish-white streaks or waves resembling cirrus cloud. These light up progressively from west to east, following the sun's movement. They are seldom seen at altitudes greater than 10°. In the higher latitudes of the belt mentioned, they may remain luminous all night until they begin to vanish slowly in the morning twilight. In the lower latitudes of the belt the clouds are visible only for a time after dusk or before dawn. A good display of noctilucent cloud is said to be an unforgettable sight.

The height of the cloud is very constant, about 50 or 51 miles, so that it is in the *D* region of the high atmosphere (*see* page 83). The light is sunlight scattered by rather dense accumulations of dust that collect at this great height. The origin of the dust is uncertain, but may be meteoric.

Our knowledge of the geographical extent and distribution of these displays is very slight and all new observations will thus be valuable. The observer should record, at intervals, the altitude of the base of the cloud, as accurately as posssible, and the horizontal and vertical extent of the cloud, expressed as whole degrees of azimuth and altitude. The duration of the phenomenon and its colour or any colour changes, should also be given.

Mother-of-Pearl Cloud. In some winters, in very clear sky, after the passage of a large, deep depression to the region of northern Scandinavia, a high form of cloud, known as mother-of-pearl cloud, has been seen in Norway, Scotland and elsewhere in north-west Europe, almost wholly within the period December to February. This cloud is of very delicate structure, somewhat lenticular in form. Its distinguishing feature is that it shows iridescence, which remains visible after sunset; iridescence on ordinary clouds never persists after sunset. The colouring is exceptionally brilliant if the angular distance of the cloud from the sun is less than 40°. They are most spectacular just after sunset, or just before sunrise. They remain visible for half-an-hour or more after sunset, suddenly fading when the sun sinks too low to illuminate them. Before sunrise there is a correspondingly sudden appearance.

Mother-of-pearl cloud differs from noctilucent cloud in being true cloud, composed of very minute water drops. Its height is from about 12 to 18 miles so that it is much higher in the atmosphere than the familiar types of ordinary high cloud. It is a rare phenomenon and its geographical distribution is very restricted. If seen, full details should be recorded including the size and shape of the clouds, their positions and angular distances from the sun, the distribution of the colours and the time at which the clouds darken, in the evening, or become illuminated, in the morning.

AURORAL DISPLAYS

General remarks. Associated with a severe magnetic storm there is always a great auroral display. When observing conditions are good this is one of the most beautiful and impressive of natural phenomena. As no instruments are necessary, and since reports of auroral displays are of particularly great scientific value, a fairly full description of aurora is given here, along with suggestions about methods of reporting observations.

Regions of occurrence. Aurora is primarily a polar phenomenon. It occurs most frequently in the two so-called auroral zones: these are rings of about 20° (1400 miles) radius, centred on the geomagnetic axis poles (which are different from the magnetic poles usually marked on maps). The northern auroral zone is centred at about 79°N., 70°W., in north-west Greenland; it runs from Cape Farewell across Iceland, over the Norwegian Sea, passing 250 miles north of North Cape, and over the Arctic Ocean south of Franz Josef Land to meet the Alaskan coast near the mouth of the Mackenzie River. Its highest latitude is 81°N., reached in the Arctic Ocean at about 110°E. Crossing Alaska it descends to lower latitudes, traverses Hudson Bay at about 60°N., and passes over Davis Strait to Cape Farewell again. The southern auroral zone is centred at about 79°S., 110°E. and runs across Antarctica from the coast of Little America at about 150°W., through the Falkland Islands Dependency, to the coast of Enderby Land at about 70°E., and over the Antarctic Sea, reaching its lowest latitude, 59°S., at 110°E.

Even during quiet atmospheric conditions, there are strong electric currents flowing in the *E* layer around these two zones. It appears very likely that the quiet auroral arcs which seem to occur every night in the auroral zones are a visible manifestation of these currents. The process by which the gases of the upper atmosphere emit light under the influence of electric currents is similar to the process of light emission from a neon advertising tube.

During disturbed ionospheric conditions, such as follow the arrival at the earth of material ejected from the sun during a solar flare, the aurora moves from its position in the auroral zones and manifests great activity. Such an auroral display is observable from a wide range of latitudes during the course of the night. In particular, during a great ionospheric and magnetic storm, aurora is seen from sub-tropical and tropical latitudes, sometimes causing panic among the inhabitants of the countries where such displays are very rare. The duration of a display at low latitudes is very variable, from a few minutes to some hours, depending on the characteristics of the ionospheric disturbance concerned.

Height. It has been found that the commonest auroral forms, quiet arcs, which have a fairly distinct lower border, are nearly always situated in the *E* layer. The average height of the lower edge is about 65 miles. An auroral arc is often several hundred miles in length and the height above the earth of the lower edge is the same all along it; the effect of the curvature of the earth can therefore be clearly seen, producing the characteristic arc shape.

Another very characteristic feature of auroral forms is the appearance of a folded curtain, produced by bundles of upward-stretching rays. The line of an auroral ray is found to be along the direction of the magnetic force at the place concerned. In the latitudes where aurora is most common, the lines of magnetic force stand at about 20° from the vertical, inclined away from the geomagnetic pole. Rays may stretch up to heights of over 600 miles, particularly just after sunset or just before dawn, when the upper parts are still sunlit, being outside the earth's shadow.

Aurora is entirely a phenomenon of the high atmosphere, where the air density is low. There are no authenticated measurements of heights less than 40 miles.

Variation during a night. During a great magnetic storm the time of maximum disturbance can occur at any time. Although maximum auroral activity is closely connected with maximum magnetic disturbance there is a tendency for auroral activity to reach a peak at any place within an hour or two of local midnight.

Seasonal variation. During a year there are two maxima of auroral activity around the equinoxes, which are fairly well marked. Of the twelve greatest auroral displays occuring during 1874 to 1954, three occurred in March and four in September.

Sunspot cycle variations. The great auroral displays are associated with great solar activity and therefore tend to occur around the times of maximum sunspot number. The observations made during and after the International Geophysical Year showed that in sub-auroral latitudes maximum auroral frequency coincided with the period of maximum activity of the sun (1957) and that a secondary maximum, almost as great as the primary, followed in 1959. At times of minimum sunspot number, auroral displays show the same tendency as magnetic storms to recur at 27-day intervals, these being the periods of time required for successive appearances opposite the earth of the same point on the sun's surface.

Observation of aurora. It is desirable to record all occurrences of aurora, and to give as good a description as possible, since there is much yet to be learnt about this phenomenon. Reports from ships are used in conjunction with reports from observers on land and in aircraft to compile full descriptions of all displays. These are required in connection with the study of many problems connected with long distance radio communication and other practical matters.

While auroral reports are required from all latitudes, marine observers who are familiar with auroral features can make a unique contribution to auroral studies by keeping a watch for aurora in tropical regions. Several of the great tropical displays of the past have been very poorly recorded because nearly all observers in the tropics are unaccustomed to seeing aurora and either do not recognize it at all or do not report its appearance properly. In addition, reports from all southern latitudes are very valuable, because nearly the whole of the inhabited southern hemisphere is at low latitudes where aurora is not often seen and there is therefore little auroral information available, except for that obtained by Antarctic expeditions.

The information required is as follows:

TIME. The time of each observation should be given in G.M.T. The times of outstanding events should be recorded to the nearest minute. Examples of such events are: the change from quiet to active forms, the onset of flaming activity, the increase in elevation of a previously stationary form, etc.

ACTIVITY. When an auroral form exhibits no movement or brightness variations it is said to be quiet. When there are small irregular movements or brightness variations it is said to be active. Two characteristic types of activity are given special names. When the light from a particular auroral form waxes and wanes fairly regularly (with a period of between 10 and 100 seconds) it is said to be pulsating. The most impressive type of activity is that known as flaming, in which waves of light appear to sweep across the forms from the horizon to the zenith.

BRIGHTNESS. Four grades of brightness are recognized and are specified as follows: weak, when the light is similar in brightness to that of the Milky Way; moderate, like cirrus cloud in full moonlight; bright, like cumulus cloud in full moonlight; and brilliant, when the auroral forms appear brighter than any moonlit cloud. When the brightness is judged to be intermediate between two of these grades it can be expressed in such a way as " weak to moderate".

FORMS. The common forms and the symbols used to denote them are given in the drawings of Fig. 30. Aurora often appears as a GLOW (Fig. 30a) on the poleward horizon, almost always in the direction of the magnetic meridian; such a glow is the upper part of some other auroral form whose lower edge is below the horizon. A common form, particularly in high latitudes, is an ARC crossing the magnetic meridian; this may be HOMOGENEOUS, i.e. uniform in brightness (Fig. 30b), or RAYED, i.e., with vertical ray-structure (Fig. 30c). The reason for the arc shape is given above, under Height. Multiple arcs, running parallel to one another across the sky, are not uncommon. The sky between an arc and the horizon may appear to be darker than the surrounding sky at the same altitude; this is only a contrast effect, and stars may be seen undimmed in the so-called " dark segment". When the form has not the regular shape of an arc but has folds along its length it is called a BAND; this also may be HOMOGENEOUS (Fig. 30d) or RAYED (Fig. 30e). Rayed bands in which the rays are long look like curtains or draperies. An active rayed band overhead is perhaps the most impressive of all auroral forms, particularly if there are colour changes in the waving folds. Single RAYS (Fig. 30f) or bundles of rays are often seen after the break-up of a rayed arc or band. When such rays rise from behind a surface feature, a searchlight effect is produced. All rays in any display are very nearly parallel to one another, but perspective causes convergence and produces fan-like formations. Rays overhead always appear to converge to a point called the magnetic zenith, which is displaced from the overhead zenith towards the equator by an amount depending on the distance from the geomagnetic axis pole. For the British Isles, for example, the magnetic zenith is about 20° south of the overhead zenith. When rays surround this point, the form produced is called a CORONA (Fig. 30g). Particularly towards the end of a display the aurora appears in patches, called SURFACES (Fig. 30h), which are like diffuse clouds, without any arc-type or ray-type structure. In lower latitudes an auroral display often consists largely of deep red surfaces.

ELEVATION. This is measured as altitude in degrees from the horizon. The most important measurement is that of the elevation of the lower edge of an arc at its highest point. This can be indicated by the letter h: thus $h = 25°$ means that the highest point of the lower edge of an arc is at an altitude of 25°.

DIRECTION. It is usually sufficient to give this in terms of true compass points, but accurate directions of features such as isolated bright rays are of value; these should be given in degrees of true azimuth. A sketch with angles marked on it is often easier to make and to read than a description in words.

COLOUR. Very often the intensity of auroral light is too low to stimulate the colour-sensitive part of the eye and all the forms appear pale and grey, like clouds illuminated by weak moonlight. But when the intensity increases, a variety of colours is seen. The commonest is yellow-green, one of the characteristic colours emitted by oxygen gas under the conditions prevailing in the ionosphere. Sometimes a red coloration is predominant. This usually comes from oxygen also, but in aurora at very low levels red nitrogen light has been found. Nitrogen, however, gives mainly blue and violet shades; and these are strongest in the long sunlit rays which occur just after sunset and just before dawn. Many mixtures of these and other colours are possible.

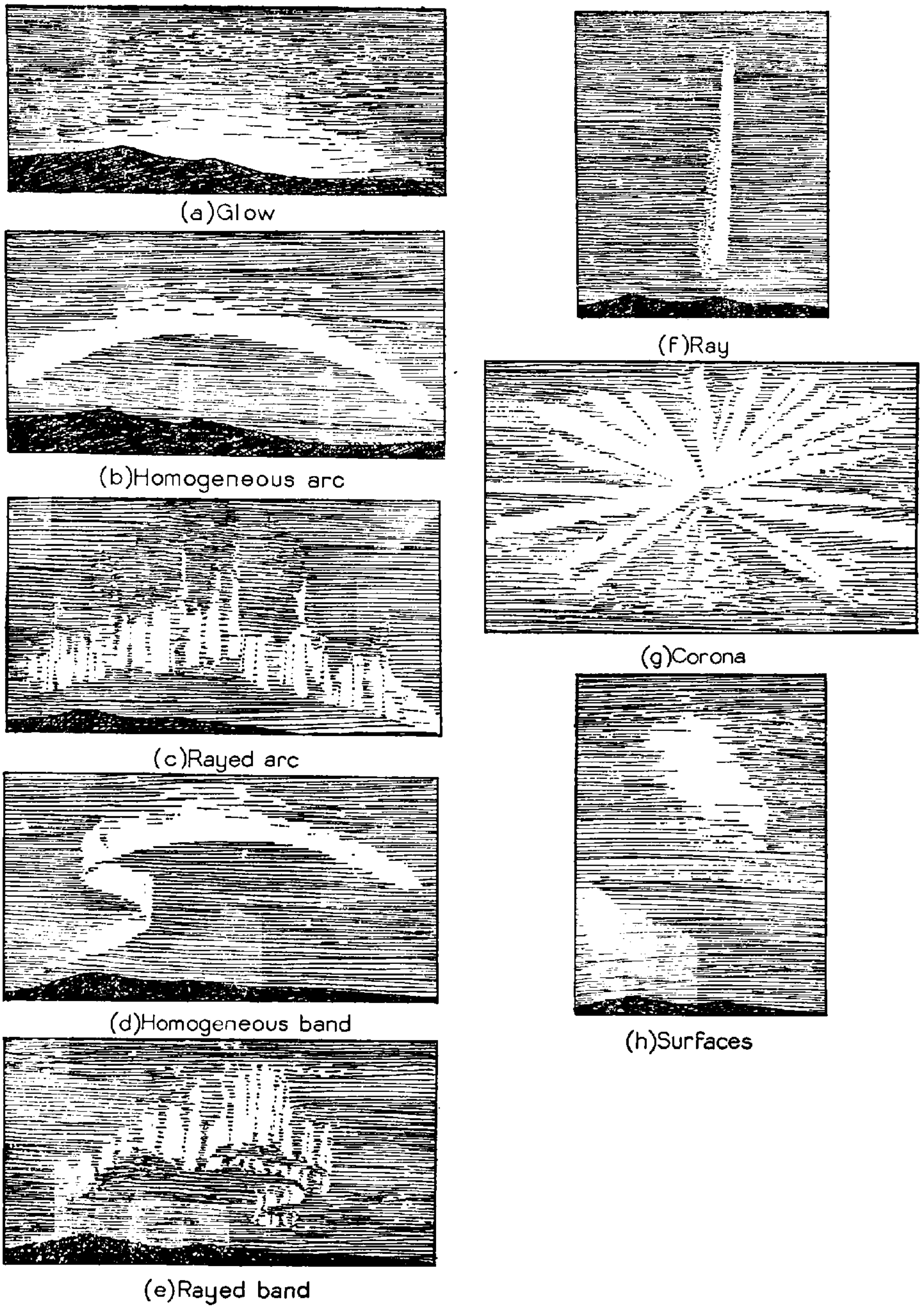

Fig.30 Auroral forms

Photography of aurora. Because auroral light is of low intensity, time exposures are required for photography and this is not often possible on shipboard Given steady conditions, an exposure of 30 seconds, with a lens aperture of f/3.5 and a fast film, should give a reasonable image of a bright auroral feature.

AIRGLOW

On a clear starlight night, in the absence of normal or abnormal twilight, moonlight, lunar twilight, thin high cloud over the sky, auroral displays or artificial illumination from towns, etc., the sky background is not dark, but has a certain degree of luminosity. While some of this luminosity is due to the combined light of stars too faint to be seen individually without the aid of a telescope, the greater part is due to a faint glow known as the airglow. Older names for this were "permanent aurora" and "earthlight".

The airglow is generally uniform over the sky except towards the horizon where it is usually somewhat brighter. The intensity is not always the same on different nights and there are exceptional nights when the sky background appears to be unusually light. There are no means of estimating the intensity of the glow by visual observation, so that the phenomenon is not one which can be usefully observed at sea.

METEORS AND METEORITES

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 upper part of the earth's atmosphere and become visible by the incandescence produced by the friction of very rapid passage through it. It is estimated that many thousands of millions of these objects enter the atmosphere daily, but all except a minute fraction of these are much too faint to be naked eye objects. The vast majority of all meteors are entirely disintegrated and subsequently settle down slowly to the earth's surface in the form of extremely fine dust. A number, however, of greater size, may more or less wholly survive the disintegrating effect and fall to the earth's surface as solid objects of varying sizes. These are called meteorites. On rather rare occasions they have been observed to fall into the sea, the actual splash being seen. Such an event should be recorded in the logbook in full detail. No meteor should be described as a meteorite unless it is definitely known to have reached the land surface or have fallen into the sea.

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 small fragments of matter varying in size from grains of sand to a pea. Larger objects are known as fireballs. These may be as bright as a first magnitude star or may equal the planets Jupiter or Venus, or, in the very finest examples, may greatly exceed the full moon in brilliancy. Objects which fall as meteorites usually appear first as one of these very bright meteors, but the reverse does not hold good, as the majority of the brighter meteors are completely disintegrated in the air.

Appearance and speed of meteors. The appearance of meteors is as varied as their brightness. Some travel fast, others slowly. The apparent path is usually a straight line or arc, but it may assume other forms. Some leave streaks of sparks or luminous vapour, known as trails. In many cases the trail disappears immediately, but in others it remains visible for seconds or minutes, or in rare cases for periods up to two hours or more. When the trail remains visible for some time, changes may be observed in it, caused by the air currents of the high upper air, combined with the fall of the material due to gravity. Most large meteors and fireballs are strongly coloured and the colours may change during the flight. Sometimes the meteor appears to break up, the detached portions then proceeding separately, or it may appear to explode at the end of its course. The trails are usually reddish, white or golden, whatever the colour (or changing colours) of the meteor itself.

The duration of a meteor's flight is rarely more than three seconds, and is apt to be greatly overestimated. The actual speed of a meteor when it enters the earth's atmosphere is usually between 10 and 45 miles per second. The average height above the earth's surface is 75–80 miles at the time of appearance and 45–50 miles at the time of disappearance. The height of the beginning and end of a meteor's visible path in the atmosphere and its speed are determined by observations made by two observers some distance apart, up to 100 miles or more. At much greater distances the same meteor could not be seen by both observers, since an individual meteor is only visible over a small part of the earth's surface and would thus be below the horizon of one of the observers. In this joint observation each observer notes the points of appearance and disappearance of the meteor in the sky as accurately as possible, and the duration of its flight. The information derived from such observations is valuable, not only in extending our knowledge of meteors, but also in making inferences about the temperature of the very attenuated atmosphere at very great heights above the earth's surface.

Frequency of meteors. Meteor showers. The number of meteors seen in a given time is usually greater on nights of higher atmospheric transparency, since more of the fainter meteors are seen, and these are much more numerous than the brighter ones. On nights of equal clarity, about twice as many are visible in July to December as in January to June. Furthermore on any single night of the year the hourly rate of meteor appearance is greater after midnight than before it. These remarks refer to average conditions. On certain nights it may be seen that meteors are more numerous than usual and that their tracks, produced backward, would all converge to the same point or small area in the sky. Such a group of meteors, with the same radiant point, constitute a meteor shower. Many of these occur annually, though not always with the same intensity; some recur only after an interval of a number of years, and others are unpredicted and unexpected. Prolific showers, with perhaps many thousand meteors per hour, such as were given by the Leonids in November of 1799, 1833 and 1866, have been extremely rare of more recent years. The collection of meteors forming a shower are moving in the same general orbit in space and in a few cases the orbit of a shower has been found to be the same as that of a known comet, of whose material the meteors originally formed a part.

Observation of meteors. The complete observation of a meteor comprises:

(1) The positions of the points of appearance and disappearance in the sky.

(2) The duration of the flight.

(3) The magnitude of the meteor relative to a named star or planet, or a general estimate, such as first magnitude.

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

It is not necessary to record the meteorological conditions at the time of a meteor observation, but if the flight is only partially seen, owing to cloud, this should be noted.

Owing to the suddenness of a meteor's appearance, it is often difficult to fix in mind the points of appearance and disappearance. This should be done as accurately as possible with respect to neighbouring stars, and from a star atlas. The right ascension and declination of each point can then be found. Alternatively, the position can sometimes be given as an angular distance from one named star in the direction towards another named star. Such observations of position, if reasonably accurate, say to the nearest half-degree, are of use in determining the radiant point of the meteor or for combining with another observation made at sea or on land, to find its height and speed. Positions by azimuth and estimated altitude are hardly accurate enough for these purposes. An observation of the brightness and appearance of a fine meteor is however of interest, even if its track in the sky has not been exactly determined.

Observations of a persistent meteor trail are of interest. The shape of the trail and its position relative to at least two named stars should be drawn at suitable intervals of time until it disappears. If carefully timed observations of the same trail are received from two or more observing ships, some information about the speed and direction of the wind at the time in the high atmosphere can be computed.

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. The occurrence or non-occurrence of showers on a particular night is often of considerable astronomical interest, and it may happen that the conditions are such that a meteor shower is visible only in restricted longitudes.

CHAPTER 11

Phenomena of the Lower Atmosphere

ABNORMAL REFRACTION AND MIRAGE

Good descriptions and sketches of the various forms of mirage and the effects of abnormal refraction are always of interest, especially of the more striking forms, such as a well-developed superior mirage, with its double image, one inverted and one erect, above the object. Unusual phenomena should be carefully reported, such as the apparent discontinuity or distortion of the horizon line that has been occasionally seen, also lateral mirages and the complicated mixed mirages of the Strait of Messina, known by the name, of Italian origin, of "Fata Morgana". When lights are seen at abnormal distances, the normal distance of visibility should be given. In all observations of abnormal refraction and mirage, the temperature of air and sea, the type and amount of cloud present, and the direction and force of the wind should be noted.

BROCKEN SPECTRE

In a foggy atmosphere an observer, standing with his back to the sun, when this is at low altitude, will sometimes see the shadow of himself, or of his head, thrown upon the fog, together with coloured rings of light surrounding the shadow. The phenomenon was first noted on the Brocken mountain in Germany but it is not confined to mountain districts and it is most common in Arctic regions, where it is seen on every occasion of simultaneous sunshine and fog.

The coloured rings are now usually known as a "glory". A typical series of colours seen in a well-developed one is as follows. There is a general whitish-yellow colour round the shadow, surrounded with rings of colour in order outwards: dull red, bluish-green, reddish-violet, blue, green, red, green, red. A white rainbow at a considerable distance outside the glory, is sometimes also seen.

The shadow of the observer on thick fog may be seen at night, if there is a bright artificial light behind him.

COLOURED SUNS AND MOONS

The various red or orange colours ordinarily exhibited by the sun or moon when near the horizon are due to the fact that these bodies are then viewed through a great thickness of the dust-laden lower atmosphere, which absorbs most of the sunlight of shorter wavelengths, leaving the longer ones, mainly yellow and red, to come through.

Occasionally in twilight the moon appears to be of a greenish colour, usually a pale greenish-blue or a pale apple-green colour. This is an effect of colour contrast, when the twilight hues of the surrounding sky are brighter than usual, either purplish or reddish, or when the moon is near, or covered by, thin, brightly-tinted cloud.

Coloured suns or moons, not an effect of colour contrast, are sometimes seen. This phenomenon may be produced by dust or smoke haze in the lower atmosphere, e.g., a scirocco laden with dust from the Sahara may give a blue sun or moon in the Mediterranean, and a similar colour may be given in the region of extensive bush fires. The phenomenon may also be produced by volcanic dust at high atmospheric levels. Blue and green moons were observed on many occasions after the great eruption of Krakatau in 1883 and the sun assumed many different and often quite brilliant colours. Shades of red and copper, green, golden-green, blue, silvery and leaden were seen on various days in different localities.

Coloured suns and moons were seen over much of western Europe between 26th and 30th September 1950. These were produced by the smoke from an extensive forest fire in Canada which began on 23rd September. The sun's colour was observed in different places as steel-grey, deep blue and purple.

Any observations of this kind are of interest.

CORONÆ

A corona consists of one or more coloured rings round the sun or moon as centre, when this is covered with middle or lower cloud of sufficient thinness to allow the greater part of the light to come through. It is distinguished from a halo by its smaller size and different colouring, as explained below. A fully-developed corona shows a bluish-white or yellowish glow, usually 2° or 3° in diameter, round the sun (or moon). Outside this is a brownish-red ring. The inner glow and the brownish ring together constitute what is called the aureole. Outside this are coloured rings, in the opposite colour sequence to that of a halo, viz., violet or blue nearest the sun and red furthest out. Sometimes the whole of this colour sequence is repeated outwards a second or, on rare occasions, even a third or fourth time. A corona showing the outer coloured rings is comparatively infrequent, but the aureole alone is the commonest of optical meteorological phenomena and is formed, at any rate partially, whenever broken cloud edges of cumulus, stratus or stratocumulus pass over the sun or moon.

While the radii of the various halos are constant, that of a corona varies on different occasions, being dependent on the size of the water-drops in the cloud. The outside radius of a fully-developed corona is usually much smaller than that of the 22° halo, and is generally between 5° and 8°. After great volcanic eruptions, when fine dust is suspended at great heights in the atmosphere, an aureole comparable in size with the 22° halo has been seen; it is known as Bishop's ring.

Faint coronæ are visible round the bright planets, Venus and Jupiter, and also Mars when this is sufficiently bright, providing the cloud is very thin. They may sometimes be seen round the brightest stars, especially if binoculars are used.

A yellowish blur 2° or 3° in diameter is often seen round the sun or moon and is sometimes formed by higher cloud than that which normally gives coronæ. Although it has a fairly sharply defined circular edge it must not be regarded as an aureole unless bounded by the characteristic brownish-red ring.

In certain circumstances the sun or moon may show a halo and a corona simultaneously.

The name "corona" is also given to one of the forms of aurora (*see* page 88), and to the outer part of the sun's atmosphere (*see* page 77); these are usually distinguished as the "auroral corona" and the "solar corona", respectively.

CORPOSANTS

The electrical phenomenon known as Corposants or St. Elmo's Fire is not infrequently observed at sea during squalls and thunderstorms. It is a luminous appearance seen at the extremities of masts and sometimes on the stays, aerial, jackstaff or other parts of the ship. It may appear as a brush discharge of radiating streamers several inches long, or as luminous globes, a number of which are sometimes seen along the aerial. At other times a structureless glow envelops an elongated object, such as a mast or an aerial. St. Elmo's Fire is usually bluish or greenish in colour, but a violet glow has been reported and sometimes the colour is pure white.

CREPUSCULAR RAYS

The word "crepuscular" means "associated with twilight". Occasionally, soon after sunset, the clear sky appears to be divided into lighter and darker rays by lines diverging from the position of the sun below the horizon. The lighter rays are those illuminated by sunshine; they are usually coloured pink, but may, on different occasions, show some shade of red or orange. The darker rays are shadows, from which the sunlight is cut off by clouds near or just below the horizon or by the irregularities of hills and mountains on the horizon. They appear greenish by contrast with the pink rays.

As the light rays come from the sun, and so are practically parallel, their apparent divergence is an effect of perspective. In favourable circumstances the light rays and shadows extend right across the sky and appear to converge, by perspective, to a point a little above the eastern horizon. These "anti-crepuscular rays" are generally ill-defined.

It is not necessary to record this phenomenon in the logbook unless it shows some feature of special interest, such as unusually distinct colouring or a well-defined convergence to the eastern horizon.

On rare occasions one or more bands have been seen extending up into the sky, from the western horizon, at a later stage of twilight. They appear of a deep blue colour, darker than the general blue of the sky, and are probably shadows of mountains well below the horizon. It is of interest to record these observations.

There are two other allied phenomena which are frequently seen and are of no special interest, unless some unusual feature is observed. The first consists of pale blue or whitish rays diverging from the sun in the daytime when it is behind cumulus or cumulonimbus cloud. The rays are sharply defined and separated by deep blue bands, which are the shadows of parts of the irregular cloud-edge. The second is associated with stratus or other cloud obscuring the sun. If there are small gaps in the cloud, sunbeams pierce these, directed more or less downward, and are rendered luminous by mist or dust in the air. This is popularly known as "the sun drawing water".

DUSTFALL AT SEA

Dust from the land may be blown over the adjacent sea by high winds, but not normally in appreciable quantity. In special regions, e.g., the Red Sea, sand or dust storms are not infrequent and are sometimes severe.

Desert dust or sand may be carried up to high levels of the atmosphere and finally be dispersed over so great an area as not to form any perceptible deposit on falling. The desert dust from Australia carried north-westward by the south-east monsoon reduces visibility over the East Indies region but is not observed as dustfall.

On the other hand, falls of fine reddish or brownish dust from the Sahara, carried by the trade wind, are experienced over a large area of the eastern North Atlantic adjacent to the coast of Africa, centred roughly on Cape Verde Islands. At times this deposit may lie quite thickly on board ship. Visibility in this area is often poor; not infrequently the sun appears blood-red and at night all but the brightest stars at high altitudes are obscured.

Considerable or heavy dustfall may be experienced after a great volcanic eruption. Dust from the eruption of Krakatau in 1883 was collected on ship-board in the Indian Ocean at a distance of 1,000 miles. After the eruption of Hekla in March 1947, dust was similarly collected at a distance of 450 miles.

THE GREEN FLASH

At sunset, the small segment of the upper part of the sun's disc, which is the last to disappear, may turn emerald-green or bluish-green at the instant of its setting. The phenomenon thus usually lasts only a fraction of a second, which is the reason for calling it the "green flash", but longer durations of the colour are occasionally seen.

The green flash is not always seen and when it is seen it is not always equally brilliant. It can range from a green of extreme brilliance and purity, conspicuous without optical aid, down to a trace of grey-green coloration observable only with binoculars.

The green flash is produced by the unequal refraction of light of different colours, when the sun is at very low altitudes. This gives fringes of colours of the shorter wave-lengths, green, blue and violet, along the sun's upper limb and a fringe of the colour of the longest wave-length, red, along the sun's lower limb. The fringes of the upper limb cannot usually be seen while the main body of the sun is still above the horizon, as the general sunlight is too strong, but when most of this is cut off by the horizon they spring suddenly into view. Normally, only the green fringe is seen, the light of still shorter wavelengths usually being absorbed by its horizontal passage through the lower atmosphere. The flash is, however, occasionally seen as a blue one, or as green quickly changing to blue. On very rare occasions the violet colour has been seen.

The green colour occasionally appears in other ways. Sometimes when refraction is marked, and the sun's disc is perhaps distorted, binoculars will show that the upper limb appears to be "boiling", giving off shreds or tongues of green "vapour ". Occasionally the sun's upper limb has been seen with a narrow green rim when half or more of the disc remained above the horizon.

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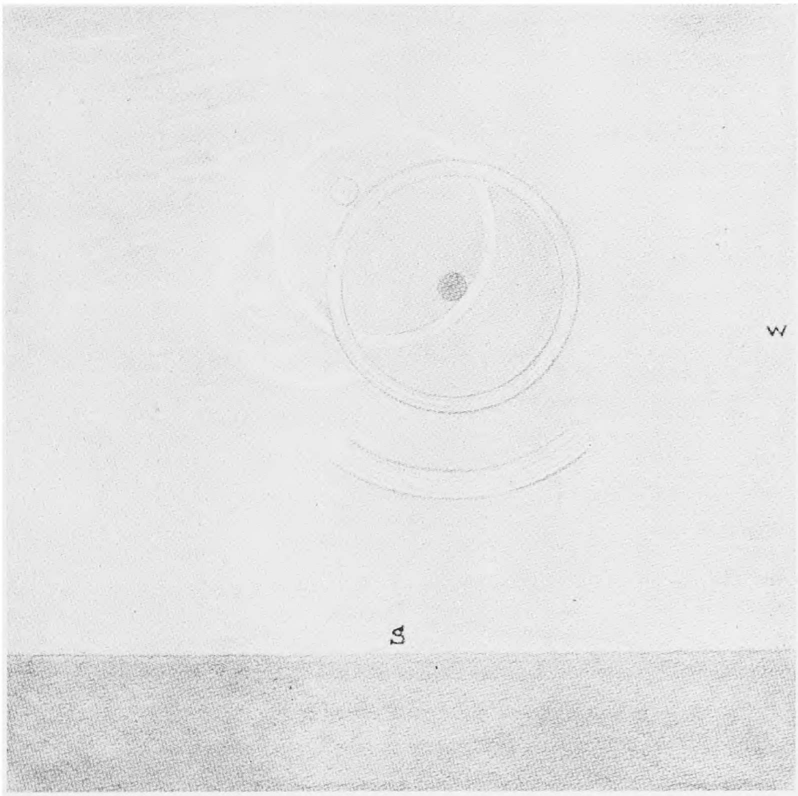

FIG. 31. Solar halos

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

"6th March 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 $21\frac{1}{2}$°, the breadth of the spectrum subtending an angle of $\frac{3}{4}$°. 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."

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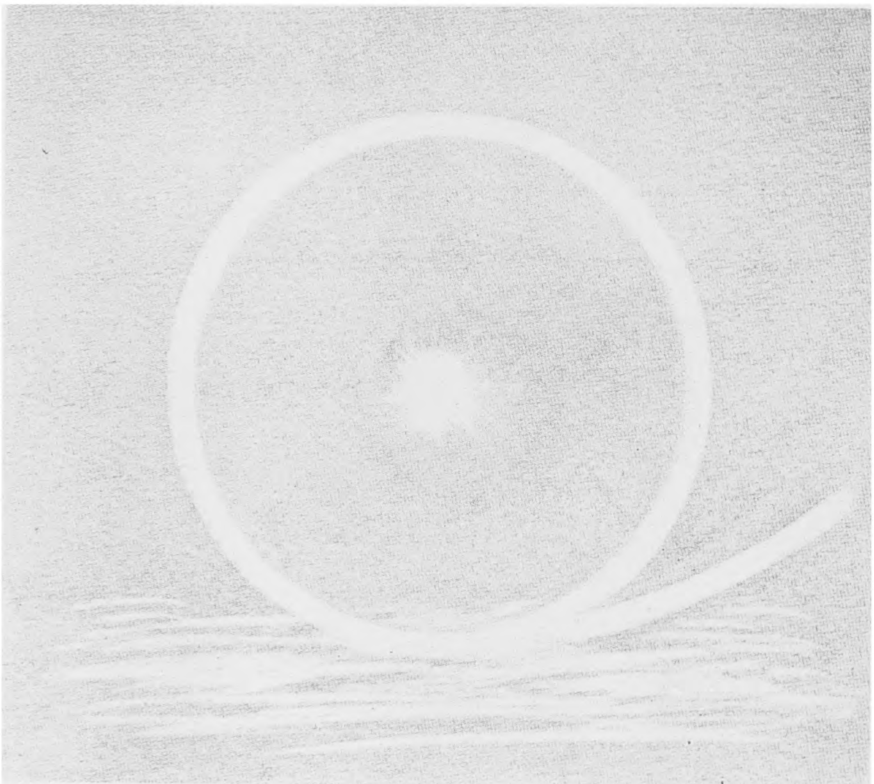

FIG. 32. Lunar halo

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

"The above sketch represents the lunar halo and arc of contact as observed on the night of 28th February 1923, in Latitude 16° 16′ S., Longitude 89° 43′ E. (approx.) The complete circle was $22\frac{1}{2}$° 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."

A sea horizon is not essential for observing the green flash; it may be equally well seen when the sun sets behind a distant land surface. It has also often been seen when the upper limb sinks below a bank or bar of hard-edged cloud at low altitude, and if there are several parallel bars of cloud in clear sky the phenomenon may be seen more than once on the same evening. When the lower line of the sun appears from behind cloud near the horizon the converse phenomenon, the "red flash", has sometimes been seen.

The green flash occurs also with the moon, but has seldom been observed, presumably because it is fainter and rarely looked for. On the other hand, it has been frequently seen at the setting of the bright planets Venus and Jupiter, and an observation of a blue flash from Venus is on record. Many interesting varieties of phenomena may occur before these planets set, the observation usually requiring binoculars. Colour changes may be seen, usually between white, red and green, or two images may appear of the same or different colours. The planet may exhibit slow "swimming" movements, obviously due to abnormal refraction.

The most favourable condition for seeing the green flash, at any rate brilliantly, is probably some degree of abnormal refraction, whereby the vertical extent of the colour separation described above is greater than that produced by normal refraction. In addition, the green flash is most likely to be seen when the air is relatively dust-free, and without mist or haze, so that the sun remains brighter and less red than usual at low altitudes. The green flash has been well observed at sunrise, but less frequently, perhaps because it is less often looked for. Also, owing to its short duration the phenomenon is liable to be missed unless the exact spot at which the sun will appear is known.

The green flash has sometimes been called, rather inappropriately, the "green ray". It will be obvious from the remarks made above that it exhibits a considerable variety of appearances at different times. Further observations, giving as much detail as possible, will be very useful in increasing our knowledge of this interesting phenomenon and the conditions most favourable for its appearance.

Other phenomena, involving green coloration of the sky in the vicinity of the sun at the moment of sunset, are occasionally seen, and observations of these are also of interest, as they exhibit much variety. Some examples are (i) a momentary ray of green light shooting up into the sky, sometimes to a considerable altitude at or just before the final instant of sunset, (ii) an appearance resembling a rapidly rotating green searchlight beam. (iii) A transitory appearance as of green mist in the sky above the setting sun.

HALO PHENOMENA

General remarks. A halo is usually understood to mean a luminous ring, with the sun or moon at its centre. Only two such rings are observable as complete circles, the halos of 22° and 46° radius. Many analogous phenomena are, however, seen at times in various parts of the sky, including complete rings not centred on the sun or moon, arcs of halos not formed as complete rings, and diffuse images of the sun or moon, known as mock suns or moons. These, with the true halos, are grouped under the name of "halo phenomena". A number of these may, in suitable conditions, be seen simultaneously. The composite phenomenon is then called a "halo complex" and may, on exceptional occasions, be of great intricacy and beauty. Fig. 33 is from a drawing of the halo complex at Danzig observed by the astronomer Hevelius on 20th February 1661. It shows the more common phenomena and some of the rarer ones.

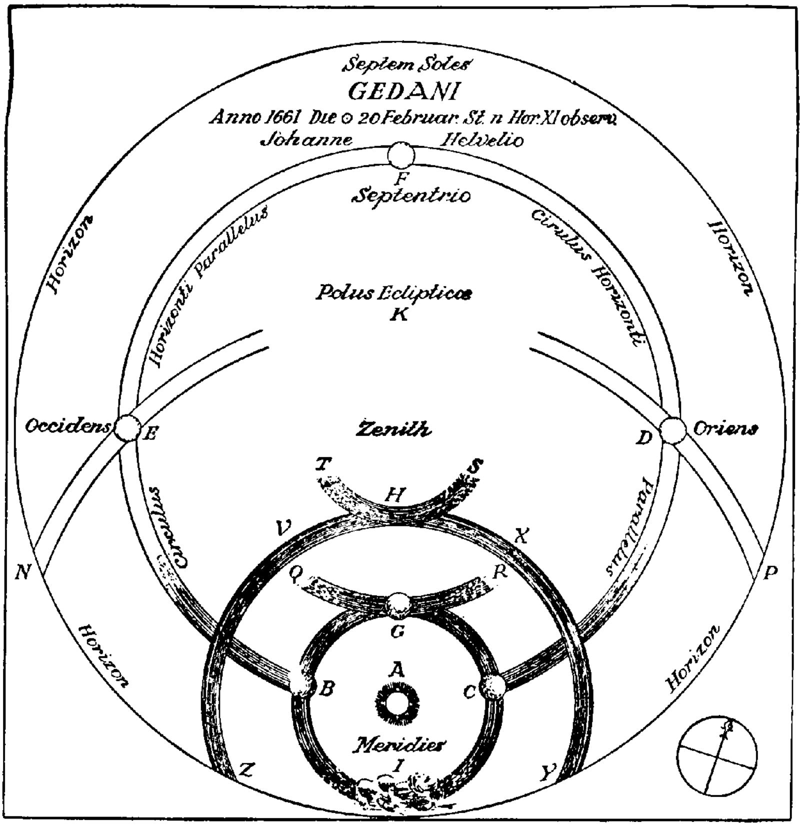

FIG. 33. Halo complex observed at Danzig on 20th February 1661

To avoid repetition, the sun is assumed to be the source of light in the following remarks. Lunar halo phenomena are in general as readily seen as solar ones, if the moon is near or at the full. The actual luminosity of a lunar halo is much less, but so is the brightness of the sky against which it is seen.

Some halo phenomena are always white, from their mode of formation; others, including the 22° and 46° halos, are coloured. With one exception, however, the circumzenithal arc, the colours are very seldom as brilliant and pure as those of a rainbow. The actual degree of brilliance, however, varies considerably. Sometimes the colour is very impure, perhaps showing only reddish and yellowish tinges; at other times it is much clearer and may show more of the spectrum, and in exceptional cases the whole of it. The red end of the spectrum is always nearest the sun and therefore on the inside of the 22° and 46° halos. In the case of arcs that show colour, the red is also nearest to the sun, whether the arc is convex or concave to the sun. The red side of the mock sun is also nearest the sun. Less colour is usually seen in lunar halo phenomena, but it is sometimes quite distinct.

The observation of halos. High latitudes, especially the polar regions, are the most favourable for frequent and brilliant displays of halo phenomena, which can be formed not only by cirrostratus cloud, but also by ice fog. Many fine displays occur, however, in temperate latitudes, where the late spring is an especially good season.

Cirrostratus is the most favourable cloud for the production of halo phenomena; the thinner and more uniform its texture the better. On the most suitable occasions, the blue sky is only dimmed with a uniform milky appearance. When the cloud is thicker in some places than others, and especially when wisps and streaks of cirrus are mixed with it, not only are the phenomena less distinct but straight or curved lines of cloud may be mistaken for additional halo phenomena.

When thin cirrostratus is present and one or more of the commoner halo phenomena are well seen, the prospects of seeing some of the rarer halo phenomena are good and a careful general look over the whole sky may result in something else being seen. Attention should chiefly be concentrated on the following regions (i) that surrounding the sun up to a radius of at least 46° (ii) a belt of the sky, at the same altitude as the sun, all round the horizon, (iii) the overhead sky, with the zenith as centre.

On account of the methods of formation of halo phenomena, the reflection and refraction of light by ice crystals, the position of each halo, etc., is always precisely the same relative to the sun or, in some cases, to the zenith. A halo phenomenon is thus identified by its position in the sky; its appearance is of secondary importance, though, in some cases, this helps in the identification. The most essential part of a halo observation is therefore the determination of its position by angular measurement with reference to the sun (or moon) or, in appropriate cases, the horizon or the zenith. Most of the rarer phenomena can only thus be identified with certainty.

The altitude of the sun, to the nearest degree, should also always be given, since this affects the precise position of certain halo phenomena, and in some cases determines what phenomena it is possible to see at the time. The radius of the relatively well-defined inner edge of any halo, or part of a halo, centred on the sun should be measured in degrees from the sun's centre. In the case of arcs situated vertically above the sun such as the circumzenithal arc, the distance of the lowest part of the arc from the sun is all that is required. It is useful, however, to estimate the extent of any such arc as a fraction of the small circle of which it forms part.

The mock sun ring is identified by its parallelism to the horizon, at the sun's altitude; no measurements are required. A phenomenon situated on it, such as the anthelion or other bright spot, or the point of intersection of an arc with it, is measured in the form of azimuth distance from the sun.

The above statement should be sufficient to indicate to the observer the lines on which he should proceed. The most difficult cases are certain abnormal phenomena such as are shown in Fig. 31. The diameter of the halo not centred on the sun could be measured by sextant; the altitude and azimuth of the estimated centre of the halo will then give its position. The position of the elliptic arc shown in Fig. 31 could be measured by taking the altitude and azimuth of each of the two ends, and of the point on the halo equidistant from these.

Having established the position, any point of special interest should be noted, such as an exceptional degree of brightness or colour, variations in brightness in different parts of a halo, or a halo appearing elliptical instead of circular, etc. In the case of the rarer phenomena, the fullest possible information should be recorded, preferably accompanied by a sketch, on which all angular measurements are shown. In sketching halo phenomena the size of the sun (or moon) is usually exaggerated, sometimes very greatly. Even in landscape paintings by well-known artists, the same thing usually occurs. The discs of the sun and moon are about half-a-degree in diameter and therefore only about one-ninetieth of the diameter of the common halo of 22° radius.

Description of halo phenomena. The following three phenomena are those most frequently seen, either singly or in combination.

(i) HALO OF 22°. This, in complete or partial form, is very common in temperate latitudes and if looked for can probably be seen on the average about one day out of three (BGCI, Fig. 33). The outer edge shades off gradually; in favourable circumstances it is several degrees wide. The sky inside the halo, except for a patch surrounding the sun, is darker than that outside it. The edge of the halo nearest the sun is a dull red, followed outwards by a yellowish tinge. Outside this the halo is usually whitish, but if the other colours are purer and stronger it may be greenish. Blue can seldom be seen; on extremely rare occasions it has been seen with a tinge of violet outside.

(ii) PARHELIA OF 22°. Parhelia (mock suns) and paraselenae (mock moons) are one of the most frequent and most striking of halo phenomena. They are luminous, sometimes very brilliant, blurred images of the sun, seen at the same altitude of the sun, or either side of it (B and C, Fig. 33). They cannot be formed when the sun's altitude exceeds 60° 45′. When this altitude is 10° or less the mock suns are situated approximately on the 22° halo. With increasing altitude the mock suns are formed further outside the halo; when the sun's altitude is 55° they lie about 14° outside the halo. They always lie on the horizontal mock sun ring (*see* below), which may or may not be visible at the time. Mock suns are often quite brightly coloured, and when at all bright, they are drawn out to long pointed horizontal white tails, on the side away from the sun. A single mock sun, often very brilliant, may not infrequently be seen in a small patch of cirrostratus cloud in a clear evening sky, the cloud not being extensive enough to give any other halo phenomena. A mock sun may be formed on aeroplane trail cloud, when it has widened out sufficiently; other halo phenomena have been seen similarly formed.

(iii) UPPER CONTACT ARC TO 22° HALO. This is a curved arc situated vertically above the sun, tangent to the highest point of the halo of 22°; it cannot be formed if the sun's altitude exceeds 70°. Its shape varies greatly according to the sun's altitude, being sometimes convex to the sun, at other times concave to the sun. A similar arc, also changing with the sun's altitude, may be seen tangent to the lowest point of the 22° halo, but is less common. When the sun's altitude is 29° or more the upper and lower contact arcs may join, outside the 22° halo. With higher solar altitudes this may produce a halo of nearly elliptical form, known as the Circumscribed Halo. QGR, Fig. 33, shows the upper contact arc and Fig. 32, part of the lower contact arc. The upper contact arc may be seen coloured.

The following phenomena are occasionally seen:—

(iv) HALO OF 46°. This is much less common than the 22° halo and when visible is often incomplete, since a very large area of cloud of suitable type is necessary to show the whole of it (ZVXY, Fig. 33). It is usually less bright than the 22° halo. It is often whitish in colour but when colouring is seen, it is generally purer than that of the 22° halo.

(v) CIRCUMZENITHAL ARC. In favourable circumstances, this shows the purest and most vivid colouring of all halo phenomena. It has been mistaken for a rainbow, but should not be, as it is in the same azimuth as the sun, but at a higher altitude and convex to the sun (THS, Fig. 33), while a rainbow is seen on the opposite side of the observer to the sun (*see* page 104). It is usually a comparatively short arc. The upper part of the 46° halo may or may not be visible at the same time. If the 46° halo is present the circumzenithal arc may touch its highest point or it may pass above it at varying distances up to 12°. These variations depend on the sun's altitude.

(vi) PARHELIC CIRCLE (MOCK SUN, OR MOON, RING). This is a white circle, parallel to the horizon, so that if complete it is seen in all azimuths. It is of the same altitude as the sun and thus passes horizontally through the sun and through the mock suns, if these are visible (BEFDC, Fig. 33). The part within the 22° halo is often missing. The mock sun ring is usually rather diffuse and faint, but sometimes it is bright and well-defined, with a width of a degree or so.

(vii) SUN PILLAR. During very cold weather a vertical pillar of white light is not infrequently seen above the sun, when this is at low altitude; it may also extend vertically below the sun. When the sun is on or below the horizon, the upper part of the pillar only is seen, and may be more conspicuous than it was before sunset. After sunset the pillar is usually of a red or orange colour.

The occurrence of other halo phenomena ranges from comparatively rare to extremely rare. Some of them have been recorded at sea from time to time. Some have only once been observed. Other halos have been centred on the sun, with various radii between 8° and 32°. Should one of these very rare halos be observed, its radius should be most carefully measured. Other possible phenomena in the region of the sun comprise secondary halos of 22°, centred on the common mock suns of the ordinary halo of 22°, also arcs other than those already described situated vertically above or below the sun.

In the mock sun ring region the phenomena include mock suns, other than the common ones, at various points on the ring, and arcs crossing the mock sun ring obliquely. The more usual positions of these mock suns are (*a*) 180° in azimuth from the sun (anthelion) (F, Fig. 33) and (*b*) one on either side, 120° in azimuth from the sun. These mock suns or arcs may sometimes be seen even though the mock sun ring is not visible.

In the region of the zenith, arcs of various lengths and curvatures are seen at times. They may be symmetrically developed on either side of the zenith and some may extend down opposite the sun to reach the mock sun ring.

There are a few other phenomena not included in the above grouping, e.g., various forms of cross, centred on the sun or moon, are occasionally seen (Fig. 34). The vertical arm is usually formed by part of a sun pillar and the

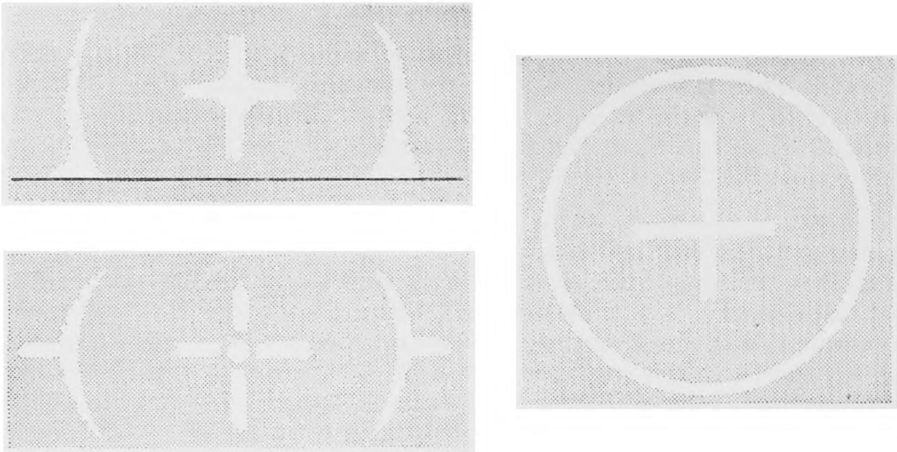

FIG. 34. Forms of halo cross

horizontal arm by a short portion of the mock sun circle. Abnormal phenomena of unknown origin are also sometimes reported. One such observation is shown in Fig. 31, in which is seen the ordinary 22° halo, with an arc below, probably part of the 46° halo, though its radius is shown too small. The remarkable complete halo passing nearly, but not quite, through the sun and the markedly elliptical arc outside it cannot be related to any of the known phenomena.

IRIDESCENT CLOUD

Patches of delicate, but often vivid, colouring are occasionally seen at any time of the day on altocumulus and other middle and high clouds, often covering quite a large extent of cloud. It may form a very beautiful spectacle, especially if the sun is hidden from the observer's view by lower cloud. Red and green are the most common colours, but others, such as lilac, may be seen. Sometimes the colours lie in bands parallel to the edge of the cloud, but often they form an irregular mosaic, delicately shading into one another. The colouring resembles that of coronæ, but the bands of colour do not form concentric circles with the sun as centre. Sometimes a number of coloured patches may be seen along a straight line passing through the sun.

Iridescence is usually seen on cloud near the sun or within about 30° of the sun, but may occur at greater distances. It seems to be most frequently observed on cloud that is either in process of formation or evaporation. The colouring is not normally seen after sunset or before sunrise, but brilliant iridescence, continuing after sunset, or appearing before sunrise, may be seen on a very rare high form of cloud, *see* Mother-of-Pearl Cloud (page 85).

If the observer is in doubt as to whether he is seeing ordinary sunset cloud colouring, or iridescent colouring towards the time of sunset, it should be remembered that the former may cover large areas of cloud, or many isolated clouds, with one colour. Iridescence, on the other hand, usually shows much smaller areas of different colour on one cloud and the colouration is purer and more prismatic, in this respect resembling the colours of the rainbow.

When seen, remarks on the nature and extent of the colouring, the type of cloud and the approximate angular distance from the sun will be useful.

LIGHTNING

Anything unusual observed during a thunderstorm is worth recording. Some points in connection with lightning are given below.

Lightning varies in colour on different occasions; it is normally white, with perhaps a bluish tinge. Sometimes it is quite a bright violet. Other colours seen are reddish-white, yellowish-white, mauve and blue.

Variations of the ordinary appearance of forked lightning have been seen:—

(i) Inequalities of brightness in different parts of the path, known as chain, or beaded lightning, from the impression left on the eye.

(ii) Rocket lightning, so called from the relative slowness of the flash, so that the progressive lengthening of the streak can be seen.

The special form known as ball lightning resembles a ball of fire, either falling from a cloud or moving more or less horizontally. It usually lasts only a few seconds and may disappear noiselessly or with an abrupt clap of thunder. Ball lightning has been seen at close range and it has sometimes passed into or through a building. Careful observations of this uncommon, but not extremely rare, form of lightning are specially desired. Rare forms of lightning have been seen shooting upwards from the top of cumulonimbus cloud, in various branching or rocket-like forms.

A high frequency of visible flashes sometimes results from more than one storm in different directions being operative at the same time, so that at night there is almost continuous illumination of the sea or landscape. Such a lightning rate has been known to persist for several hours, but this is very rare.

Occasional reports of ships being struck by lightning are received, but this event is probably of much less frequent occurrence than in the days of wooden sailing ships. Descriptions of the effect on the ship and on the compasses (*see* page 113) will be of interest. Observations of recent years show that in nearly all cases the foremast or fore part of the vessel is struck.

RAINBOWS

Solar rainbows. The normal appearance of a bright rainbow is as follows. The chief or primary bow shows the sequence of colours, violet, blue, green, yellow and red, the red being on the outside or top of the bow. In contact with the inside of this bow, one or two fainter "supernumerary bows" can frequently be seen 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; they are essentially red, or red and green, though other colours may be seen. In cases of exceptionally brilliant rainbows up to five supernumerary bows may be seen.

Concentric with the primary bow, but 9° outside 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 is fainter, being produced by two such reflections. The sky between the primary and secondary bow is rather darker than that inside the primary bow, or the general sky in the neighbourhood. The secondary bow is commonly seen, but if the primary bow is faint the secondary one may not be visible.

Both the primary and secondary bows are seen when the observer has his back towards the sun. 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 $40\frac{1}{4}$°; in the secondary bow the radii are 51° for red light and 54° for violet light, all the values given being approximate. Hence the normal breadth of the primary bow is about $1\frac{3}{4}$° 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, its centre being 42° below the horizon, and hence no primary bow can be formed if the sun's altitude exceeds 42°. Similarly no secondary rainbow can be formed if the sun's altitude exceeds 54°. 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. Thunderstorm rain passing away from the observer gives the most favourable circumstances for the production of bright rainbows.

When the observer is at ground level and the rain cloud is distant, the rainbow arcs are always less than semicircles, unless the sun is on the horizon, when they form semicircles. When however, the rain is near, and especially if the observer is in an elevated position, such as on the bridge of a ship, the bows will be greater than a semicircle and may even form complete circles. Several accounts have been received of bows forming complete circles as far as the water line on each side of the ship.

One of the halo phenomena, the circumzenithal arc, may show bright rainbow colouring, but is always in such a position that the observer must face the sun to see it (*see* page 101).

Rainbows do not always show the same colouring. The colours seen, and their relative width and intensity, vary according to the size of the raindrops producing the bow. The colours are most brilliant and best defined with very large raindrops such as occur in thunderstorm rain. With fairly large drops, vivid violet and green may be seen, and also pure red, but little or no blue. With smaller drops the red weakens and with still smaller ones the green goes, leaving only the violet. Just before sunset, when the sun is red in colour, especially in autumn and winter, an all-red rainbow may be produced.

If the raindrops are extremely small, as in the case in some cloud and in fog, a white rainbow may be formed. Such a bow is called a "fog-bow" or "Ulloa's Ring". In all rainbows there is some overlapping of the colours; in a white rainbow the overlapping is so complete that white light is reconstituted. For a white rainbow to be seen, the observer must be near the cloud or near or in the fog.

Lunar rainbows. Lunar rainbows are formed in the same way 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 usually fainter than a solar one and it is not always possible to distinguish colour; the appearance is then whitish. Quite frequently, however, colour may be observed; more rarely the whole sequence of colour can be seen. Secondary and supernumerary lunar rainbows are very rarely seen, on account of their faintness.

Observation of rainbows. The observer who wishes to make useful observations of normal rainbows should record the colours seen, in sequence, with an indication of their relative widths and intensities. If supernumerary bows are seen below the primary bow, the number of these and their colouring should be noted. If the secondary bow is unusually bright it is worth while looking for supernumerary bows just above it; these have rarely been seen on account of their faintness. An additional primary bow may be seen when the sea is sufficiently calm to give a reflected image of the sun in the sea, which acts as the light source for the bow. The position of this bow with regard to that formed by the sun itself varies with the sun's altitude. The secondary bow from the sun's reflected image is almost always too faint to be observable.

Abnormal bows, or arcs of bows, perhaps intersecting the normal bows, and sometimes white in colour, have occasionally been seen and it is of special interest to record these as fully as possible, since no explanation has yet been found for some of them. They sometimes meet the horizon at the same point as one of the normal bows. In such cases the sequence of colour, or the absence of colour, should be noted. It is essential to give angular measurements of such bows, in the form of azimuths of the ends of the bow or arc, in which case the sun's azimuth should also be given. If a normal bow is also seen, the difference in azimuth between the points where the normal and abnormal bows meet the horizon will serve to establish the position of the latter. If an abnormal bow is seen concentric with the normal primary or secondary bow the difference of altitude of the bows at their highest point should be given.

SCINTILLATION

Scintillation, or twinkling, is the more or less rapid change of apparent brightness of a star, accompanied also at relatively low altitudes by colour changes. It is due to minor changes in the refractive power of the atmosphere. The amount of twinkling is always greatest towards the horizon and least in the zenith. The general amount varies considerably on different nights, so that at the zenith twinkling may be considerable, slight or entirely absent. Nights without appreciable twinkling towards the horizon are rare. When the changes of brightness are small the fluctuations are slower; in proportion as they are greater they become more rapid.

Colour change is usually shown by stars at altitudes not exceeding 34°; it never occurs at altitudes greater than 51°. The brightest stars, e.g., Sirius, at low altitudes show it most, and in favourable conditions, the changes may be very striking, the star flashing blood-red, emerald-green, bright blue, etc.

Scintillation is also observed in the case of terrestrial lights. The shimmering seen near the ground on a hot day is akin to it.

The bright planets do not usually appear to twinkle, as they have discs of definite size, although these are not visible without optical aid. Each point on the disc twinkles independently of the others, so that on the average the light is steady. The planet Mercury, only seen in twilight and at relatively low altitudes, may however be seen to twinkle because of the small size of its disc, and, exceptionally, other planets at very low altitudes may exhibit some twinkling.

The relative degree of twinkling in different parts of the world, e.g., in temperate as compared with tropical latitudes, is not very well-known and any information bearing on this will be of interest. It is probably greatest in temperate latitudes, which are subject to the passage of depressions.

SKY COLORATION, DAYTIME

The light of the sky in day time is due to the illumination of the atmosphere by sunlight. The molecules of air exert a selective action on the colour constituents of sunlight, scattering mainly blue rays towards the observer and letting the others pass away.

Dust is always present in greater or less degree in the atmosphere, and in certain states of weather larger particles are present in the lower part of the atmosphere. The presence of dust tends to weaken the blue of the sky, because each particle reflects the whole of the white light. The greater the number of particles and the larger their size the more the sky becomes whitish-blue. For the same reason the cloudless sky is always whiter near the horizon than at higher altitudes. After heavy rain, such as that due to the passage of a depression, the larger dust particles have been washed out of the air and the sky is often a very deep blue.

The sky is often whitened within the region of smoke pollution from a large town. Natural dust from desert sources, at higher levels in the air, also has the same effect, e.g., the white skies seen in the region of the East Indies in the south-east monsoon, caused by dust from the Australian desert. The dust from great volcanic eruptions may whiten the sky for weeks or months afterwards, over more or less considerable areas of the globe. After the Krakatau eruption the colour of the sky at various times of the day in equatorial regions was described as white, smoky, yellowish or reddish.

The unclouded sky may also be whitened by what is known as " optical haze", which also makes distant terrestrial objects indistinct. This occurs on hot days and is the result of innumerable little convective uprisings of air, causing confused and variable refraction of light. The shimmering of terrestrial objects on a hot day also results from the same cause.

The sky may sometimes be covered by a layer of cirrostratus, so thin and uniform as not to be visible as cloud, but sufficient to dim the blueness, giving the sky a milky appearance.

A somewhat dirty green coloration of clear patches in a generally overcast sky is sometimes seen at sea in the daytime, not to be confused with the green coloration of part of the clear twilight sky in the west. This daytime coloration is associated with bad or windy weather, or is considered a prognostic of such weather. Observations of it and of the accompanying or subsequent weather will be welcomed, as it is not yet fully understood. It appears to occur most frequently in the Roaring Forties.

SKY COLORATION AT TWILIGHT

When clouds, particularly middle and upper clouds, occur about the time of sunset or sunrise, or in bright twilight, their coloration is often very beautiful. The cloud colours are mainly shades of orange, rose or red, since the direct sunlight illuminating the cloud has passed through a great length of the lower layers of the atmosphere. Shades of purple are sometimes seen, since a cloud may at the same time be indirectly illuminated by scattered blue light from higher atmospheric levels. On rare occasions colouring of exceptional magnificence occurs.

Colour phenomena also occur in a cloudless sky during the twilight periods. These vary considerably and are best developed in arid or semi-arid land regions. Some of those which occur more commonly everywhere are mentioned here. The Primary Twilight Arch appears after the sun has set, as a bright, but not very sharply-defined, segment of reddish or yellowish light, resting on the western horizon. After the sun has set, a pink or purple glow may be seen, covering a considerable part of the western sky, known as the First Purple Light. It reaches its greatest brightness when the sun is about 4° below the horizon, and disappears when it is about 6° below.

At sunset, a steely-blue segment, darker than the rest of the sky, begins to rise from the *eastern* horizon. This is the shadow of the earth thrown by the sun on to the earth's atmosphere. The Earth-shadow is bordered by a narrow band of rose or purple colour, called the Counterglow. The whole rises fairly quickly in altitude, the shadow encroaching on the counterglow and soon obliterating it. With increasing general darkness the edge of the shadow weakens, but may sometimes be traced up to its passage through the zenith. In the later stages of twilight, this shadow edge has come down nearly to the *western* horizon, leaving a slightly more luminous segment between it and the horizon. This is the Secondary Twilight Arch. Just before the ending of astronomical twilight, it is sometimes seen as a fairly well-defined whitish arch on the horizon, with an altitude of only a few degrees at its apex. This might be confused with an auroral arc visible at very low altitude.

Analogous phenomena, in the reverse order, occur before sunrise. Other colours are often seen in the cloudless twilight sky, portions of which may be green, yellow, orange or red, according to the amount of dust and water-vapour present in the air. Instead of the purple light after sunset, the sky very often shows some shade of clear green, probably when the air is relatively free from dust.

SKY COLORATION AT NIGHT

Between the visible stars, brighter and fainter, the background of the clear night sky is not wholly dark. Part of the general luminosity of the sky is due to the accumulated light of the brighter telescopic stars, which cannot be seen as individual stars with the unaided eye. The remainder is due to the airglow, which may vary in intensity on different nights, *see* page 90. The airglow is greenish in colour but it is usually too faint for the colour to be seen. In bright moonlight the sky is generally somewhat greenish, but it is probable that when the air is relatively dust-free and the full moon is at high altitude it becomes bluish. Opinion varies on this point, as the colour of faint light is not equally well seen by different persons.

TWILIGHT

Twilight is due to the illumination of the higher levels of the atmosphere by the sun when this is below the observer's horizon. The last stage of twilight is very faint and indefinite and it is not possible to say exactly when it ends. Astronomical twilight is defined as ending when the sun's centre is 18° below the horizon, since by that time sixth magnitude stars, the faintest that can be seen by the naked eye, have become visible in the region of the zenith.

Another and shorter twilight period, that of civil twilight, is recognized; this ends when the sun is 6° below the horizon. This is assumed to mark the ending of the time when outdoor labour is possible. The period of civil twilight is important to the seaman because experience has shown that subsequent to it the horizon is not sufficiently clearly visible to obtain good stellar observations. In the later stages of civil twilight such observations can be made, the brighter fixed stars being visible and the horizon still remaining clearly visible. Similar definitions apply to morning twilight.

The duration of twilight varies according to the latitude. It is shortest in the tropics where the apparent track of the sun down to the horizon is steepest. It also varies to some extent at different seasons, being shortest in all latitudes about the time of the equinoxes. The following table shows the extent of these variations between the equator and latitude 60° N. or S.; A.T. and C.T. refer to astronomical and civil twilight respectively:—

	Equator		30°		50°		60°	
	A.T.	C.T.	A.T.	C.T.	A.T.	C.T.	A.T.	C.T.
	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.	h.m.
Midwinter	1·16	0·26	1·26	0·31	2·1	0·45	2·48	1·9
Equinoxes	1·10	0·24	1·20	0·28	1·52	0·37	2·31	0·48
Midsummer	1·15	0·26	1·37	0·32	—	0·51	—	1·59

In the belt between latitude 48½° and the Arctic Circle, there is no true night for some weeks of the midsummer period, as the sun does not sink as much as 18° below the horizon. There is a similar belt in the southern hemisphere, six months later, during the southern summer. In polar regions there is a long twilight period of about two months between the long polar periods of summer daylight and winter night.

At rare intervals abnormally long duration of twilight is observed. This is caused by the presence of fine dust suspended in the upper air. The dust may be due to a great volcanic eruption, such as that of Krakatau in 1883 or to the fall of an exceptionally large meteor, such as that of 30th June, 1908 in Siberia. Observations of exceptionally bright and long-continued twilight will be of value.

WATERSPOUTS

A waterspout is a whirlwind over the sea, appearing as a funnel-shaped column usually extending from the lower surface of cumulonimbus cloud to the sea. In travelling over the sea this column often becomes oblique or bent; it may become looped. The spout 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. A noise of "rushing wind" may be heard. A waterspout in most cases forms downwards from the base of the cloud, appearing in its earlier stages as a dark funnel hanging from the cloud. The sea surface below becomes agitated and the funnel finally dips into the centre of the spray. The waterspout may last from a few minutes up to half an hour or more. Sometimes the spout, formed of condensed water-vapour, does not reach the sea, and retreats again up into the cloud. Several may be seen at the same time.

Observations of waterspouts, with sketches or photographs, and details of their mode of formation and dissipation are of value. The diameter of the spout and the direction of rotation should be noted. If it is possible to determine the rate of rotation, this information is very valuable. Sometimes a streak or mark on the spout enables this to be done. The spout is a hollow tube; double walled spouts have occasionally been recorded. The approximate vertical height of a spout may be found by sextant measurement of the angle subtended, together with the known or estimated distance from the ship. The height of a waterspout from sea surface to cloud base is usually from 1,000 ft. to 2,000 ft. It may, however, be as little as 100 ft. or as much as 5,000 ft. There is a very great variation in the observed diameters of waterspouts, from 3 ft. to about 700 ft.

Though waterspouts are infrequent in high latitudes their frequency does not depend wholly on latitude. In general, more are observed in lower latitudes but their frequency in tropical and equatorial regions varies considerably in different oceans. Waterspouts are most common in the following regions: the Equatorial Atlantic; the South Atlantic; the eastern coast of the United States, south of lat. 35°N.; the Gulf of Mexico; part of the Eastern Mediterranean; the Bay of Bengal; the Gulf of Siam.

CHAPTER 12

Marine Phenomena

SEA COLORATION

The normal colour of the sea in the open ocean in middle and low latitudes is an intense blue or ultramarine. The following modifications occur elsewhere:

(i) In all coastal regions and in the open sea in higher latitudes, where the minute floating animal and vegetable life of the sea, called plankton, is in greater abundance, the blue of the sea is modified to shades of bluish-green and green. This results from a soluble yellow pigment, given off by the plant constituents of the plankton.

(ii) When the plankton is very dense, the colour of the organisms themselves may discolour the sea, giving it a more or less intense brown or red colour. The Red Sea, Gulf of California, the region of the Peru current, South African waters and the Malabar Coast of India are particularly liable to this, seasonally.

(iii) The plankton is sometimes killed more or less suddenly, by changes of sea temperature, etc., producing dirty-brown or grey-brown discolouration and "stinking water". This occurs on an unusually extensive scale at times off the Peruvian coast, where the phenomenon is called "Aguaje".

(iv) Larger masses of animate matter, such as fish spawn or floating kelp, may produce other kinds of temporary discoloration.

(v) Mud brought down by rivers produces discoloration, which in the case of the great rivers may affect a large sea area. Soil or sand particles may be carried out to sea by wind or duststorms, and volcanic dust may fall over a sea area. In all such cases the water is more or less muddy in appearance. Submarine earthquakes may also produce mud or sand discoloration in relatively shallow water, and oil has sometimes been seen to gush up. The sea may be extensively covered with floating pumice stone after a volcanic eruption.

It is desirable to record all cases of unusual sea coloration. To determine the cause, microscopic examination of a sample may be necessary, and whenever possible a sample should be taken for subsequent examination at the National Institute of Oceanography. The sample can be preserved for a considerable time if a few drops of 40 per cent. formalin or of a strong solution of corrosive sublimate are added. Port Meteorological Officers in U.K. ports carry sets of bottles and preservative for this purpose and will supply any shipmaster on request.

ABNORMAL RISES OF SEA LEVEL AND ABNORMAL WAVES

Both these phenomena are popularly included in the term " tidal waves ", but neither has any connection with the tides. If either occurs, however, at a coast in conjunction with a high tide, its effect will obviously be greater and more destructive.

Abnormal rises of sea level, on which ordinary sea and swell waves are superimposed, are produced by severe storms. High water levels are thus caused on many coasts, but fortunately the rise is rarely large enough to cause great damage. With strong westerly winds the water level at Cuxhaven, at the mouth of the Elbe, may rise 8 feet above the normal. On exceptional occasions the rise has reached 11 feet above the normal. Destructive rises mainly occur in connection with tropical revolving storms; rises of as much as 19 and 15 feet have been experienced on parts of the east coast of the United States.

Submarine earthquakes and landslides, and violent volcanic eruptions near a coast or on an island, produce abnormal waves. Sometimes these are visible waves, at other times shock waves, the latter giving the sensation in severe cases of the ship having struck a rock. The visible waves may travel many hundreds of miles, or in very severe disturbances for many thousands of miles.

Single high waves in fair weather, with smooth or moderate sea, are almost certainly of seismic origin. Sometimes there may be two or more such waves at intervals. On the other hand, isolated giant waves which have been reported in gale conditions, are probably caused by a synchronism of the larger waves in a sea or swell cycle. Some of these have been estimated to reach or exceed a height of 60 feet.

Observations of abnormal waves and rises of sea level are always of interest and should be carefully recorded. Whenever an actual shock is felt, it should be described as fully as possible, stating the exact time and the ship's position.

MARINE BIOLUMINESCENCE

This phenomenon, still commonly known as " phosphorescence ", exhibits many different forms. The more remarkable of these include:

(*a*) the diffused white light, which may give enough light to read by, or to illuminate clouds: it is called "white water" or "milky sea". The even glow is believed to be due to light from marine bacteria of microscopic size. It is especially prevalent in the Arabian Sea.

(*b*) systems of moving parallel bands.

(*c*) rapid light flashes on the sea surface.

(*d*) upwelling of subsurface water, breaking into vivid luminosity at the surface.

(*e*) the great systems of bands rotating round a central luminous "hub", known as "phosphorescent wheels".

The last-named is a well-authenticated, but in general, rather infrequent phenomenon, apparently confined to the Indian Ocean north of the equator and the China Sea region. One or more wheels may occur simultaneously, rotating in the same or opposite directions.

While progress has been made in classifying the varied forms of luminescence, it is not yet possible to explain how the majority of them are caused, either as regards the animal organisms involved or the nature of the stimulus producing light-emission. Many of the apparent movements of luminous areas, e.g. those of the "spokes" of the wheel, are much too rapid to be caused by the actual movements of organisms through the water. The most inexplicable phenomenon is that of luminescence in the air a few feet above the sea surface when there is no light in the water; this has been reported on several occasions.

Most of our knowledge of the varied forms of marine bioluminescence has been derived from the observations recorded in ships' logbooks and continued observations will be of the greatest value. When sufficient information is accumulated marine biologists will be able to work on the problems connected with the causation of the various phenomena. Observations should be as precise and detailed as possible and should include estimations of the direction, length and width of moving bands and of the size of what appear to be individual luminous organisms. A water-sample would be useful if it could be treated with a preservative. In the case of moving or rotating bands a careful estimate of the time interval between the passage of successive bands should be made. If a wheel is seen it is important to note if it has a visible centre and to estimate the distance of the centre from the ship, also to record the direction of rotation of the wheel. The wheel sometimes forms from parallel moving bands, or changes into these, and all changes of form of the luminescence should be recorded.

Interesting experiments on the possible nature of the stimulus may be made: (i) By trying the effect of flashing light on the sea, e.g. from an Aldis light; sometimes this initiates or increases luminescence, but not always. (ii) The effect of the switching on and off of radar. (iii) No observation of a wheel recorded by a sailing vessel has been found and it is therefore possible that it is produced by sound or vibration waves through the water from a modern vessel. It would be of great value to note the effect on the wheel, if any, produced by stopping the ship for a few minutes.

The luminiscence usually appears white, in the case of "white water", and various shades of blue and green, in other forms. Other colours have, however, been recorded. In all observations it is important to give the colour; in the case of the more striking moving forms, observers apparently find them so impressive in other ways that this important factor is almost invariably overlooked. There is thus very little information, for example, about the colour of the light of the wheel.

ABNORMAL COMPASS DEVIATIONS

A ship's magnetic compass may show appreciable deviation during the progress of a considerable or severe magnetic storm (*see* Magnetic Disturbances, page 84).

When an aurora of an active type is seen, especially in latitudes lower than those in which aurora is normally seen, the possibility of deflections of the magnetic compass should always be borne in mind. Mere brightness of aurora in a region when auroræ frequently occur is no criterion of the occurrence of a magnetic storm, e.g., a bright, colourless and relatively quiescent aurora seen in August or September in the western Atlantic on the Belle Isle route.

If a ship be struck by lightning, a sudden abnormal deviation of the compass may result. This error may be of a temporary or a permanent nature. Chronometers may also be affected.

Abnormal magnetic variation occurs locally in various regions. These variations, if experienced, should always be recorded, particularly if no mention of abnormal variation is made in the appropriate Admiralty Pilot or on Admiralty charts of the region.

Part IV Meteorological Work at Sea

CHAPTER 13

Organisation of Voluntary Meterological Work at Sea

Historical. M. F. Maury, an officer of the U.S. Navy, was the first man to realise the commercial and scientific value of weather information collected from ships. Due to his initiative, the first International Meteorological Conference was held at Brussels in 1853 to consider international co-operation and a uniform system of observation. Following this conference, the British Meteorological Office was established in 1854, under Admiral FitzRoy, as a Department of the Board of Trade.

On assuming office, FitzRoy issued a circular letter to the captains of merchant ships, inviting their co-operation in observing the weather at sea, and by 1855, 105 ships of the Mercantile Marine and 32 ships of the Royal Navy were equipped with instruments for this purpose.

Observations were originally recorded in a "Weather Register" whose general form was agreed upon at the Brussels Conference. In 1874, Captain Henry Toynbee, who had then been Marine Superintendent of the Meteorological Office for seven years, drew up a "Meteorological Log" based on the original Weather Register, but incorporating improvements. This was approved internationally and brought into use by the Meteorological Office for British ships. This Log has been the means of providing climatological atlases for all oceans, and has provided a basis for scientific investigation. It underwent very little change up to the end of the first world war, when the use of climatological logbooks was gradually discontinued in favour of observations made at synoptic hours and transmitted by radio. In 1953 the method of setting out the observations was entirely rearranged to produce the present day meteorological logbook which is a combined record of observations made and radio weather messages sent.

In 1861, FitzRoy instituted the system whereby certain ports were informed by telegraph of impending gales and were asked to hoist visual gale warning signals for the benefit of shipping. Except for a short break in 1867–68, this system has been maintained up to the present day.

The invention of wireless telegraphy opened up a new era in marine meteorology. As early as 1906, H.M. ships sent observations to the Meteorological Office by radio, while in 1909 a number of transatlantic liners commenced a similar service of reports by radio. Owing to the disruption caused by the 1914-18 war, it was not until 1921, as a result of arrangements made by the International Meteorological Organization, that radio weather messages from merchant ships were organised on a satisfactory scale, and an international code was introduced for the purpose. In this year a number of Selected Ships commenced not only recording their observations, but transmitting them by radio in a special code at the internationally agreed hours of 0000, 0600, 1200 and 1800 G.M.T. These messages were sent from all oceans through designated shore radio stations to various meteorological centres in accordance with an international scheme. The number of ships which continued to merely record their observations six times daily, at the end of the watch, was gradually reduced as the number recording and reporting at the synoptic hour was increased. To-day all observing ships report at the main synoptic hours and the data recorded in this manner can still be used for climatological purposes.

At a meeting of the International Convention for Safety of Life at Sea, held in 1929, provision was made (in Article 35) for the international encouragement of meteorological work at sea. This Convention was revised in 1948 and again in 1960 (*see* Chapter 14).

During the 1939–45 war, observations from merchant ships again ceased. In 1946, as a result of a conference held in London, it was agreed that all meteorological services of the British Commonwealth would co-operate in organizing meteorological work at sea. In 1947 the World Meteorological Organization introduced a new universal code for the sending of radio weather messages by voluntary observing ships of all nations.

Throughout the history of the Marine Division of the Meteorological Office, observations at sea have been made on a voluntary basis. The number of ships making observations at any time depends upon requirements but is limited by practical considerations. The captains and officers of ships undertaking this work are referred to as the "Corps of Voluntary Marine Observers", their ships comprising the "Voluntary Observing Fleet".

Marine meteorology and the British Commonwealth. The arrangements for this generally follow those organised and kept up to date by the World Meteorological Organization (*see* page 116).

Voluntary Observing Ships of all nations are divided into three main classes: "Selected Ships", "Supplementary Ships" and "Auxiliary Ships". The first-named observe wind, weather, pressure and barometric tendency, temperatures, clouds and waves. They are equipped with a marine mercurial barometer fitted with a Gold slide, a barograph, wet and dry bulb thermometers in a modified Stevenson screen, and a sea thermometer and bucket.

Supplementary Ships make the same observations with the exception of barometric tendency, sea temperature and waves, and are not therefore equipped with barograph, bucket or sea thermometer.

Auxiliary Ships make similar observations to those made by Supplementary Ships, except that they do not report cloud. They use their own instruments, which have been previously checked by a Port Meteorological Officer or Merchant Navy Agent, to observe pressure and temperature. They only record and report when in areas where shipping is normally sparse.

In addition to the above, many ships engaged in the coastwise and short-sea trades around the British Isles are supplied with a canvas bucket and thermometers. They radio sea-water temperatures to the British Meteorological Office. Several ships trading across the North Sea, and trawlers operating in distant waters, are asked to radio reports of wind and weather, not involving the use of instruments, at synoptic hours whenever possible.

Each Meteorological Service is responsible for recruiting its own ships. In addition, each Service may recruit ships of other registries which are normally based in their ports.

Representatives of Commonwealth and foreign Meteorological Services may, if they wish, visit any British Selected or Supplementary Ship to discuss local problems, supply forms, maps or local information, attend instruments, take extracts from log-books or express appreciation of services rendered. They may also, if the situation warrants (i.e., paucity of observations in their area), visit other British ships and request their co-operation as Auxiliary Ships, when in the area of the Service concerned. Commonwealth Services inform the British Meteorological Office of the names of Selected and Supplementary Ships recruited by them. The British Meteorological Office promulgates this information, together with the names of all ships recruited in Britain, in each July number of *The Marine Observer.*

The World Meteorological Organization. While the Commonwealth Conference provides for uniformity of practice in marine meteorology among the various Services of the British Commonwealth, the World Meteorological Organization performs a similar function internationally.

Meteorology is so international in character that co-operation is necessary between all countries of the world. This was recognised as long ago as 1872 when the International Meteorological Organization (I.M.O.) was formed, which has ever since acted as an advisory body to National Meteorological Services, its primary functions being the standardisation of codes and procedure, the improvement of meteorological practice, and the promotion of research. The Selected Ship Scheme and the issue of weather bulletins for shipping on a world-wide basis, are co-ordinated in this way.

The I.M.O. was a demi-official body, and in 1947 it was decided that, in view of the growing world importance of meteorology for commercial, economic and scientific purposes, it was necessary to change the status of this organisation. As a result an intergovernmental body, the World Meteorological Organization (W.M.O.), held its first congress in Paris during 1951, and took over the duties and responsibilities of the I.M.O. In this organisation technical problems are deliberated by a number of technical commissions, whose members are all experts in their particular sphere. All aspects of maritime meteorology are thus dealt with by the Maritime Commission, which advises the W.M.O. as necessary.

The instructions to observers issued by the Marine Division of the Meteorological Office conform to the advice of the W.M.O. Such changes of codes and procedure as occur from time to time are the result of international agreement. It is inevitable that progress in meteorology should bring changes of procedure. Such changes are kept to a minimum, and the basic aim is that every change should achieve greater world-wide application and uniformity, and hence simplicity.

All meteorological work done by ships' officers is entirely voluntary. Only by a voluntary scheme can the requisite high standard of observations be maintained. The benefit of this work to mariners lies in the fact that it forms the basis of the meteorological services for shipping outlined below.

Voluntary observing ships are requested to report their observations at the standard synoptic hours, viz. 0000, 0600, 1200, 1800 G.M.T., using the standard International Weather Code, either in full or abbreviated form. Information regarding this code and full instructions for coding are to be found in the *Ships' Code and Decode Book* (*M.O.* 509) or in the *Admiralty List of Radio Signals, Vol. III.*

Meteorological services for shipping. The first meteorological service for shipping was the issue of visual Gale Warnings, started in 1861. In 1924, a Radio Weather Shipping Bulletin was instituted; this contained weather reports from certain coastal stations and forecasts for areas around the British Isles. Since then, meteorological warnings of all kinds have been broadcast direct to shipping by radio on an international basis, under arrangements made by the World Meterological Organization.

Present day weather messages to shipping aim at providing not only forecasts but such basic information as will enable simple synoptic charts to be drawn on board ship. Such messages are generally known as "bulletins". They usually contain:

A brief statement of the meteorological situation.

Area forecasts.

Land Station reports.

Ships' reports.

Analyses in the International Analysis Code (I.A.C. (Fleet)).

An example of such a bulletin is the Atlantic Weather Bulletin, full particulars of which are given in *M.O.* 509, *Ships' Code and Decode Book* and in the *Admiralty List of Radio Signals, Vol. III.* Briefer bulletins for the benefit of coastal shipping are issued by G.P.O. coast stations on W/T and R/T and by the British Broadcasting Corporation (see *M.O. Leaflet No.* 3, obtainable free from the Meteorological Office).

The experience of generations of observers is available in the vast number of observations from the sea that have been collected since 1854. The task of the Marine Division of the Meteorological Office has been not only to collect these observations, but to classify and analyse them scientifically and to prepare climatological and other material based upon them, for the information of mariners, and of the world in general. The observations, being (except for those from weather ships) the only ones available from the oceans, are put to many other useful purposes, and are of great value for research into meteorological problems. Most of the analysis is carried out with the aid of punched cards, and the final results, after careful scrutiny by climatological experts, are issued in the form of atlases for the different oceans. The atlases contain mean values for each month of the various meteorological elements observed at sea, and enable the user to assess average conditions at any time in almost any part of the world. The following atlases are available for free issue to ships of the Voluntary Observing Fleet and may be inspected at any Port Meteorological Office.

Quarterly Surface Current Charts of the Atlantic.
Atlas of Sea Surface Currents, Indian Ocean.
Atlas of Sea Surface Currents, South Pacific.
Quarterly Surface Current Charts of the Eastern North Pacific.

Quarterly Surface Current Charts of the Western North Pacific.

Monthly Meteorological Charts of the Atlantic.

Monthly Meteorological Charts of the Eastern Pacific.

Monthly Meteorological Charts and Current Chart of the Greenland and Barents Seas.

Monthly Meteorological Charts of the Indian Ocean.

Monthly Meteorological Charts of the Western Pacific.

Monthly Sea Surface Temperatures and Surface Current Circulation of Japan Sea and Adjacent Waters.

Monthly Ice Charts of the Arctic Seas.

Monthly Ice Charts of the Western North Atlantic.

Guidance for conduct of the work at sea. Direct contact between the Marine Division of the Meteorological Office and ships' captains and observers is maintained through Port Meteorological Officers at Cardiff, Glasgow, Liverpool, London and Southampton, and Merchant Navy Agents at Hull, Leith and Newcastle.

Indirect contact with the Observing Fleet is maintained through the medium of *The Marine Observer*, a quarterly publication which contains articles on meteorology, oceanography, ice, etc. of interest to seamen. A large section in each number is devoted to observations of phenomena of a meteorological or general scientific nature, mostly extracted from the meteorological logbooks of ships of the British Commonwealth.

Instruments are supplied to ships either by Port Meteorological Officers or by Agents and are delivered by hand. When it is desired to return instruments lent by the Meteorological Office, the appropriate Port Meteorological Officer or Agent should be advised. When this is not possible, as for example at certain small ports, application should be made to the Marine Superintendent of the Meteorological Office for instructions. Similar remarks apply to the return of damaged instruments for repair or replacement.

Any accident to an instrument, even though no apparent damage is done, should be reported to the Port Meteorological Officer or Agent. This is necessary because the constants of the instrument may 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 any attempt be made to repair the instrument on board the ship.

CHAPTER 14

International Convention for the Safety of Life at Sea, 1960*

SAFETY OF NAVIGATION

Regulation 2

Danger Messages

(*a*) The master of every ship which meets with dangerous ice, a dangerous derelict, or any other direct danger to navigation, or a tropical storm, or encounters sub-freezing air temperatures associated with gale force winds causing severe ice accretion on superstructures, or winds of force 10 or above on the Beaufort scale for which no storm warning has been received is bound to communicate the information by all the means at his disposal to ships in the vicinity, and also to the competent authorities at the first point on the coast with which he can communicate. 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. It should be broadcast to all ships in the vicinity and sent to the first point on the coast to which communication can be made, with a request that it be transmitted to the appropriate authorities.

(*b*) Each Contracting Government will take all steps necessary to ensure that when intelligence of any of the dangers specified in paragraph (*a*) is received, it will be promptly brought to the knowledge of those concerned and communicated to other interested Governments.

(*c*) The transmission of messages respecting the dangers specified is free of cost to the ships concerned.

(*d*) All radio messages issued under paragraph (*a*) of this Regulation shall be preceded by the Safety Signal, using the procedure as prescribed by the I.T.U. Radio Regulations.

Regulation 3

Information required in Danger Messages

The following information is required in danger messages:

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

(i) the kind of ice, derelict or danger observed;

(ii) the position of the ice, derelict or danger when last observed;

(iii) the time and date (Greenwich Mean Time) when danger last observed.

*See *International Conference on Safety of Life at Sea*, 1960, H.M.S.O., London.

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

(i) 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 is developing or exists in his neighbourhood.

(ii) Time, date (Greenwich Mean Time) and position of ship when the observation was taken.

(iii) As much of the following information as is practicable should be included in the message:
—barometric pressure, preferably corrected (stating, millibars, inches, or millimetres, and whether corrected or uncorrected);
—barometric tendency (the change in barometric pressure during the past three hours);
—true wind direction;
—wind force (Beaufort scale);
—state of the sea (smooth, moderate, rough, high);
—swell (slight, moderate, heavy) and the true direction from which it comes. Period or length of swell (short, average, long) would also be of value;
—true course and speed of ship.

(*c*) Subsequent Observations. When a master has reported a tropical or other dangerous storm, it is desirable, but not obligatory, that further observations be made and transmitted hourly, if practicable, but in any case at intervals of not more than three hours, so long as the ship remains under the influence of the storm.

(*d*) Winds of force 10 or above on the Beaufort scale for which no storm warning has been received.

This is intended to deal with storms other than the tropical storms referred to in paragraph (*b*); when such a storm is encountered, the message should contain similar information to that listed under paragraph (*b*) but excluding the details concerning sea and swell.

(*e*) Sub-freezing air temperatures associated with gale force winds causing severe ice accretion on superstructures.

(i) Time and Date (Greenwich Mean Time).

(ii) Air temperature.

(iii) Sea temperature (if practicable).

(iv) Wind force and direction.

Examples

Ice

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

Derelicts

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

Danger to Navigation

TTT Navigation. Alpha lightship not on station. 1800 GMT. January 3.

Tropical Storm

TTT Storm. 0030 GMT. August 18. 2204 N., 11354 E. Barometer corrected 994 millibars, tendency down 6 millibars. Wind NW., force 9, heavy squalls. Heavy easterly swell. Course 067, 5 knots.

TTT Storm. Appearances indicate approach of hurricane. 1300 GMT. September 14. 2200 N., 7236 W. Barometer corrected 29.64 inches, tendency down .015 inches. Wind NE., force 8, frequent rain squalls. Course 035, 9 knots.

TTT Storm. Conditions indicate intense cyclone has formed. 0200 GMT. May 4. 1620 N., 9203 E. Barometer uncorrected 753 millimetres, tendency down 5 millimetres. Wind S. by W., force 5. Course 300, 8 knots.

TTT Storm. Typhoon to southeast. 0300 GMT. June 12. 1812 N., 12605 E. Barometer falling rapidly. Wind increasing from N.

TTT Storm. Wind force 11, no storm warning received. 0300 GMT. May 4. 4830N., 30W. Barometer corrected 983 millibars, tendency down 4 millibars. Wind SW., force 11 veering. Course 260, 6 knots.

Icing

TTT experiencing severe icing. 1400 GMT. March 2. 69 N., 10 W. Air temperature 18 (F.). Sea temperature 29 (F.). Wind NE., force 8.

Regulation 4

Meteorological Services

(*a*) 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. Administrations shall encourage the use of instruments of a high degree of accuracy, and shall facilitate the checking of such instruments upon request.

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

(i) To warn ships of gales, storms and tropical storms, both by the issue of radio messages and by the display of appropriate signals at coastal points.

(ii) To issue daily, by radio, weather bulletins suitable for shipping, containing data of existing weather, waves and ice, forecasts, and when practicable, sufficient additional information to enable simple weather charts to be prepared at sea and also to encourage the transmission of suitable facsimile weather charts.

(iii) To prepare and issue such publications as may be necessary for the efficient conduct of meteorological work at sea and to arrange, if practicable, for the publication and making available of daily weather charts for the information of departing ships.

(iv) To arrange for selected ships to be equipped with tested instruments (such as a barometer, a barograph, a psychrometer, and suitable apparatus for measuring sea temperature) for use in this service, and to take meteorological observations at main standard times for surface synoptic observations (at least four times daily, whenever circumstances permit) and to encourage other ships to take observations in a modified form, particularly when in areas where shipping is sparse; these ships to transmit their observations by radio for the benefit of the various official meteorological services, repeating the information for the benefit of ships in the vicinity. When in the vicinity of a tropical storm, or of a suspected tropical storm, ships should be encouraged to take and transmit their observations at more frequent intervals whenever practicable, bearing in mind navigational preoccupations of ships' officers during storm conditions.

(v) To arrange for the reception and transmission by coast radio stations of weather messages from and to ships. Ships which are unable to communicate direct with shore shall be encouraged to relay their weather messages through ocean weather ships or through other ships which are in contact with shore.

(vi) To encourage all masters to inform ships in the vicinity and also shore stations whenever they experience a wind speed of 50 knots or more (force 10 on the Beaufort scale).

(vii) To endeavour to obtain a uniform procedure in regard to the international meteorological services already specified, and, as far as is practicable, to conform to the Technical Regulations and recommendations made by the World Meteorological Organization, to which the Contracting Governments may refer for study and advice any meteorological question which may arise in carrying out the present Convention.

(*c*) The information provided for in this Regulation shall be furnished in form for transmission and transmitted in the order of priority prescribed by the Radio Regulations, and during transmission "to all stations" of meteorological information, forecasts and warnings, all ship stations must conform to the provisions of the Radio Regulations.

(*d*) 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 Contracting Governments concerned.

TABLE I

TEMPERATURE CORRECTION OF THE M.O. KEW-PATTERN BAROMETER MK. I
(Inch Scale)

To be used with barometers having National Physical Laboratory certificate dated ON OR BEFORE 31st DECEMBER 1954.

These corrections are to be **subtracted** *from the barometer readings to reduce them to standard temperature conditions.*

Attached Thermometer (°F.)	Barometer Reading (Inches)										
	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0
40	·024	.024	·025	·026	·026	·027	·027	·028	·028	·029	·029
41	·026	·027	·028	·028	·029	·029	·030	·030	·031	·031	·032
42	·029	·030	·030	·031	·031	·032	·033	.033	·034	·034	·035
43	·031	·032	·033	·033	·034	·035	·035	·036	·037	·037	·038
44	·034	·035	·035	·036	·037	·037	·038	·039	·039	·040	·041
45	·036	·037	·038	·039	·039	·040	·041	·042	·042	·043	·044
46	·039	·040	·040	·041	·042	·043	·044	·044	·045	·046	·047
47	·041	·042	·043	·044	·045	·046	·046	·047	·048	·049	·050
48	·044	·045	·046	·046	·047	·048	·049	·050	·051	·052	·053
49	·046	·047	·048	·049	·050	·051	·052	·053	·054	·055	·056
50	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·058
51	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061
52	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	·064
53	·056	·057	·058	·060	·061	·062	·063	·064	·065	·066	·067
54	·059	·060	·061	·062	·063	·064	·066	·067	·068	·069	·070
55	·061	·062	·064	·065	·066	·067	·068	·070	·071	·072	·073
56	·064	·065	·066	·067	·069	·071	·070	·072	·074	·075	·076
57	·066	·067	·069	·070	·071	·073	·074	·075	·076	·078	·079
58	·069	·070	·071	·073	·074	·075	·077	·078	·079	·081	·082
59	·071	·072	·074	·075	·077	·078	·079	·081	·082	·083	·085
60	·074	·075	·076	·078	·079	·081	·082	·084	·085	·086	·088
61	·076	·078	·079	·080	·082	·083	·085	·086	·088	·089	·091
62	·079	·080	·082	·083	·085	·086	·088	·089	·091	·092	·094
63	·081	·083	·084	·086	·087	·089	·090	·092	·093	·095	·097
64	·083	·085	·087	·088	·090	·091	·093	·095	·096	·098	·099
65	·086	·088	·089	·091	·093	·094	·096	·097	·099	·101	·102
66	·088	·090	·092	·094	·095	·097	·099	·100	·102	·104	·105
67	·091	·093	·094	·096	·098	·100	·101	·103	·105	·107	·108
68	·093	·095	·097	·099	·101	·102	·104	·106	·108	·109	·111
69	·096	·098	·100	·101	·103	·105	·107	·109	·110	·112	·114
70	·098	·100	·102	·104	·106	·108	·110	·111	·113	·115	·117
71	·101	·103	·105	·107	·108	·110	·112	·114	·116	·118	·120
72	·103	·105	·107	·109	·111	·113	·115	·117	·119	·121	·123
73	·106	·108	·110	·112	·114	·116	·118	·120	·122	·124	·126
74	·108	·110	·112	·114	·116	·118	·121	·123	·125	·127	·129
75	·111	·113	·115	·117	·119	·121	·123	·125	·127	·130	·132
76	·113	·115	·117	·120	·122	·124	·126	·128	·130	·132	·135
77	·116	·118	·120	·122	·124	·127	·129	·131	·133	·135	·137
78	·118	·120	·123	·125	·127	·129	·131	·134	·136	·138	·140
79	·121	·123	·125	·127	·130	·132	·134	·136	·139	·141	·143
80	·123	·125	·128	·130	·132	·135	·137	·139	·142	·144	·146
81	·125	·128	·130	·133	·135	·137	·140	·142	·144	·147	·149
82	·128	·130	·133	·135	·138	·140	·142	·145	·147	·150	·152
83	·130	·133	·135	·138	·140	·143	·145	·148	·150	·153	·155
84	·133	·135	·138	·140	·143	·145	·148	·150	·153	·155	·158
85	·135	·138	·140	·143	·146	·148	·151	·153	·156	·158	·161
86	·138	·140	·143	·146	·148	·151	·153	·156	·159	·161	·164
87	·140	·143	·146	·148	·151	·153	·156	·159	·161	·164	·167
88	·143	·145	·148	·151	·153	·156	·159	·162	·164	·167	·170
89	·145	·148	·151	·153	·156	·159	·162	·164	·167	·170	·172
90	·148	·150	·153	·156	·159	·162	·164	·167	·170	·173	·175
91	·150	·153	·156	·159	·161	·164	·167	·170	·173	·175	·178
92	·153	·155	·158	·161	·164	·167	·170	·173	·175	·178	·181
93	·155	·158	·161	·164	·167	·170	·172	·175	·178	·181	·184
94	·158	·160	·163	·166	·169	·172	·175	·178	·181	·184	·187
95	·160	·163	·166	·169	·172	·175	·178	·181	·184	·187	·190
96	·162	·165	·169	·172	·175	·178	·181	·184	·187	·190	·193
97	·165	·168	·171	·174	·177	·180	·183	·186	·190	·193	·196
98	·167	·170	·174	·177	·180	·183	·186	·189	·192	·196	·199
99	·170	·173	·176	·179	·183	·186	·189	·192	·195	·198	·202
100	·172	·175	·179	·182	·185	·188	·192	·195	·198	·201	·204

TABLE II

TEMPERATURE CORRECTION OF THE M.O. KEW-PATTERN BAROMETER MK. 2

(Inch Scale)

To be used with barometers having National Physical Laboratory certificate dated ON OR AFTER 1st JANUARY, 1955.

The following corrections are to be subtractracted *from the barometer readings to reduce them to standard temperature conditions.*

Attached Thermometer (°F.)	Barometer Reading (Inches)										
	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0
40	·020	·020	·021	·021	·021	·022	·022	·022	·023	·023	·024
41	·022	·023	·023	·024	·024	·024	·025	·025	·026	·026	·026
42	·025	·025	·026	·026	·027	·027	·028	·028	·029	·029	·029
43	·027	·028	·028	·029	·029	·030	·030	·031	·031	·032	·032
44	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035	·035
45	·032	·033	·034	·034	·035	·035	·036	·036	·037	·038	·038
46	·035	·035	·036	·037	·037	·038	·039	·039	·040	·041	·041
47	·037	·038	·039	·039	·040	·041	·041	·042	·043	·043	·044
48	·040	·041	·041	·042	·043	·043	·044	·045	·046	·046	·047
49	·042	·043	·044	·045	·045	·046	·047	·048	·048	·049	·050
50	·045	·046	·046	·047	·048	·049	·050	·050	·051	·052	·053
51	·047	·048	·049	·050	·051	·051	·052	·053	·054	·055	·056
52	·050	·051	·051	·052	·053	·054	·055	·056	·057	·058	·059
53	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062
54	·055	·056	·057	·058	·059	·060	·061	·062	·063	·064	·065
55	·057	·058	·059	·060	·061	·062	·063	·064	·065	·066	·068
56	·060	·061	·062	·063	·064	·065	·066	·067	·068	·069	·071
57	·062	·063	·064	·065	·067	·068	·069	·070	·071	·072	·074
58	·064	·066	·067	·068	·069	·070	·072	·073	·074	·075	·077
59	·067	·068	·069	·071	·072	·073	·074	·076	·077	·078	·080
60	·069	·071	·072	·073	·075	·076	·077	·078	·080	·081	·083
61	·072	·073	·075	·076	·077	·078	·080	·081	·082	·084	·086
62	·074	·076	·077	·078	·080	·081	·083	·084	·085	·087	·089
63	·077	·078	·080	·081	·082	·084	·085	·087	·088	·089	·092
64	·079	·081	·082	·084	·085	·087	·088	·090	·091	·092	·094
65	·082	·083	·085	·086	·088	·089	·091	·092	·094	·095	·097
66	·084	·086	·087	·089	·090	·092	·094	·095	·097	·098	·100
67	·087	·088	·090	·091	·093	·095	·096	·098	·099	·101	·103
68	·089	·091	·092	·094	·096	·097	·099	·101	·102	·104	·106
69	·092	·093	·095	·097	·098	·100	·102	·103	·105	·107	·108
70	·094	·096	·098	·099	·101	·103	·104	·106	·108	·110	·111
71	·097	·098	·100	·102	·104	·105	·107	·109	·111	·112	·114
72	·099	·101	·103	·105	·106	·108	·110	·112	·114	·115	·117
73	·102	·103	·105	·107	·109	·111	·113	·115	·116	·118	·120
74	·104	·106	·108	·110	·112	·114	·115	117	·119	·121	·123
75	·106	·108	·110	·112	·114	·116	·118	·120	·122	·124	·126
76	·109	·111	·113	·115	·117	·119	·121	·123	·125	·127	·129
77	·111	·113	·115	·118	·120	·122	·124	·126	·128	·130	·132
78	·114	·116	·118	·120	·122	·124	·126	·128	·131	·133	·135
79	·116	·118	·121	·123	·125	·127	·129	·131	·133	·135	·138
80	·119	·121	·123	·125	·127	·130	·132	·134	·136	·138	·141
81	·121	·123	·126	·128	·130	·132	·135	·137	·139	·141	·143
82	·124	·126	·128	·131	·133	·135	·137	·140	·142	·144	·146
83	·126	·129	·131	·133	·135	·138	·140	·142	·145	·147	·149
84	·129	·131	·133	·136	·138	·140	·143	·145	·147	·150	·152
85	·131	·134	·136	·138	·141	·143	·145	·148	·150	·153	·155
86	·134	·136	·138	·141	·143	·146	·148	·151	·153	·156	·158
87	·136	·139	·141	·144	·146	·148	·151	·153	·156	·158	·161
88	·139	·141	·144	·146	·149	·151	·154	·156	·159	·161	·164
89	·141	·144	·146	·149	·151	·154	·156	·159	·162	·164	·167
90	·143	·146	·149	·151	·154	·157	·159	·162	·164	·167	·170

TABLE III

CORRECTION OF M.O. INCH BAROMETERS, MK. 1, TO STANDARD GRAVITY IN LATITUDE 45°

To be used with barometers having National Physical Laboratory certificate dated ON OR BEFORE 31st DECEMBER, 1954.

These corrections are to be **subtracted** *for latitudes 0°–44° and* **added** *for latitudes 46°–90°.*

Lat. N. or S. (subtract correction)	Correction At 29 in.	Correction At 31 in.	Lat. N. or S. (add correction)
°	in.	in.	°
22	·055	·058	68
21	·056	·060	69
20	·058	·062	70
19	·060	·064	71
18	·062	·066	72
17	·063	·067	73
16	·065	·069	74
15	·066	·070	75
14	·067	·072	76
13	·068	·073	77
12	.070	·074	78
11	·071	·075	79
10	·072	·076	80
9	·072	·077	81
8	·073	·078	82
7	·074	·079	83
6	·075	.080	84
5	·075	·080	85
4	·075	·080	86
3	·075	·080	87
2	·075	·080	88
1	·075	·080	89
0	·076	·081	90

Lat. N. or S. (subtract correction)	Correction At 29 in.	Correction At 31 in.	Lat. N or S. (add correction)
°	in.	in.	°
45	·000	·000	45
44	·002	·002	46
43	·005	·005	47
42	·008	·008	48
41	·010	·011	49
40	·013	·014	50
39	·015	·016	51
38	·018	·019	52
37	·021	·022	53
36	·023	·025	54
35	·026	·027	55
34	·028	·030	56
33	·031	·033	57
32	·033	·035	58
31	·036	·038	59
30	·038	·040	60
29	·040	·043	61
28	·042	·045	62
27	·045	·048	63
26	·047	·050	64
25	·049	·052	65
24	·051	·054	66
23	·053	·056	67

TABLE IV

CORRECTION OF M.O. INCH BAROMETERS, MK. 2, TO STANDARD GRAVITY, i.e. 980·665 cm./sec²

To be used with barometers having National Physical Laboratory certificate dated ON OR AFTER 1st JANUARY, 1955.

Lat. N. or S.	Correction At 29 in.	Correction At 31 in.	Lat. N. or S.	Correction At 29 in.	Correction At 31 in.	Lat. N. or S.	Correction At 29 in.	Correction At 31 in.	Lat. N. or S.	Correction At 29 in.	Correction At 31 in.
°	in.	in.	°	in.	in.	°	in.	in.	°	in.	in.
0	—·078	—·083	25	—·051	—·054	46	+·001	+·001	67	+·052	+·055
			26	·048	·052	47	·004	·004	68	·054	·057
5	—·077	—·082	27	·046	·050	48	·007	·007	69	·055	·059
6	·076	·081	28	·044	·047	49	·009	·010	70	·057	·061
7	·075	·081	29	·042	·045	50	·012	·013	71	·059	·063
8	·075	·080	30	·040	·042	51	·014	·015	72	·061	·065
9	·074	·079	31	·037	·040	52	·017	·018	73	·062	·066
10	·073	·078	32	·035	·037	53	·020	·021	74	·064	·068
11	·072	·077	33	·033	·035	54	·022	·024	75	·065	·069
12	·071	·076	34	·030	·032	55	·025	·026	76	·066	·071
13	·070	·075	35	·028	·029	56	·027	·029	77	·067	·072
14	·069	·074	36	·025	·027	57	·030	·032	78	·069	·073
15	·068	·072	37	·023	·024	58	·032	·034	79	·070	·074
16	·066	·071	38	·020	·021	59	·035	·037	80	·071	·075
17	·065	·069	39	·017	·019	60	·037	·039	81	·071	·076
18	·063	·068	40	·015	·016	61	·039	·042	82	·072	·077
19	·062	·066	41	·012	·013	62	·041	·044	83	·073	·078
20	·060	·064	42	·009	·010	63	·044	·047	84	·074	·079
21	·058	·062	43	·007	·007	64	·046	·049	85	+·074	+·079
22	·056	·060	44	·004	·004	65	·048	·051			
23	·055	·058	45	—·001	—·002	66	+·050	+·053	90	+·075	+·080
24	—·053	—·056									

TABLE V

CORRECTION OF INCH BAROMETERS TO MEAN SEA LEVEL

These corrections are to be **added** *to the barometer readings.*

Height in feet	Temperature of Air (Dry Bulb in Screen), °F. 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	·117	·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

TABLE VI

TEMPERATURE CORRECTION OF THE M.O. KEW-PATTERN BAROMETER MK. 1

(Millibar Scale)

To be used with barometers having National Physical Laboratory certificate dated ON OR BEFORE 31st DECEMBER, 1954.

These corrections are to be **subtracted** *from the barometer readings when the attached thermometer is ABOVE 285°A., and* **added** *when it is BELOW 285°A., to reduce the barometer readings to 285°A.*

Attached thermometer (add correction)	Barometer readings (mb.) 880	900	920	940	960	980	1000	1020	1040	1060	Attached thermometer (subtract correction)
284°A	0·1	0·1	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	286°A
283	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·4	0·4	287
282	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	288
281	0·6	0·6	0·6	0·6	0·7	0·7	0·7	0·7	0·7	0·7	289
280	0·8	0·8	0·8	0·8	0·8	0·8	0·9	0·9	0·9	0·9	290
279	0·9	0·9	0·9	1·0	1·0	1·0	1·0	1·1	1·1	1·1	291
278	1·1	1·1	1·1	1·1	1·1	1·2	1·2	1·2	1·2	1·3	292
277	1·2	1·2	1·3	1·3	1·3	1·3	1·4	1·4	1·4	1·5	293
276	1·4	1·4	1·4	1·5	1·5	1·5	1·5	1·6	1·6	1·6	294
275	1·5	1·5	1·6	1·6	1·6	1·7	1·7	1·7	1·8	1·8	295
274	1·7	1·7	1·7	1·8	1·8	1·9	1·9	1·9	1·9	2·0	296
273	1·8	1·9	1·9	1·9	2·0	2·0	2·1	2·1	2·1	2·2	297
272	2·0	2·0	2·1	2·1	2·1	2·2	2·2	2·3	2·3	2·3	298
271	2·1	2·2	2·2	2·3	2·3	2·3	2·4	2·4	2·5	2·5	299
270	2·3	2·3	2·4	2·4	2·5	2·5	2·6	2·6	2·7	2·7	300
269	2·4	2·5	2·5	2·6	2·6	2·7	2·7	2·8	2·8	2·9	301
268	2·6	2·6	2·7	2·7	2·8	2·9	2·9	3·0	3·0	3·1	302
267	2·7	2·8	2·8	2·9	3·0	3·0	3·1	3·1	3·2	3·3	303
266	2·9	2·9	3·0	3·1	3·1	3·2	3·3	3·3	3·4	3·4	304
265	3·0	3·1	3·2	3·2	3·3	3·3	3·4	3·5	3·5	3·6	305
264	3·2	3·3	3·3	3·4	3·5	3·5	3·6	3·7	3·7	3·8	306
263	3·3	3·4	3·5	3·5	3·6	3·7	3·8	3·8	3·9	4·0	307
262	3·5	3·6	3·6	3·7	3·8	3·9	3·9	4·0	4·1	4·2	308
261	3·6	3·7	3·8	3·9	3·9	4·0	4·1	4·2	4·3	4·3	309
260	3·8	3·9	3·9	4·0	4·1	4·2	4·3	4·4	4·4	4·5	310
259	3·9	4·0	4·1	4·2	4·3	4·4	4·5	4·5	4·6	4·7	311
258	4·1	4·2	4·3	4·3	4·4	4·5	4·6	4·7	4·8	4·9	312
257	4·2	4·3	4·4	4·5	4·6	4·7	4·8	4·9	5·0	5·1	313
256	4·4	4·5	4·6	4·7	4·8	4·9	5·0	5·1	5·1	5·2	314
255	4·5	4·6	4·7	4·8	4·9	5·0	5·1	5·2	5·3	5·4	315

TABLE VII

TEMPERATURE CORRECTION OF THE M.O. KEW-PATTERN BAROMETER MK. 2

(Millibar Scale)

To be used with barometers having National Physical Laboratory certificate dated ON OR AFTER 1st JANUARY, 1955.

These corrections are to be **subtracted** *from the barometer readings to reduce them to 0°C.*

Attached Thermometer		Barometer Readings (Millibars)						
		920	940	960	980	1000	1020	1040
°A.	°C.							
273	0	0·00	0·00	0·00	0·00	0·00	0·00	0·00
274	1	0·16	0·16	0·16	0·17	0·17	0·17	0·18
275	2	0·32	0·32	0·33	0·34	0·34	0·35	0·36
276	3	0·48	0·48	0·49	0·50	0·51	0·52	0·53
277	4	0·63	0·64	0·65	0·67	0·68	0·70	0·71
278	5	0·79	0·80	0·82	0·84	0·85	0·87	0·89
279	6	0·95	0·97	0·99	1·01	1·03	1·05	1·07
280	7	1·11	1·13	1·15	1·18	1·20	1·22	1·25
281	8	1·26	1·29	1·32	1·35	1·38	1·40	1·43
282	9	1·42	1·45	1·48	1·52	1·55	1·57	1·60
283	10	1·58	1·61	1·64	1·68	1·71	1·74	1·77
284	11	1·74	1·77	1·81	1·84	1·88	1·91	1·95
285	12	1·89	1·93	1·97	2·01	2·05	2·09	2·13
286	13	2·05	2·09	2·13	2·18	2·22	2·26	2·30
287	14	2·21	2·25	2·30	2·34	2·39	2·44	2·48
288	15	2·36	2·41	2·46	2·51	2·56	2·61	2·66
289	16	2·52	2·57	2·63	2·68	2·73	2·78	2·83
290	17	2·68	2·73	2·79	2·84	2·90	2·96	3·01
291	18	2·84	2·89	2·95	3·01	3·07	3·13	3·19
292	19	2·99	3·05	3·12	3·18	3·24	3·30	3·36
293	20	3·15	3·22	3·28	3·35	3·41	3·48	3·54
294	21	3·31	3·38	3·44	3·51	3·58	3·65	3·72
295	22	3·46	3·54	3·61	3·68	3·75	3·82	3·89
296	23	3·62	3·70	3·77	3·84	3·92	3·99	4·07
297	24	3·78	3·86	3·93	4·01	4·09	4·17	4·25
298	25	3·93	4·02	4·10	4·18	4·26	4·34	4·42
299	26	4·09	4·18	4·26	4·34	4·43	4·51	4·60
300	27	4·25	4·34	4·42	4·51	4·60	4·69	4·77
301	28	4·40	4·49	4·59	4.68	4·77	4·86	4·95
302	29	4·56	4·65	4·75	4·84	4·94	5·03	5·13
303	30	4·72	4·81	4·91	5·01	5·11	5·20	5·30
304	31	4·88	4·97	5·07	5·18	5·28	5·37	5·47
305	32	5·03	5·13	5·24	5·34	5·44	5·55	5·65
306	33	5·19	5·29	5·40	5·51	5·61	5.72	5·82
307	34	5·34	5·45	5·56	5·67	5·78	5·89	6·00
308	35	5·50	5·61	5·72	5·84	5·95	6.06	6·17
309	36	5·65	5·76	5·88	6·00	6·11	6·23	6·35
310	37	5·81	5·92	6·04	6·17	6·28	6·40	6·53
311	38	5·97	6·09	6·21	6·34	6·46	6·58	6·71
312	39	6·13	6·25	6·37	6·51	6·63	6·75	6·88
313	40	6·28	6·41	6·54	6·67	6·80	6·93	7·06

TABLE VIII

CORRECTION OF M.O. MILLIBAR BAROMETERS, MK. 1, TO STANDARD GRAVITY IN LATITUDE 45°

To be used with barometers having National Physical Laboratory certificate dated ON OR BEFORE 31st DECEMBER, 1954.

These corrections are to be **subtracted** *for latitudes 0°–44° and* **added** *for latitudes 46°–90°.*

Lat. N. or S. (subtract correction)	Correction At 980 mb.	Correction At 1040 mb.	Lat. N. or S. (add correction)
°	mb.	mb.	°
24	1·73	1·83	66
23	1·79	1·91	67
22	1·86	1·97	68
21	1·92	2·04	69
20	1·98	2·10	70
19	2·03	2·16	71
18	2·09	2·22	72
17	2·14	2·28	73
16	2·19	2·32	74
15	2·23	2·38	75
14	2·29	2·42	76
13	2·32	2·46	77
12	2·36	2·50	78
11	2·39	2·54	79
10	2·42	2·57	80
9	2·46	2·61	81
8	2·48	2·63	82
7	2·50	2·66	83
6	2·53	2·68	84
5	2·54	2·70	85
0	2·59	2·75	90

Lat. N. or S. (subtract correction)	Correction At 980 mb.	Correction At 1040 mb.	Lat. N. or S. (add correction)
°	mb.	mb.	°
45	0·00	0·00	45
44	0·09	0·09	46
43	0·18	0·19	47
42	0·27	0·29	48
41	0·36	0·38	49
40	0·45	0·47	50
39	0·54	0·57	51
38	0·63	0·67	52
37	0·71	0·75	53
36	0·80	0·85	54
35	0·89	0·94	55
34	0·97	1·03	56
33	1·05	1·11	57
32	1·13	1·20	58
31	1·21	1·29	59
30	1·29	1·37	60
29	1·37	1·45	61
28	1·44	1·53	62
27	1·52	1·61	63
26	1·59	1·69	64
25	1·66	1·76	65

TABLE IX

CORRECTION OF M.O. MILLIBAR BAROMETERS, MK. 2, TO STANDARD GRAVITY, i.e., 980.665 cm./sec.²

To be used with barometers having National Physical Laboratory certificate dated ON OR AFTER 1st JANUARY, 1955.

Lat. N. or S.	Correction At 980 mb.	Correction At 1040 mb.
°	mb.	mb.
0	—2·63	—2·79
5	—2·59	—2·75
6	2·57	2·73
7	2·55	2·71
8	2·53	2·68
9	2·50	2·66
10	2·47	2·62
11	2·44	2·59
12	2·41	2·55
13	2·37	2·51
14	2·33	2·47
15	2·28	2·42
16	2·24	2·37
17	2·19	2·32
18	2·14	2·27
19	2·08	2·21
20	2·03	2·15
21	1·97	2·09
22	1·91	2·02
23	1·84	1·95
24	—1·78	—1·88

Lat. N. or S.	Correction At 980 mb.	Correction At 1040 mb.
°	mb.	mb.
25	—1·71	—1·81
26	1·64	1·74
27	1·57	1·66
28	1·49	1·58
29	1·42	1·50
30	1·34	1·42
31	1·26	1·34
32	1·18	1·25
33	1·10	1·17
34	1·02	1·08
35	0·93	0·99
36	0·85	0·90
37	0·76	0·81
38	0·67	0·72
39	0·59	0·62
40	0·50	0·53
41	0·41	0·43
42	0·32	0·34
43	0·23	0·24
44	0·14	0·15
45	—0·05	—0·05

Lat. N. or S.	Correction At 980 mb.	Correction At 1040 mb.
°	mb.	mb.
46	+0·04	+0·04
47	0·13	0·14
48	0·22	0·23
49	0·31	0·33
50	0·40	0·42
51	0·49	0·52
52	0·58	0·61
53	0.66	0.70
54	0·75	0·80
55	0·84	0·89
56	0·92	0·98
57	1·00	1·06
58	1·09	1·15
59	1·17	1·24
60	1·24	1·32
61	1·32	1·40
62	1·40	1·48
63	1·47	1·56
64	1·54	1·64
65	1·61	1·71
66	+1·68	+1·79

Lat. N. or S.	Correction At 980 mb.	Correction At 1040 mb.
°	mb.	mb.
67	+1·75	+1·86
68	1·81	1·92
69	1·87	1·99
70	1·93	2·05
71	1·99	2·11
72	2·05	2·17
73	2·10	2·23
74	2·15	2·28
75	2·19	2·33
76	2·24	2·37
77	2·28	2·42
78	2·32	2·46
79	2·35	2·50
80	2·38	2·53
81	2·41	2·56
82	2·44	2·59
83	2·46	2·62
84	2·48	2·64
85	+2·50	+2·66
90	+2·54	+2·70

TABLE X

CORRECTION OF MILLIBAR BAROMETERS TO MEAN SEA LEVEL

These corrections are to be added *to the barometer readings.*

Height in feet	Air Temperature (dry bulb in screen), °F.										Height in feet
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	
5	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	5
10	0·4	0·4	0·4	0·4	0·4	0·4	0·4	0·4	0·3	0·3	10
15	0·6	0·6	0·6	0·6	0·6	0·5	0·5	0·5	0·5	0·5	15
20	0·8	0·8	0·8	0·8	0·8	0·7	0·7	0·7	0·7	0·7	20
25	1·0	1·0	1·0	0·9	0·9	0·9	0·9	0·9	0·9	0·9	25
30	1·2	1·2	1·1	1·1	1·1	1·1	1·1	1·1	1·0	1·0	30
35	1·4	1·4	1·4	1·3	1·3	1·3	1·3	1·3	1·2	1·2	35
40	1·6	1·6	1·6	1·5	1·5	1·4	1·4	1·4	1·4	1·4	40
45	1·8	1·8	1·8	1·7	1·7	1·6	1·6	1·6	1·5	1·5	45
50	2·0	2·0	2·0	1·9	1·9	1·8	1·8	1·8	1·7	1·7	50
55	2·2	2·2	2·2	2·1	2·1	2·0	2·0	1·9	1·9	1·9	55
60	2·4	2·4	2·4	2·3	2·3	2·2	2·2	2·1	2·1	2·0	60
65	2·6	2·6	2·6	2·5	2·5	2·4	2·4	2·3	2·3	2·2	65
70	2·8	2·8	2·8	2·7	2·7	2·6	2·5	2·5	2·4	2·4	70
75	3·1	3·0	2·9	2·9	2·8	2·8	2·7	2·7	2·6	2·5	75
80	3·3	3·2	3·1	3·0	3·0	2·9	2·9	2·8	2·8	2·7	80
85	3·5	3·4	3·3	3·2	3·2	3·1	3·1	3·0	2·9	2·9	85
90	3·7	3·6	3·5	3·4	3·4	3·3	3·2	3·2	3·1	3·1	90
95	3·9	3·8	3·7	3·6	3·6	3·5	3·4	3·4	3·3	3·3	95
100	4·1	4·0	3·9	3·8	3·8	3·7	3·6	3·5	3·5	3·4	100

TABLE XI

APPROXIMATE BAROMETER CORRECTIONS FOR TEMPERATURE AND HEIGHT

	Inches	Millibars*
Temperature ..	–·003 inch for each degree F. the attached thermometer reads above freezing point.	Subtract the temperature of the attached thermometer, in degrees A., from 285° A (taking account of sign), and divide by 6, to get the correction in millibars.
Height ..	The height in feet, increased by 10 per cent., gives the correction in thousandths of an inch.	The height in feet, increased by 10 per cent., and divided by 30, gives the correction in millibars.

Examples—

Inch barometer,	attached thermometer 56° F.	Temperature correction		—·072 in.
	height 90 feet	Height	„	+·099 „
Millibar barometer (N.P.L. certificate before 1st January, 1955):				
	attached thermometer 299°A.	Temperature	„	—2·3 mb.
	height 90 feet	Height	„	+3·3 „

* In the case of barometers with N.P.L. certificate dated on or after 1st January, 1955, the temperature of the attached thermometer should be subtracted from 273°A. or, if the thermometer is graduated in °C., from 0°C.

TABLE XII

EQUIVALENTS IN MILLIBARS OF INCHES OF MERCURY AT 0°C. (32°F.) AND STANDARD GRAVITY 980.665 CM./SEC.[2]

(Hundredths of an inch)

Inches	0	1	2	3	4	5	6	7	8	9
	Millibars									
27·0	914·3	914·7	915·0	915·3	915·7	916·0	916·4	916·7	917·0	917·4
27·1	917·7	918·1	918·4	918·7	919·1	919·4	919·7	920·1	920·4	920·8
27·2	921·1	921·4	921·8	922·1	922·5	922·8	923·1	923·5	923·8	924·1
27·3	924·5	924·8	925·2	925·5	925·8	926·2	926·5	926·9	927·2	927·5
27·4	927·9	928·2	928·5	928·9	929·2	929·6	929·9	930·2	930·6	930·9
27·5	931·3	931·6	931·9	932·3	932·6	933·0	933·3	933·6	934·0	934·3
27·6	934·6	935·0	935·3	935·7	936·0	936·3	936·7	937·0	937·4	937·7
27·7	938·0	938·4	938·7	939·0	939·4	939·7	940·1	940·4	940·7	941·1
27·8	941·4	941·8	942·1	942·4	942·8	943·1	943·4	943·8	944·1	944·5
27·9	944·8	945·1	945·5	945·8	946·2	946·5	946·8	947·2	947·5	947·9
28·0	948·2	948·5	948·9	949·2	949·5	949·9	950·2	950·6	950·9	951·2
28·1	951·6	951·9	952·3	952·6	952·9	953·3	953·6	953·9	954·3	954·6
28·2	955·0	955·3	955·6	956·0	956·3	956·7	957·0	957·3	957·7	958·0
28·3	958·3	958·7	959·0	959·4	959·7	960·0	960·4	960·7	961·1	961·4
28·4	961·7	962·1	962·4	962·8	963·1	963·4	963·8	964·1	964·4	964·8
28·5	965·1	965·5	965·8	966·1	966·5	966·8	967·2	967·5	967·8	968·2
28·6	968·5	968·8	969·2	969·5	969·9	970·2	970·5	970·9	971·2	971·6
28·7	971·9	972·2	972·6	972·9	973·2	973·6	973·9	974·3	974·6	974·9
28·8	975·3	975·6	976·0	976·3	976·6	977·0	977·3	977·7	978·0	978·3
28·9	978·7	979·0	979·3	979·7	980·0	980·4	980·7	981·0	981·4	981·7
29·0	982·1	982·4	982·7	983·1	983·4	983·7	984·1	984·4	984·8	985·1
29·1	985·4	985·8	986·1	986·5	986·8	987·1	987·5	987·8	988·1	988·5
29·2	988·8	989·2	989·5	989·8	990·2	990·5	990·9	991·2	991·5	991·9
29·3	992·2	992·6	992·9	993·2	993·6	993·9	994·2	994·6	994·9	995·3
29·4	995·6	995·9	996·3	996·6	997·0	997·3	997·6	998·0	998·3	998·6

TABLE XII—(contd.)

Inches	0	1	2	3	4	5	6	7	8	9
	Millibars									
29·5	999·0	999·3	999·7	1000·0	1000·3	1000·7	1001·0	1001·4	1001·7	1002·0
29·6	1002·4	1002·7	1003·0	1003·4	1003·7	1004·1	1004·4	1004·7	1005·1	1005·4
29·7	1005·8	1006·1	1006·4	1006·8	1007·1	1007·5	1007·8	1008·1	1008·5	1008·8
29·8	1009·1	1009·5	1009·8	1010·2	1010·5	1010·8	1011·2	1011·5	1011·9	1012·2
29·9	1012·5	1012·9	1013·2	1013·5	1013·9	1014·2	1014·6	1014·9	1015·2	1015·6
30·0	1015·9	1016·3	1016·6	1016·9	1017·3	1017·6	1017·9	1018·3	1018·6	1019·0
30·1	1019·3	1019·6	1020·0	1020·3	1020·7	1021·0	1021·3	1021·7	1022·0	1022·4
30·2	1022·7	1023·0	1023·4	1023·7	1024·0	1024·4	1024·7	1025·1	1025·4	1025·7
30·3	1026·1	1026·4	1026·8	1027·1	1027·4	1027·8	1028·1	1028·4	1028·8	1029·1
30·4	1029·5	1029·8	1030·1	1030·5	1030·8	1031·2	1031·5	1031·8	1032·2	1032·5
30·5	1032·8	1033·2	1033·5	1033·9	1034.2	1034·5	1034·9	1035·2	1035·6	1035·9
30·6	1036·2	1036·6	1036·9	1037·3	1037·6	1037·9	1038·3	1038·6	1038·9	1039·3
30·7	1039·6	1040·0	1040·3	1040·6	1041·0	1041·3	1041·7	1042·0	1042·3	1042·7
30·8	1043·0	1043·3	1043·7	1044·0	1044·4	1044·7	1045·0	1045·4	1045·7	1046·1
30·9	1046·4	1046·7	1047·1	1047·4	1047·7	1048·1	1048·4	1048·8	1049·1	1049·4

To reduce millimeters of pressure to millibars, increase the number of millimetres by one third.

Example 764·8 millimetres
add 254.9

1019·7 millibars

Thousandths of an Inch			
Inch	Millibar	Inch	Millibar
·001	·0	·006	·2
·002	·1	·007	·2
·003	·1	·008	·3
·004	·1	·009	·3
·005	·2		

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THE DIURNAL VARIATION OF BAROMETRIC PRESSURE, IN THE ZONES OF LATITUDE 0°–10°, AND 10°–20°, N. OR S.

TABLE XIII—CORRECTION TO BE APPLIED TO THE OBSERVED PRESSURE FOR DIURNAL VARIATION

Local Time		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0°–10°,N. or S.	mb.	–0·6	–0·1	+0·3	+0·7	+0·8	+0·6	+0·2	–0·4	–0·9	–1·3	–1·4	–1·1	–0·6	+0·1	+0·7	+1·3	+1·5	+1·4	+1·0	+0·5	–0·1	–0·6	–0·9	–0·9	–0·6
	in.	–·018	–·003	+·009	+·021	+·024	+·018	+·006	–·012	–·027	–·038	–·041	–·032	–·018	+·003	+·021	+·038	+·044	+·041	+·030	+·015	–·003	–·018	–·027	–·027	–·018
10°–20°,N. or S.	mb.	–0·5	–0·1	+0·3	+0·7	+0·8	+0·6	+0·2	–0·3	–0·8	–1·1	–1·2	–1·0	–0·5	+0·1	+0·7	+1·1	+1·3	+1·2	+0·9	+0·3	–0·2	–0·6	–0·8	–0·8	–0·5
	in.	–·015	–·003	+·009	+·021	+·024	+·018	+·006	–·009	–·024	–·032	–·035	–·030	–·015	+·003	+·021	+·032	+·038	+·035	+·027	+·009	–·006	–·018	–·024	–·024	–·015

TABLE XIV—AVERAGE VALUES OF THE BAROMETRIC CHANGE IN AN HOUR, DUE TO THE DIURNAL VARIATION

		0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
0°–10°,N. or S.	mb.	–0·5	–0·4	–0·4	–0·1	+0·2	+0·4	+0·6	+0·5	+0·4	+0·1	–0·3	–0·5	–0·7	–0·6	–0·6	–0·2	+0·1	+0·4	+0·5	+0·6	+0·5	+0·3	0	–0·3
	in.	–·015	–·012	–·012	–·003	+·006	+·012	+·018	+·015	+·012	+·003	–·009	–·015	–·021	–·018	–·018	–·006	+·003	+·012	+·015	+·018	+·015	+·009	·000	–·009
10°–20°,N. or S.	mb.	–0·4	–0·4	–0·4	–0·1	+0·2	+0·4	+0·5	+0·5	+0·3	+0·1	–0·2	–0·5	–0·6	–0·6	–0·4	–0·2	+0·1	+0·3	+0·6	+0·5	+0·4	+0·2	0	–0·3
	in.	–·012	–·012	–·012	–·003	+·006	+·012	+·015	+·015	+·009	+·003	–·006	–·015	–0·18	–0·18	–·012	–·006	+·003	+·009	+·018	+·015	+·012	+·006	·000	–·009

These tables are based on observations made in British ships, at the hours 0000, 0400, 0800, 1200, 1600, 2000, local time, between 1919–38.

In the tropics, should the barometer, after correction for diurnal variation (Table XIII) be as much as 3 millibars (approximately 0·1 inch) below the monthly normal for the locality, as shown on meteorological charts, the mariner should be on the alert, as there is a distinct possibility that a tropical storm has formed, or is forming. A comparison of subsequent hourly changes in his barometer with the corresponding figures in Table XIV will show whether these changes indicate a real further fall in pressure, and if so, its amount.

Caution: When entering a barometric pressure in the log, or when including it in a wireless weather report the correction for diurnal variation must not be applied.

TABLE XV

CONVERSION OF TEMPERATURE READINGS ON THE FAHRENHEIT SCALE TO THE CELSIUS (FORMERLY 'CENTIGRADE') AND ABSOLUTE SCALES

°F.	°C.	°A.	°F.	°C.	°A.	°F.	°C.	°A.
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 XVI

DEW-POINT (°C.)

(FOR USE WITH STEVENSON SCREEN)

Dry Bulb	Depression of Wet Bulb																									Dry Bulb
°C.	0°	0·2°	0·4°	0·6°	0·8°	1·0°	1·2°	1·4°	1·6°	1·8°	2·0°	2·5°	3·0°	3·5°	4·0°	4·5°	5·0°	5·5°	6·0°	6·5°	7·0°	7·5°	8·0°	8·5°	9·0°	°C.
40	40	40	40	39	39	39	39	38	38	38	38	37	36	36	35	34	34	33	32	32	31	30	29	29	28	40
39	39	39	39	38	38	38	38	37	37	37	37	36	35	35	34	33	33	32	31	31	30	29	28	28	27	39
38	38	38	38	37	37	37	37	36	36	36	35	35	34	34	33	32	32	31	30	29	29	28	27	26	26	38
37	37	37	37	36	36	36	36	35	35	35	34	34	33	32	32	31	30	30	29	28	28	27	26	25	24	37
36	36	36	35	35	35	35	34	34	34	34	33	33	32	31	31	30	29	29	28	27	26	26	25	24	23	36
35	35	35	34	34	34	34	33	33	33	33	32	32	31	30	30	29	28	28	27	26	25	24	24	23	22	35
34	34	34	33	33	33	33	32	32	32	32	31	31	30	29	29	28	27	26	26	25	24	23	22	22	21	34
33	33	33	32	32	32	32	31	31	31	31	30	30	29	28	28	27	26	25	25	24	23	22	21	20	19	33
32	32	32	31	31	31	31	30	30	30	30	29	29	28	27	26	26	25	24	23	23	22	21	20	19	18	32
31	31	31	30	30	30	30	29	29	29	29	28	28	27	26	25	25	24	23	22	21	21	20	19	18	17	31
30	30	30	29	29	29	29	28	28	28	28	27	27	26	25	24	24	23	22	21	20	19	18	19	17	16	30
29	29	29	28	28	28	28	27	27	27	27	26	25	25	24	23	22	22	21	20	19	18	17	16	15	14	29
28	28	28	27	27	27	27	26	26	26	25	25	24	24	23	22	21	20	20	19	18	17	16	15	14	13	28
27	27	27	27	26	26	26	25	25	25	24	24	23	23	22	21	20	19	18	18	17	16	15	14	13	11	27
26	26	26	25	25	25	25	24	24	24	23	23	22	22	21	20	19	18	17	16	15	14	13	12	11	10	26
25	25	25	24	24	24	24	23	23	23	22	22	21	20	20	19	18	17	16	15	14	13	12	11	10	8	25
24	24	24	23	23	23	23	22	22	22	21	21	20	19	19	18	17	16	15	14	13	12	11	9	8	7	24
23	23	23	22	22	22	21	21	21	21	20	20	19	18	17	17	16	15	14	13	12	10	9	8	7	5	23
22	22	22	21	21	21	20	20	20	20	19	19	18	17	16	15	14	13	12	11	10	9	8	6	5	3	22
21	21	21	20	20	20	19	19	19	18	18	18	17	16	15	14	13	12	11	10	9	8	6	5	3	1	21
20	20	20	19	19	19	18	18	18	17	17	17	16	15	14	13	12	11	10	9	7	6	5	3	1	0	20
19	19	19	18	18	18	17	17	17	16	16	16	15	14	13	12	11	10	9	7	6	4	3	1	0	−2	19
18	18	18	17	17	17	16	16	16	15	15	15	14	13	12	11	10	8	7	6	4	3	1	−0	−2	−5	18
17	17	17	16	16	16	15	15	15	14	14	14	13	12	11	9	8	7	6	4	3	1	−0	−3	−5	−7	17
16	16	16	15	15	15	14	14	14	13	13	12	11	10	9	8	7	6	4	3	1	0	−2	−5	−7	−10	16
15	15	15	14	14	14	13	13	12	12	12	11	10	9	8	7	6	4	3	1	0	−2	−5	−7	−10	−14	15
14	14	14	13	13	13	12	12	11	11	11	10	9	8	7	6	4	3	1	0	−2	−4	−7	−10	−13	−18	14
13	13	13	12	12	11	11	11	10	10	9	9	8	7	6	4	3	1	0	−2	−4	−7	−9	−13	−17	−23	13
12	12	12	11	11	10	10	10	9	9	8	8	7	6	4	3	1	0	−2	−4	−6	−9	−12	−16	−22	−33	12
11	11	11	10	10	9	9	9	8	8	7	7	6	4	3	1	0	−2	−4	−6	−8	−12	−15	−21	−30		11
10	10	10	9	9	8	8	8	7	7	6	6	4	3	2	0	−2	−3	−6	−8	−11	−15	−19	−27			10

TABLE XVI—(contd.)

Dry Bulb	Depression of Wet Bulb																					Dry Bulb
°C.	°0	0·2°	0·4°	0·6°	0·8°	1·0°	1·2°	1·4°	1·6°	1·8°	2·0°	2·5°	3·0°	3·5°	4·0°	4·5°	5·0°	5·5°	6·0°	6·5°	7·0°	°C.
9	9	9	8	8	7	7	6	6	5	5	4	3	2	0	—1	—3	—5	—8	—10	—14	—18	9
8	8	8	7	7	6	6	5	5	4	4	3	2	0	—1	—3	—5	—7	—10	—13	—17		8
7	7	7	6	6	5	5	4	4	3	3	2	1	—1	—3	—4	—7	—9	—12	—16			7
6	6	6	5	5	4	4	3	3	2	1	1	—0	—2	—4	—6	—9	—11	—15				6
5	5	5	4	4	3	2	2	1	1	0	0	—2	—4	—6	—8	—10	—14	—15				5
4	4	4	3	2	2	1	1	0	0	—1	—1	—3	—5	—7	—10	—11	—14	—18				4
3	3	3	2	1	1	0	0	—1	—2	—2	—3	—5	—7	—8	—11	—14	—17					3
2	2	2	1	0	0	—1	—1	—2	—3	—3	—4	—5	—8	—10	—13	—16						2
1	1	1	0	—1	—1	—2	—2	—3	—4	—4	—5	—7	—9	—12	—15	—19						1
0	0	—1	—1	—2	—2	—3	—4	—4	—5	—6	—7	—9	—11	—14	—18							0
—1	—1	—2	—2	—3	—4	—4	—5	—6	—6	—7	—8	—10	—13	—17								
—2	—2	—3	—4	—4	—5	—6	—6	—7	—8	—9	—10	—12	—15	—19								
—3	—3	—4	—5	—5	—6	—7	—8	—9	—9	—10	—11	—14	—18									
—4	—5	—5	—6	—7	—7	—8	— 9	—10	—11	—12	—13	—16										
—5	—6	—6	—7	—8	—9	—10	—10	—11	—13	—14	—15	—18										
—6	—7	—7	—8	—9	—10	—11	—12	—13	—14	—15	—17											
—7	—8	—9	—9	—10	—11	—12	—13	—15	—16	—17	—19											
—8	—9	—10	—11	—12	—13	—14	—15	—16	—18	—19												
—9	—10	—11	—12	—13	—14	—15	—17	—18	—19													
—10	—11	—12	—13	—14	—15	—17	—18															
—11	—12	—13	—14	—16	—17	—18																
—12	—13	—14	—16	—17	—18																	
—13	—15	—16	—17	—18																		
—14	—16	—17	—18																			
—15	—17	—18	—19																			
—16	—18	—19																				
—17	—19																					

In the tables, lines are ruled to draw attention to the fact that above the line evaporation is going on from a water surface, while 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 the lines.

For dry bulb temperatures below 0°C. (32°F.) it will be noticed that, when the depression of the wet bulb is zero, i.e., when the temperature of the wet bulb is equal to that of the dry bulb, the dew-point is still below the dry bulb, and the relative humidity is less than 100 per cent. These apparent anomalies are a consequence of the method of computing dew-points and relative humidities now adopted by the Meteorological Office, in which the standard saturation pressure for temperatures below 0°C. (32°F.) is taken as that over water, and not as that over ice.

TABLE XVII

DEW-POINT (°C.)

(FOR USE WITH ASPIRATED PSYCHROMETER)

Dry Bulb	Depression of Wet Bulb																			Dry Bulb
°C.	0°	0·5°	1·0°	1·5°	2·0°	2·5°	3·0°	3·5°	4·0°	4·5°	5·0°	5·5°	6·0°	6·5°	7·0°	7·5°	8·0°	8·5°	9·0°	°C.
40	40	39	39	38	38	37	36	36	35	35	34	33	33	32	31	31	30	29	29	40
39	39	38	38	37	37	36	35	35	34	33	33	32	32	31	30	29	29	28	27	39
38	38	37	37	36	36	35	34	34	33	32	32	31	30	30	29	28	28	27	26	38
37	37	36	36	35	35	34	33	33	32	31	31	30	29	29	28	27	27	26	25	37
36	36	35	35	34	34	33	32	32	31	30	30	29	28	28	27	26	25	25	24	36
35	35	34	34	33	33	32	31	31	30	29	29	28	27	26	26	25	24	24	23	35
34	34	33	33	32	31	31	30	30	29	28	28	27	26	25	25	24	23	22	22	34
33	33	32	32	31	30	30	29	28	28	27	26	26	25	24	23	23	22	21	20	33
32	32	31	31	30	29	29	28	27	27	26	25	25	24	23	22	22	21	20	19	32
31	31	30	30	29	28	28	27	26	26	25	24	24	23	22	21	20	20	19	18	31
30	30	29	29	28	27	27	26	25	25	24	23	22	22	21	20	19	18	17	17	30
29	29	28	28	27	26	26	25	24	24	23	22	21	20	20	19	18	17	16	15	29
28	28	27	27	26	25	25	24	23	22	22	21	20	19	19	18	17	16	15	14	28
27	27	26	26	25	24	24	23	22	21	21	20	19	18	17	16	16	15	14	13	27
26	26	25	25	24	23	23	22	21	20	19	19	18	17	16	15	14	13	12	11	26
25	25	24	24	23	22	21	21	20	19	18	18	17	16	15	14	13	12	11	10	25
24	24	23	23	22	21	20	20	19	18	17	16	16	15	14	13	12	11	10	8	24
23	23	22	22	21	20	19	19	18	17	16	15	14	13	12	11	10	9	8	7	23
22	22	21	21	20	19	18	17	17	16	15	14	13	12	11	10	9	8	7	5	22
21	21	20	20	19	18	17	16	16	15	14	13	12	11	10	9	8	6	5	4	21
20	20	19	19	18	17	16	15	14	14	13	12	11	10	9	7	6	5	4	2	20
19	19	18	17	17	16	15	14	13	12	11	10	9	8	7	6	5	3	2	0	19
18	18	17	16	16	15	14	13	12	11	10	9	8	7	6	5	3	2	0	−1	18
17	17	16	15	15	14	13	12	11	10	9	8	7	6	4	3	2	0	−2	−3	17
16	16	15	14	14	13	12	11	10	9	8	7	5	4	3	2	0	−2	−4	−6	16
15	15	14	13	12	12	11	10	9	8	7	5	4	3	1	0	−2	−4	−6	−8	15
14	14	13	12	11	10	10	9	7	6	5	4	3	1	0	−2	−4	−6	−8	−11	14
13	13	12	11	10	9	8	7	6	5	4	3	1	0	−2	−4	−6	−8	−11	−14	13
12	12	11	10	9	8	7	6	5	4	3	1	0	−2	−4	−6	−8	−10	−13	−17	12
11	11	10	9	8	7	6	5	4	3	1	0	−2	−3	−5	−8	−10	−13	−17	−22	11
10	10	9	8	7	6	5	4	3	1	0	−2	−3	−5	−7	−10	−13	−16	−21	−29	10

TABLE XVII—(contd.)

Dry Bulb	Depression of Wet Bulb																			Dry Bulb
°C.	0°	0·5°	1·0°	1·5°	2·0°	2·5°	3·0°	3·5°	4·0°	4·5°	5·0°	5·5°	6·0°	6·5°	7·0°	7·5°	8·0°	8·5°	9·0	°C.
9	9	8	7	6	5	4	3	1	0	—2	—3	—5	—7	—9	—12	—16	—20	—27	—45	9
8	8	7	6	5	4	3	1	0	—2	—3	—5	—7	—9	—12	—15	—19	—25	—25	—36	8
7	7	6	5	4	3	1	0	—1	—3	—5	—7	—9	—11	—14	—18	—19	—24	—34		7
6	6	5	4	3	1	0	—1	—3	—4	—6	—8	—11	—14	—14	—18	—23	—32			6
5	5	4	3	2	0	—1	—3	—4	—6	—8	—10	—11	—14	—18	—22	—30				5
4	4	3	2	0	—1	—2	—4	—6	—8	—9	—11	—14	—17	—22	—28	—45				4
3	3	2	1	—1	—2	—4	—5	—6	—8	—11	—13	—16	—21	—27	—39					3
2	2	1	0	—2	—3	—4	—6	—8	—10	—13	—16	—20	—25	—34						2
1	1	0	—2	—3	—4	—6	—8	—10	—12	—15	—19	—24	—31							1
0	0	—1	—3	—4	—6	—8	—9	—12	—14	—18	—22	—29	—44							0
—1	—1	—2	—4	—5	—7	—9	—11	—14	—17	—21	—26	—37								
—2	—2	—4	—5	—7	—9	—11	—13	—16	—19	—24	—32									
—3	—3	—5	—6	—8	—10	—12	—15	—18	—23	—29	—44									
—4	—4	—6	—8	—10	—12	—14	—17	—21	—26	—36										
—5	—5	—7	—9	—11	—13	—16	—19	—24	—31											
—6	—6	—8	—10	—13	—15	—18	—22	—28	—39											
—7	—7	—10	—12	—14	—17	—20	—25	—32												
—8	—8	—11	—13	—16	—19	—23	—28	—40												
—9	—9	—12	—14	—17	—21	—25	—33													
—10	—10	—13	—16	—19	—23	—28	—39													
—11	—11	—15	—17	—21	—25	—32														
—12	—12	—16	—19	—23	—28	—38														
—13	—13	—17	—20	—25	—31	—47														
—14	—14	—18	—22	—27	—35															
—15	—15	—20	—24	—29	—40															
—16	—16	—21	—25	—32																
—17	—17	—22	—27	—35																

See footnotes to Table XVI (page 135)

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TABLE XVIII

DEW-POINT (°F.)

(FOR USE WITH STEVENSON SCREEN)

Dry Bulb	Depression of Wet Bulb																					Dry Bulb
°F.	0°	0·5°	1·0°	1·5°	2·0°	2·5°	3·0°	3·5°	4·0°	4·5°	5·0°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	°F.
100	100	99	99	99	97	97	96	95	95	95	94	92	91	90	88	87	86	84	83	81	80	78	100
99	99	99	98	97	97	96	95	95	94	93	93	91	90	89	87	86	84	83	81	80	78	77	99
98	98	97	97	96	95	95	94	94	93	92	92	90	89	88	86	85	83	82	80	79	77	76	98
97	97	96	96	95	94	94	93	93	92	91	91	89	88	87	85	84	82	81	79	78	76	74	97
96	96	95	95	94	93	93	92	92	91	90	90	88	87	85	84	83	81	80	78	76	75	73	96
95	95	94	94	93	92	92	91	90	90	89	89	87	86	84	83	81	80	78	77	75	74	72	95
94	94	93	93	92	91	91	90	89	89	88	87	86	85	83	82	80	79	77	76	74	72	71	94
93	93	92	92	91	90	90	89	88	88	87	86	85	84	82	81	79	78	76	75	73	71	69	93
92	92	91	91	90	89	89	88	87	87	86	85	84	83	81	80	78	77	75	73	72	70	68	92
91	91	90	90	89	88	88	87	86	86	85	84	83	81	80	79	77	75	74	72	70	69	67	91
90	90	89	89	88	87	87	86	85	85	84	83	82	80	79	77	76	74	73	71	69	68	66	90
89	89	88	88	87	86	86	85	84	84	83	82	81	79	78	76	75	73	71	70	68	66	64	89
88	88	87	87	86	85	85	84	83	83	82	81	80	78	77	75	74	72	70	69	67	65	63	88
87	87	86	86	85	84	84	83	82	82	81	80	79	77	76	74	72	71	69	67	66	64	62	87
86	86	85	85	84	83	83	82	81	80	80	79	78	76	75	73	71	70	68	66	64	62	60	86
85	85	84	84	83	82	82	81	80	79	79	78	77	75	73	72	70	69	67	65	63	61	59	85
84	84	83	83	82	81	81	80	79	78	78	77	75	74	72	71	69	67	66	64	62	60	58	84
83	83	82	82	81	80	79	79	78	77	77	76	74	73	71	70	68	66	64	63	61	58	56	83
82	82	81	81	80	79	79	78	77	76	76	75	73	72	70	68	67	65	63	61	59	57	55	82
81	81	80	80	79	78	77	77	76	75	75	74	72	71	69	67	66	64	62	60	58	56	54	81
80	80	79	79	78	77	76	76	75	74	74	73	71	69	68	66	64	62	61	59	57	54	52	80
79	79	78	78	77	76	75	75	74	73	72	72	70	68	67	65	63	61	59	57	55	53	50	79
78	78	77	77	76	75	74	74	73	72	71	71	69	67	66	64	62	60	58	56	54	52	49	78
77	77	76	76	75	74	73	73	72	71	70	69	68	66	64	63	61	59	57	55	52	50	48	77
76	76	75	75	74	73	72	72	71	70	69	68	67	65	63	61	60	58	55	53	51	48	46	76
75	75	74	74	73	72	71	71	70	69	68	67	66	64	62	60	58	56	54	52	50	47	44	75
74	74	73	73	72	71	70	69	69	68	67	66	64	63	61	59	57	55	53	50	48	46	43	74
73	73	72	72	71	70	69	68	68	67	66	65	63	62	60	58	56	54	52	49	47	44	41	73
72	72	71	70	70	69	68	67	66	66	65	64	62	61	59	57	55	52	50	48	45	42	39	72
71	71	70	69	69	68	67	66	65	65	64	63	61	59	57	55	53	51	49	46	43	41	37	71
70	70	69	68	68	67	66	65	64	64	63	62	60	58	56	54	52	50	47	45	42	39	36	70
69	69	68	67	67	66	65	64	63	63	62	61	59	57	55	53	51	48	46	43	40	37	34	69
68	68	67	66	66	65	64	63	62	61	61	60	58	56	54	52	49	47	45	42	39	36	32	68
67	67	66	65	65	64	63	62	61	60	59	59	57	55	53	50	48	46	43	40	37	34	30	67
66	66	65	64	64	63	62	61	60	59	58	57	55	53	51	49	47	44	42	38	35	32	28	66
65	65	64	63	63	62	61	60	59	58	57	56	54	52	50	48	45	43	40	37	34	30	26	65
64	64	63	62	62	61	60	59	58	57	56	55	53	51	49	47	44	41	38	35	32	28	23	64
63	63	62	61	61	60	59	58	57	56	55	54	52	50	48	45	43	40	37	34	30	26	21	63
62	62	61	60	59	59	58	57	56	55	54	53	51	48	46	44	41	38	35	32	28	23	19	62
61	61	60	59	58	58	57	56	55	54	53	52	50	47	45	42	40	37	34	30	26	21	16	61
60	60	59	58	57	57	55	55	53	53	51	50	48	46	44	41	38	35	32	28	23	19	13	60
59	59	58	57	56	55	54	54	52	52	50	49	47	45	42	40	37	34	30	26	22	16	9	59
58	58	57	56	55	54	53	52	51	50	49	48	46	43	41	38	35	32	28	24	19	13	6	58
57	57	56	55	54	53	52	51	50	49	48	47	45	42	40	37	34	30	26	22	17	10	1	57
56	56	55	54	53	52	51	50	49	48	47	46	43	41	38	35	32	29	25	19	13	7		56
55	55	54	53	52	51	50	49	48	47	46	45	42	40	37	34	30	27	22	17	11	2		55
54	54	53	52	51	50	49	48	47	46	45	43	41	38	35	32	29	25	20	14	8	1		54
53	53	52	51	50	49	48	47	46	45	43	42	40	37	34	31	27	23	18	12	5			53
52	52	51	50	49	48	47	46	45	43	42	41	38	36	32	29	25	21	16	9	0			52
51	51	50	49	48	47	46	45	43	42	41	40	37	34	31	28	23	19	13	6				51
50	50	49	48	47	46	45	43	42	41	40	38	36	33	29	26	21	17	10	2				50
49	49	48	47	46	45	44	42	41	40	39	37	35	32	28	24	19	14	7					49
48	48	47	46	45	44	43	41	40	39	38	36	33	30	26	22	17	12	4					48
47	47	46	45	44	43	42	40	39	37	36	35	32	29	25	21	15	9	1					47
46	46	45	44	43	42	40	39	38	36	35	34	30	27	23	19	13	6						46
45	45	44	43	42	40	39	38	36	35	34	32	29	25	21	17	10	2						45
44	44	43	42	41	39	38	37	35	34	32	31	28	23	19	14	8							44
43	43	42	41	39	38	37	36	34	33	31	29	26	22	17	12	5							43
42	42	41	40	38	37	36	34	33	32	30	28	25	21	16	10	2							42
41	41	40	38	37	36	35	33	32	30	29	27	23	19	13	7	4							41
40	40	39	37	36	35	34	32	31	29	27	26	22	17	12	8	1							40
39	39	38	36	35	34	32	31	29	28	26	24	20	15	12	6								
38	38	37	35	34	33	31	30	28	26	24	22	18	15	10	2								
37	37	36	34	33	32	30	29	27	25	23	21	18	13	7									
36	36	35	33	32	30	29	27	25	23	23	21	17	11	5									
35	35	34	32	31	29	28	26	25	23	21	19	14	9	1									
34	34	33	31	30	28	27	25	23	22	20	17	13	6										
33	33	32	30	29	27	26	24	22	20	18	16	10	4										
32	32	31	29	28	26	24	22	21	18	16	14	8	1										
31	31	29	28	27	25	23	21	19	17	14	12	6											
30	30	29	27	25	23	22	20	17	15	13	10	4											
29	29	27	26	24	22	20	18	16	14	11	8	1											
28	27	26	24	22	21	18	17	14	12	9	6												
27	26	25	23	21	19	17	15	13	10	7	4												
26	25	23	22	20	18	16	14	11	8	5	2												
25	24	22	21	19	17	14	12	10	7	3													
24	23	21	19	17	15	13	10	8	5	1													
23	22	20	18	16	14	12	9	6	3														
22	21	19	17	15	13	10	7	4	1														
21	20	18	16	13	11	9	6	2															
20	18	16	14	12	10	7	4	0															
19	17	15	13	11	8	5	2																
18	16	14	12	10	7	4	0																
17	15	13	11	8	5	2																	
16	14	12	9	7	4	0																	
15	13	11	8	5	2																		
14	12	10	7	4	0																		
13	11	8	5	3																			
12	10	7	4	1																			
11	8	6	3																				
10	7	5	1																				
9	6	3	0																				
8	5	2																					
7	4	1																					
6	3	0																					
5	2																						
4	1																						

See footnotes to Table XVI (page 135)

TABLE XIX

DEW-POINT (°F)

(FOR USE WITH ASPIRATED PSYCHROMETER)

Dry Bulb	Depression of Wet Bulb																
°F.	°0	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°
100	100	99	98	96	95	94	93	91	90	89	87	86	85	83	82	81	79
98	98	97	96	94	93	92	91	89	88	87	85	84	83	81	80	78	77
96	96	95	94	92	91	90	89	87	86	85	83	82	80	79	77	76	74
94	94	93	92	90	89	88	86	85	84	82	81	80	78	77	75	74	72
92	92	91	89	88	87	86	84	83	82	80	79	77	76	74	73	71	70
90	90	89	87	86	85	84	82	81	79	78	77	75	74	72	71	69	67
88	88	87	85	84	83	81	80	79	77	76	74	73	71	70	68	67	65
86	86	85	83	82	81	79	78	77	75	74	72	71	69	67	66	64	62
84	84	83	81	80	79	77	76	74	73	71	70	68	67	65	63	61	60
82	82	81	79	78	77	75	74	72	71	69	68	66	64	63	61	59	57
80	80	79	77	76	75	73	72	70	69	67	65	64	62	60	58	56	54
78	78	77	75	74	72	71	69	68	66	65	63	61	60	58	56	54	52
76	76	75	73	72	70	69	67	66	64	62	61	59	57	55	53	51	49
74	74	73	71	70	68	67	65	64	62	60	58	57	55	53	50	48	46
72	72	71	69	68	66	65	63	61	60	58	56	54	52	50	48	45	43
70	70	69	67	66	64	62	61	59	57	55	54	51	49	47	45	42	40
68	68	67	65	63	62	60	59	57	55	53	51	49	47	44	42	39	36
66	66	64	63	61	60	58	56	54	53	51	49	46	44	42	39	36	33
64	64	62	61	59	58	56	54	52	50	48	46	44	41	39	36	33	29
62	62	60	59	57	55	54	52	50	48	46	43	41	38	35	32	29	25
60	60	58	57	55	53	51	49	47	45	43	41	38	35	32	29	25	21
58	58	56	55	53	51	49	47	45	43	40	38	35	32	29	25	21	16
56	56	54	53	51	49	47	45	42	40	38	35	32	29	25	21	16	11
54	54	52	50	49	47	45	42	40	37	35	32	29	25	21	17	11	4
52	52	50	48	46	44	42	40	37	35	32	29	25	21	17	11	5	

TABLE XIX—(contd.)

Dry Bulb	Depression of Wet Bulb																
°F	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°
50	50	48	46	44	42	40	37	35	32	29	26	22	17	12	6		
48	48	46	44	42	40	37	35	32	29	26	22	18	13	7			
46	46	44	42	40	37	35	32	29	26	22	18	14	8	1			
44	44	42	40	37	35	32	30	26	23	19	14	9	2	0			
42	42	40	38	35	33	30	27	23	19	15	10	8	2				
40	40	38	35	33	30	27	24	20	16	14	9	2					
38	38	36	33	31	28	25	21	19	15	9	4						
36	36	34	31	28	25	23	19	15	10	5							
34	34	32	29	26	23	20	16	11	6								
32	32	29	27	23	20	17	12	7	1								
	Depression of Wet Bulb																
	0°	0·5°	1·0°	1·5°	2·0°	2·5°	3·0°	3·5°	4·0°	4·5°	5·0°	5·5°	6·0°	6·5°	7·0°	7·5°	
30	30	29	27	26	24	23	21	19	17	15	13	11	8	5	3	0	
28	28	26	25	23	22	20	18	16	14	12	10	7	4	1			
26	25	24	22	21	19	17	15	13	11	9	6	4	0				
24	23	21	20	18	16	14	12	10	8	5	2						
22	21	19	17	16	14	11	9	7	4	1							
20	19	17	15	13	11	9	6	4	1								
18	16	14	12	10	8	6	3	0									
16	14	12	10	8	5	3	0										
14	12	10	7	5	2	0											
12	10	7	5	2	0												

See footnotes to Table XVI (page 135)

TABLE XX

CONVERSION OF NAUTICAL MILES TO STATUTE MILES AND KILOMETRES

Nautical Miles	Statute Miles	Kilometres	Nautical Miles	Statute Miles	Kilometres
1	1·2	1·9	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	93
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 XXI

CONVERSION OF FEET TO METRES

Feet	Metres	Feet	Metres	Feet	Metres	Feet	Metres
1	0·30	20	6·1	200	61	2,000	610
2	0·61	30	9·1	300	91	3,000	910
3	0·91	40	12·2	400	122	4,000	1,220
4	1·22	50	15·2	500	152	5,000	1,520
5	1·52	60	18·3	600	183	6,000	1,830
6	1·83	70	21·3	700	213	7,000	2,130
7	2·13	80	24·4	800	244	8,000	2,440
8	2·44	90	27·4	900	274	9,000	2,740
9	2·74	100	30·5	1,000	305	10,000	3,050
10	3·05						

TABLE XXII

TO OBTAIN APPROXIMATELY THE TRUE FORCE AND DIRECTION OF THE WIND, FROM ITS APPARENT FORCE AND DIRECTION, ON THE DECK OF A MOVING VESSEL

Apparent force of wind, Beaufort scale.	Apparent direction of wind, in degrees off the bow.	0°						10°						20°						30°					
	Speed of vessel in knots	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30
1	True direction, degrees off the bow ..	180	180	180	180	180	180	174	178	179	179	179	179	167	176	177	178	178	179	163	174	176	177	177	178
	True force, Beaufort scale	1	3	4	5	6	7	1	3	4	5	6	7	1	3	4	5	6	7	1	3	4	5	6	7
2	True direction, degrees off the bow ..	—	180	180	180	180	180	96	171	175	177	177	178	100	163	171	174	175	176	105	157	168	171	173	174
	True force, Beaufort scale	0	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
3	True direction, degrees off the bow ..	0	180	180	180	180	180	24	126	167	172	175	176	44	116	156	166	170	172	62	116	150	161	166	169
	True force, Beaufort scale	2	1	2	4	5	5	2	1	3	4	5	6	2	2	3	4	5	6	2	2	3	4	5	6
4	True direction, degrees off the bow ..	0	0	180	180	180	180	15	32	116	159	169	172	30	56	110	145	159	166	45	73	112	138	153	160
	True force, Beaufort scale	3	1	1	3	4	5	3	2	1	3	4	5	3	2	2	3	4	5	3	3	3	3	4	5
5	True direction, degrees off the bow ..	0	0	0	180	180	180	13	21	43	112	152	164	27	40	68	108	137	152	39	56	82	110	130	144
	True force, Beaufort scale	4	3	1	1	2	4	4	3	2	2	3	4	4	3	3	3	3	4	4	4	3	3	4	4
6	True direction, degrees off the bow ..	0	0	0	0	180	180	13	17	25	49	102	144	25	33	47	71	103	130	37	48	63	85	107	125
	True force, Beaufort scale	5	4	3	2	1	2	5	4	3	2	2	3	5	4	4	3	3	4	5	4	4	4	4	4
7	True direction, degrees off the bow ..	0	0	0	0	0	—	12	15	20	28	47	83	24	29	38	51	71	97	36	43	54	68	85	103
	True force, Beaufort scale	6	5	4	3	2	0	6	5	4	4	3	2	6	5	5	4	4	4	6	6	5	4	4	4
8	True direction, degrees off the bow ..	0	0	0	0	0	0	12	14	17	21	30	45	23	27	33	41	53	69	34	40	47	57	69	84
	True force, Beaufort scale	7	6	6	5	4	3	7	6	6	5	4	3	7	7	6	5	4	4	7	7	6	6	5	5
9	True direction, degrees off the bow ..	0	0	0	0	0	0	11	13	15	18	22	30	22	25	30	35	43	53	33	38	44	51	59	70
	True force, Beaufort scale	8	8	7	6	5	4	8	8	7	6	5	4	8	8	7	6	6	5	8	8	7	7	6	6
10	True direction, degrees off the bow ..	0	0	0	0	0	0	11	12	14	16	19	23	22	24	28	32	37	44	33	37	41	47	53	60
	True force, Beaufort scale	9	9	8	7	6	6	9	9	8	7	6	6	9	9	8	7	7	6	9	9	8	8	7	7
11	True direction, degrees off the bow ..	0	0	0	0	0	0	11	12	13	15	17	20	22	24	26	29	33	38	33	36	39	43	48	54
	True force, Beaufort scale	10	10	9	8	8	7	10	10	9	8	8	7	10	10	9	9	8	7	10	10	9	9	8	8
12	True direction, degrees off the bow ..	0	0	0	0	0	0	11	12	13	14	16	18	22	23	25	28	31	35	32	35	38	41	45	49
	True force, Beaufort scale	11	11	10	9	9	8	11	11	10	10	9	8	11	11	10	10	9	9	11	11	10	10	10	9

Apparent force of wind, Beaufort scale.	Apparent direction of wind, in degrees off the bow.	40°						50°						60°						Apparent force of wind, Beaufort scale
	Speed of vessel in knots	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30	
1	True direction, degrees off the bow ..	161	172	175	177	177	177	158	171	175	176	176	177	156	171	174	176	176	176	1
	True force, Beaufort scale	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	
2	True direction, degrees off the bow ..	110	154	165	169	171	173	115	152	163	168	170	172	120	151	162	167	169	171	2
	True force, Beaufort scale	1	3	4	5	5	6	2	3	4	5	6	6	2	3	4	5	6	7	
3	True direction, degrees off the bow ..	75	118	146	157	163	167	86	121	145	155	162	165	96	125	145	154	160	164	3
	True force, Beaufort scale	2	3	4	4	5	6	3	3	4	4	5	6	3	3	4	5	6	6	
4	True direction, degrees off the bow ..	59	85	116	138	150	156	70	97	121	138	148	155	82	104	125	139	147	153	4
	True force, Beaufort scale	3	3	3	4	5	6	4	3	4	4	5	6	4	4	4	5	6	6	
5	True direction, degrees off the bow ..	52	70	93	115	131	142	64	82	102	119	131	141	75	92	109	123	133	141	5
	True force, Beaufort scale	4	4	4	4	4	5	4	4	4	5	5	6	5	5	5	5	6	6	
6	True direction, degrees off the bow ..	49	61	77	95	112	125	60	73	88	103	117	127	71	84	98	110	121	130	6
	True force, Beaufort scale	5	5	5	4	5	5	6	5	5	5	5	6	6	5	6	6	6	7	
7	True direction, degrees off the bow ..	47	56	68	80	95	109	58	68	79	91	103	114	69	79	90	100	110	119	7
	True force, Beaufort scale	6	6	5	5	5	5	6	6	6	6	6	6	7	6	6	6	7	7	
8	True direction, degrees off the bow ..	45	53	61	71	82	94	56	64	73	82	93	102	67	75	84	93	102	109	8
	True force, Beaufort scale	7	7	6	6	6	6	8	7	7	7	7	7	8	7	7	7	7	8	
9	True direction, degrees off the bow ..	45	50	57	65	73	82	56	62	69	76	84	93	66	73	80	87	94	102	9
	True force, Beaufort scale	9	8	8	7	7	7	9	8	8	8	8	8	9	8	8	8	8	8	
10	True direction, degrees off the bow ..	44	49	53	60	66	74	54	60	66	72	78	85	65	71	77	83	89	96	10
	True force, Beaufort scale	10	9	9	8	8	8	10	9	9	9	9	8	10	9	9	9	9	9	
11	True direction, degrees off the bow ..	44	47	51	56	62	68	54	58	63	68	73	79	65	69	74	79	85	91	11
	True force, Beaufort scale	11	10	10	9	9	9	11	10	10	10	10	9	11	10	10	10	10	10	
12	True direction, degrees off the bow ..	43	46	50	54	58	63	54	57	61	66	70	75	64	68	72	77	81	86	12
	True force, Beaufort scale	12	11	11	10	10	10	12	11	11	11	10	10	12	11	11	11	11	11	

Beaufort Wind Scale ..	0	1	2	3	4	5	6	7	8	9	10	11	12
Average Velocity in Knots	0	2	5	9	13	18	24	30	37	44	52	60	68

When the apparent force of the wind is zero, it is obvious that the speed of the wind is just equal to the speed of the ship, and the direction of the wind diametrically opposite to the direction in which the ship is proceeding.

Beaufort 12 was formerly defined as " any wind above 65 knots ", no matter by how much it exceeded this limit. In 1946 it was decided, internationally, to extend the Beaufort scale to force 17 (109–118 knots), in order to make provision for the much greater wind speeds observed in the upper air. The upper limit for force 11 was altered from 65 to 63, and the limits for force 12 were taken as 64–71 knots.

As it is unlikely that mariners will be able to estimate winds exceeding force 12, the table above is not extended further than force 12 for apparent wind force, and if the true wind, computed from the apparent wind and the speed of the ship, is over 71 knots, it is shown as greater than force 12 (>12).

TABLE XXII—(contd.)

TO OBTAIN APPROXIMATELY THE TRUE FORCE AND DIRECTION OF THE WIND, FROM ITS APPARENT FORCE AND DIRECTION, ON THE DECK OF A MOVING VESSEL

Apparent force of wind, Beaufort scale.	Apparent direction of wind, in degrees off the bow.	60°						70°						80°						90°					
	Speed of vessel in knots	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30
1	True direction, degrees off the bow ..	156	171	174	176	176	176	157	170	174	175	175	176	157	170	173	175	175	176	158	170	173	175	175	176
	True force, Beaufort scale	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7
2	True direction, degrees off the bow ..	120	151	162	167	169	171	125	152	161	166	169	171	130	153	162	166	169	171	135	154	162	167	169	171
	True force, Beaufort scale	2	3	4	5	6	7	2	3	4	5	6	7	2	3	4	5	6	7	3	4	4	5	6	7
3	True direction, degrees off the bow ..	96	125	145	154	160	164	105	129	144	154	160	164	112	133	146	155	160	164	121	139	150	157	161	164
	True force, Beaufort scale	3	3	4	5	6	6	3	3	4	5	6	7	3	4	4	5	6	7	3	4	5	6	6	7
4	True direction, degrees off the bow ..	82	104	125	139	147	153	92	113	129	141	148	154	101	120	134	143	150	155	111	126	138	146	152	156
	True force, Beaufort scale	4	4	4	5	6	6	4	4	5	5	6	7	4	4	5	6	6	7	4	5	5	6	7	7
5	True direction, degrees off the bow ..	75	92	109	123	133	141	85	102	116	128	136	143	95	110	122	132	139	145	105	118	129	137	143	148
	True force, Beaufort scale	5	5	5	5	6	6	5	5	5	6	6	7	5	5	6	6	7	7	5	5	6	6	7	8
6	True direction, degrees off the bow ..	71	84	98	110	121	130	82	94	106	117	126	133	92	104	114	123	131	137	102	112	122	129	136	141
	True force, Beaufort scale	6	5	6	6	6	7	6	6	6	6	7	7	6	6	6	7	7	8	6	6	7	7	8	8
7	True direction, degrees off the bow ..	69	79	90	100	110	119	79	89	99	108	117	124	89	99	108	116	123	129	99	108	116	123	129	134
	True force, Beaufort scale	7	6	6	6	7	7	7	7	7	7	7	8	7	7	7	8	8	8	7	7	8	8	8	9
8	True direction, degrees off the bow ..	67	75	84	93	102	109	77	86	94	102	109	116	88	96	103	110	117	123	98	105	112	118	124	129
	True force, Beaufort scale	8	7	7	7	7	8	8	8	8	8	8	8	8	8	8	8	9	9	8	8	9	9	9	9
9	True direction, degrees off the bow ..	66	73	80	87	94	102	76	83	90	97	104	110	87	93	100	106	112	116	97	102	109	114	119	124
	True force, Beaufort scale	9	8	8	8	8	8	9	9	9	9	9	9	9	9	9	9	9	10	9	9	9	10	10	10
10	True direction, degrees off the bow ..	65	71	77	83	89	96	75	81	87	93	99	104	86	91	97	102	108	112	96	101	106	111	116	120
	True force, Beaufort scale	10	9	9	9	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	11	11
11	True direction, degrees off the bow ..	65	69	74	79	85	91	75	80	85	90	95	100	85	90	95	99	104	108	95	100	104	109	113	116
	True force, Beaufort scale	11	10	10	10	10	10	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	12
12	True direction, degrees off the bow ..	64	68	72	77	81	86	74	79	83	87	92	96	84	88	93	97	101	106	94	98	103	106	110	114
	True force, Beaufort scale	12	11	11	11	11	11	12	12	12	11	11	11	12	12	12	12	12	12	12	12	12	12	>12	>12

Apparent direction of wind, in degrees off the bow.	100°						110°						120°						Apparent force of wind, Beaufort scale
Speed of vessel in knots	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30	
True direction, degrees off the bow ..	159	171	174	175	175	176	162	171	174	175	176	176	164	172	175	176	176	177	1
True force, Beaufort scale	2	3	4	5	6	7	2	4	4	5	6	7	2	4	4	5	6	7	
True direction, degrees off the bow ..	139	156	163	167	169	171	145	159	164	168	170	172	150	162	166	170	171	172	2
True force, Beaufort scale	3	4	5	5	6	7	3	4	5	6	6	7	3	4	5	6	7	7	
True direction, degrees off the bow ..	128	143	153	158	162	165	134	148	156	160	164	166	142	152	159	163	166	168	3
True force, Beaufort scale	3	4	5	6	7	7	4	4	5	6	7	8	4	5	6	6	7	8	
True direction, degrees off the bow ..	119	132	143	149	154	158	127	139	147	153	157	160	135	145	152	156	159	162	4
True force, Beaufort scale	4	5	6	6	7	8	4	5	6	7	7	8	5	5	6	7	8	8	
True direction, degrees off the bow ..	114	126	135	142	147	151	123	133	141	146	150	154	131	140	146	151	154	157	5
True force, Beaufort scale	5	6	6	7	8	8	5	6	7	8	8	8	6	6	7	8	8	9	
True direction, degrees off the bow ..	111	121	129	135	140	145	120	129	136	141	145	149	129	136	142	147	150	153	6
True force, Beaufort scale	6	7	7	8	8	9	6	7	7	8	9	9	6	7	8	8	9	9	
True direction, degrees off the bow ..	109	117	124	130	135	139	118	126	132	136	141	145	128	134	139	143	147	150	7
True force, Beaufort scale	7	8	8	8	9	9	7	8	8	9	9	10	7	8	8	9	10	10	
True direction, degrees off the bow ..	107	114	120	126	131	135	117	123	128	133	137	140	126	132	136	140	143	146	8
True force, Beaufort scale	8	8	9	9	10	10	8	9	9	10	10	11	8	9	9	10	10	11	
True direction, degrees off the bow ..	106	112	117	122	127	131	116	121	126	130	134	137	125	129	134	138	141	144	9
True force, Beaufort scale	9	9	10	10	10	11	9	10	10	10	11	12	9	10	10	11	11	12	
True direction, degrees off the bow ..	105	110	115	119	123	127	115	119	124	128	131	134	124	128	132	135	138	141	10
True force, Beaufort scale	10	10	11	11	11	12	10	11	11	11	12	12	10	11	11	12	12	>12	
True direction, degrees off the bow ..	104	109	113	117	121	125	114	119	123	126	129	132	123	128	131	134	137	139	11
True force, Beaufort scale	11	11	12	12	12	12	11	12	12	12	>12	>12	11	12	12	>12	>12	>12	
True direction, degrees off the bow ..	104	108	112	115	118	121	114	118	121	124	127	130	123	127	130	133	135	137	12
True force, Beaufort scale	12	12	>12	>12	>12	>12	12	>12	>12	>12	>12	>12	12	>12	>12	>12	>12	>12	

Beaufort Wind Scale ..	0	1	2	3	4	5	6	7	8	9	10	11	12
Average Velocity in Knots	0	2	5	9	13	18	24	30	37	44	52	60	68

See footnotes overleaf.

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TABLE XXII—(contd.)

TO OBTAIN APPROXIMATELY THE TRUE FORCE AND DIRECTION OF THE WIND, FROM ITS APPARENT FORCE AND DIRECTION, ON THE DECK OF A MOVING VESSEL

Apparent force of wind, Beaufort scale.	Apparent direction of wind, in degrees off the bow.	120°						130°						140°						150°					
	Speed of vessel in knots	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30
1	True direction, degrees off the bow ..	164	172	175	176	176	177	167	173	175	176	177	177	169	174	176	177	177	178	172	176	177	178	178	178
	True force, Beaufort scale	2	4	4	5	6	7	3	4	5	5	6	7	3	4	4	5	6	7	3	4	5	6	6	7
2	True direction, degrees off the bow ..	150	162	166	170	171	172	155	164	169	171	172	174	160	167	171	173	174	174	165	170	173	174	175	176
	True force, Beaufort scale	3	4	5	6	7	7	3	4	5	6	7	7	3	4	5	6	7	8	3	4	5	6	7	8
3	True direction, degrees off the bow ..	142	152	159	163	166	168	148	157	162	165	168	170	155	161	166	168	170	172	160	166	169	171	172	174
	True force, Beaufort scale	4	5	6	6	7	8	4	5	6	6	7	8	4	5	6	7	7	8	4	5	6	7	7	8
4	True direction, degrees off the bow ..	135	145	152	156	159	162	142	151	156	160	164	165	150	157	161	164	166	168	158	163	166	168	170	171
	True force, Beaufort scale	5	5	6	7	8	8	5	6	6	7	8	8	5	6	6	7	8	9	5	6	7	7	8	9
5	True direction, degrees off the bow ..	131	140	146	151	154	157	140	146	152	156	158	161	148	154	158	161	163	165	156	160	163	166	167	168
	True force, Beaufort scale	6	6	7	8	8	9	6	6	7	8	8	9	6	6	7	8	9	9	6	7	7	8	9	10
6	True direction, degrees off the bow ..	129	136	142	147	150	153	138	144	149	152	156	158	147	151	155	158	160	162	155	159	161	163	166	167
	True force, Beaufort scale	6	7	8	8	9	9	7	7	8	8	9	10	7	7	8	9	9	10	7	8	8	9	9	10
7	True direction, degrees off the bow ..	128	134	139	143	147	150	137	142	146	150	152	155	146	150	153	156	158	160	154	157	160	162	163	165
	True force, Beaufort scale	7	8	8	9	9	10	8	8	9	9	10	10	8	8	9	10	10	11	8	8	9	10	10	11
8	True direction, degrees off the bow ..	126	132	136	140	143	146	135	140	144	147	150	153	145	148	151	154	157	158	154	156	159	160	162	164
	True force, Beaufort scale	8	9	9	10	10	11	9	9	10	10	11	11	9	9	10	10	11	11	9	9	10	10	11	12
9	True direction, degrees off the bow ..	125	129	134	138	141	144	135	138	142	145	148	150	144	147	150	152	155	156	154	155	157	159	161	163
	True force, Beaufort scale	9	10	10	11	11	12	9	10	10	11	11	12	10	10	11	11	12	12	10	10	11	11	12	12
10	True direction, degrees off the bow ..	124	128	132	135	138	141	134	137	141	143	146	149	144	146	149	151	154	156	153	155	156	158	160	162
	True force, Beaufort scale	10	11	11	12	12	>12	10	11	11	12	12	>12	10	11	11	12	>12	>12	10	11	12	12	>12	>12
11	True direction, degrees off the bow ..	123	128	131	134	137	139	134	137	140	142	145	147	143	146	148	150	152	154	153	155	156	158	160	161
	True force, Beaufort scale	11	12	12	>12	>12	>12	11	12	12	>12	>12	>12	11	12	12	>12	>12	>12	11	12	>12	>12	>12	>12
12	True direction, degrees off the bow ..	123	127	130	133	135	137	134	136	138	141	143	145	143	145	147	149	150	152	153	154	156	157	159	160
	True force, Beaufort scale	12	>12	>12	>12	>12	>12	12	>12	>12	>12	>12	>12	12	>12	>12	>12	>12	>12	12	>12	>12	>12	>12	>12

Apparent direction of wind, in degrees off the bow.	160°						170°						180°						Apparent force of wind, Beaufort scale.
Speed of vessel in knots	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30	
True direction, degrees off the bow ..	174	177	178	178	178	179	177	179	179	179	179	179	180	180	180	180	180	180	1
True force, Beaufort scale	3	4	5	6	6	7	3	4	5	6	6	7	3	4	5	6	6	7	
True direction, degrees off the bow ..	170	174	175	176	176	177	175	177	178	178	178	178	180	180	180	180	180	180	2
True force, Beaufort scale	3	4	5	6	7	8	3	4	5	6	7	8	3	4	5	6	7	8	
True direction, degrees off the bow ..	168	171	173	174	175	176	173	175	176	177	177	177	180	180	180	180	180	180	3
True force, Beaufort scale	4	5	6	7	7	8	4	5	6	7	7	8	4	5	6	7	8	8	
True direction, degrees off the bow ..	166	169	171	172	173	174	173	174	175	176	176	177	180	180	180	180	180	180	4
True force, Beaufort scale	5	6	7	7	8	9	5	6	7	7	8	9	5	6	7	7	8	9	
True direction, degrees off the bow ..	164	167	169	170	172	172	172	173	174	175	175	176	180	180	180	180	180	180	5
True force, Beaufort scale	6	7	7	8	9	10	6	7	7	8	9	10	6	7	7	8	9	10	
True direction, degrees off the bow ..	164	166	168	169	170	171	172	173	174	175	175	175	180	180	180	180	180	180	6
True force, Beaufort scale	7	8	8	9	10	10	7	8	8	9	10	10	7	8	8	9	10	10	
True direction, degrees off the bow ..	163	165	167	168	169	170	171	172	174	174	174	175	180	180	180	180	180	180	7
True force, Beaufort scale	8	8	9	10	10	11	8	8	9	10	10	11	8	8	9	10	10	11	
True direction, degrees off the bow ..	162	164	166	167	168	169	171	172	173	174	174	174	180	180	180	180	180	180	8
True force, Beaufort scale	9	9	10	11	11	12	9	9	10	11	11	12	9	9	10	11	11	12	
True direction, degrees off the bow ..	162	164	165	166	168	168	171	172	173	173	174	174	180	180	180	180	180	180	9
True force, Beaufort scale	10	10	11	11	12	>12	10	10	11	11	12	>12	10	10	11	11	12	>12	
True direction, degrees off the bow ..	162	163	164	165	167	168	171	172	173	173	173	174	180	180	180	180	180	180	10
True force, Beaufort scale	11	11	12	12	>12	>12	11	11	12	12	>12	>12	11	11	12	>12	>12	>12	
True direction, degrees off the bow ..	162	163	164	165	166	167	171	171	172	173	173	174	180	180	180	180	180	180	11
True force, Beaufort scale	12	12	>12	>12	>12	>12	12	12	>12	>12	>12	>12	12	12	>12	>12	>12	>12	
True direction, degrees off the bow ..	162	163	164	165	166	167	171	171	172	172	173	173	180	180	180	180	180	180	12
True force, Beaufort scale	>12	>12	>12	>12	>12	>12	>12	>12	>12	>12	>21	>12	>12	>12	>12	>12	>12	>12	

Beaufort Wind Scale ..	0	1	2	3	4	5	6	7	8	9	10	11	12
Average Velocity in Knots	0	2	5	9	13	18	24	30	37	44	52	60	68

See footnotes on first page of this Table.

APPENDIX

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 a 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 (one centimetre per second per second).

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

The unit of **Pressure,** in the C.G.S. system, is a dyne per square centimetre, but as this unit is exceedingly small a practical unit of atmospheric pressure is substituted, which is one thousand times as great, and is known as a **Millibar.** A **Bar,** which is one thousand millibars, is very nearly equal to the mean atmospheric pressure at sea level.

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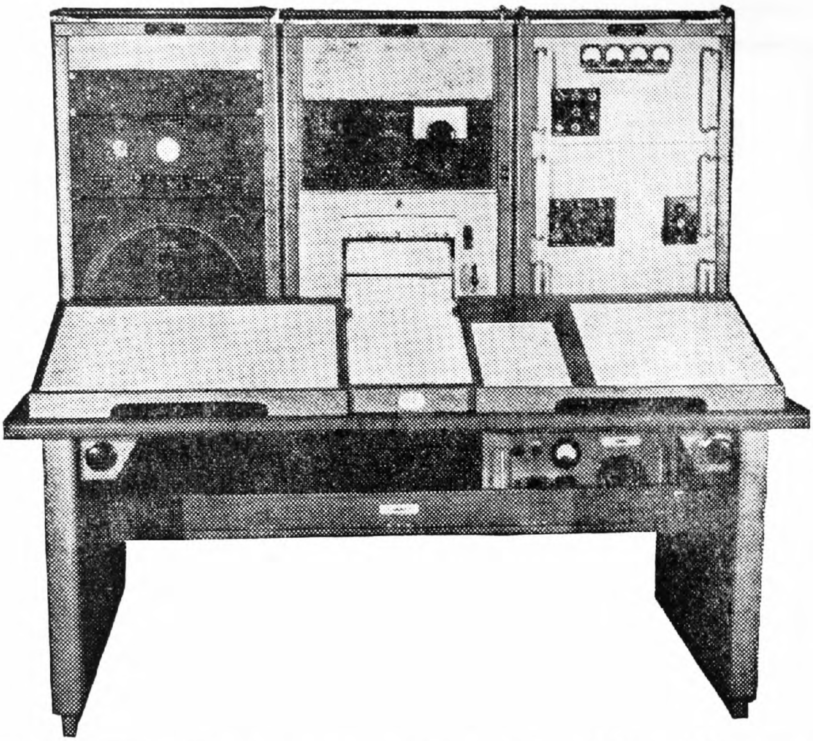

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The equipment counts a noisy signal equivalent to a normal signal transmitted over a distance of 100 Km, and can be recorded with an accuracy better than that plotted by a hand operator (± 0.25 c/s).
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The equipment produces a finer structural record of atmospheric conditions over each signal period, and can be installed without any modifications being made to existing Cintel equipment. Full technical details available on request.

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