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THE MARINE OBSERVER'S HANDBOOK

7th EDITION



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CONTENTS

	<i>Page</i>
<i>Foreword</i>	vii

PART I INSTRUMENTAL OBSERVATIONS

CHAPTER	1	The Barometer and the Barograph	1
„	2	Dry and Wet Bulb Thermometers, Stevenson Screens, Aspirated and Sling Psychrometers. Sea Thermometers	19
„	3	Miscellaneous Instruments and Methods	29

PART II NON-INSTRUMENTAL OBSERVATIONS

CHAPTER	4	Wind, Weather and Visibility	34
„	5	Clouds and cloud height by estimation	43
		Cloud Photographs <i>facing</i>	50
„	6	Ocean Waves	51
„	7	Observations of Ocean Currents and Ice	58

PART III PHENOMENA

CHAPTER	8	Meteorological Phenomena	64
„	9	Miscellaneous Phenomena	79
„	10	Astronomical Phenomena	86

PART IV METEOROLOGICAL WORK AT SEA

CHAPTER	11	Organisation of Voluntary Meteorological Work at Sea	92
„	12	Extracts from the International Convention for the Safety of Life at Sea, 1948. Safety of Navigation, Regulations 2, 3 and 4	96

CONTENTS—*contd.*

TABLES

	<i>Page</i>
I Temperature Correction of the M.O. Pattern Kew Barometer (Inch Scale)	99
II Correction of Inch Barometers to Mean Sea Level	101
III Correction of Inch Barometers to standard gravity in latitude 45°	101
IV Corrections to be applied to the Readings of Kew Pattern Mercury Barometers (millibar graduations) to reduce them to 285° A.	102
V Correction of pressure in millibars to Mean Sea Level	103
VI Correction of Millibar Barometers to standard gravity in latitude 45°	103
VII Approximate barometer corrections for temperature and height	104
VIII Equivalents in millibars of inches of mercury at 32° F. in latitude 45°	105
IX Correction to be applied to the observed pressure for diurnal variation <i>facing</i>	106
X Average values of the barometric change in an hour, due to diurnal variation <i>facing</i>	106
XI Conversion of temperature readings on the Fahrenheit Scale to Centigrade and Absolute Scales	107
XII Relative Humidity (per cent.) (for use with Stevenson Screen)	108
XIII Relative Humidity (per cent.) (for use with Aspirated Psychrometer)	110
XIV Dew-point, ° F. (for use with Stevenson Screen)	112
XV Dew-point, ° F. (for use with Aspirated Psychrometer)	114
XVI Conversion of nautical miles to statute miles and kilometres	116
XVII Conversion of feet to metres	116
XVIII To obtain approximately the true force and direction of the wind, from its apparent force and direction, on the deck of a moving vessel <i>facing</i>	116

APPENDIX

Units of the C.G.S. (centimetre—gramme—second) System	117
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ILLUSTRATIONS

<i>Fig.</i>		<i>Page</i>
1	A simple mercury barometer	1
2	Diagram of the Standard Pattern Marine Barometer	2
3	The Gold Slide	8 facing
4	The Marine Barometer	Between pages 8 and 9
5	The Portable Barograph	9 facing
6	Reading an inch barometer	9
7	Reading a millibar barometer	9
8	Reading the barometer. Errors due to parallax	10
9	Record card for error of aneroid barometer	12
10	Diagram showing characteristic of barometric tendency	16
11	Mean diurnal variation of pressure	17
12	Muslin and wick for wet bulb thermometers	22
13	Air and sea thermometer protectors	24 facing
14	The Portable Stevenson Screen	25 facing
15	Various sources of local heating in a Merchant Ship	25
16	The standard canvas bucket	32 facing
17	The cup anemometer	Between pages 32 and 33
18	The thermograph	
19	The hair hygograph	
20	The cloud searchlight	
21	A cloud searchlight in use at sea	33 facing
22	The British radio-sonde	
23	Wind, parallelogram of velocities	
24	Wave form of the sea-surface	
25	Characteristics of a simple wave	51
26	Representation of a trochoidal wave form	53
27	Refraction of a wave approaching the shore at an angle	54
28	Estimation of wave height at sea	56
29	Halos—Hevelius' diagram	66
30	Solar Halos	68 facing
31	Lunar Halo	69 facing
32	Halos—Mock sun ring and cross	69

CLOUD PHOTOGRAPHS

Between pages 50 and 51

- C_L 1 Fair weather cumulus.
- C_L 2 Towering cumulus.
- C_L 3 Cumulonimbus without anvil.
- C_L 4 Stratocumulus formed by the spreading out of cumulus.
- C_L 5 Stratocumulus not formed by the spreading out of cumulus.
- C_L 6 Stratus.
- C_L 7 Ragged low clouds of bad weather (scud).
- C_L 8 Cumulus and stratocumulus.
- C_L 9 Cumulonimbus with anvil.
- C_M 1 Thin altostratus.
- C_M 2 Thick altostratus (or nimbostratus)
- C_M 3 Single layer of altocumulus or high stratocumulus.
- C_M 4 Altocumulus in isolated patches—often lenticular.
- C_M 5 Altocumulus in bands (increasing).
- C_M 6 Altocumulus formed from the spreading out of cumulus.
- C_M 7 (a) Double-layered altocumulus. (b) Thick opaque layer of altocumulus.
(c) Altocumulus associated with altostratus.
- C_M 8 Altocumulus castellatus.
- C_M 8 Altocumulus floccus.
- C_M 9 Altocumulus in several layers generally associated with fibrous veils and a chaotic appearance of the sky.
- C_H 1 Fine cirrus not increasing.
- C_H 2 Dense cirrus in patches or twisted sheaves.
- C_H 3 Cirrus, often anvil-shaped, usually dense.
- C_H 4 Hooked cirrus.
- C_H 5 Cirrus or cirrostratus increasing ; still below 45° altitude.
- C_H 6 Cirrus or cirrostratus increasing and reaching above 45° altitude.
- C_H 7 Veil of cirrostratus covering whole sky.
- C_H 8 Cirrostratus not increasing and not covering whole sky.
- C_H 9 Cirrocumulus.

FOREWORD

This new edition of 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 merely deals with meteorological instruments and the practical aspect of making observations. A 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 11 and 12.

The seaman is so dependent on the weather, not only for his personal comfort but for the actual safety of his ship, 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 in general, making him more alert and more ready for emergencies. The practised 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 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. It is better to have no observation than an inaccurate or erroneous one. Synoptically, a lone ship's observation from "somewhere in the ocean" may hold the key to an otherwise obscure meteorological situation; if inaccurate, the forecaster may be entirely misled in making his deductions and as a result, a small ship or an aircraft may be lost, directly or indirectly as a result of that inaccuracy.

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. The investigator has only his judgment and experience to go on, in deciding whether to reject an apparently erroneous observation or not. Observers at sea would perhaps be surprised at the many uses to which their observations are put, both commercially and scientifically. The value of these observations is fairly obvious, however, when one considers the vast expanse of the sea compared with the land of the world—and the fact that the world in general is almost entirely dependent upon the goodwill of voluntary observers for information from the oceans.

By taking an intelligent interest in meteorological observations, the seaman not only benefits himself and his ship, but he contributes to the cause of science and benefits the world in general and his fellow seamen in particular, in assisting materially towards increasing our knowledge of meteorology, and improving the technique of forecasting.

MARINE BRANCH,

METEOROLOGICAL OFFICE.

March 1950.

Advantage has been taken of the reprint to insert an additional paragraph about waves on page 55 ; to re-write the last section on page 95, as a consequence of the International Meteorological Organisation being replaced by the World Meteorological Organisation ; and to make a few minor corrections elsewhere.

The changes are identical with those in Amendment List No. 1.

October 1951.

Part I Instrumental Observations

CHAPTER 1

The barometer and the barograph

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. 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).

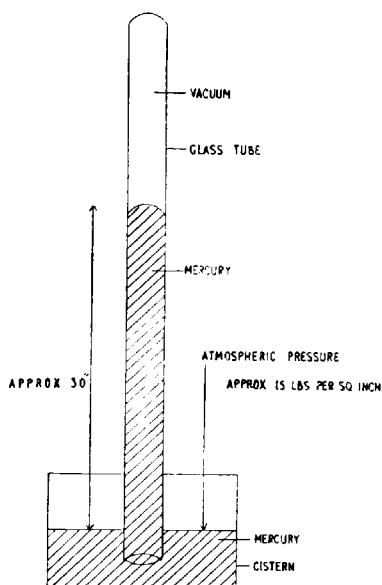
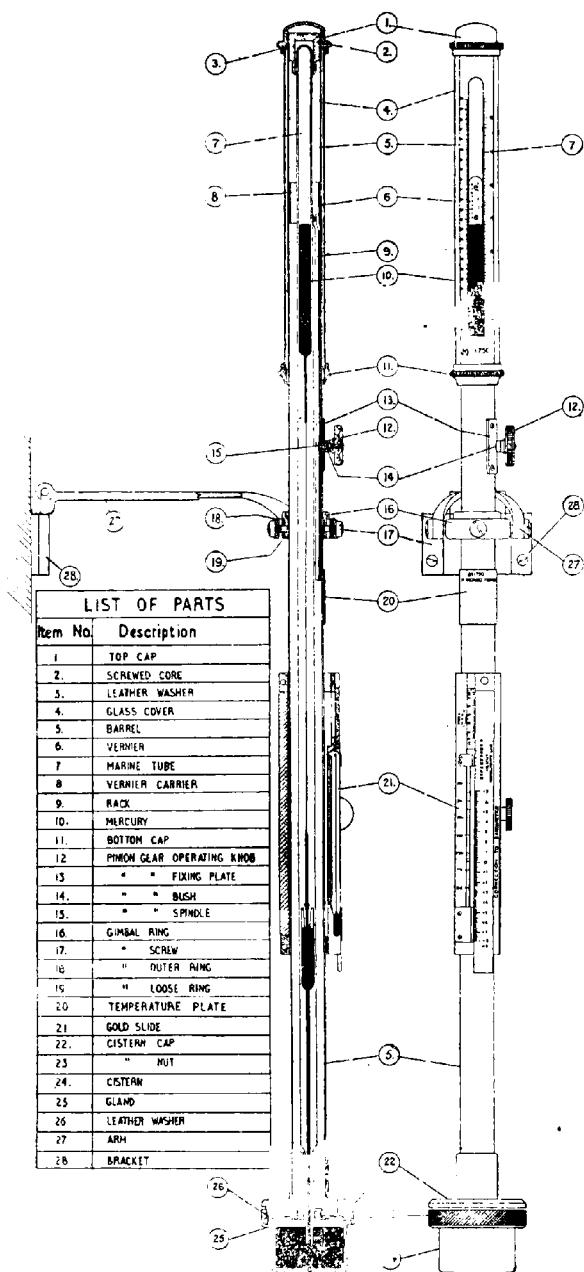


FIG. 1. A simple mercury barometer

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 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.,



**STANDARD PATTERN MARINE BAROMETER
WITH GOLD SLIDE FOR EFFECTING CORRECTIONS**

FIG. 2

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 inch barometers, it is graduated in degrees Fahrenheit.

Graduation of barometer scales. From the invention of the barometer until 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).

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.

CORRECTIONS TO INCH BAROMETERS

For a given sea-level pressure, the length of the mercury column of the barometer is not a constant, but varies to some extent with the temperature of the mercury, the force of gravity at the place of observation and the height above sea level at which the reading is taken.

In order to make barometer readings comparable all over the world and at any altitude and temperature, it is necessary to relate these readings to a common datum. It is customary to adjust the measured length of the column of mercury to the length that would be measured if the instrument were at a standard level in latitude 45° and the temperature of the mercury were 32° F. For altitudes of not more than a few hundred feet, the standard adopted for altitude is mean sea level. These corrections are given in Tables I, II, III, at the end of this book.

Other corrections are necessary because the metal scale of the instrument expands with heat, capillarity* tends to depress the mercury in the tube and the quantity of mercury in the cistern varies according to the length of the mercury column in the tube. These corrections can be made very small by suitable allowances in the process of construction but with every instrument there

* 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.

remains a small residual "index correction". For instruments tested at the National Physical Laboratory, this index correction is measured there and its amount is stated on the 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.

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. 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 metal at a temperature of 62° F.

For a barometer graduated in inches, the net effect of the different standard temperatures for the *metal 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. (see Table I). 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 reading. 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 metal scale.

Correction for altitude. 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. As this plate is moved vertically upwards, the total weight above it must decrease by the weight of the column of air through which the plate has passed, and the pressure will fall accordingly. A 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 corrected 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 II). 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.

Correction for latitude. The barometer reading has now to be corrected for latitude. 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. Standard gravity is taken as the force of gravity in latitude 45° and the length of the mercury column is accordingly corrected to what it would be in that latitude. The correction is 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, 27 and 30 inches.

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. and the index correction is $+ .005$.

	Inches
Uncorrected reading	30.240
Index correction	+ .005
	<hr/> 30.245
Temperature correction for 60° F. (Table I)	— .085
	<hr/> 30.160
Height correction for 36 feet at air temperature of 58° F. (Table II)	+ .039
	<hr/> 30.199
Gravity correction in latitude 51° N. (Table III)	+ .016
	<hr/> 30.215
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 VII.

MILLIBARS

As has already been explained, 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 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.

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

Millibar barometers. These are graduated in millibars with a longer line at each tenth millibar. By means of the vernier the pressure can be read to one-tenth of a millibar. One thousand millibars equal one bar. This is equivalent to a pressure of 29.53 inches, or 750.1 millimetres, of mercury at the freezing point of fresh water in latitude 45°, and is thus very nearly equal to the average pressure of the atmosphere at sea level. An increase of one millibar (.0295 inch) in atmospheric pressure, therefore, indicates an increase of about a thousandth of the previous pressure.

CORRECTIONS TO MILLIBAR BAROMETERS

Index correction. Most millibar barometers are calibrated so as to read, as nearly as possible, correctly at 285° A.,* in latitude 45°, at mean sea level. However careful the calibration, it will usually be found that the reading, under these conditions, will be slightly erroneous. A correction, the index correction, must be applied as in the case of inch barometers (*see* page 5).

Corrections for temperature, altitude and latitude. These corrections are given in Table IV (temperature), Table V (altitude), and Table VI (latitude). They are similar in form to the corresponding tables for inch barometers and require no further explanation.†

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., and the index correction of the barometer is + 0.3 mb.

	mb.
Uncorrected reading	1017.3
Index correction	+ 0.3
	<u>1017.6</u>
Temperature correction for 298° A. (Table IV)	— 2.3
	<u>1015.3</u>
Height correction for 53 feet at air temperature of 78° F. (Table V)	+ 1.8
	<u>1017.1</u>
Gravity correction in latitude 27° N. (Table VI)	— 1.5
Corrected barometer reading	<u>1015.6</u>

* *See* page 20.

† In the earlier editions of this handbook, another method of correcting millibar barometers for index error, temperature, altitude and gravity was given, with the appropriate tables. This method will now be briefly described.

Although the barometer will probably not be quite accurate at 285° A, mean sea level and latitude 45°, there will be a temperature, not very different from 285°, at which it will read correctly at mean sea level and that latitude. This was called the standard temperature of the barometer and was usually engraved on a brass plate on the instrument.

The standard temperature of the barometer was corrected, by means of a table, to the temperature at which the instrument would read correctly in the latitude and at the altitude of the place of observation. This was known as the adjusted fiducial temperature. Another table gave the correction, in millibars, to be applied to the barometer reading, as a function of the adjusted fiducial temperature and the temperature of the attached thermometer of the instrument.

Although this method has some advantage in speed over the method detailed in the present edition, it was felt that to have a method of correction differing so radically from that in use for inch barometers might lead to some confusion, especially as it is probable that most millibar barometers at sea are equipped with Gold Slides (described later in this chapter), and that the tables would only be used in the event of a Gold Slide going out of order.

The Gold Slide. Meteorological Office marine barometers are fitted with a Gold Slide. This attachment still further simplifies the reduction and correction of millibar barometer readings and obviates the use of tables. (See Fig. 3.)

A sliding piece, moveable 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 VIII. In many foreign countries, barometric pressure is given in millimetres. 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.

It must be clearly understood that in barometers graduated with both millibar and inch scales, 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 4.) It will thus be seen that the correction for temperature is different for each scale and it is only when both readings have been fully corrected that they will agree, on conversion.

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.

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. 8.)

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 movements 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 loil 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

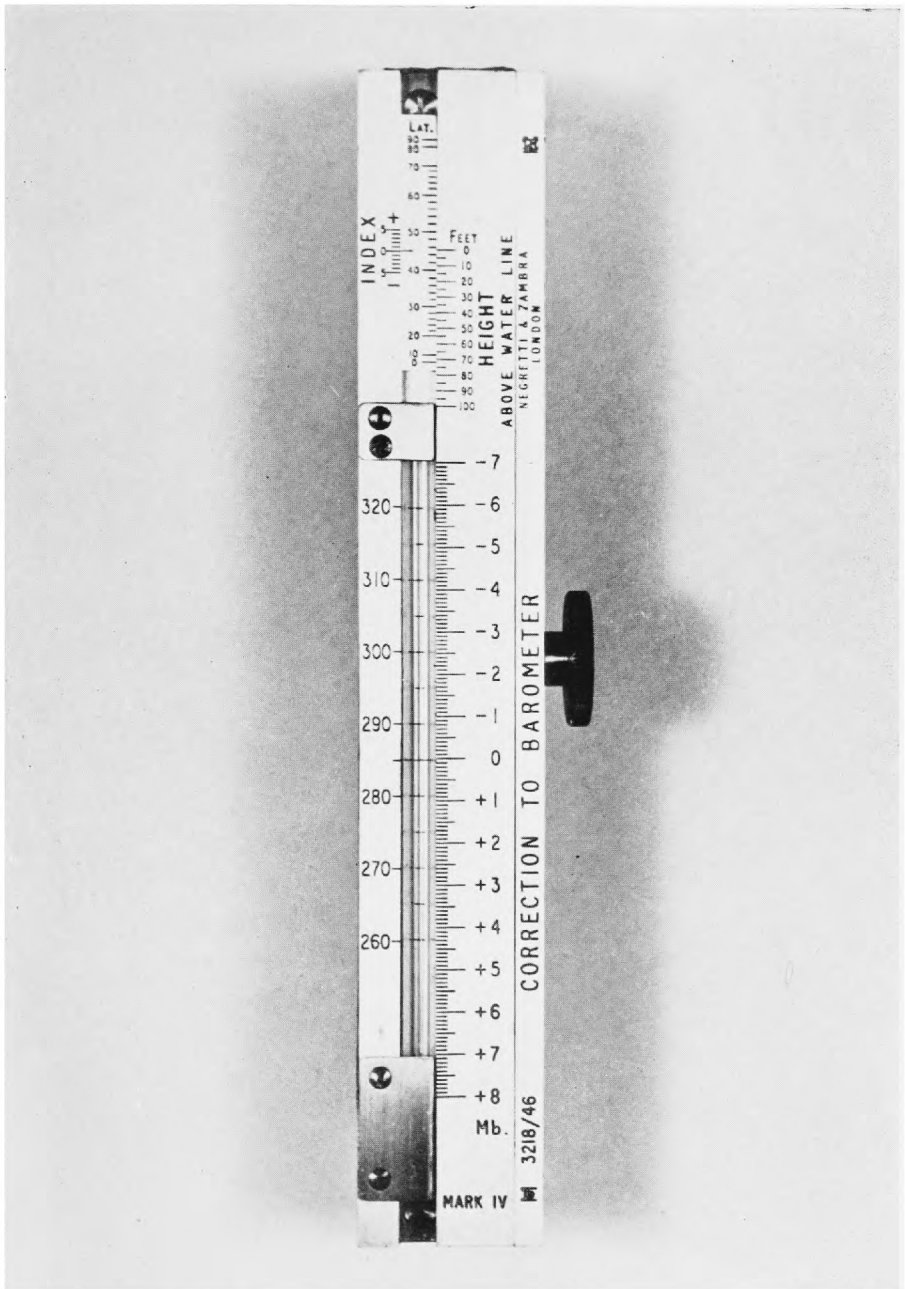
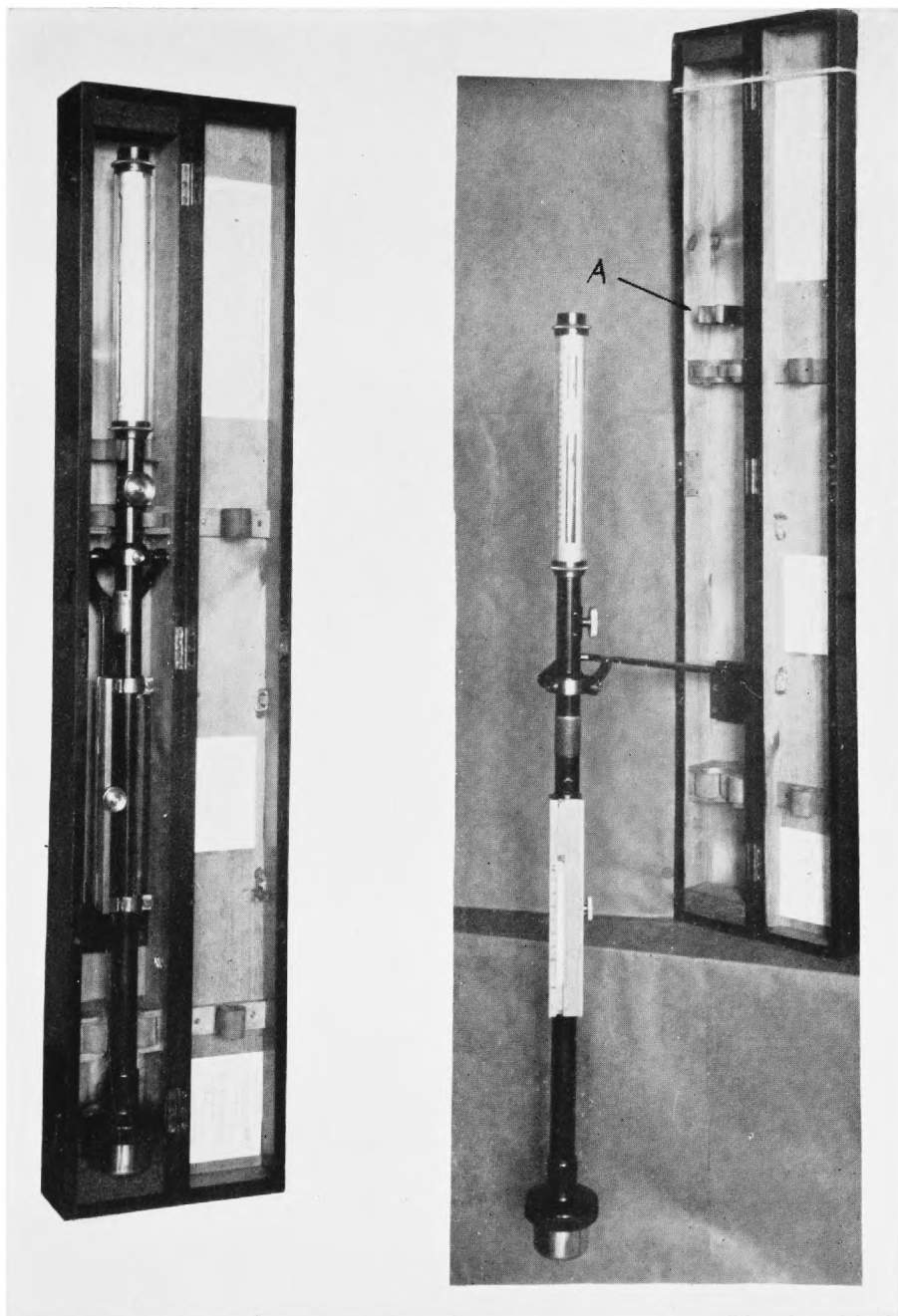


FIG. 3. The Gold Slide



(a)

(b)

FIG. 4. The Marine Barometer

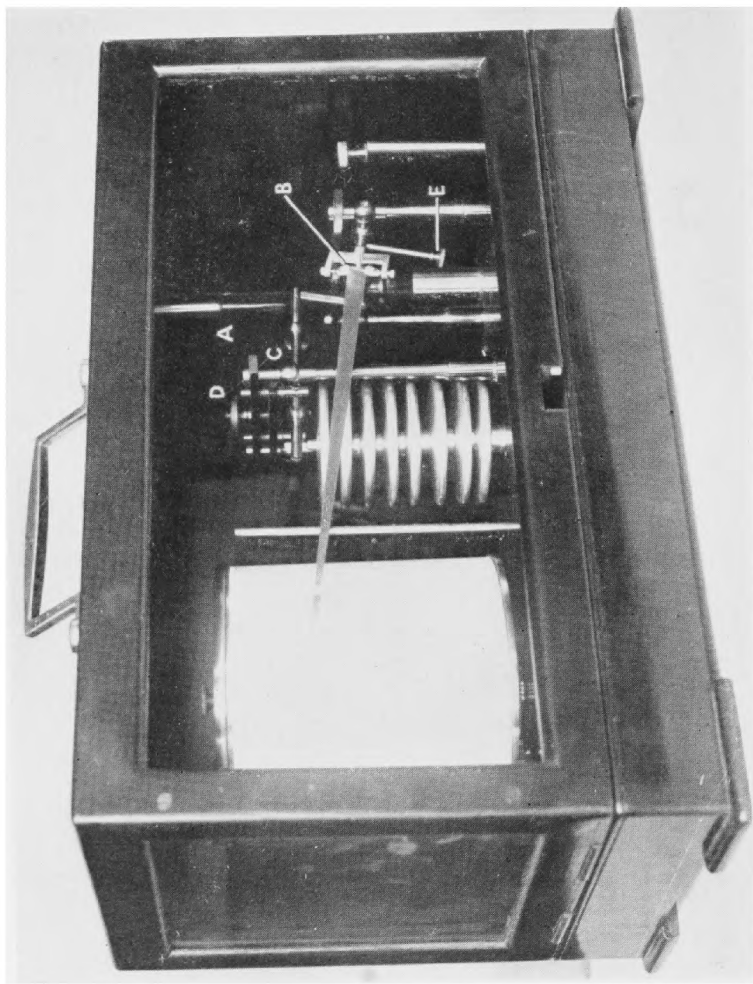


FIG. 5. The Portable Barograph

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 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.

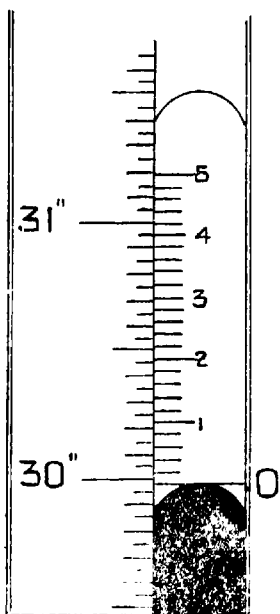


FIG. 6

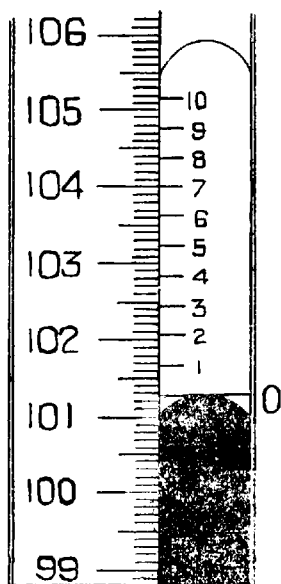
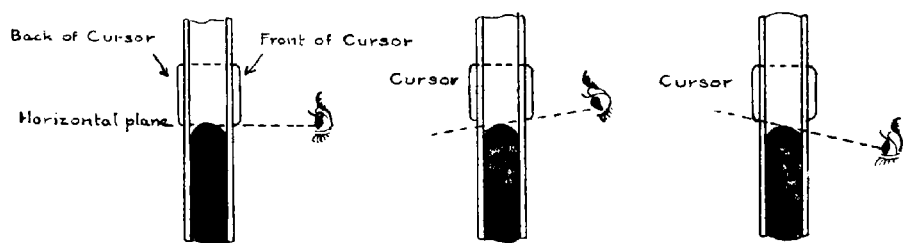


FIG. 7

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. 6 and 7 illustrate the process of reading the vernier, which is done in the same way as that of a sextant. Fig. 6 shows an inch barometer, the reading being 29·989 inches, while Fig. 7 shows a millibar barometer, the reading being 1012·7 millibars.

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. 8.)



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 POSITION 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

FIG. 8

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. On the inch barometer an error of ·05 inch is sometimes made by taking the zero of the vernier at the lowest graduation which appears on the vernier scale instead of at the lower edge of the vernier. 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. Observers who wish to obtain an exact mean should take three pairs of readings, one of each pair being the highest reading obtainable and the other the lowest. The result recorded is the mean of the whole set. Thus, if observations obtained were as follows :—

<i>Highest Reading</i>			<i>Lowest Reading</i>		
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. This instrument is more useful in showing changes in pressure than for the measurement of the actual pressure value. 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.

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. Nor do they 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 II, V, VII.)

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 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.

Date and Port	Temp. °F.	Range of Readings		Actual Reading	Error	P.M.O. or Agent
		190	100			
	28.00	948				
	28.50	965				
	29.00	982				
	29.50	999				
	30.00	1016				
	30.50	1033				
	31.00	1050				

FIG. 9. Record card for error of aneroid barometer

It may be mentioned here that 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. 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. 9 shows the record card supplied by the Marine Branch of the Meteorological Office to ships of the Observing Fleet.

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 a recent type of barograph 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, B denotes the gate suspension and the adjustment is made by means of the milled head E, which clamps the rod carrying the bearing in any desired position in its cylindrical socket.

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 C by means of the milled head screw D on the central bridge. In other instruments the adjustment is made by raising or lowering the point in the base plate to which the lowest of the set of aneroid boxes is fixed. This is done either by a milled head screw on the base plate near the aneroid boxes or by a screw or square head underneath the instrument.

Standardizing of 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 lever, termed a time marker, which on being depressed moves the pen slightly (A in Fig. 5).

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 clock and drum described above are standard, and the instructions given with reference to them apply also in the case of the thermograph or hygrograph (see pages 29 and 30).

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. Up to the present, however, 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 has lately been tried out with satisfactory results. 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 may be supported on rubber pads.

These barographs are now being issued to Selected Ships and will in time supersede the smaller type of barograph now in use.

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 wireless reports 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.

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.

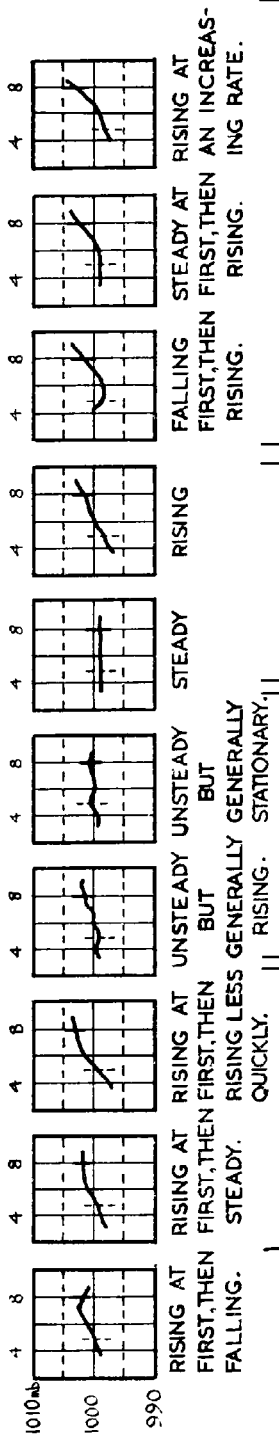
The characteristic of the barometric tendency. This is the name given to the coded description of the nature of the changes the pressure has undergone in the last three hours. It is generally required in ships' wireless reports, and is read off from the barograph trace. The diagrams in Fig. 10 show the 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 *Marine Observer's Guide* (M.O. 477), in *The International Meteorological Code (Decode for use of shipping)* (M.O. 509) and in the *Admiralty List of Radio Signals, Vol. III, Part A*.

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 about 10 and 22 hours and the

DIAGRAM SHOWING CHARACTERISTIC OF BAROMETRIC TENDENCY.

NET RESULT BAROMETER SAME OR HIGHER THAN 3 HOURS AGO



NET RESULT BAROMETER LOWER THAN 3 HOURS AGO.

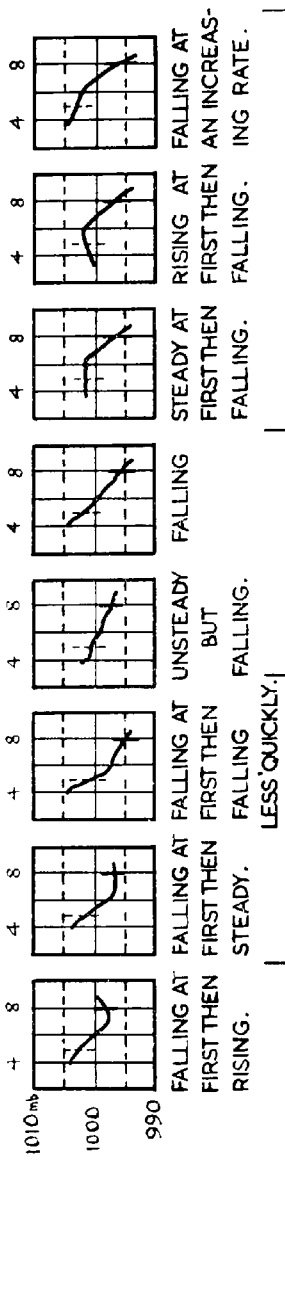


Fig. 10

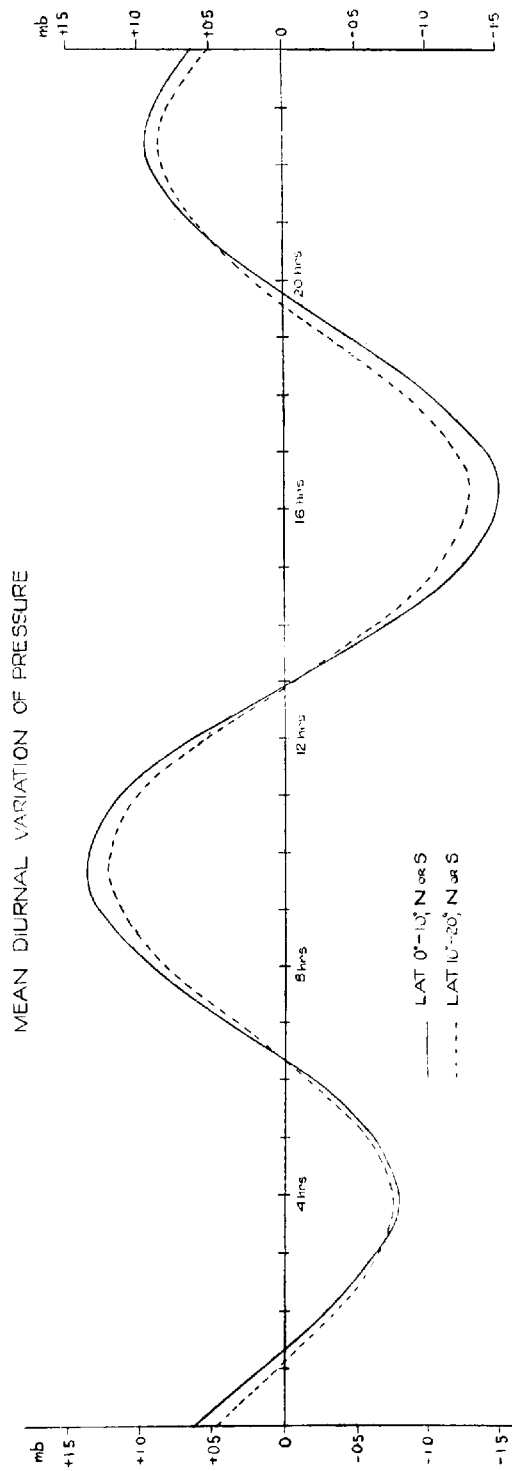


Fig. 11

minimum values 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*.

In the Monthly Meteorological Charts prepared by the Marine Branch of the British Meteorological Office for the Atlantic (M.O. 483), the Western Pacific (M.O. 484), the Eastern Pacific (M.O. 518), and the Indian Ocean (M.O. 519), 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 IX and X (*see also* Fig. 11). In the tropics, should the barometer, after correction for diurnal variation (Table IX) 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 X 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.

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 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 -38°F , while alcohol freezes only at -202°F , though it becomes a thick liquid, and therefore useless for thermometric purposes, at -130°F .

Graduation of 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 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.

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

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

(4) **THE ABSOLUTE SCALE.** In the above scales, temperatures below the zero of the scale have to be indicated as negative temperatures. Thus a temperature of 5° below zero on the Centigrade scale must be written as -5° C. The Absolute scale of temperature is the Centigrade scale with 273 added to every graduation and is indicated by the letter A. Thus the freezing point of water is 273° A. and the boiling point is 373° A., while a temperature of -5° C. is 268° A. The principal advantage of the Absolute scale for meteorological work is that all negative values are avoided, and 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, so far as our present knowledge goes, the temperature at which any substance has no heat at all, the whole of its previous heat having been converted into some other form of energy. Temperature on the Absolute scale is 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 Centigrade readings to Fahrenheit use the following rule :—Multiply by $9/5$ and add 32. Similarly, to convert from Fahrenheit to Centigrade, subtract 32 and multiply by $5/9$. From Fahrenheit to Absolute, proceed as for Centigrade and add 273. Table XI gives the values on the Centigrade 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. 13a.

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 it is graduated only to whole degrees, as far as possible the reading 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 particularly desirable at temperatures below freezing point, for the computation of relative humidity and the dew point (see pages 23 and 24). 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. 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 hygrometer, 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 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 40° F. in a hot dry climate, such as that of Khartoum during part of the year. It sometimes amounts to 15° or 20° F. in England, but at sea the difference seldom reaches 10° 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 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. 12a).

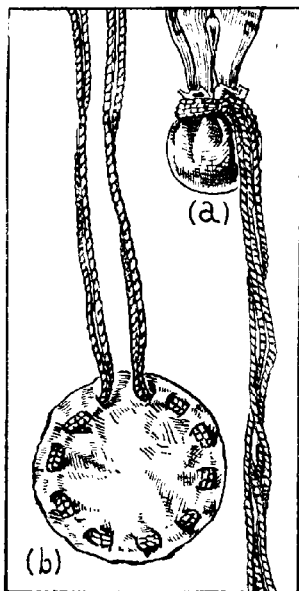


FIG. 12

(a) Wet bulb (ordinary muslin and wick). (b) Muslin cap.

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. 12b). 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 record 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. 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. 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 32° F. until all the water has been converted to ice. It then begins to fall gradually to the true wet bulb reading. No reading must be recorded until the temperature of the wet bulb has fallen below that of the dry bulb and remains steady. Dry windy weather may cause the ice to evaporate completely before the time of the next reading, in which case the procedure of wetting the bulb must be gone through again. The original coating of ice will give satisfactory 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.

Humidity tables. The data to be obtained from the readings of the dry and wet bulb thermometers, using the tables provided, are the relative humidity and the dew-point.

The *relative humidity* is the amount of water vapour actually present in the air, expressed as a percentage of the amount the air could contain at that

temperature if it were saturated. 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 XII and XIV give relative humidity and 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 XII and XIV are to be used for observations in which the thermometers are exposed in the standard "Stevenson Screen". In the tables, lines are ruled 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. Owing to this, interpolation must not be made between figures on different sides of the line.

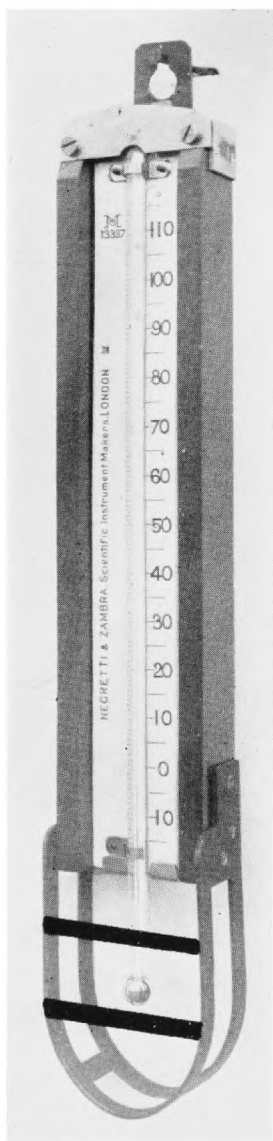
For low dry bulb temperatures (30° F. or less) the depression of the wet bulb in the tables is shown by steps of $\frac{1}{2}$ ° F., instead of 1° F., as both relative humidity and dew point change so rapidly at low temperatures with changes in this factor. In order that values of the wet bulb depression 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.

THE STEVENSON SCREEN

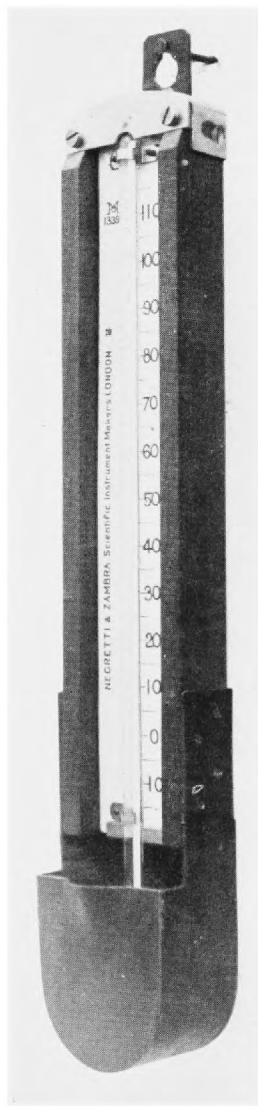
Dry and wet bulb thermometers are normally exposed, at sea, in a standard marine type "Stevenson Screen". This is a box or compartment, the inside of which is protected from the sun and rain, on all four sides, by "jalousies" or louvres, which, however, let the air in freely. Various patterns of Stevenson screen are made; the type used at sea (shown in Fig. 14), is known as the portable Stevenson screen.

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



(a)



(b)

FIG. 13. Air and sea thermometer protectors

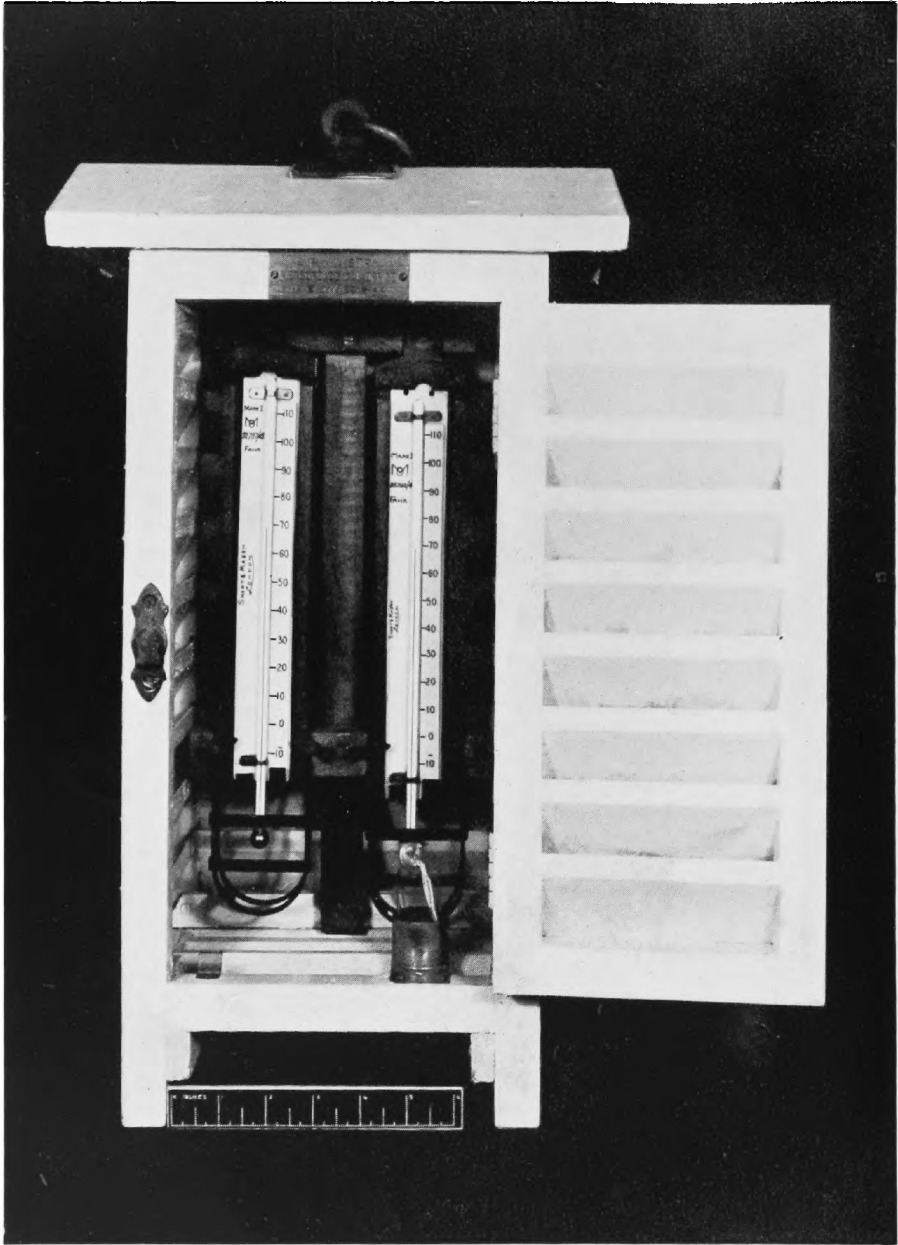


FIG. 14. The portable Stevenson screen

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. In steamships 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 usually most suitable. The most suitable location is where the air will

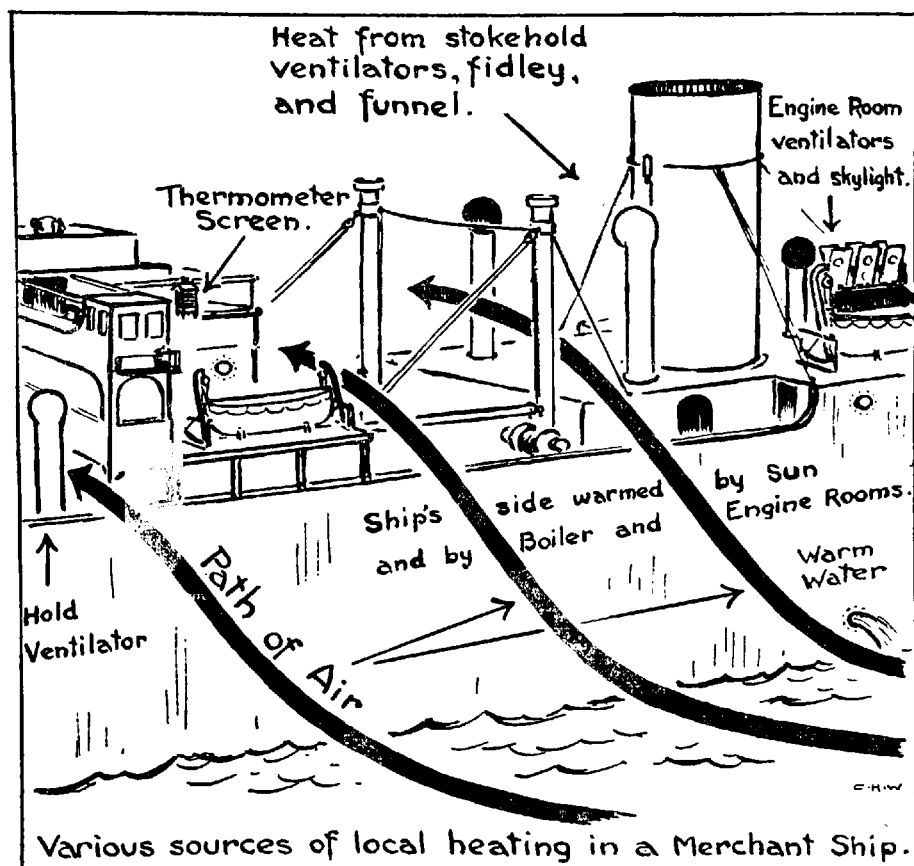


FIG. 15

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. 15.)

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.

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 maximum value when the wind is about 4 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 4 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 4 knots. This operation is called "aspiration" of the bulbs. Each bulb is protected from radiation by highly polished metal tubes or shields so that the instrument can be placed in strong sunshine without any risk of the readings being affected by solar 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 XII and XIV, at the end of this book, which are used for computing relative humidity and dew point from dry and wet bulb readings in a Stevenson screen, are based on the average ventilation inside such a screen, which is considerably less than that due to a wind of 4 knots. Special humidity tables are therefore required to compute relative humidity and dew point from the readings of an aspirated or sling psychrometer. These are printed as Tables XIII and XV. As with Tables XII and XIV, 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 International Meteorological Organisation, in 1947, recommended that the standard method of obtaining dry and wet bulb temperatures at sea should no longer be from thermometers exposed in a Stevenson screen but from an aspirated or sling psychrometer. Experiments are now being carried out in the British Meteorological Office to determine the most suitable form of such an instrument for use at sea.

* Latin—*aspirare*, to blow upon.

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 THERMOMETERS

Sea surface temperatures, bucket method. An ordinary thermometer, fitted with a sea thermometer protector (*see* Fig. 13b), is used for observations of the temperature of the sea surface. This protector has a guard round the bulb, to minimise the risk of breakage, but, unlike the air thermometer protector, this guard is closed in and forms a reservoir for retaining a small quantity of sea-water around the bulb, should it be necessary to remove the thermometer from the bucket to read it (*see also* page 28).

The water used for taking the sea surface temperature should be drawn in a special bucket from over the ship's side. The standard canvas bucket now issued by the British Meteorological Office contains a spring lid, opening inwards, at the top of the bucket. This opens to admit water when the bucket is immersed and closes again when the bucket is lifted out of the water, thereby preventing spilling of the water. 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. (*See* Fig. 16).

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. 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.

It has been the custom for many years to use canvas buckets on board ship for taking the temperature of sea-water. Recent investigations, however, indicate that there are many objections, not only to the use of a canvas bucket, but also to the present type of sea thermometer with the receptacle for holding water. Experiments are now being made with a newly designed bucket with the object of reducing the errors to which sea water temperature observations are liable, and also with an improved type of thermometer.

Engine-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. 17). 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 m.p.h. 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, close the switch. Time the interval from one bell ring to the next. If the wind is strong, take the time for five or ten rings. Open the switch 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. 18).

If the thermograph is to be used on board ship to give a continuous record of the temperature of the outside air, the instrument should be exposed in a Stevenson screen, and the same precautions should be 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 24).

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.

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. 19).

If the hygrograph is to be used on board ship to give a continuous record of the relative humidity of the outside air, this instrument, too, should 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 raingauge. 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-gauge 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-gauge is not level, the reading will be erroneous and the heaving of the ship makes it impossible, apart from mounting the gauge 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 should be used to follow the balloon, in case it should rise too high to be followed by the naked eye. Care must be 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 must be 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. 20). 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 measurable ; 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 should be set up as far apart as is practicable (*see* Fig. 21).

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, the observation is much more difficult 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 must, of course, be 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.

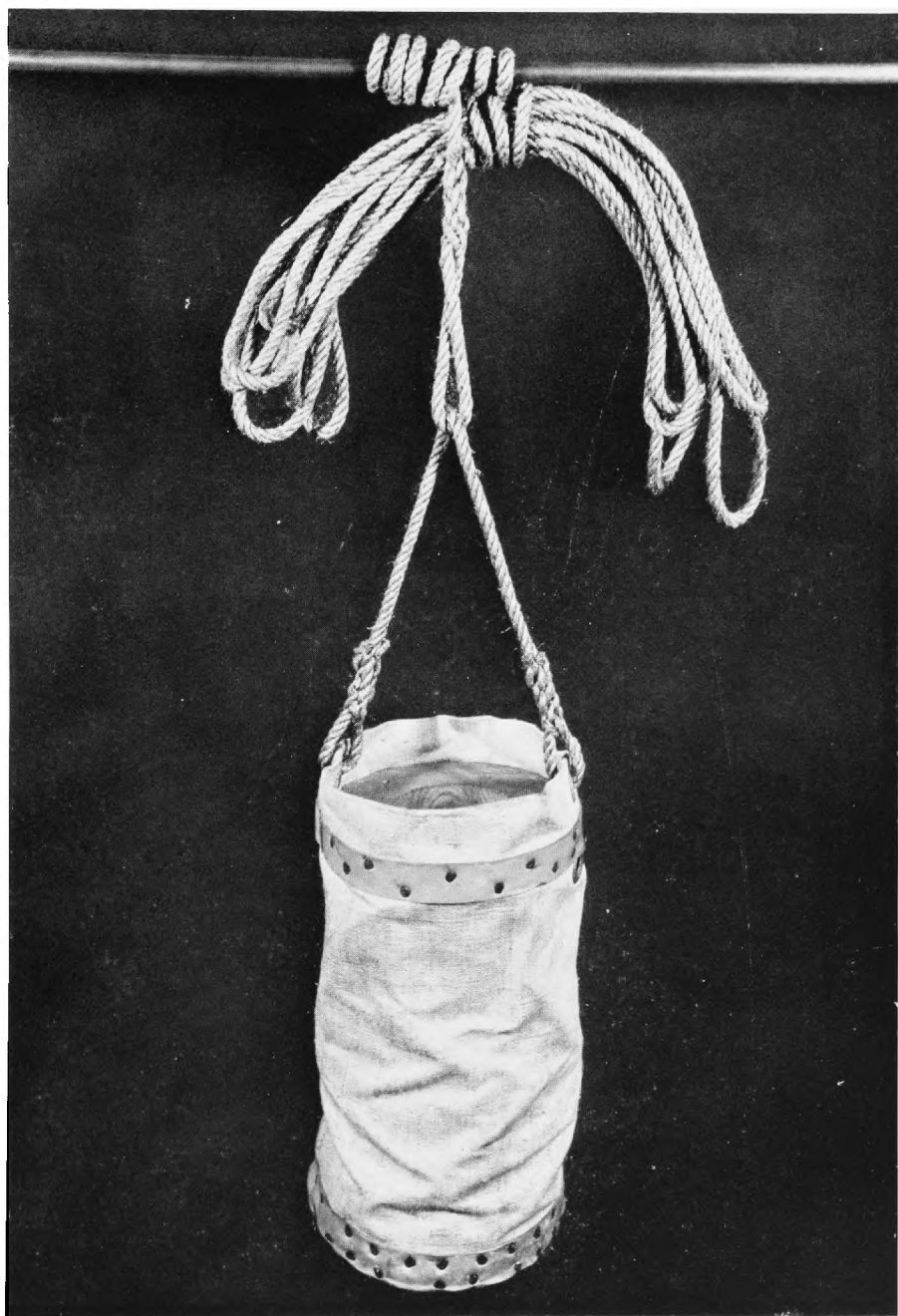


FIG. 16. The standard canvas bucket

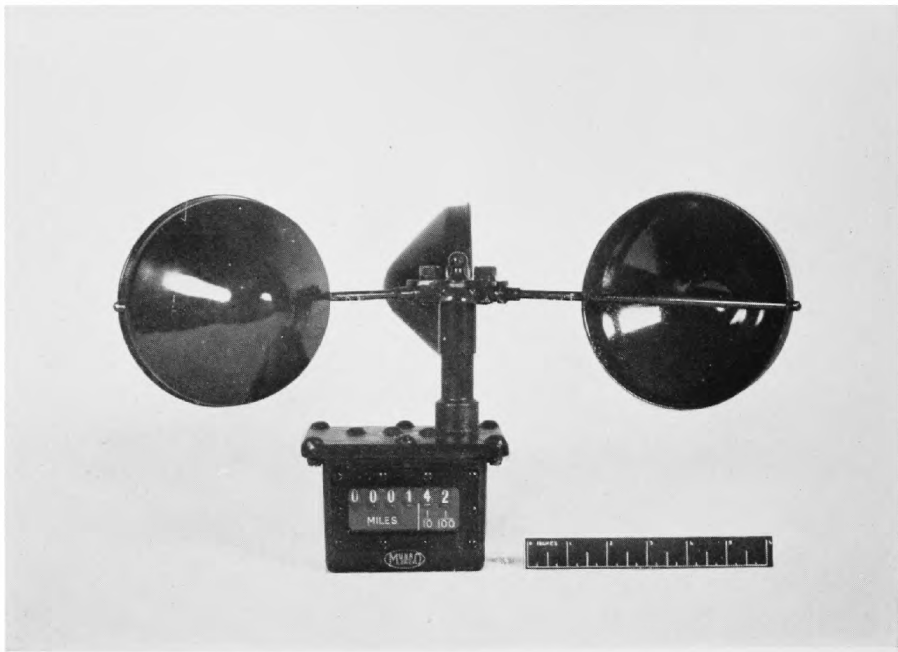


FIG. 17. The cup anemometer

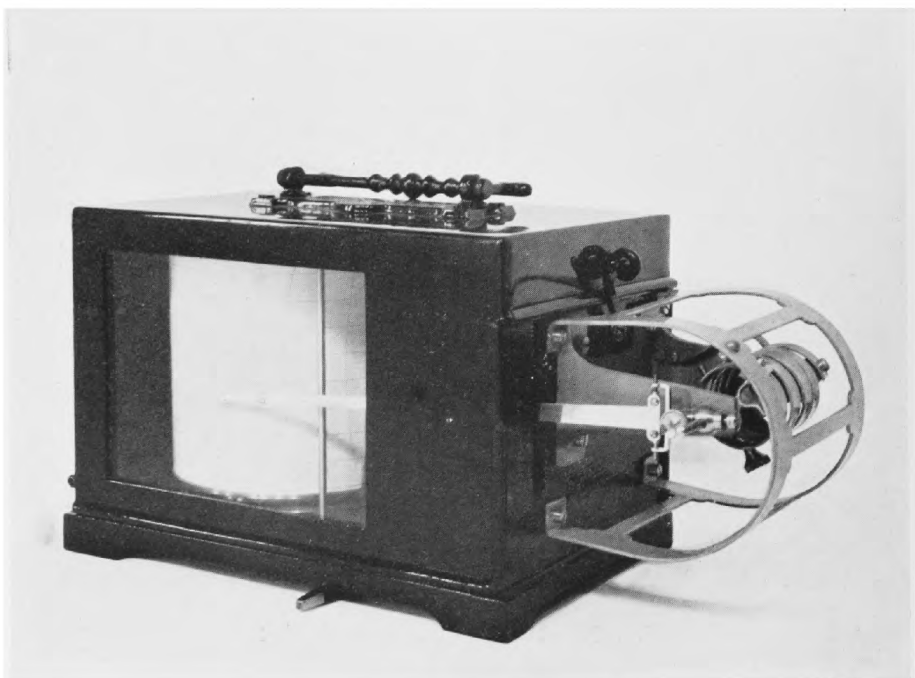


FIG. 18. The thermograph

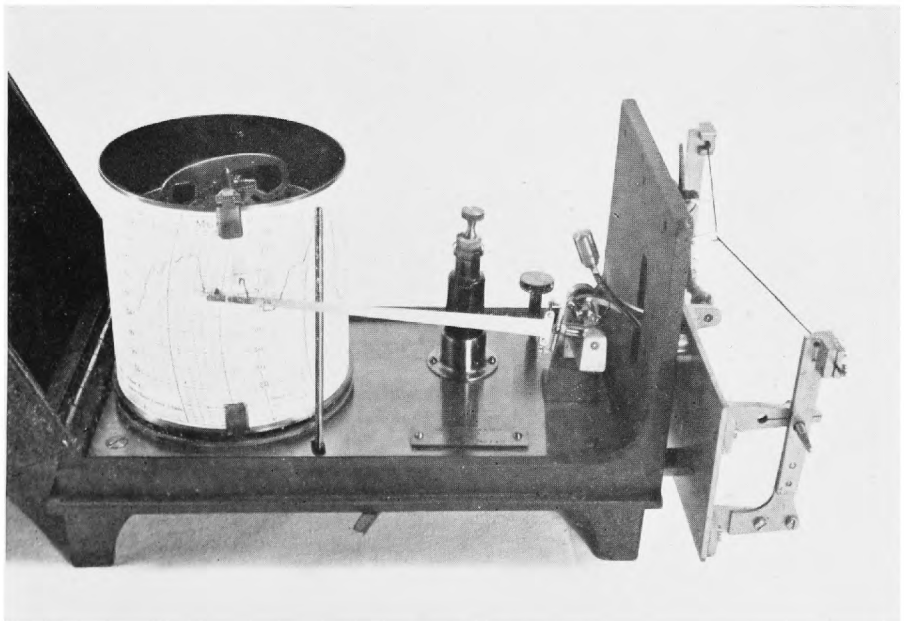
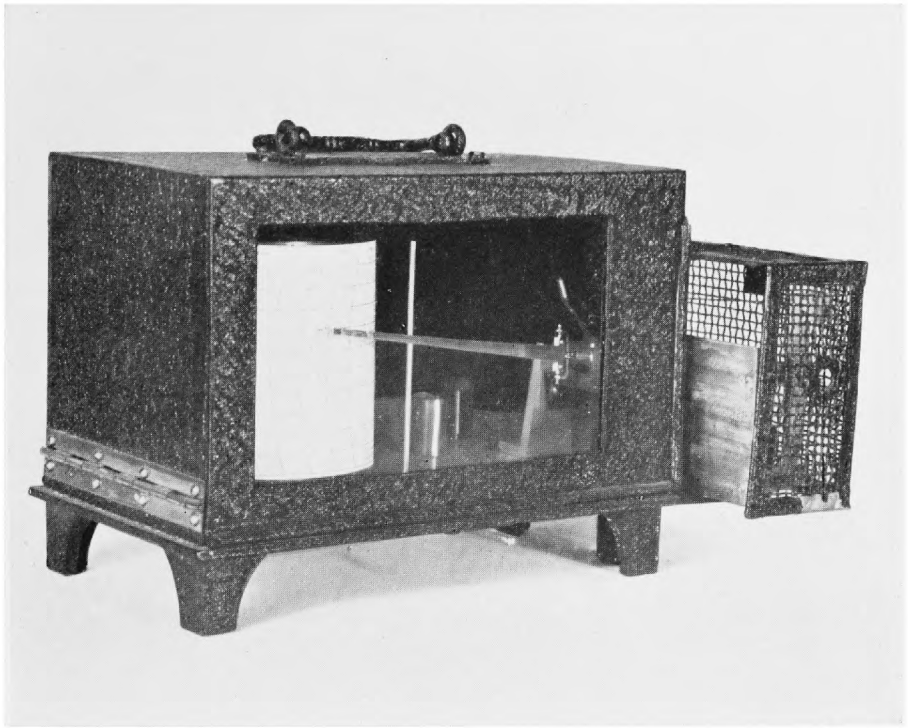


FIG. 19. The hair hygrometer. In the lower picture the wire cage has been removed to show the hair mechanism

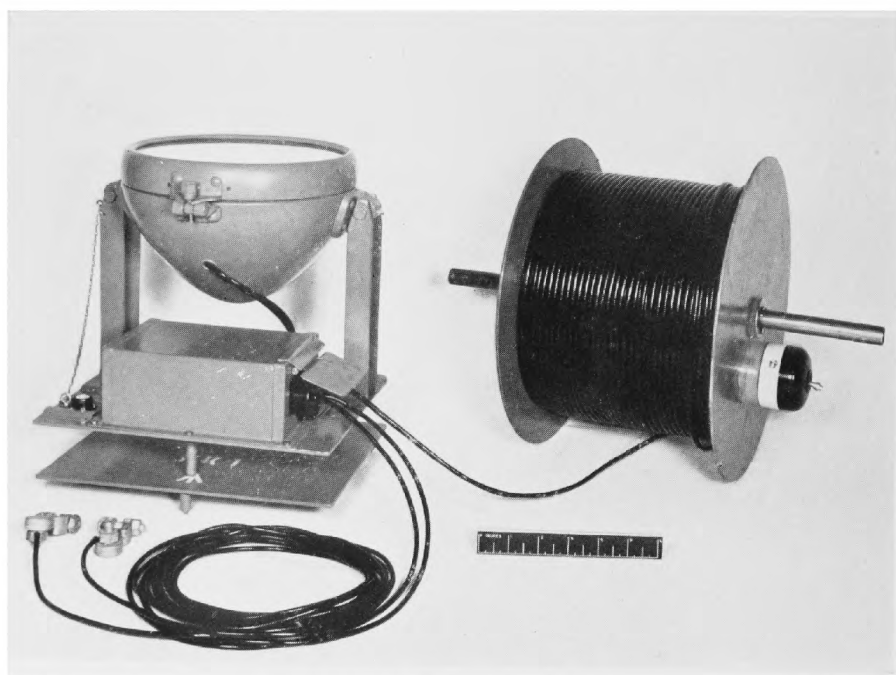


FIG. 20. The cloud searchlight

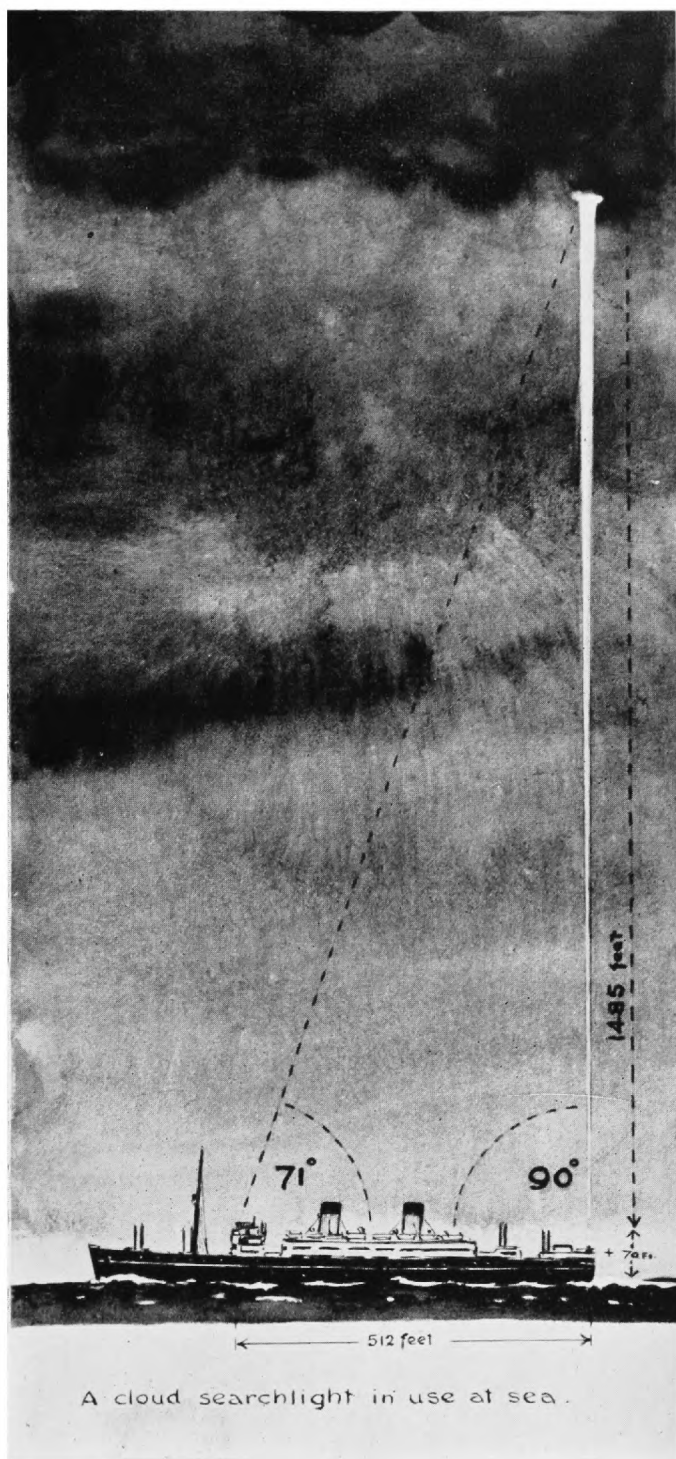


FIG. 21

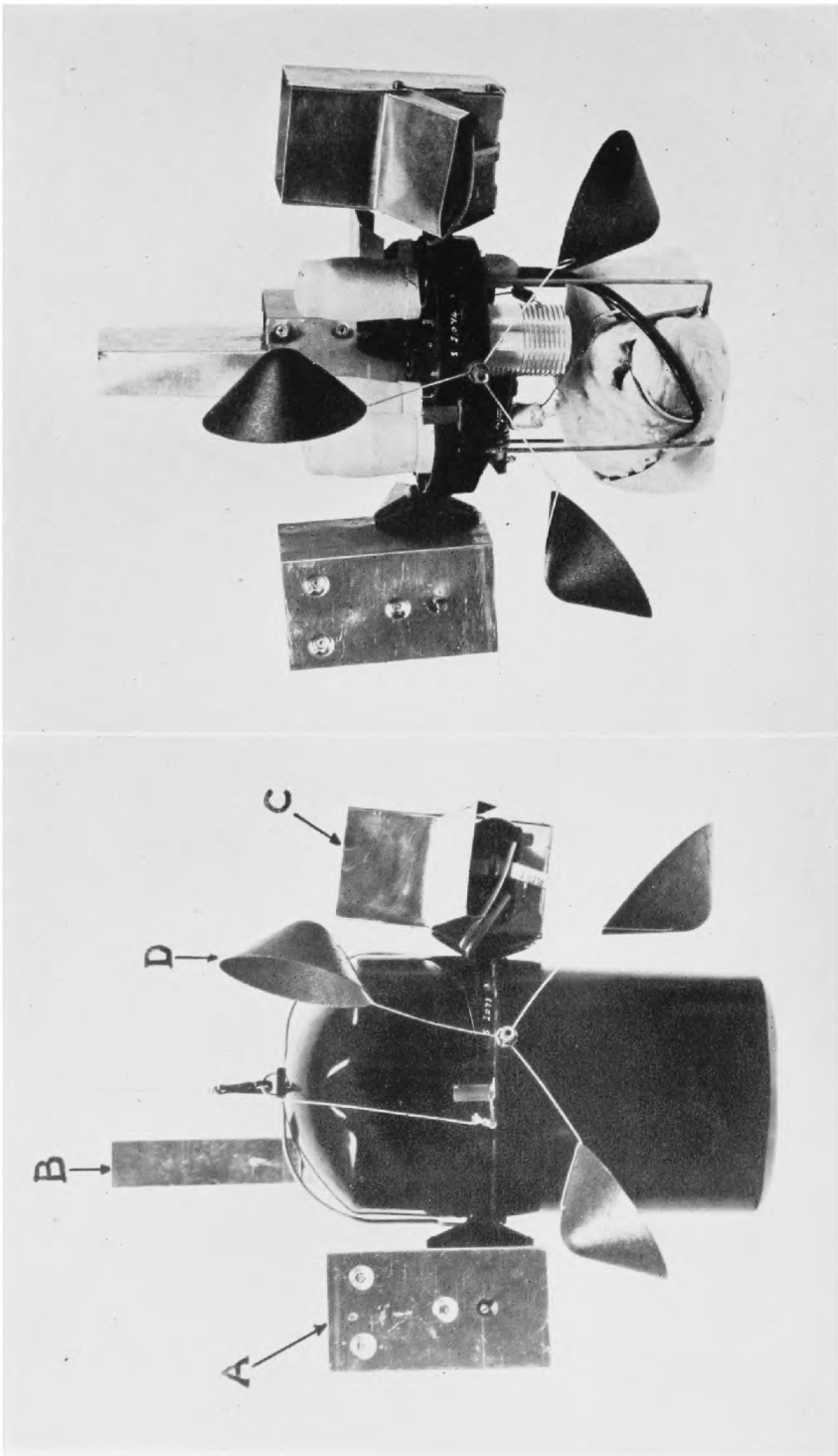


FIG. 22. The British radio-sonde with the cover removed (right) showing the transmitter.
A—barometer ; B—thermometer ; C—hygrometer ; D—windmill

More up-to-date information is obtainable from instruments, self-recording or otherwise, carried in aeroplanes, while in recent years a new instrument, the radio-sonde, has been developed, which seems to be the most satisfactory method of obtaining routine observations from the upper air (*see* Fig. 22). The radio-sonde 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 moveable 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.

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, Dunstable (in Bedfordshire), the Central Forecasting Office of Great Britain ; St. Eval, in Cornwall ; Leuchars, in Fife ; and Irvinestown, in Northern Ireland. Observations are generally made twelve times a day, the observers recording for 15 minutes at each time of observation.

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 with more or less accuracy. 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 observation, 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. The new specification, brought into use on 1st January, 1941, is shown on pages 35 and 36.

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

*See note to Table XVIII.

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.	—	$\frac{1}{2}$
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.	$\frac{1}{2}$	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.	$3\frac{1}{2}$	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	$8\frac{1}{2}$
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.)	$9\frac{1}{2}$	13
7	30	28-33	13.9-17.1	Moderate gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. (Spindrift begins to be seen.)	$13\frac{1}{2}$	19
8	37	34-40	17.2-20.7	Fresh gale	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well-marked streaks along the direction of the wind.	18	25

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*
9	44	41-47	20·8-24·4	Strong gale	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Spray may affect visibility.	23	32
10	52	48-55	24·5-28·4	Whole gale	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 rolling of the sea becomes heavy and shocklike. Visibility affected.	29	41
11	60	56-63	28·5-32·6	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	68	64-71	32·7-36·9	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.

* 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. The probable maximum wave height is reached by about one wave in ten.

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.

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 35 and 36.

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 the same direction as the hands of a watch, i.e., W-N-E-S ; and the term “backing” to denote a change in the opposite direction to the hands of a watch.

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 XVIII,

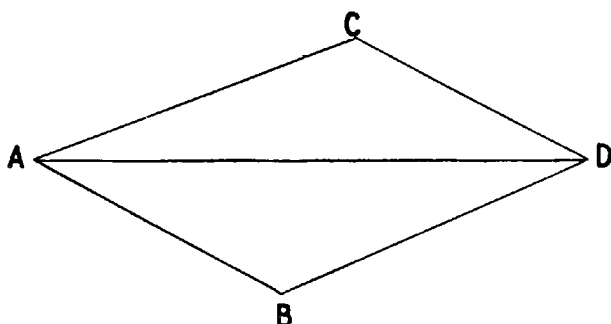


FIG. 23. Wind, parallelogram of velocities

as explained below. In Fig. 23 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

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

the angle BDA being then calculated from the rule of sines. Table XVIII 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 an 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. Admiral Beaufort devised a descriptive system known as the Beaufort Notation which, in an extended form, is still in use for brief descriptions of the weather, past and present.

THE LETTERS OF THE BEAUFORT NOTATION USED TO INDICATE THE STATE OF THE WEATHER

b = Blue sky whether with clear or hazy atmosphere, or sky not more than one-quarter clouded.	q = Squalls.
bc = Sky between one-quarter and three-quarters clouded.	r = Rain.
c = Mainly cloudy (not less than three-quarters covered.)	rs = Sleet (i.e., rain and snow together).
d = Drizzle or fine rain.	s = Snow.
e = Wet air.	t = Thunder.
f = Fog.	tl = Thunderstorm.
g = Gale.*	u = Ugly, threatening sky.
h = Hail.	v = Unusual visibility.
jp = Precipitation in sight of ship.	w = Dew.
kq = Line squall.	x = Hoar Frost.
l = Lightning.	y = Dry Air.
m = Mist	z = Dust haze ; the turbid atmosphere of dry weather.
o = Overcast sky (i.e., the sky completely covered with a uniform layer of thick or heavy cloud.	

The above notation provides a simple means of logging either the actual weather at the time of observation (present weather) or a general summary of the conditions over the interval since the last observation was made (past weather). 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.

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

† In previous editions, "p" indicated *showers of rain*. It should now be used only as a prefix.

The following are further examples of the use of Beaufort notation—

cs_s = Cloudy with continuous slight snow.

oid = Overcast with intermittent slight drizzle.

bif = Blue sky with fog patches.

cqprh = Cloudy with squalls and shower of moderate rain and hail.

ccrm = 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.

Appearance of the sky. The letters “b, c, o, u” are used to describe the general appearance of the sky. The use of the letters “b, c, o” is supplementary to the estimate of the amount of sky covered by cloud, referred to in the section on cloud. The letter “o” should only be used when the whole sky is completely covered with a uniform layer of thick or heavy cloud. In cases where the lower layer is broken and another layer is seen above, although the sky apparently remains completely covered with cloud, the correct Beaufort letter is “c” and not “o”. The use of “o” indicates a cloud layer in which there are no breaks.

Precipitation. A distinction is drawn, in the Beaufort notation, 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.

The duration of precipitation necessary to justify the use of the word “continuous” in reports of past weather cannot be rigidly fixed. If it were to rain without a break for two hours the description would undoubtedly be “continuous rain”. Rain of only half-an-hour’s duration would not be described as continuous; neither would a period of one hour’s rain in the middle of a period without rain. In this latter case the description in Beaufort letters “c, cr, c” might be appropriate. If, however, the hour’s rain came at the beginning of a period and was the continuation of continuous rain in the previous period, it would still be reported as continuous rain in the new report. The appropriate Beaufort letters might then be, for example “rr, c”. Rain which began an hour or more before the report and of which there was no evidence of cessation at the time the report was made would, of course, be reported as “rr”, both in past, and present weather. Observers should cultivate the practice of noting the times of onset and cessation of precipitation. It is important to note if precipitation occurs in the hour previous to the time of observation.

Beaufort letter “e” indicates a state in which the air deposits water copiously on exposed surfaces without rain falling and it occurs when a warm, saturated

or practically saturated air mass replaces a cold, dry air mass. On the other hand, "w" indicates water drops deposited by the condensation of water vapour from the air, mainly on horizontal surfaces cooled by nocturnal radiation.

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. If they are nearly the same, i.e., if the air is almost saturated, then the obscurity may be described as mist or fog. If the difference between wet and dry bulb is appreciable, i.e., if the air is relatively dry, then the obscurity must necessarily be described as haze. 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 but less than one mile, it is known as mist.

The coding of present and past weather. While the Beaufort Notation is admirable for the purpose of logging weather it is not very suitable for transmission by W/T. For this purpose a "figure" code is used. Details of the codes for present weather (ww) and past weather (W) are available in the *Marine Observers' Guide* (M.O. 477), in the *Decode for use of Shipping* (M.O. 509) and in the *Admiralty List of Radio Signals Vol. III, Part A*. The Beaufort Notation is used in the original record. The appropriate numbered equivalents for use in the coded message are easily derived from it, provided supplementary remarks have been made in the log.

Visibility. In the past, the unsatisfactory nature of such vague terms as "fog", "mist" and "haze" led to a demand for a more precise method of indicating the degree of transparency of the atmosphere. On land, observations are made on 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 it is convenient to use the same scale of distances as is used for land observations, modified for marine use as shown below—

VISIBILITY SCALE (WASHINGTON 1947)

(Specification for use at sea)

<i>Code Figure</i>		<i>Code Figure</i>	
90	Less than 50 yards.	95	1 nautical mile.
91	50 yards.	96	2 nautical miles.
92	200 yards.	97	5 nautical miles.
93	500 yards.	98	10 nautical miles.
94	1,000 yards.	99	25 nautical miles or more.

Note. 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 *Marine Observer's Guide* (M.O. 477) and *Admiralty List of Radio Signals, Vol. III, Part A*.

In a long vessel the determination of the lowest numbers 90, 91 offers no difficulty as standard objects on the ship 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 distance, particularly when the height of the eye is great, as in the case of an observer on the bridge of a large liner.

The letter "v" of the Beaufort Notation is used to denote abnormal clearness and transparency of the atmosphere. With such exceptional visibility distant objects stand out from their background with great distinctness and show more sharply-defined detail than usual. At such times it is so clear that stars may be seen to rise and set at night with the unaided eye, and the pole of a steamer's mast, hull down, may be seen on the horizon by day. In cases when "v" is applicable the visibility may be much more than 25 miles, in fact even more than 100 miles.

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. Any deterioration in visibility can usually 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

An observation of cloud involves :—

- (i) Its identification as one of several well-known types.
- (ii) An estimation of the height of its base expressed in hundreds or thousands of feet above the point of observation.
- (iii) An estimation of its amount expressed as a fraction of sky covered.

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

			<i>Approximate height of base</i>
High	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Cirrus (Ci)</div> </div>	} Above 20,000 feet.	
	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Cirrostratus (Cs)</div> </div>		
	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Circumcumulus (Cc)</div> </div>		
Middle	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Altostratus (As)</div> </div>	} 6,500 to 20,000 feet.	
	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Altostratus (As)</div> </div>		
	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Nimbostratus* (Ns)</div> </div>		
Low	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Stratus (St)</div> </div>	} Below 8,000 feet.	
	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Stratocumulus (Sc)</div> </div>		
	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;">Cumulus (Cu)</div> </div>		

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 like meridian 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.

The relevant facts to note in connection with the observation of cirrus are as follows :—

- (i) Whether increasing or not.
- (ii) Whether in polar bands.
- (iii) Whether issuing from a cumulonimbus (Anvil cirrus).

Before sunrise and after sunset, cirrus is 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.

* See footnote on page 48.

† See after page 50 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 47–49.)

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 structure 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.
- (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.

In observing cirrostratus the relevant facts to note are :—

- (i) Whether increasing or not.
- (ii) Whether in polar bands and associated with cirrus.
- (iii) Whether covering the whole sky.

Observation of cirrostratus at night consists in 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.

Alto cumulus (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 is infrequent in the case of cirrocumulus and only the higher forms of stratocumulus can show it. Irisation or iridescence is a phenomenon of the same type as the corona ; it is a sure mark of altocumulus as distinguished from cirrocumulus or stratocumulus (*See also* page 72).

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 castellatus” and “altocumulus lenticularis”. Altocumulus castellatus 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.

Points to note in observing altocumulus are :—

- (i) Whether in a single layer or in bands.
- (ii) If in bands, whether increasing or decreasing.

- (iii) Whether associated with altostratus.
- (iv) Presence of lenticular altocumulus.
- (v) Presence of altocumulus castellatus.
- (vi) Occurrence in several layers associated with fibrous veils and a chaotic appearance of the sky.

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 **fractonimbus (Fb)**, **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 detail. 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 globular masses or rolls; the smallest of the regularly arranged elements are fairly large; they

* Latin; Virga—streak, bough or broom.

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 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 (fractonimbus).

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 "mammatus cumulus". 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.

Cloud forms should be logged, using the standard abbreviations which have been shown in brackets after the names of the clouds, e.g., Cu for cumulus, Cc for cirrocumulus. Sometimes it will be appropriate to log more than one type for each of the classes low, middle and high cloud.

Coding the observations. The procedure when translating the information into the form of a coded message for transmission by W/T is slightly different. 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 clouds.
- 1 Cumulus with little vertical development and seemingly flattened.
- 2 Cumulus of considerable development, generally towering, with or without other cumulus or stratocumulus ; bases all at the same level.
- 3 Cumulonimbus with tops lacking clear-cut outlines but distinctly not cirriform or anvil-shaped ; with or without cumulus, stratocumulus or stratus.
- 4 Stratocumulus formed by the spreading out of cumulus ; cumulus also often present.
- 5 Stratocumulus not formed by the spreading out of cumulus.
- 6 Stratus or fractostratus or both, but not fractostratus of bad weather.
- 7 Fractostratus and/or fractocumulus, of bad weather ("scud") usually under altostratus or nimbostratus. (By "bad weather" is meant the conditions usually prevailing before, during or after precipitation.)
- 8 Cumulus and stratocumulus other than those formed by the spreading out of cumulus, with bases at different levels.
- 9 Cumulonimbus having a clearly fibrous (cirriform) top, often anvil-shaped, with or without cumulus, stratocumulus, stratus or "scud".

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

Code Figure

- 0 No altocumulus, altostratus, or nimbostratus clouds.
- 1 Thin altostratus (semi-transparent everywhere) through which the sun and moon would be seen dimly as through ground glass.
- 2 Thick altostratus, or nimbostratus.* (Through portions of the sheet the position of the sun or moon may be indicated by a light patch).
- 3 Thin (semi-transparent) altocumulus ; cloud elements not changing much ; at a single level.
- 4 Thin (semi-transparent) altocumulus in patches (often almond or fish-shaped) ; cloud elements continually changing and/or occurring at more than one level.
- 5 Thin (semi-transparent) altocumulus in bands or in a layer gradually spreading over the sky and usually thickening as a whole ; it may become partly opaque or double-layered.
- 6 Altocumulus formed by the spreading out of cumulus.
- 7 Any of the following cases :—
 - (a) double-layered altocumulus, usually opaque in parts, not increasing ;
 - (b) a thick (opaque) layer of altocumulus, not increasing.
 - (c) Altostratus and altocumulus both present at the same or different levels.
- 8 Altocumulus in the form of cumulus-shaped tufts or altocumulus with turrets.
- 9 Altocumulus of a chaotic sky ; generally at different levels ; dense cirrus in patches is usually also present.

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

Code Figure

- 0 No cirrus, cirrocumulus, or cirrostratus clouds.
- 1 Filaments or strands of cirrus, scattered and not increasing (often "mares' tails").
- 2 Dense cirrus in patches or twisted sheaves usually not increasing ; possibly but not certainly the remains of the upper part of cumulonimbus.
- 3 Cirrus, often anvil-shaped ; either the remains of the upper portions of cumulonimbus or part of a distant cumulonimbus the rest of which is not visible. (If there is any doubt as to the cumulonimbus origin or association, code C_H 2 should be used.)
- 4 Cirrus (often hook-shaped) gradually spreading over the sky and usually thickening as a whole.
- 5 Cirrus and cirrostratus, often in bands converging towards the horizon ; or cirrostratus alone ; in either case gradually spreading over the sky and usually thickening as a whole, but the continuous layer not reaching 45° altitude.

* 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. Nimbostratus is classified as a low cloud on page 43 because its base, the only part visible from the ground, is at low cloud level.

- 6 Cirrus and cirrostratus, often in bands converging towards the horizon ; or cirrostratus alone : in either case gradually spreading over the sky and usually thickening as a whole, and the continuous layer exceeding 45° altitude.
- 7 Cirrostratus covering the whole sky.
- 8 Cirrostratus not increasing and not covering the whole sky ; cirrus and cirrocumulus may be present.
- 9 Cirrocumulus alone or cirrocumulus with some cirrus or cirrostratus, but the cirrocumulus being the main cirriform cloud present. (Cirrocumulus may be present in C_H 1 to C_H 8).

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. The classification “low,” “middle” and “high” refers roughly to height. Low clouds have their bases below 8,000 feet. Middle clouds may occur at any level between 6,500 feet and 20,000, while high clouds are those above 20,000 feet. These limits are not precisely fixed ; thus high clouds may sometimes occur at altitudes below 20,000 feet and even below 18,000 feet.

At meteorological stations ashore, cloud height is usually measured by pilot balloons or (at night) by cloud searchlights. (*See* page 31.)

Apart from 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. Of the low clouds it is useful to remember that stratus is generally very low, its height varying from near the surface to approximately 2,000 feet. Stratocumulus occurs most commonly between 1,500 feet and 5,000 feet though the upper limit is rather flexible and may extend to 8,000 feet. The base of cumulus usually lies between 2,000 feet and 5,000 feet and that of cumulonimbus between 1,000 feet and 5,000 feet. Nimbostratus may occur at any height between 300 feet and 8,000 feet.

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.

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, when the individual cloudlets of an altocumulus layer appear large it is probable that the height is near the lower limit of the middle cloud band, whereas a layer whose cloudlets appear small, is probably nearer the upper limit. 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.

The unaided eye observation of cloud height at night is difficult because of the difficulty of recognising the various cloud types. On land the difficulty has been overcome by the use of the "Ceiling Light Projector", or cloud searchlight, which permits the accurate measurement of cloud height at night. The method is being tried out experimentally at sea. For details *see* page 31.

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, then 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 G. A. Clarke

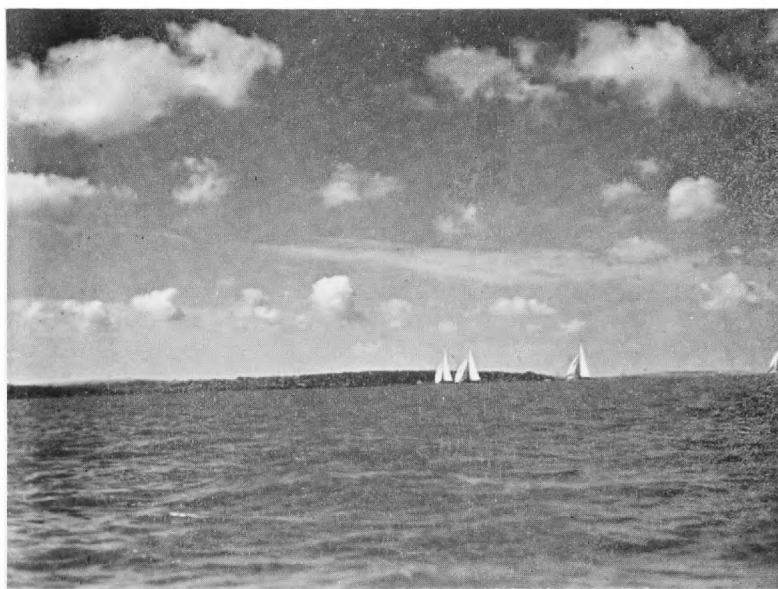


Photo by Naval Meteorological Service, Admiralty

C_L I Fair weather cumulus. The clouds look rather like cauliflowers. The bases tend to be flat and to be at a uniform level. They are scattered and have a flat and deflated appearance. The horizontal extension is greater than the vertical. The words "Fair Weather" are not to be interpreted as a forecast; they refer to the weather at the time, and imply that there is no evidence in the sky of precipitation at the time in the neighbourhood.

The lower photograph shows fair weather cumulus with ragged fragments (fractocumulus) and some altocumulus cloud in the background.

Cloud Plate I

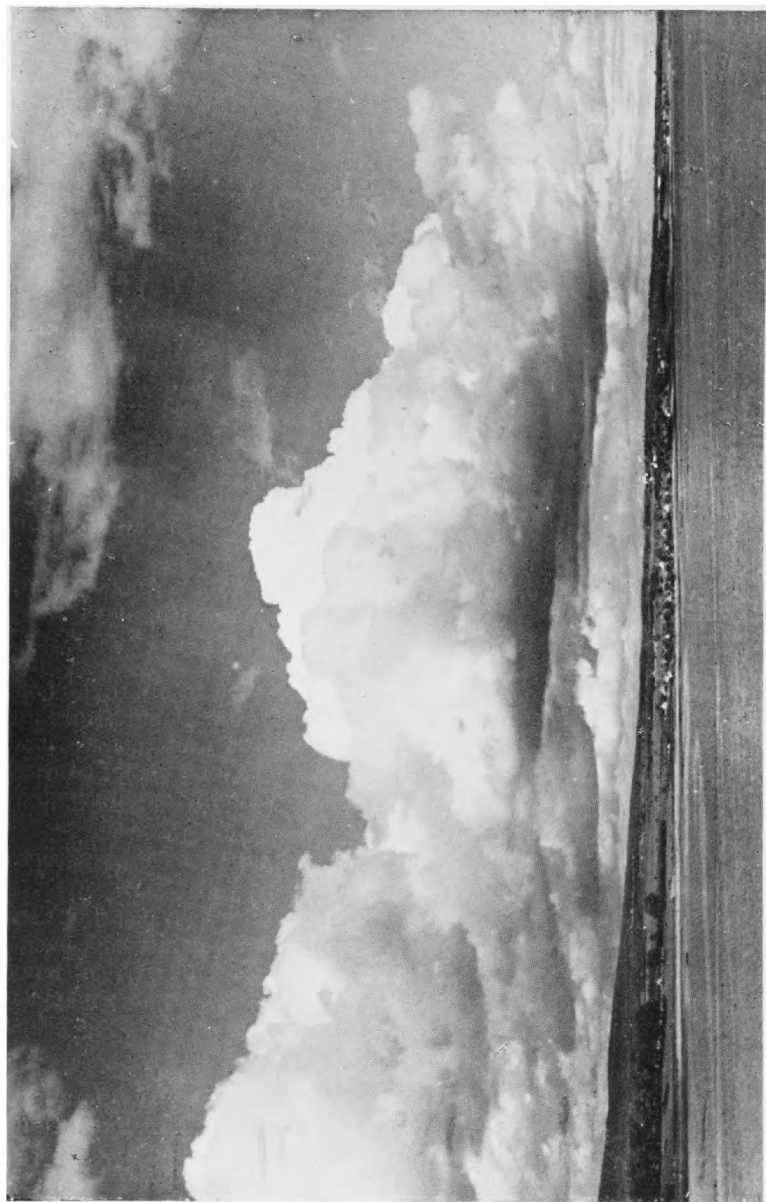


Photo by Cdr. E. R. Trendell, R.N.

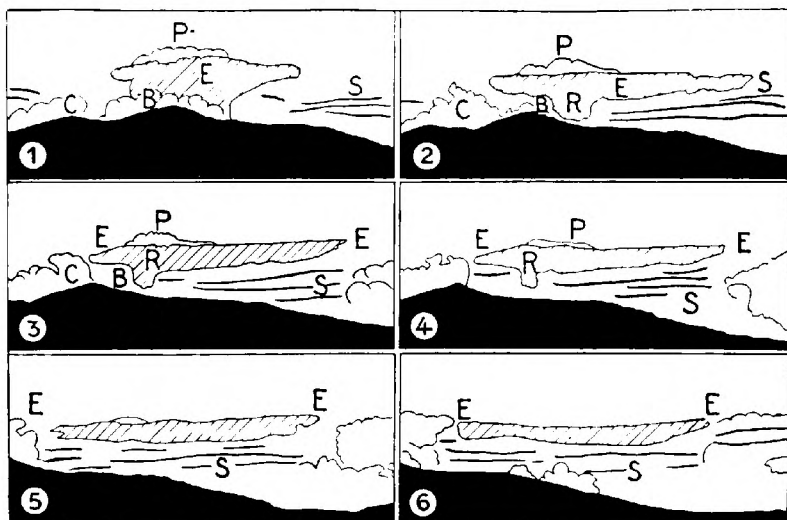
CL 2 Towering cumulus. The difference between these and the fair weather cumulus is that the tops of the clouds instead of remaining rounded (and apparently quiescent) begin to bulge upwards and "rising heads" appear. These can be seen clearly in the photograph. Their edges are still well defined and are not softening at the top into cirrus cloud.



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C_L 3 Cumulonimbus without anvil. Distinguished from C_L 2 by the fact that the tops are beginning to acquire a fibrous appearance and by showers falling from the base. The tops are however not cirriform or anvil-shaped and the type is therefore C_L 3 and not C_L 9.

Cloud Plate III



Reproduced from the International Atlas of Clouds

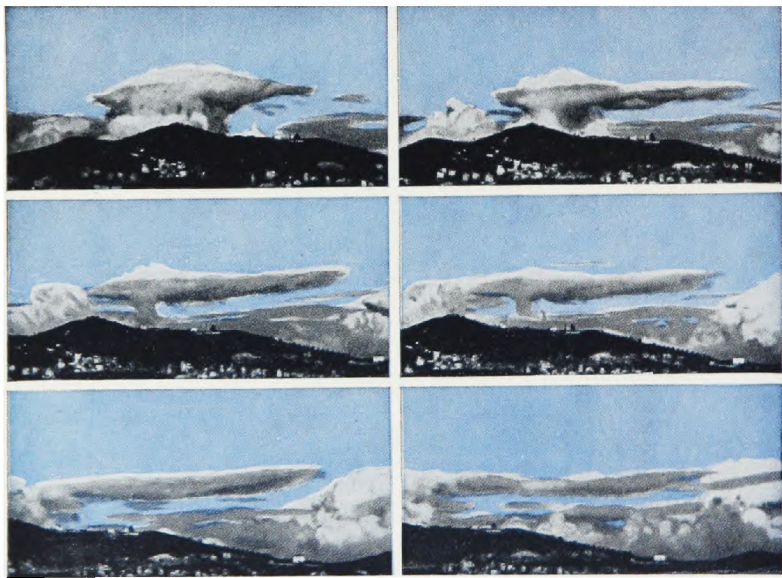


Photo by the Fundació Concepció Rabell, Barcelona

C_L4 Stratocumulus formed by the spreading out of cumulus. This cloud is formed in two ways : (a) during the day when there is a stable layer on or an inversion which the convective cumulus clouds reach and cannot penetrate ; (b) in the evening when convection weakens, with or without an inversion above the cumulus. It is most common in the evening.

"The time from the beginning to the end of the series shown is 20 minutes. 1. It is clear that the top of the cloud that is growing out is of the rounded cumulus type (B) without any cirriform parts. The spreading out has been at (E) and the head of the cumulus has penetrated the extension at (P). 2. (P) has developed a little, but (B) is decreasing and (E) which is increasing in extent, is beginning to separate off, so that the extreme base of the cloud (R) is now seen. 3. (P) grows smaller, (B) has completely settled down and is detached at (R), while (E) is still developing in extent. 4. (P) has completely settled down, (R) is melting away, (E) is completely independent. 5 and 6. There is no longer any trace of (P) or (R) while (E) is fully formed : notice the pendant shreds of cloud on the lower surface. On all the photographs other bands of stratocumulus may be seen in the distance which are being drawn out into stratus ; they probably originated in the same way."

Cloud Plate IV



Photo by C. J. P. Cave



Photo by G. A. Clarke

CL5 Stratocumulus not formed by the spreading out of cumulus. The individual cloud masses may be detached and more or less lenticular in shape as in the upper photograph, or close together in a continuous (or nearly continuous) layer. Strato-cumulus is often a dark cloud particularly in winter, but it may be fairly light—usually when it is at a fairly high level

Cloud Plate V



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Photo by G. H. D. Evans

C_L 6 Stratus. The upper illustration shows orographic cloud over Fitful Head, Sumburgh. With a moist onshore wind the lift provided by the headland is sufficient to cause condensation, producing stratus cloud. An observer on the headland would describe this cloud as fog. The lower picture shows the stratus of lifted fog.

Cloud Plate VI



Photo by G. A. Clarke



Photo by G. A. Clarke

C_L 7 Ragged low clouds of bad weather. These low clouds, collectively known as **fractonimbus**, often show up very dark against a relatively lighter background of altostratus or nimbostratus. The upper picture shows fractocumulus of bad weather below a background of nimbostratus ; the predominant feature of the lower picture are the ragged low clouds (fractostratus).

Cloud Plate VII



Photo by C. J. P. Cave



Photo by G. A. Clarke

C_L 8 Cumulus and stratocumulus. The base of the cumulus is lower than that of the stratocumulus, distinguishing C_L 8 from C_L 2 or C_L 4.

Cloud Plate VIII



Photo by F. Ludlam



Photo by C. J. P. Cave

C_L 9 Cumulonimbus with anvil. The cumulonimbus cloud in the background of the upper picture has a clearly defined anvil of false cirrus. In the foreground is a cumulonimbus which has not yet reached this stage of development. The well marked protuberances which distinguish it from large cumulus are present. If this cloud were observed alone it would be described as C_L 3.



Photo by G. A. Clarke

C_M 1 Typical **altostratus (thin)**. This is a darkish veil usually covering the whole sky, though not always. It looks rather like a thinly fogged photographic plate. The sun or moon appears as though shining through ground glass and does not cast a shadow. Halo phenomena are not seen in altostratus. A sheet of this cloud resembles thick cirrostratus (see C_H 7) from which it is often derived.



Photo by G. A. Clarke

C_M 2 Typical **altostratus (thick)** (sun and moon invisible) or **nimbostratus**. The sun and moon are generally hidden or are indicated only by the lighter colour of one part of the cloud. Typical thick altostratus can be formed either by a thickening of thin altostratus or by the fusing together of the cloudlets in a sheet of altocumulus. The picture illustrates an example rather on the thin side ; in many cases the lightness will be less evident or will not appear at all.



Photo by C. J. P. Cave

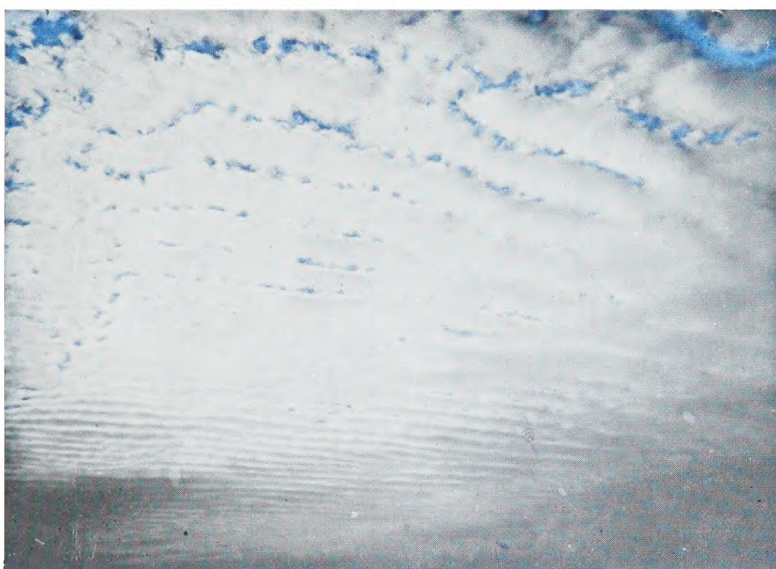


Photo by G. A. Clarke

C_M 3 Single layer of **altocumulus** or **high stratocumulus**. Altocumulus often looks like sheep's fleeces. This type generally forms a single layer ; it is fairly regular, and of uniform thickness, the cloudlets always being separated by clear spaces or lighter gaps ; the cloudlets are neither very large nor very dark. This layer is generally fairly persistent, it does not change or disappear quickly. Cases of altocumulus which are so dense that the waves do not show lighter parts should be reported as C_M 7.

Cloud Plate XI



Photo by G. A. Clarke

C_M 4 **Altocumulus** in isolated patches—often lenticular. The cloudlets may be as small as cirrocumulus, but lenticular altocumulus shows delicate colouring (irisation). Where this is so, the clouds are often scattered over the sky quite irregularly and may be at different levels. Though individually they may be changing, the amount of cloud over the whole sky generally remains about the same.



Photo by Lindenberg Observatory

C_M 5 **Altocumulus** in bands (increasing). In this type either the bands are great elongated masses, sometimes appearing rather dark, often of a roughly lenticular shape, or the ordinary altocumulus waves are crossed by blue lanes, so that they appear like bands (with the waves across the bands). An essential feature of this type is that the sky becomes more and more covered. Often the layer thickens up as in the photograph or has another layer of cloud lower and darker forming beneath it.



Photo by G. A. Clarke

C_M 6 **Altocumulus** formed from the spreading out of cumulus. Cumulus clouds of sufficiently great vertical development may undergo an extension of their summits while their bases may gradually melt away. The process is similar to that of C_L 4 but at a higher level. The cloud which looks anvil-shaped must not be confused with C_L 3.



Photo by the Office National Météorologique, Paris

C_M 7 (a) **Double-layered altocumulus**. The higher layer includes the very lightly shadowed tessellations and ripples. The lower layer of typical altocumulus is strongly shaded.



Photo by F. W. Baker

C_M7 (b) Thick opaque layer of **altocumulus**



Photo by C. J. P. Cave

C_M7 (c) **Altocumulus** associated with **altostratus**. Different types are comprised in this section. There may be two definite layers of altostratus and altocumulus or the altocumulus may be thickening into altostratus by the cloudlets fusing together or altostratus may break up into altocumulus.

Cloud Plate XIV



Photo by G. A. Clarke

C_M 8 Altocumulus castellatus. The character common to the types of altocumulus C_M 8 is vertical development, a turret or a dome shape. These clouds are often the precursors of thunderstorms. Altocumulus castellatus is composed of small cumuli-form masses with more or less vertical development, either detached or forming a band as in the above example.

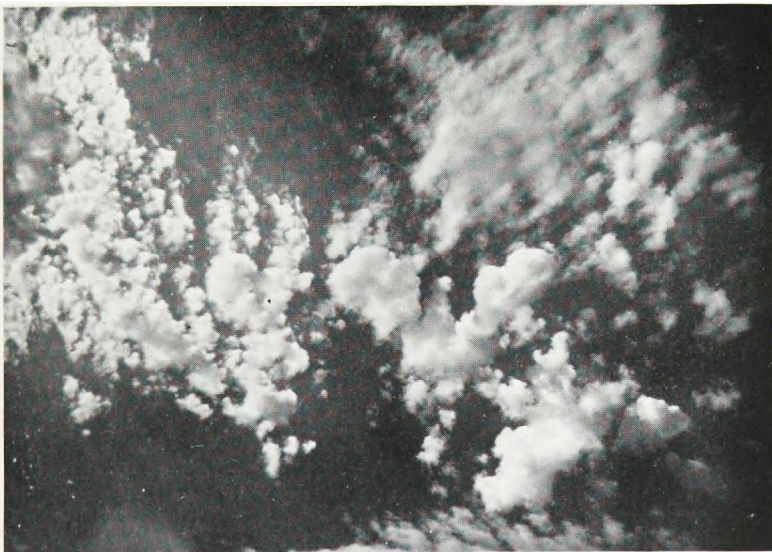


Photo by G. A. Clarke

C_M 8 Altocumulus floccus. The cloudlets are of ragged appearance without definite shadows and with the rounded parts slightly domed. There are often pronounced trails (*virga*) of cirriform appearance



Photo by G. A. Clarke



Photo by the Office National Météorologique, Paris

C_M 9 Altocumulus in several layers generally associated with fibrous veils and a chaotic appearance of the sky. The sky has a disordered, heavy and stagnant appearance. It is very complex with patches of medium cloud more or less fragmentary, superposed, often badly defined and giving all the transitional forms between low altocumulus and the fibrous veil.



Photo by G. A. Clarke



Photo by the Fundació Concepció Rabell, Barcelona

C_H I Fine cirrus not increasing; sparse. Wisps of cloud at a very high level; they may be scattered over a large part of the sky but they do not amount to very much; the amount does not increase noticeably either in time or in any particular direction.

The clouds do not collect into sheets and bands, and there is no tendency for the elements to fuse together into masses of cirrostratus. The cirrus cloud whose strands end in an upturned hook or tuft must not be included in this class.

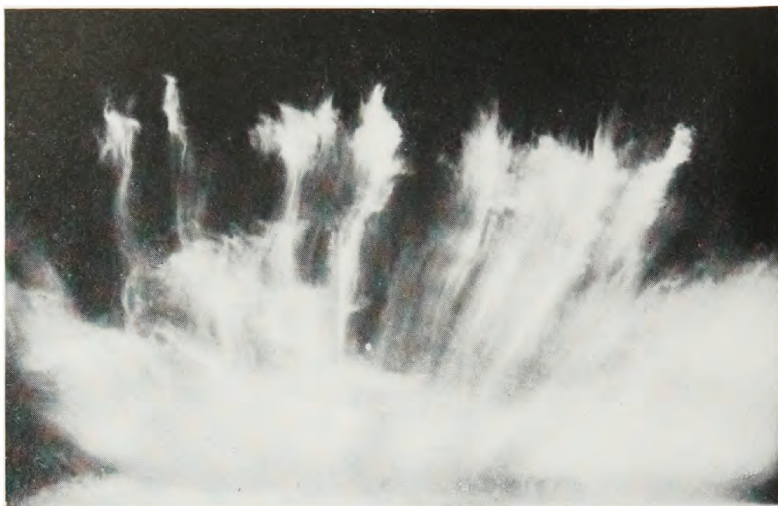


Photo by G. A. Clarke



Photo by G. A. Clarke

C_H 2 Dense cirrus in patches or twisted sheaves. Cirrus of this type is more “woolly” in appearance than C_H 1 and is possibly, but not certainly, the débris of the upper part of cumulonimbus.



Photo by the Fundació Concepció Rabell, Barcelona

C_H 3 Cirrus, often anvil-shaped, usually dense, which is known to be either the remains of the upper part of a disintegrated cumulonimbus or part of a distant cumulonimbus the rest of which is not visible at the time of observation.



Photo by the Fundació Concepció Rabell, Barcelona

C_H 4 Hooked cirrus. This type of cirrus, which is in the form of streaks ending in a little upturned hook or in a small tuft, increases in amount both in time and in a certain direction. In this direction it reaches to the horizon, where there is a tendency for the cloud elements to fuse together, but the clouds do not pass into cirrostratus.

Cloud Plate XIX



Photo by G. A. Clarke

C_H 5 Cirrus or cirrostratus increasing ; still below 45° altitude ; often in polar bands. Sheet of fibrous cirrus partly uniting into cirrostratus, especially towards the horizon in the direction where the cirrus strands tend to fuse together ; the cirrus is often in a herring-bone formation or in great bands converging more or less to a point on the horizon. In this class is also included a sheet of cirrostratus which does not cover the sky and is below 45° altitude.



Photo by G. A. Clarke

C_H 6 Cirrus or cirrostratus increasing and reaching above 45° altitude ; often in polar bands. The definition of this type is the same as the previous one, with the exception that the cloud reaches more than 45° above the horizon. (*Note.*—Altitudes if not measured instrumentally are deceptive ; it is common to over-estimate a point in the sky. A point at 30° altitude will appear to be about 45° altitude.)



Photo by G. A. Clarke

C_H 7 Veil of cirrostratus covering the whole sky, either (a) a thin uniform nebulous veil, sometimes hardly visible, sometimes relatively dense, always without definite detail, but producing halo phenomena round the sun and moon ; or (b) a white fibrous sheet, with more or less clearly defined fibres, often like a sheet of fibrous cirrus from which indeed it may be derived.



Photo by G. A. Clarke

C_H 8 Cirrostratus not increasing and not covering the whole sky. This is a case of veil or sheet cirrostratus reaching the horizon in one direction but leaving a segment of blue sky in the other direction ; this segment of blue sky does not grow smaller, otherwise it would be reported as C_H 5 or C_H 6. Generally the edge of the sheet is clear-cut and does not tail off into scattered cirrus. The photograph shows a sheet of cirrostratus with a well-defined edge and some scattered cumulus clouds (C_L 1).

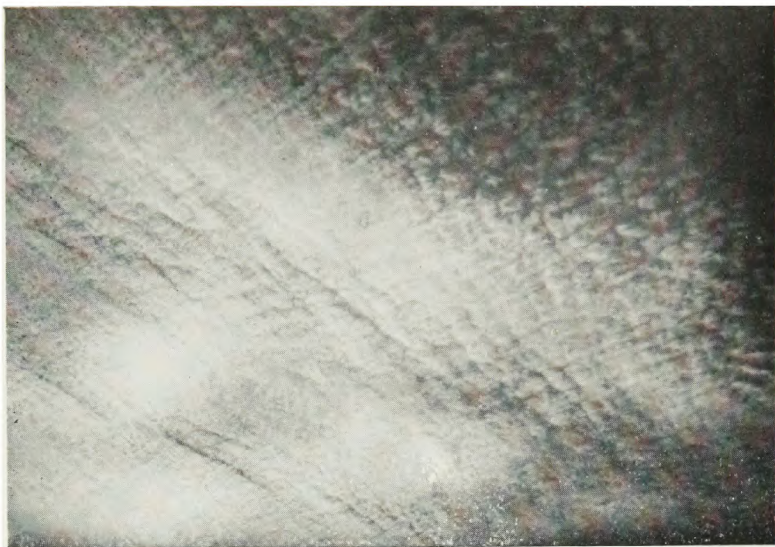


Photo by C. J. P. Cave



Photo by G. A. Clarke

C_H 9 Cirrocumulus is a wavy type of "mackerel" sky with a delicate fine structure. Cirrocumulus is not to be confused with small altocumulus. There must be either evident connection with cirrus or cirrostratus or the cloud observed must result from a change in cirrus or cirrostratus. The lower picture shows cirrocumulus predominating and a little cirrus. Cirrocumulus may occur with any of the types C_H 1 to C_H 8.

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 in any plane at a particular place will, in general, notice a complicated wave form such as is shown in Fig. 24, which may be regarded as the result of the superposition of a number of simple symmetrical wave-motions having different lengths and speeds.



FIG. 24. Wave form of the sea-surface

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. 24 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".

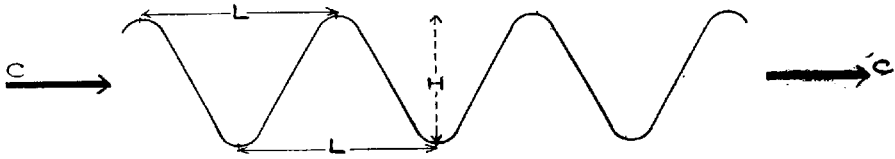


FIG. 25. Characteristics of a simple wave

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 :—

$$\text{Speed} = 3.1 \times \text{Period.}$$

$$\text{Length} = 5.1 \times (\text{Period})^2.$$

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 :—

<i>Period</i> (secs.)	<i>Length</i> (feet)	<i>Speed</i> (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.

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

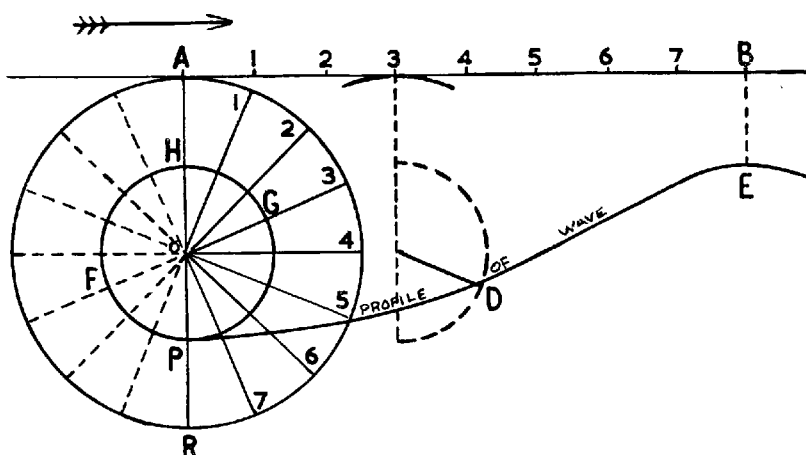


FIG. 26. Representation of a trochoidal wave form

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 become again 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. A rough rule states that swell loses one third of its height in a distance in nautical miles numerically equal to its length in feet. Thus a swell of 1,000 feet length will lose one third of its height in travelling a distance of 1,000 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.

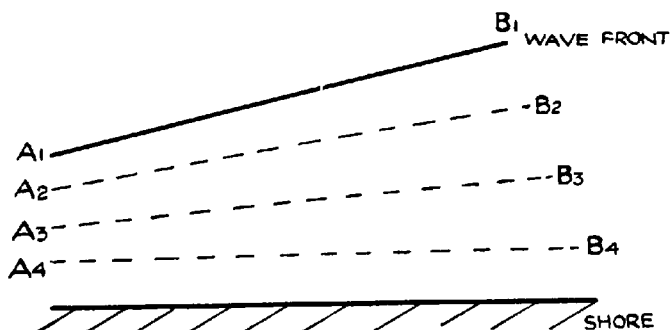


FIG. 27. Refraction of a wave approaching the shore at an angle

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. 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 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 best method therefore, seems to be 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 it used to be the practice for the observer to note "sea" and "swell". Under the new system, however, he should merely give details of the two systems of "waves", specifying direction, period and height of both, when possible.

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. There is no method available at present for *measuring* the height of the waves from aboard a 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. 28.) 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. 28 (a)

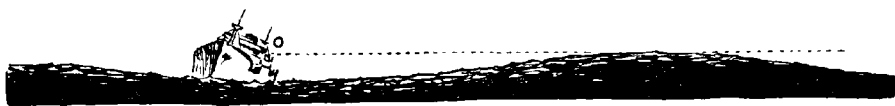


FIG. 28 (b)

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 practical.

Observing waves from Weather Ships. It is hoped that wave-recorders which can record the period and height of the waves, will soon be adapted for use from Weather Ships. Even if 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.

The traditional descriptive terms for sea and swell will of course continue to be used for all general purposes other than meteorological reports.

CHAPTER 7

Observations of Ocean Current and Ice

OCEAN CURRENT OBSERVATION

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 astronomical or land 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. Quarterly current charts have been prepared for the Atlantic and Indian Oceans and for the north-western part of the Pacific Ocean. 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. A study of shipping casualties will show the value to the mariner of accurate information concerning currents.

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.

Currents of varying rate and direction may be experienced along the track made in 24 hours, therefore when reliable fixes, such as by stellar observations at twilight, are obtained, the current should be determined between the star fixes concerned. Each of these currents determined at shorter intervals than 24 hours should be recorded, in addition to the "noon to noon" set and drift. When coasting, sets and drifts obtained from land fixes are very desirable, except in waters known to be tidal.

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 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, 1948, Safety of Navigation, Regulations 2, 3 and 4 (*see* Chapter 12).

Provision for reporting ice has been made in the new 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 now in general use for the various kinds of sea ice :—

ANCHOR-ICE. All submerged ice attached to the bottom irrespective of the nature of its formation.

BARRIER ICE OR SHELF ICE. A form of land ice or land ice afloat in the Antarctic, produced by an accumulation of horizontal layers of snow which has reached the intermediate opaque "névé" or "firn" stage before passing into true glacier ice. Portions of the barrier break off to form tabular bergs.

BAY ICE. Term formerly in use for newly-formed "level ice", of sufficient thickness to impede or prevent navigation. The alternative terms "young ice" and "level ice", or in certain cases "winter ice" and "fjord ice", are now preferred. In the Antarctic the term has been used at times for heavy land-floes.

BERG. *See* Iceberg.

BERGY BITS. Medium-sized pieces of glacier ice, which may originate either from a glacier or from disrupted hummocky ice. Typical bergy bits have been described as about the size of a cottage. Cf. Growler and Floeberg.

BLACK ICE. Thin dark-looking ice with no snow on it. A variety of "young ice".

BRASH. Small fragments, not more than 6 feet across, the wreckage of other forms of ice. Also ice in a waterlogged state and appearing of darker tone. The American equivalent is generally "mush". In appearance not unlike "sludge" or "slush", but brash fragments are of widely varying size.

CLOSE PACK. Pack composed of floes, mostly in contact, such that navigation becomes difficult except for specially constructed ships.

CONSOLIDATED PACK. The heaviest form of pack ice, other than heavy polar ice. No lanes or leads. Quite unnavigable.

DRIFT ICE. Loose, very open pack, where water preponderates over ice. Vessels can usually proceed at full or moderate speed with little alteration of course. The floes are in most cases smaller and lighter than those in close or open pack, and are often associated with rotten ice and brash. A term formerly much in use, but liable to confusion with "drivis", the Norwegian equivalent of "pack ice". Cf. Open pack.

FAST ICE OR LANDFAST ICE. Sea ice of widely varying width, which remains fast along the coast in the position of growth, and which may attain a thickness

considerably above the average. When thick ice of this nature breaks off and drifts away it forms "land-floes".

FJORD ICE. Term used by Scandinavians for level ice originating in fjords. Cf. Winter ice.

FLOE. A piece of sea ice other than fast ice, large or small. Light floes are anything up to 2-3 feet in thickness; floes of greater thickness, both level and hummocked, are called "heavy floes".

FLOEBERG. A massive piece of sea ice or hummock (a berg in appearance but a floe in origin).

GLACIER ICE. Any ice originating from land glaciers, whether found on land or floating in the sea as bergs.

GROWLER. A piece of ice almost awash, smaller than a bergy bit, and appearing greenish in colour.

HUMMOCK. A ridge or hillock of sea ice due to rafting and pressure. Cf. Floeberg.

ICEBERG. A large mass of floating ice, broken from a glacier.

ICE FIELD. A area of pack ice consisting of very large floes several miles across, of such extent that its limits cannot be seen from the masthead.

ICE FOOT. Ice step attached to the coast, unmoved by tides, and remaining after the fast ice has moved away.

ICE STREAM. An isolated strip of brash or pack ice pressed together by wind, swell or tide.

ICE TONGUE. A long, narrow tongue of ice, attached to the shore at one end, found in the Antarctic. An ice tongue may be many miles in length.

LAND-FLOE. See Fast ice.

LANDEFAST ICE. See Fast ice.

LEVEL ICE. All unhummocked ice, no matter of what age or thickness. In the early stages it is more usually termed "young ice". Cf. Bay ice, Fjord ice, Winter ice.

MUSH. See Brash.

OPEN PACK. Floes seldom in contact and with many leads and pools, so that navigation is comparatively easy for ordinary vessels.

PACK 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, approximately circular, about 1-6 feet across, and with raised rims, due to the pieces striking against each other.

POLAR ICE. Extremely heavy floes up to 10 feet or more in thickness, of considerable age and great extent, originally very heavily hummocked, but ultimately reduced by weathering to a more or less even surface.

ROTTEN ICE. Floes which have become much honeycombed in the process of melting.

SEA ICE. Any form of ice found at sea which has originated from the freezing of sea water.

SLUDGE OR SLUSH. The initial stages in the freezing of sea water, when it assumes a greasy appearance, and a scum of ice crystals is formed on the surface. Cf. Brash.

TABULAR BERG. Flat-topped iceberg generally broken off from barrier or shelf ice.

WINTER ICE. Term used by Scandinavians for level ice of one season's growth.

YOUNG ICE. Level ice in its earliest stages, with or without snow cover, comparatively salt and with characteristic crystalline structure. When without snow cover often known as "black ice".

Other terms associated with ice and ice navigation are :—

BESET. Situation of a vessel when closely surrounded by ice and unable to move.

BLINK. See Ice-blink and Land-blink.

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.

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

DEBACLE. The break-up of the ice in rivers in spring.

FLAW. See Shore-lead.

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

HUMMOCKING. Process of pressure formation by which level ice becomes broken up into hummocky pack. Where the floes rotate in the process it is termed "screwing".

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

ICE-BLINK. Yellowish-white glare in the sky, produced by reflection of pack ice on clouds. The pack ice may be beyond the range of vision. Ice-blink is rarely, if ever, given by icebergs except of very large size, such as tabular bergs. Cf. Water-sky, Land-blink.

ICE EDGE. The boundary at any given time between pack ice and the open sea. It may be a regular line with considerable tightening of the floes along the edge, known as a "sea bar", or may consist of a succession of ice streams or patches, or may be frayed out into a number of points and bights, with perhaps off-lying isolated fragments. The position of the ice edge depends on wind and tide, and varies considerably from month to month and year to year. The average position for any given month, based on observations over a number of years, is described as the monthly ice limit.

LAND-BLINK. Similar to ice-blink, but produced by ice-covered land.

LANE OR LEAD. A navigable passage through pack ice; a lead may still be so named even if covered with young ice.

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".

OPEN WATER. Free navigable water in an ice-encumbered sea. Cf. Pool.

POOL. Any enclosed sea water area in the pack, other than a lane or lead. Not to be confused with fresh water pools formed by melting on the surface of old polar ice. The name polyn'ya is used in Russian to denote areas of open sea water of different sizes, some of very wide extent.

PRESSURE AREA. Area of hummocked ice formed by floes pressed together and piled up.

PRESSURE RIDGE. Ridge or wall of hummocked ice where one floe has been pressed against another.

RAFTING. Caused by floes meeting, when the edges are broken off and one floe passes over the other. A mild form of pressure.

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

SEA BAR. *See* Ice edge.

SEA SMOKE. *See* Frost smoke.

SCREWING. *See* Hummocking.

SHORE-LEAD. Stretch of navigable open water formed when pack ice moves away from the fast ice under the influence of wind or tide. The edge of the fast ice is sometimes called the "flaw".

TIDE CRACK. The line of junction between an immovable ice foot and fast ice, the latter being subject to rise and fall of the tide.

WATER-SKY. Dark streak in the sky, due to reflection on the clouds of open water, or broad lanes, or pools. Cf. Ice-blink.

WATER SMOKE. *See* Frost smoke.

WORKING. Making headway through pack ice.

Part III Phenomena

GENERAL REMARKS ON ALL PHENOMENA

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 two 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*, and selected ones will also be communicated to the appropriate scientific authorities.

GENERAL METHODS OF OBSERVATION OF PHENOMENA

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-glare" spectacles 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 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 can also be made at the time. Accuracy of size and relative position of the main features of what is seen is the prime requirement; elaboration of detail and artistic merit are of secondary importance.

For making notes or sketching at night, the minimum amount of artificial light should be used. If available, coloured paper makes an excellent background for the use of white or colour chalks. For phenomena at night, a dark blue or indigo paper is best. For cloud sketches by day, a blue-tinted cartridge paper is good.

Photographs are often preferable to sketches. A photograph and a coloured sketch make a good combination. 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.

CHAPTER 8

Meteorological Phenomena

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.

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 84) will be of interest. There is some evidence that the foremast or fore part of a modern ship is that most likely to be struck.

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 or yards and sometimes on the stays, aerial 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.

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. It is more often, but not always, counter-clockwise in the northern hemisphere and clockwise in the southern. The spout is a hollow tube ; on rare occasions double walled spouts have 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.

Waterspouts are in general more common in the tropics. Their occurrence does not however depend entirely on latitude ; they are especially frequent off the east coast of the United States, the coasts of China and Japan, and in the Mediterranean and Gulf of Mexico. In the North Sea an average of about two per annum is recorded.

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

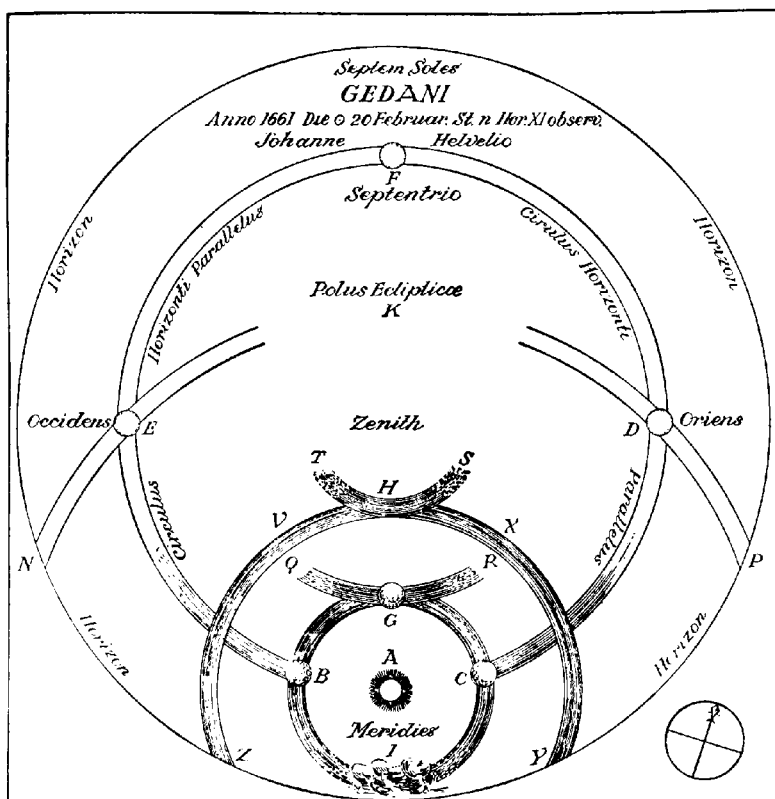


FIG. 29

Halo Complex observed at Danzig, 20th February, 1661.

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. 29 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.

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 never as brilliant and pure as those of a bright 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 shows more of the spectrum. 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 moon) 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. 30. 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. 30 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. 29). 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. 29). They cannot be formed when the sun's altitude exceeds $60^\circ 45'$. 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. 29, shows the upper contact arc and Fig. 31, 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. 29). 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

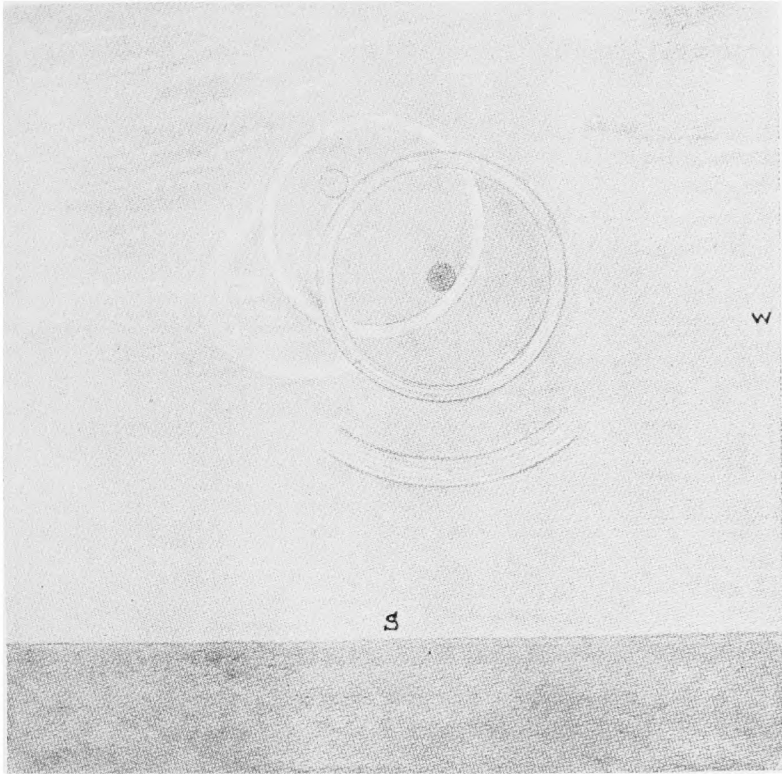


FIG. 30

SOLAR HALOS
CARIBBEAN SEA

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

“ March 6th, 1925. Position at Noon : Latitude $13^{\circ} 09' N.$, Longitude $75^{\circ} 07' W.$ At 11.45 a.m. a halo, showing the colours of the spectrum, formed around the sun with a radius of $21\frac{1}{2}^{\circ}$, the breadth of the spectrum subtending an angle of $\frac{3}{4}^{\circ}$. 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.”

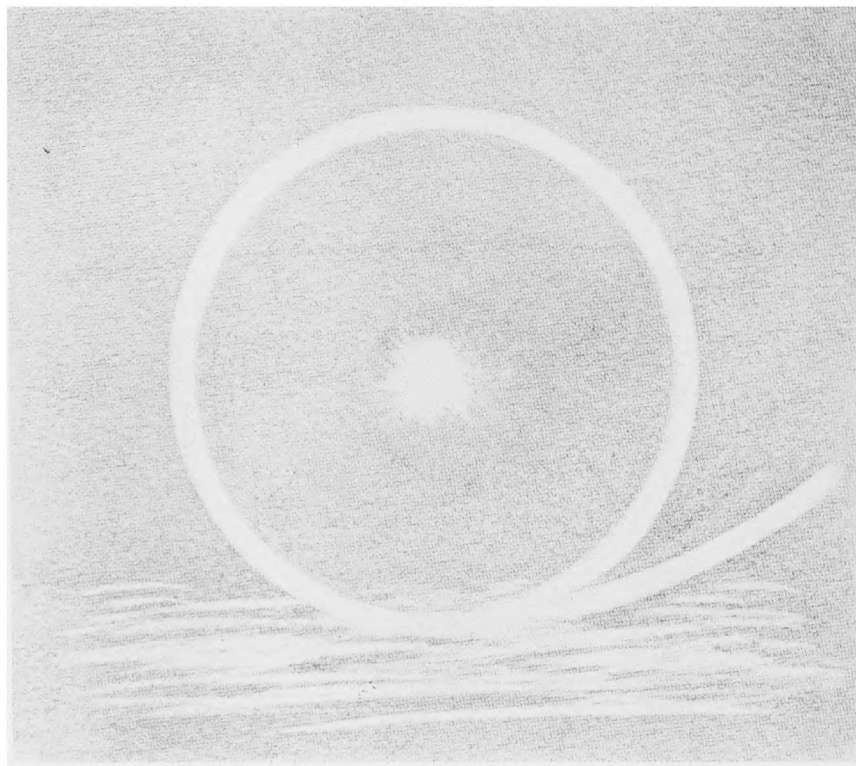


FIG. 31

LUNAR HALO

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

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

higher altitude and convex to the sun (THS, Fig. 29), while a rainbow is seen on the opposite side of the observer to the sun (*see* page 70). 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. 29). 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 seen centred on the sun, with various radii between 8° and 32° . Should one of these very rare halos be observed, it 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, called the anthelion (F, Fig. 29) 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.

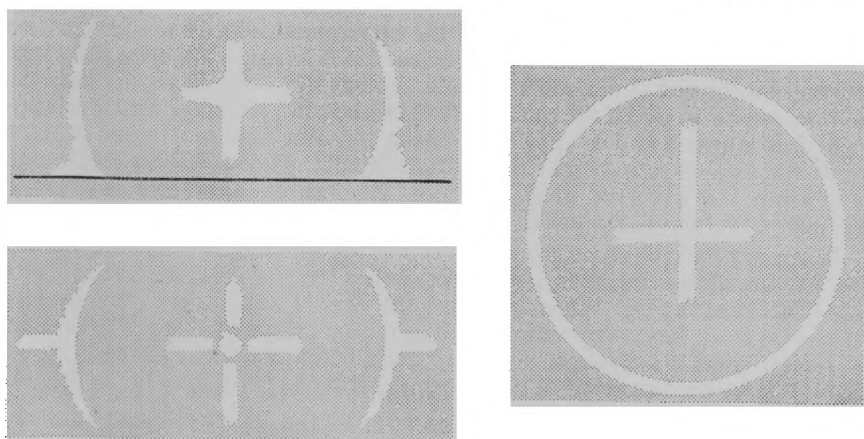


FIG. 32
Forms of Halo Cross

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. 32). The vertical arm is usually formed by part of a sun pillar and the 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. 30, 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.

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 are one or two fainter "supernumerary bows", with the colours in the same order, the first inner bow being much fainter than the primary bow and the second fainter still. Supernumerary bows do not, however, show the full range of spectrum colours; 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 $40\frac{1}{4}^\circ$; 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 $1\frac{3}{4}^\circ$ 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 69).

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.

The observer who wishes to make useful observations of rainbows should record the colours seen and their sequence. If supernumerary bows are seen, their number and colouring should be noted. If the secondary bow is unusually bright, supernumerary bows should be looked for closely above it. These have been seen on rare occasions but are very faint. Observations of any bows seen, other than those above described, should be recorded in as full detail as possible. Bows or arcs of bows have sometimes been seen which have not yet been explained. In other cases additional bows are produced by the reflected image of the sea in calm waters, giving bows independently of the main ones. In all observations of unusual bows the state of the sea should therefore be recorded. A bow may occur in the opposite direction, between the observer and the sun, but it is so faint that an observation of it is of extreme rarity. It is essential in recording unusual bows that angular measurements should be given; these may usually be taken from one of the common bows. Arcs of unusual bows sometimes meet one of the ordinary bows at the horizon.

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 82), and to the outer part of the sun's atmosphere ; these are usually distinguished as the "auroral corona" and the "solar corona", respectively.

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.

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.

In some winters, in very clear sky after the passage of a deep depression to north or east, a very rare high form of cloud, known as mother-of-pearl cloud, has been seen in Norway and elsewhere in north-west Europe. By simultaneous photography at the ends of a base-line, it has been shown that these clouds are about 16 miles high. They show an exceptionally brilliant form of iridescent colouring, if within 40° of the sun, particularly before sunset. This colouring may persist until half-an-hour or more after sunset. Ordinary cloud iridescence is not seen after sunset.

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.

CREPUSCULAR RAYS

Three similar classes of phenomena are grouped under this name.

(i) Sunbeams piercing a layer of stratus or other low cloud, directed downwards to the earth's surface and rendered luminous by the mist and dust in the air. This is popularly known as "the sun drawing water". A similar effect may also be produced when the sun is behind hills or mountain peaks in the daytime.

(ii) Pale blue or whitish beams diverging upwards and outwards from the sun when this is behind cumulus or cumulonimbus cloud. The beams are sharply defined and separated by steely or violet-blue streaks which are the shadows of parts of the irregular cloud-edge. Blue bands or arcs are occasionally seen in the sky when the sun is low or below the horizon. These may be hill or mountain shadows.

(iii) The red or rose-coloured sunbeams, diverging upwards, formed in twilight when the sun is below the horizon, coming through the openings of a cloud edge or of hill or mountain ranges, which may be either on or below the horizon. The shadows may or may not be very noticeable; they appear greenish by contrast.

In the case of either (ii) or (iii), the beams and shadows may persist right across the sky until they converge by perspective on the horizon at the antisolar point.

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 of the horizon line that has been occasionally seen, also lateral mirages and the mixed ones known as "Fata Morgana* ". When the 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 should be noted.

* The name—of Italian origin—given to the complicated mirages of the Strait of Messina.

THE GREEN FLASH

Two separate phenomena associated with the moment of sunset or sunrise occur. The first one described below is the more common and is called the green flash or sometimes the green ray. The latter name would be more appropriate for the second phenomenon.

(i) When the sun sets in favourable conditions, the small segment of the upper part of its disc may momentarily turn a vivid green, or bluish-green, or, much more rarely, cobalt-blue. Very exceptionally, the last impression of the colour is violet. The phenomenon only lasts a fraction of a second ; no sooner does the green colour flash than the last segment of the sun, and the colour, disappears. The green colour is often very brilliant and is then conspicuous without optical assistance. When less brilliant, it may be well visible in binoculars. In still less favourable circumstances, the colour, as seen in binoculars, is just a tinge of grey-green.

For some little time before the sun finally sets its red disc sometimes appears, by effects of refraction, to be "boiling" upwards, giving off shreds or tongues of green vapour. This phenomenon is usually followed by the green flash described above. Both phenomena depend on the unequal refraction of light of different colours, when the sun is very near the horizon.

The green flash may be observed at sunrise, but is liable to be missed unless the exact point at which the sun will appear is known.

The green flash may be looked for before sunset, if the upper limb of the sun passes behind a bank or bar of hard-edged cloud at low altitude. In general, binoculars are necessary for this observation. On the reappearance of the lower limb of the sun from behind a hard-edged cloud, a red flash has sometimes been seen.

The green flash occurs also with the moon, but has been seldom observed, presumably because it is fainter and rarely looked for. It has been seen at the setting of the bright planets Venus and Jupiter, and many interesting varieties of the phenomenon occur, if observed with binoculars, including perhaps slow lateral "swimming" movements of the planet, or its separation into two images, white and red, or red and green, or alternate colour changes when the image is single.

The most favourable conditions for seeing the green flash are probably (a) the air relatively free from dust, as when "washed clean" after heavy rain so that the sun remains brighter and less red than usual near the horizon, (b) the existence of abnormal refraction. The phenomenon is not, however, always observed when conditions appear favourable. Many seamen have never seen it, but if looked for it will be found to be by no means rare. A sea horizon is not necessary ; a distant hard-edged land surface will exhibit it equally well.

(ii) In the second phenomenon, an actual ray of green light is seen to shoot up momentarily from the sun at or just after sunset, sometimes to a considerable altitude, or an appearance of a rapidly rotating green searchlight beam may be seen. Another variety of the phenomenon is an appearance as of a green mist over the sky above the setting sun. This is transitory and should not be confused with the green patches of clear sky not infrequently seen after sunset in the brighter stages of twilight.

Further observations of these phenomena will be of value, if the detail of what is actually seen is 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.

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 $48\frac{1}{2}^{\circ}$ 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 Krakatoa 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.

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 Krakatoa 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

The clear starlight night is illuminated by the green light of the permanent aurora (*see* page 83). This is visible as a very slight luminosity, but is too faint to show colour. 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.

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 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. Green moons were observed on many occasions after the great eruption of Krakatoa 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.

Any observations of this kind are of interest.

NOCTILUCENT CLOUD

This rare phenomenon is not true cloud. It is produced by the reflection of sunlight from masses of volcanic or meteoric dust high in the stratosphere. The average height of these masses is 51 miles, found by simultaneous photographs taken a considerable distance apart. Noctilucent clouds have been seen only between latitudes 45° and 60° , north or south, mainly between the middle of May and the middle of August. They are not visible in the daytime, but begin to appear in a clear sky about a quarter of an hour after sunset. They somewhat resemble cirrus in form, but are distinguished by standing out bright against the sunset afterglow, whereas any true cirrus present at this time would show dark against the afterglow. Noctilucent cloud is seldom seen at a higher altitude than 10° above the horizon. It is bluish-white or silvery white in colour and is brightest about an hour after sunset, but it may remain visible all through the dark hours.

CHAPTER 9

Miscellaneous 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 discoloration 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.

PHOSPHORESCENCE OF THE SEA

Careful observations of the more interesting forms of phosphorescence are valuable. These include (i) the diffused light producing the "milky sea"* , which may give light enough to read by and to illuminate clouds (ii) stationary bands, (iii) the great rotating band systems, called "phosphorescent wheels", a well-authenticated but comparatively rare phenomenon, of which no explanation is known.

Observations should include estimates of the length and width of bands, whether stationary or not. In the "wheel", the bands appear to rotate in a regular manner, and a careful observation of the time at which successive bands pass the ship should be made. The evidence of previous observations is that this rate is too rapid to be merely an apparent effect produced by the ship's motion past stationary bands. Confirmation of this and any other details with regard to this phenomenon will be welcomed. The phosphorescent wheel has been observed in the Indian Ocean and China Seas.

* Also known as "white water".

Phosphorescence may occur in any part of the oceans but is most frequent in the warm tropical seas. It appears to be particularly prevalent in the Arabian Sea, especially in July and August.

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 Krakatoa in 1883 was collected on ship-board in the Indian Ocean at a distance of 900 miles. After the eruption of Hekla in March, 1947, dust was similarly collected at a distance of 450 miles.

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 should always be given.

AURORÆ AND MAGNETIC STORMS

General remarks. A fine display of aurora is one of the most beautiful and impressive of natural phenomena. It is the visible manifestation of the passage through the upper atmosphere of electrically charged particles ejected from the sun, but the process is not yet fully understood. The height of the patches of luminous gases averages about 60 miles, but may lie anywhere between about 40 and 600 miles. The brightness of aurora varies within wide limits; it may be so faint as to be hardly visible, while on the other hand it is said sometimes to surpass the full moon in brightness in high latitudes. The duration of an aurora is very variable, from a few minutes to some hours, even in relatively low latitudes. In high latitudes it not infrequently persists all night, from dusk to dawn.

Regions of occurrence. Aurora in the northern hemisphere occurs most frequently along a line which forms an approximate oval, of radius 23° , centred in the extreme north-west of Greenland. This line runs south of Cape Farewell, and along the south coast of Iceland. It passes just north of North Cape, touches the north of Novaya Zemlya, skirts Cape Chelyuskin and then goes eastward into the north of Alaska. Thence it descends to lower latitudes, crossing Hudson Bay and the Labrador coast in about latitude 58° N.

Along this line aurora of some kind can probably be seen on every clear night; 250 miles southward of this maximum zone, the average auroral frequency decreases to about 70–100 nights a year, and to 20–25 nights 500 miles south of the zone. As the maximum zone is not centred on the geographical pole, auroræ are seen in lower latitudes in some parts of the northern hemisphere than in others. In the western North Atlantic they are occasionally seen as far south as latitude 20° N., so that, at corresponding latitudes, many more auroræ are seen in North America than in Europe. In the eastern North Atlantic and eastern North Pacific, the limit is about latitude 30° N. to 40° N. In the western Pacific, it is about latitude 45° N. Auroræ are probably never seen in the Indian Ocean, north of the equator.

Less is known about the frequency and distribution of aurora in the southern hemisphere. The most favourable longitudes are probably those between about longitude 50° E. and 180° , particularly between longitude 90° E. and 130° E., which includes the region south of Australia and New Zealand.

Forms of auroræ. These are very varied and are subject at times to rapid changes. All the forms contained in the international classification, which is now adopted, are mentioned below, but full descriptions of each cannot be given here.

ARCS. These are of many forms. The simplest is a segment of a circle, of more or less uniform light. The altitude of the highest point differs on different occasions. This point is usually on or near the observer's magnetic meridian, in lower latitudes, but occurs in almost every magnetic azimuth in high latitudes. The sky between the arc and the horizon appears darker than the surrounding sky at the same altitude, and is known as the "dark segment". This is a contrast effect and stars may be seen undimmed in it. Two or more concentric arcs may be seen at the same time. An arc may have patches of different brightness, or it may be elliptical or irregular in form. Providing that traces of twilight and zodiacal light are absent, a faint glow near the horizon resembling dawn, is often the upper part of an arc, the lower part of which is below the horizon.

Arcs showing flickering light or rhythmic appearance and disappearance are called *Pulsating Arcs*. Sometimes, arcs are made up of a great number of

separate, more or less vertical rays ; these are called *Arcs with Ray-Structure*.

RAYS. These often extend from an arc towards the zenith. They are of different lengths and widths and are sometimes grouped into fan-shaped formations. They are liable to rapid changes and also to darting movements towards the zenith.

BANDS. These appear as ribbons of light, often with a sharply-defined lower border, less regular in form than arcs, and subject to more rapid movement. Their light is often more or less uniform, but if they are composed of short separate rays they are called *Bands with Ray-Structure*.

DRAPERIES OR CURTAINS are one of the most impressive forms, especially when the colouring is vivid, but are seldom seen except in fairly high latitudes. They often appear in rapid motion.

DIFFUSED PATCHES sometimes fill a large part of the sky. Smaller ones resemble illuminated clouds, without distinct outlines. They often appear after a fine display of rays or curtains, and may be violet, red, white or greenish in colour. Patches sometimes appear and disappear every few seconds, retaining the same irregular shape ; these are called *Pulsating Patches*.

CORONA. When rays extend so high towards the zenith as to converge by perspective, an auroral corona is formed. A complete corona is perhaps the finest of all auroral phenomena. It forms a more or less regular crown of light round a comparatively dark centre. Sometimes it appears to be in rapid rotation about the point of convergence.

FLAMING AURORA. This is a characteristic form, appearing as bright bands or arcs which rapidly move upwards in succession in the direction of the magnetic zenith. This frequently occurs after active displays of rays and curtains and is frequently followed by the formation of a corona.

Magnetic storms. These are disturbances of the earth's magnetic field, shown by more or less large and sudden changes or oscillation of a freely suspended magnetic needle. Magnetic storms are due to the same cause that produces auroræ and a considerable or great magnetic storm is always accompanied by an aurora. Slight magnetic storms are not necessarily accompanied by aurora, and in high latitudes, where both are more common, there is often no apparent connection between the two phenomena. Intense magnetic storms and their associated auroræ usually occur simultaneously in both hemispheres.

The duration of magnetic storms varies greatly, from a few minutes to several days. Long-continued storms have periods of great activity, followed by intervals of complete or partial quiescence. The most intense storms usually occur during the hours of darkness. Sudden abnormal deviations of a ship's compass may occur during a big magnetic storm (*see* page 84).

The auroral display. The most usual display in temperate latitudes of Europe and the North Atlantic Ocean consists of a single or double arc, often remaining for a considerable time with little or no change. This is often seen alone, but rays may be visible diverging from it ; these may remain stationary for a time, or they may show some lateral shift. The most usual colours are white, or pale shades of green or yellow, but there may be a slight red coloration of the rays or arcs.

When an intense magnetic storm is in progress, the accompanying aurora is brighter and more active, and more varied in form and colour. It may show much movement, sometimes from instant to instant. The colour is some shade of red, rose, orange or green, generally, but sometimes violet and other colours

are seen. The colour is likely to be most vivid when the aurora rises high towards the zenith in the form of rays or draperies. When a corona is formed, the display becomes very complex, filling practically the whole sky and extending far to the south of the zenith (in the northern hemisphere). Such an aurora, if of considerable duration, usually shows alternate periods of activity and quiescence. The periods of really intense activity usually last 15–30 minutes, the intervening ones being characterised by diffuse glows or quiet arcs, or even by a complete disappearance of aurora. These are associated with the alternations of activity and quiescence in the magnetic storm, referred to above.

In places nearer the zone of maximum frequency, the usual display has not the complexity, colour, rapid movement and change of form of an aurora associated with an intense magnetic storm. It often, however, gives a brighter and more continuous light, the arc being higher in the sky, with rays up to high altitudes.

Relation of auroræ and magnetic storms to solar activity. Auroræ and magnetic storms are more frequent in the years of maximum solar activity (see Sunspots, page 86), so that the frequency and intensity of these phenomena have an 11-year period. They are not, however, wholly absent at any time of the solar cycle, except perhaps near the time of minimum activity. As auroræ are always very numerous in high latitudes, the effect of the increase of solar activity is not so much an increase in their number as in the intensity and vividness of the displays. In relatively low latitudes, the effect is mainly an increase of the number seen.

A magnetic storm and bright aurora may occur near the time of passage of an exceptionally large sunspot across the central meridian of the sun's disc, but this is not invariably the case. On the other hand, these phenomena may occur in the absence of such a centrally situated spot.

Seasonal and diurnal frequency of aurora. Aurora is probably most frequent in the late evening, from 9 p.m. till about midnight, but it can occur at any time of night, particularly in high latitudes. It is more frequent in the equinoctial months.

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. The azimuth of any part should always be given as a true bearing. In measuring the altitude of the apex of the auroral arc, the lower edge should be taken, this being usually the brightest and best defined. When an arc extends right down to the horizon it is worth recording the number of degrees between the ends, measured on the horizon. Auroral photography requires time exposures and is thus not often possible on shipboard. Observations from relatively low latitudes are of particular interest, as also are those made in any part of the southern hemisphere.

THE PERMANENT AURORA

On a clear starlight night, in the absence of twilight, moonlight, artificial light or displays of aurora, the sky background is not black, 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 permanent aurora. Generally it is uniform over the main part of the sky, but occasionally patches of somewhat greater luminosity have been seen. A faint patch of light seen in that part of the ecliptic which is 180° from the sun is, however, a phenomenon of a different character (see Gegenschein, page 91).

Towards the horizon the permanent aurora is usually brighter. In the absence of other sources of light, it appears as a faint but quite definite diffused glow along the horizon, or part of the horizon, at night, extending upwards for 10° or more.

The lightness of the sky background may remain the same for weeks on end, but it is not always the same, and exceptionally light nights are thus observed from time to time, which have no connection with abnormal duration of twilight occasionally observed (*see page 76*).

ABNORMAL COMPASS DEVIATIONS

A ship's magnetic compass may deviate during the progress of a considerable magnetic storm. If the 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 magnetic 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 10 or 20 minutes before dying out. Deviations of 2° or more have been known, but are rare. During the great magnetic storm and aurora of 25th January, 1938, a deviation of 4° eastward was observed off the Portuguese coast. Further oscillation may occur after a period of quiescence.

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.

RADIO PHENOMENA

Radio. During a considerable magnetic storm, freak radio reception may occur on certain waves, and short wave transmission may fade to complete silence. Beam radio communication, especially in a west-east or east-west direction, may be interrupted. Such conditions may last, in some degree, over a period of several days at times when the sun is unusually active.

Short wave fading also occurs occasionally from a certain form of solar disturbance known as a "bright eruption", when this is very intense. On the average such fading begins about 7 minutes after the occurrence of the bright eruption, and may last 5 or 10 minutes, gradually returning to normal within a period of 40 or 45 minutes. These fadings are confined to the daylight hemisphere of the earth, while the magnetic storm fadings may occur by day or at night.

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 and/or a fall of humidity near the surface, 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 wave lengths.

CHAPTER 10

Astronomical Phenomena

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 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.

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 and structure of rays, streaks or bands, and

sometimes curved forms like flower petals. Its form varies in different years and sometimes part of it may extend on either side as far as two or more diameters of the sun. More detail will be seen with binoculars. One observer should concentrate on sketching the form and size of the corona as accurately as he can. This observation will be of real scientific value, since 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 probably does not exceed two hours. Another observer may try to get a photograph of the corona, which will be of value, but will not show as much detail as a good sketch.

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 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.

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. Millions of these objects enter the atmosphere daily, the vast majority of which are entirely disintegrated and subsequently settle down slowly to the earth's surface in the form of extremely fine dust. A few, however, whose original bulk is greater, may partially survive the disintegrating effect and reach the earth's surface in solid form. These are called meteorites or aerolites. Some have been seen to fall 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 of the planets Jupiter or Venus, or, in the very finest examples, may greatly exceed the full moon in brilliancy. Many meteors, on the other hand, are invisible without optical aid.

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 80 miles at the time of appearance and 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 considerable value. 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 observations of the same trail are received from two or more observers, the speed and direction of the wind at great heights 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.

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 vapourising 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 is still some confusion between the appearance of a comet and a meteor. A meteor is only seen for a second or two as it flashes through the sky. A comet remains apparently fixed among the stars and sets with them in due course. It has a movement relative to the stars, but in most cases this can only be seen in a naked-eye observation by comparing its exact 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.

Observers at sea can make useful observations of a comet by noting the brightness of its head relative to some star or planet, or giving a general estimate, such as 3rd magnitude, also by giving any other information such as its colour, the presence of a tail, the general form of the tail and its length in degrees. Sometimes more than one tail is seen. The observer cannot make a sufficiently exact observation of the position of the head of the comet among the stars to be of use in determining the orbit, but angular distances of the head from two or more bright stars or planets, measured by sextant, are desirable, so that the object may be identified. Sometimes more than one comet is visible at the same time.

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, owing to the absence of suitable comparison stars.

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.

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.

Part IV Meteorological Work at Sea

CHAPTER 11

Organisation of Voluntary Meteorological 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 has undergone very little change up to the present day.

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 that radio weather reports from merchant ships were organised on a satisfactory scale. 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.

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 (see Chapter 12). A conference of Empire Meteorologists held in London in 1946 ensured that all Meteorological Services of the British Commonwealth would act in close accord in the organisation of maritime meteorology.

Throughout the history of the Marine Branch 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".

Since 1921, a specified number of vessels known as "Selected Ships" have not only recorded their observations but have transmitted them by radio, in a special code, at regular intervals, for synoptic purposes. The international hours for this purpose are 0000, 0600, 1200 and 1800 G.M.T. and the messages are sent from all oceans through designated shore stations, addressed to meteorological centres, in accordance with an international scheme. A number of ships, which decreased as time went on, continued merely to record observations at the end of each watch (e.g., at 00, 04, 08, 12, 16 and 20 hours A.T.S.) in the Meteorological Log, for climatological purposes. In recent years the need for reports from shipping by radio has so increased that the old form of Meteorological Log has been discontinued and all ships now report at fixed times G.M.T. The data recorded in this manner can still be used for climatological purposes.

The British Commonwealth scheme for the organisation of Marine Meteorology. The Conference of Empire Meteorologists (1946) agreed that all Meteorological Services of the British Commonwealth would collectively organise meteorological work at sea, ensuring uniformity of procedure and equipment and a more complete distribution of information to shipping.

For aiding navigation and providing essential weather information, in accordance with the International Convention for Safety of Life at Sea, all Meteorological Services within the British Commonwealth will arrange for certain ships of the Merchant Navy to record observations and to transmit weather messages at stated hours daily through shore radio stations detailed to receive them.

Voluntary Observing Ships are divided into two classes ; "Selected Ships" and "Supplementary Ships". Selected Ships are equipped with tested equipment as follows :—

- (i) Mercurial barometer.
- (ii) Barograph.
- (iii) Wet and dry-bulb thermometer (and a "Stevenson" screen), or an aspirated psychrometer.
- (iv) Sea thermometer.

Supplementary Ships are not equipped with the full scale of tested instruments and their observations are made in a somewhat abbreviated form.

Each Meteorological Service is responsible for recruiting its own ships. In addition, each Service may recruit, as Selected Ships, British registered ships which normally consider the ports under that Service as their home ports, or normally ply in adjacent waters. Other ships of this same category can be recruited as Supplementary Ships, where necessary.

Representatives of these Meteorological Services may, if they wish, visit any British Selected 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 Supplementary Ships, when in the area of the Service concerned. The Services concerned will inform the British Meteorological Office of the names of Selected and Supplementary Ships recruited by them. The British Meteorological Office will promulgate this information, together with the names of all ships recruited in Britain.

The ships concerned 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 *Marine Observer's Guide* (M.O.477), or in the *Admiralty List of Radio Signals*, Vol. III.

A new meteorological log for synchronised observations has been prepared and will be used in all the ships concerned.

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.

Meteorological services for shipping. The first meteorological service for shipping was the issue of visual Gale Warnings, started in 1861. Since the introduction of radio, meteorological warnings of all kinds have also been broadcast direct to shipping.

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 *International Meteorological Code. Decode for use of Shipping* and in the *Admiralty List of Radio Signals*, Vol. III, Part A. Briefer bulletins are issued by radio and radio telephony for the benefit of coastal shipping.

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 Branch of the Meteorological Office is 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 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 Hollerith machines 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.

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 Western North Pacific.

Monthly Meteorological Charts of the Atlantic.

Monthly Meteorological Charts of the Eastern Pacific.

Monthly Meteorological Charts 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 Branch of the Meteorological Office and ships' captains and observers is maintained through Port Meteorological Officers at Liverpool, London, Southampton, Cardiff and Glasgow, and Merchant Navy Agents at Leith, Newcastle and Hull.

Indirect contact with the Observing Fleet is maintained through the medium of the *Marine Observer*, a publication devoted to the needs and interests of observing officers.

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.

The World Meteorological Organisation. While the Commonwealth Conference provides for uniformity of practice in marine meteorology among the various Services of the British Commonwealth, the World Meteorological Organisation 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 Organisation (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, is 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 Organisation, held its first congress in Paris during 1951, and has taken 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 Branch 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.

CHAPTER 12

International Convention for the Safety of Life at Sea, 1948

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, 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 (Radio Section). 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 Administration will take all steps which it thinks 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 Administrations interested.

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

(d) All messages issued under this Regulation shall be preceded by the Safety Signal, using the procedure as prescribed by the Radio Regulations.

Regulation 3

Information required in Danger Messages

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

(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 when the observation was made.

(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 exists in his neighbourhood.
- (ii) Meteorological Information. Each shipmaster should add to his warning message as much of the following meteorological information as he finds practicable :—
 - the Greenwich Mean Time, date and position of the ship when the observations were taken ;
 - barometric pressure (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 other 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.

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.

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 and ice conditions, forecasts, and when practicable, sufficient additional information to enable simple weather charts to be prepared at sea.
 - (iii) To prepare and issue such publications as may be necessary for the efficient conduct of meteorological work at sea.
 - (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 standard synoptic hours (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 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 recommendations made by the International Meteorological Organisation, 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. PATTERN KEW BAROMETER
(Inch Scale)*Corrections to be applied to the barometer readings to obtain pressures in inches of mercury at 32°F.*

Attached Thermo- meter	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
°F.	+	+	+	+	+	+	+	+	+	+	+
0	·076	·077	·078	·080	·081	·082	·084	·085	·086	·088	·089
1	·073	·075	·076	·077	·078	·080	·081	·082	·083	·085	·086
2	·071	·072	·073	·074	·076	·077	·078	·079	·081	·082	·083
3	·068	·070	·071	·072	·073	·074	·075	·077	·078	·079	·080
4	·066	·067	·068	·069	·070	·071	·073	·074	·075	·076	·077
5	·063	·064	·066	·067	·068	·069	·070	·071	·072	·073	·074
6	·061	·062	·063	·064	·065	·066	·067	·068	·069	·070	·071
7	·058	·059	·060	·061	·062	·063	·064	·065	·066	·067	·068
8	·056	·057	·058	·059	·060	·061	·061	·062	·063	·064	·065
9	·053	·054	·055	·056	·057	·058	·059	·060	·060	·061	·062
10	·051	·052	·053	·053	·054	·055	·056	·057	·058	·058	·059
11	·048	·049	·050	·051	·052	·052	·053	·054	·055	·056	·056
12	·046	·047	·047	·048	·049	·050	·050	·051	·052	·053	·053
13	·043	·044	·045	·045	·046	·047	·048	·048	·049	·050	·050
14	·041	·042	·042	·043	·044	·044	·045	·045	·046	·047	·047
15	·038	·039	·040	·040	·041	·041	·042	·043	·043	·044	·045
16	·036	·036	·037	·038	·038	·039	·039	·040	·040	·041	·042
17	·033	·034	·034	·035	·035	·036	·037	·037	·038	·038	·039
18	·031	·031	·032	·032	·033	·033	·034	·034	·035	·035	·036
19	·028	·029	·029	·030	·030	·031	·031	·031	·032	·032	·033
20	·026	·026	·027	·027	·027	·028	·028	·029	·029	·029	·030
21	·023	·024	·024	·024	·025	·025	·025	·026	·026	·026	·027
22	·021	·021	·021	·022	·022	·022	·023	·023	·023	·024	·024
23	·018	·019	·019	·019	·019	·020	·020	·020	·020	·021	·021
24	·016	·016	·016	·017	·017	·017	·017	·017	·018	·018	·018
25	·013	·014	·014	·014	·014	·014	·014	·015	·015	·015	·015
26	·011	·011	·011	·011	·011	·011	·012	·012	·012	·012	·012
27	·008	·008	·009	·009	·009	·009	·009	·009	·009	·009	·009
28	·006	·006	·006	·006	·006	·006	·006	·006	·006	·006	·006
29	·003	·003	·003	·003	·003	·003	·003	·003	·003	·003	·003
30	·001	·001	·001	·001	·001	·001	·001	·000	·000	·000	·000
31	—	—	—	—	—	—	—	—	—	—	—
32	·002	·002	·002	·002	·002	·002	·002	·002	·002	·003	·003
33	·004	·004	·004	·005	·005	·005	·005	·005	·005	·005	·006
34	·007	·007	·007	·007	·007	·008	·008	·008	·008	·008	·009
35	·009	·009	·010	·010	·010	·010	·010	·011	·011	·011	·011
36	·012	·012	·012	·012	·013	·013	·013	·014	·014	·014	·014
37	·014	·014	·015	·015	·015	·016	·016	·016	·017	·017	·017
38	·017	·017	·017	·018	·018	·018	·019	·019	·020	·020	·020
39	·019	·019	·020	·020	·021	·021	·022	·022	·022	·023	·023
40	·021	·022	·022	·023	·023	·024	·024	·025	·025	·026	·026
41	·024	·024	·025	·026	·026	·027	·027	·028	·028	·029	·029
42	·026	·027	·028	·028	·029	·029	·030	·030	·031	·031	·032
43	·029	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035
44	·031	·032	·033	·033	·034	·035	·035	·036	·037	·037	·038
45	·034	·035	·035	·036	·037	·037	·038	·039	·039	·040	·041
46	·036	·037	·038	·039	·039	·040	·041	·042	·042	·043	·044
47	·039	·040	·040	·041	·042	·043	·044	·044	·045	·046	·047
48	·041	·042	·043	·044	·045	·046	·046	·047	·048	·049	·050
49	·044	·045	·046	·046	·047	·048	·049	·050	·051	·052	·053
50	·046	·047	·048	·049	·050	·051	·052	·053	·054	·055	·056

TABLE I—(contd.)

Attached Thermo- meter	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
°F.	—	—	—	—	—	—	—	—	—	—	—
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	·070	·071	·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
CORRECTION OF INCH BAROMETERS TO MEAN SEA LEVEL

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

The correction is always ADDITIVE

TABLE III
CORRECTION OF INCH BAROMETERS TO STANDARD GRAVITY IN LATITUDE 45°

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

TABLE IV

CORRECTIONS TO BE APPLIED TO THE READINGS OF KEW PATTERN MERCURY BAROMETERS (MILLIBAR GRADUATIONS) TO REDUCE THEM TO 285° A

If the temperature of the attached thermometer is $\left\{ \begin{array}{l} \text{above} \\ \text{below} \end{array} \right\} 285^{\circ}\text{A}$ $\left\{ \begin{array}{l} \text{subtract} \\ \text{add} \end{array} \right\}$ the correction.

Attached thermometer (add correction)	Barometer readings (mb.)										Attached thermometer (subtract correction)
	880	900	920	940	960	980	1000	1020	1040	1060	
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 V

CORRECTION OF PRESSURE IN MILLIBARS TO MEAN SEA LEVEL

Height in feet	Air Temperature (dry bulb in screen)										Height in feet
	0° F.	10° F.	20° F.	30° F.	40° F.	50° F.	60° F.	70° F.	80° F.	90° F.	
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	1.2	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

The correction is always ADDITIVE

TABLE VI

CORRECTION OF MILLIBAR BAROMETERS TO STANDARD GRAVITY IN LATITUDE 45°

Lat. N. or S.	Correction		Lat. N. or S.	Correction		Lat. N. or S.	Correction		Lat. N. or S.	Correction	
	At 900mb	At 1000mb		At 900 mb	At 1000mb		At 900mb	At 1000mb		At 900mb	At 1000mb
0	mb	mb	°	mb	mb	°	mb	mb	°	mb	mb
1	-2.3	-2.6	23	-1.6	-1.8	46	+0.1	+0.1	69	+1.7	+1.9
2	-2.3	-2.6	24	-1.5	-1.7	47	+0.2	+0.2	70	+1.8	+2.0
3	-2.3	-2.6	25	-1.5	-1.7	48	+0.3	+0.3	71	+1.8	+2.0
4	-2.3	-2.6	26	-1.4	-1.6	49	+0.3	+0.4	72	+1.9	+2.1
5	-2.3	-2.6	27	-1.4	-1.5	50	+0.4	+0.5	73	+1.9	+2.1
6	-2.3	-2.5	28	-1.3	-1.5	51	+0.5	+0.5	74	+2.0	+2.2
7	-2.3	-2.5	29	-1.2	-1.4	52	+0.6	+0.6	75	+2.0	+2.2
8	-2.2	-2.5	30	-1.2	-1.3	53	+0.6	+0.7	76	+2.1	+2.3
9	-2.2	-2.5	31	-1.1	-1.2	54	+0.7	+0.8	77	+2.1	+2.3
10	-2.2	-2.4	32	-1.0	-1.1	55	+0.8	+0.9	78	+2.1	+2.4
11	-2.2	-2.4	33	-0.9	-1.1	56	+0.9	+1.0	79	+2.2	+2.4
12	-2.2	-2.4	34	-0.9	-1.0	57	+0.9	+1.1	80	+2.2	+2.4
13	-2.1	-2.4	35	-0.8	-0.9	58	+1.0	+1.1	81	+2.2	+2.5
14	-2.1	-2.3	36	-0.7	-0.8	59	+1.1	+1.2	82	+2.2	+2.5
15	-2.1	-2.3	37	-0.6	-0.7	60	+1.2	+1.3	83	+2.3	+2.5
16	-2.0	-2.2	38	-0.6	-0.6	61	+1.2	+1.4	84	+2.3	+2.5
17	-2.0	-2.2	39	-0.5	-0.5	62	+1.3	+1.5	85	+2.3	+2.5
18	-1.9	-2.1	40	-0.4	-0.5	63	+1.4	+1.5	86	+2.3	+2.6
19	-1.9	-2.1	41	-0.3	-0.4	64	+1.4	+1.6	87	+2.3	+2.6
20	-1.8	-2.0	42	-0.3	-0.3	65	+1.5	+1.7	88	+2.3	+2.6
21	-1.8	-2.0	43	-0.2	-0.2	66	+1.5	+1.7	89	+2.3	+2.6
22	-1.7	-1.9	44	-0.1	-0.1	67	+1.6	+1.8	90	+2.3	+2.6
	-1.7	-1.9	45	0.0	0.0	68	+1.7	+1.9			

TABLE VII

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, attached thermometer 299° A.	Temperature „ — 2.3 mb.
height 90 feet	Height „ + 3.3 „

TABLE VIII

EQUIVALENTS IN MILLIBARS OF INCHES OF MERCURY AT 32° F. IN LATITUDE 45°
(Hundredths of an inch)

Inches	0	1	2	3	4	5	6	7	8	9
	Millibars									
27.0	914.3	914.6	915.0	915.3	915.7	916.0	916.3	916.7	917.0	917.4
27.1	917.7	918.0	918.4	918.7	919.0	919.4	919.7	920.1	920.4	920.7
27.2	921.1	921.4	921.8	922.1	922.4	922.8	923.1	923.4	923.8	924.1
27.3	924.5	924.8	925.1	925.5	925.8	926.2	926.5	926.8	927.2	927.5
27.4	927.9	928.2	928.5	928.9	929.2	929.5	929.9	930.2	930.6	930.9
27.5	931.2	931.6	931.9	932.3	932.6	932.9	933.3	933.6	933.9	934.3
27.6	934.6	935.0	935.3	935.6	936.0	936.3	936.7	937.0	937.3	937.7
27.7	938.0	938.3	938.7	939.0	939.4	939.7	940.0	940.4	940.7	941.1
27.8	941.4	941.7	942.1	942.4	942.8	943.1	943.4	943.8	944.1	944.4
27.9	944.8	945.1	945.5	945.8	946.1	946.5	946.8	947.2	947.5	947.8
28.0	948.2	948.5	948.8	949.2	949.5	949.9	950.2	950.5	950.9	951.2
28.1	951.6	951.9	952.2	952.6	952.9	953.2	953.6	953.9	954.3	954.6
28.2	954.9	955.3	955.6	956.0	956.3	956.6	957.0	957.3	957.7	958.0
28.3	958.3	958.7	959.0	959.3	959.7	960.0	960.4	960.7	961.0	961.4
28.4	961.7	962.1	962.4	962.7	963.1	963.4	963.7	964.1	964.4	964.8
28.5	965.1	965.4	965.8	966.1	966.5	966.8	967.1	967.5	967.8	968.1
28.6	968.5	968.8	969.2	969.5	969.8	970.2	970.5	970.9	971.2	971.5
28.7	971.9	972.2	972.6	972.9	973.2	973.6	973.9	974.2	974.6	974.9
28.8	975.3	975.6	975.9	976.3	976.6	977.0	977.3	977.6	978.0	978.3
28.9	978.6	979.0	979.3	979.7	980.0	980.3	980.7	981.0	981.4	981.7
29.0	982.0	982.4	982.7	983.0	983.4	983.7	984.1	984.4	984.7	985.1
29.1	985.4	985.8	986.1	986.4	986.8	987.1	987.5	987.8	988.1	988.5
29.2	988.8	989.1	989.5	989.8	990.2	990.5	990.8	991.2	991.5	991.9
29.3	992.2	992.5	992.9	993.2	993.5	993.9	994.2	994.6	994.9	995.2
29.4	995.6	995.9	996.3	996.6	996.9	997.3	997.6	997.9	998.3	998.6

TABLE VIII—(contd.)

Inches	0	1	2	3	4	5	6	7	8	9
	Millibars									
29.5	999.0	999.3	999.6	1000.0	1000.3	1000.7	1001.0	1001.3	1001.7	1002.0
29.6	1002.4	1002.7	1003.0	1003.4	1003.7	1004.0	1004.4	1004.7	1005.1	1005.4
29.7	1005.7	1006.1	1006.4	1006.8	1007.1	1007.4	1007.8	1008.1	1008.4	1008.7
29.8	1009.1	1009.5	1009.8	1010.1	1010.5	1010.8	1011.2	1011.5	1011.8	1012.1
29.9	1012.5	1012.8	1013.2	1013.5	1013.9	1014.2	1014.5	1014.9	1015.2	1015.5
30.0	1015.9	1016.2	1016.6	1016.9	1017.3	1017.6	1017.9	1018.3	1018.6	1018.9
30.1	1019.3	1019.6	1020.0	1020.3	1020.6	1021.0	1021.3	1021.7	1022.0	1022.3
30.2	1022.7	1023.0	1023.3	1023.7	1024.0	1024.4	1024.7	1025.0	1025.4	1025.7
30.3	1026.1	1026.4	1026.7	1027.1	1027.4	1027.7	1028.1	1028.4	1028.8	1029.1
30.4	1029.4	1029.8	1030.1	1030.5	1030.8	1031.1	1031.5	1031.8	1032.2	1032.5
30.5	1032.8	1033.2	1033.5	1033.8	1034.2	1034.5	1034.9	1035.2	1035.5	1035.9
30.6	1036.2	1036.6	1036.9	1037.2	1037.6	1037.9	1038.2	1038.6	1038.9	1039.3
30.7	1039.6	1039.9	1040.3	1040.6	1041.0	1041.3	1041.6	1042.0	1042.3	1042.6
30.8	1043.0	1043.3	1043.7	1044.0	1044.3	1044.7	1045.0	1045.4	1045.7	1046.0
30.9	1046.4	1046.7	1047.1	1047.4	1047.7	1048.1	1048.4	1048.7	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		

THE DIURNAL VARIATION OF BAROMETRIC PRESSURE, IN THE ZONES OF LATITUDE 0°-10°, AND 10°-20°, N. OR S.

TABLE IX—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 X—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	-.018	-.018	-.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 IX) 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 X 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 XI

CONVERSION OF TEMPERATURE READINGS ON THE FAHRENHEIT SCALE TO THE
CENTIGRADE AND ABSOLUTE SCALES

Fahr.	Cent.	Abs.	Fahr.	Cent.	Abs.	Fahr.	Cent.	Abs.
0 ..	-17.8	255.2	40	+ 4.4	277.4	80	+26.7	299.7
1 ..	17.2	55.8	41	5.0	78.0	81	27.2	300.2
2 ..	16.7	56.3	42	5.6	78.6	82	27.8	0.8
3 ..	16.1	56.9	43	6.1	79.1	83	28.3	1.3
4 ..	15.6	57.4	44	6.7	79.7	84	28.9	1.9
5 ..	15.0	58.0	45	7.2	80.2	85	29.4	2.4
6 ..	14.4	58.6	46	7.8	80.8	86	30.0	3.0
7 ..	13.9	59.1	47	8.3	81.3	87	30.6	3.6
8 ..	13.3	59.7	48	8.9	81.9	88	31.1	4.1
9 ..	12.8	260.2	49	9.4	282.4	89	31.7	304.7
10 ..	12.2	260.8	50	10.0	283.0	90	32.2	305.2
11 ..	11.7	61.3	51	10.6	83.6	91	32.8	5.8
12 ..	11.1	61.9	52	11.1	84.1	92	33.3	6.3
13 ..	10.6	62.4	53	11.7	84.7	93	33.9	6.9
14 ..	10.0	63.0	54	12.2	85.2	94	34.4	7.4
15 ..	9.4	63.6	55	12.8	85.8	95	35.0	8.0
16 ..	8.9	64.1	56	13.3	86.3	96	35.6	8.6
17 ..	8.3	64.7	57	13.9	86.9	97	36.1	9.1
18 ..	7.8	65.2	58	14.4	87.4	98	36.7	9.7
19 ..	7.2	265.8	59	15.0	288.0	99	37.2	310.2
20 ..	6.7	266.3	60	15.6	288.6	100	37.8	310.8
21 ..	6.1	66.9	61	16.1	89.1	101	38.3	11.3
22 ..	5.6	67.4	62	16.7	89.7	102	38.9	11.9
23 ..	5.0	68.0	63	17.2	90.2	103	39.4	12.4
24 ..	4.4	68.6	64	17.8	90.8	104	40.0	13.0
25 ..	3.9	69.1	65	18.3	91.3	105	40.6	13.6
26 ..	3.3	69.7	66	18.9	91.9	106	41.1	14.1
27 ..	2.8	70.2	67	19.4	92.4	107	41.7	14.7
28 ..	2.2	70.8	68	20.0	93.0	108	42.2	15.2
29 ..	1.7	271.3	69	20.6	293.6	109	42.8	315.8
30 ..	1.1	271.9	70	21.1	294.1	110	43.3	316.3
31 ..	- 0.6	72.4	71	21.7	94.7	111	43.9	16.9
32 ..	± 0.0	73.0	72	22.2	95.2	112	44.4	17.4
33 ..	+ 0.6	73.6	73	22.8	95.8	113	45.0	18.0
34 ..	1.1	74.1	74	23.3	96.3	114	45.6	18.6
35 ..	1.7	74.7	75	23.9	96.9	115	46.1	19.1
36 ..	2.2	75.2	76	24.4	97.4	116	46.7	19.7
37 ..	2.8	75.8	77	25.0	98.0	117	47.2	20.2
38 ..	3.3	76.3	78	25.6	98.6	118	47.8	20.8
39 ..	+ 3.9	276.9	79	+26.1	299.1	119	+48.3	321.3

TABLE XII
RELATIVE HUMIDITY (PER CENT.)
(FOR USE WITH STEVENSON SCREEN)

Dry Bulb	Depression of Wet Bulb																
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°
100	100	96	93	89	86	82	79	76	73	70	67	64	61	58	55	53	50
98	100	96	93	89	86	82	79	76	72	69	66	63	60	57	54	52	49
96	100	96	93	89	85	82	78	75	72	68	65	62	59	57	54	51	48
94	100	96	93	89	85	81	78	75	71	68	65	62	59	56	53	50	47
92	100	96	92	88	85	81	78	74	71	67	64	61	58	55	52	49	46
90	100	96	92	88	84	81	77	74	70	67	63	60	57	54	51	48	45
88	100	96	92	88	84	80	77	73	69	66	63	59	56	53	50	47	44
86	100	96	92	88	84	80	76	72	69	65	62	58	55	52	49	45	42
84	100	96	92	87	83	79	76	72	68	64	61	57	54	51	47	44	41
82	100	96	91	87	83	79	75	71	67	64	60	56	53	49	46	43	40
80	100	96	91	87	83	79	74	70	66	63	59	55	52	48	45	41	38
78	100	95	91	86	82	78	74	70	66	62	58	54	50	47	43	40	36
76	100	95	91	86	82	78	73	69	65	61	57	53	49	45	42	38	34
74	100	95	90	86	81	77	72	68	64	60	56	52	48	44	40	36	33
72	100	95	90	85	80	76	71	67	63	58	54	50	46	42	38	34	31
70	100	95	90	85	80	75	71	66	62	57	53	49	44	40	36	32	28
68	100	95	90	84	79	75	70	65	60	56	51	47	43	38	34	30	26
66	100	95	89	84	79	74	69	64	59	54	50	45	41	36	32	28	23
64	100	94	89	83	78	73	68	63	58	53	48	43	39	34	30	25	21
62	100	94	88	83	77	72	67	61	56	51	46	41	37	32	27	23	18
60	100	94	88	82	77	71	65	60	55	50	44	39	34	29	25	20	15
58	100	94	88	82	76	70	64	59	53	48	42	37	31	26	22	17	12
56	100	94	87	81	75	69	63	57	51	46	40	35	29	24	19	13	
54	100	93	87	80	74	68	61	55	49	43	38	32	26	21	15		
52	100	93	86	79	73	66	60	54	47	41	35	29	23	17	12		

TABLE XII—(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	100	93	86	79	72	65	58	52	45	38	32	26	20	14			
48	100	92	85	78	70	63	56	49	42	36	29	22	16				
46	100	92	84	77	69	62	54	47	40	33	26	19					
44	100	92	84	76	68	60	52	45	37	29	22						
42	100	91	83	74	66	58	50	42	34	26	18						
40	100	91	82	73	65	56	47	39	30	27	19						
38	100	91	81	72	63	54	44	39	31	22							
36	100	90	80	70	60	54	44	35	26								
34	100	90	79	70	60	50	41	31									
32	100	89	79	68	57	47	37	27									
	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°			
30	99	93	87	82	76	71	65	59	54	48	43	38	32	27			
28	98	92	86	80	74	68	62	56	51	45	39	33	28				
26	97	91	84	78	72	65	59	53	47	41	35	29					
24	96	89	82	75	69	63	56	49	43	37	30						
22	95	88	81	73	67	60	52	45	39	32							
20	94	86	79	71	64	57	49	41	35								
18	93	85	77	69	61	53	45	37									
16	92	83	75	67	58	49	41										
14	91	82	73	64	54	46											
12	90	80	70	61	51												

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 line.

For dry bulb temperatures below 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 32° F. is taken as that over water, and not as that over ice.

TABLE XIII
RELATIVE HUMIDITY (PER CENT.)
(FOR USE WITH ASPIRATED PSYCHROMETER)

Dry Bulb °F.	Depression of Wet Bulb																
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°
100	100	97	93	89	86	83	80	77	74	71	68	65	62	59	57	54	52
98	100	97	93	89	86	83	80	77	74	71	68	65	62	59	56	53	51
96	100	97	93	89	86	83	79	76	73	70	67	64	61	58	56	53	50
94	100	97	93	89	86	82	79	76	73	69	66	63	60	57	55	52	49
92	100	96	92	89	85	82	78	75	72	69	66	63	60	57	54	51	48
90	100	96	92	89	85	81	78	75	71	68	65	62	59	56	53	50	47
88	100	96	92	89	85	81	78	74	71	67	64	61	58	55	52	49	46
86	100	96	92	89	85	81	77	74	70	67	63	60	57	54	51	48	45
84	100	96	92	88	84	81	77	73	70	66	63	59	56	53	50	47	44
82	100	96	92	88	84	80	76	73	69	65	62	58	55	52	49	46	43
80	100	96	92	88	84	80	76	72	68	65	61	57	54	51	48	45	41
78	100	96	92	87	83	79	75	71	67	64	60	56	53	50	46	43	40
76	100	95	91	87	83	79	75	71	67	63	59	55	52	49	45	42	38
74	100	95	91	87	82	78	74	70	66	62	58	54	51	47	43	40	37
72	100	95	91	87	82	77	73	69	65	61	57	53	49	46	42	39	35
70	100	95	90	86	81	77	72	68	64	60	56	52	48	44	40	37	33
68	100	95	90	86	81	76	71	67	63	59	54	50	46	43	39	35	31
66	100	95	90	85	80	75	71	66	62	57	53	49	45	41	37	33	29
64	100	95	90	85	80	75	70	65	61	56	52	47	43	39	35	31	27
62	100	95	89	84	79	74	69	64	60	55	51	46	41	37	33	29	25
60	100	94	89	84	78	73	68	63	58	53	49	44	39	35	31	26	22
58	100	94	88	83	77	72	67	62	57	52	47	42	37	33	28	24	19
56	100	94	88	82	77	71	66	60	55	50	45	40	35	30	25	21	16
54	100	94	88	82	76	70	65	59	53	48	43	38	32	27	22	18	13
52	100	94	87	81	75	69	63	57	52	46	40	35	30	24	19	14	

TABLE XIII—(contd.)

Dry Bulb	Depression of Wet Bulb																
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°
50	100	93	87	80	74	68	62	56	50	44	38	33	27	21	16		
48	100	93	86	80	73	66	60	54	48	42	36	30	24	18			
46	100	93	86	79	72	65	58	52	45	39	33	27	21	15			
44	100	92	85	78	71	64	57	50	43	36	30	23	17	16			
42	100	92	84	77	69	62	55	47	40	33	27	24	18				
40	100	92	84	76	68	60	52	45	38	34	27	20					
38	100	91	83	75	66	58	50	45	38	30	23						
36	100	91	82	74	65	58	50	42	34	26							
34	100	91	81	73	64	55	47	38	30								
32	100	90	80	71	62	52	43	34	26								

	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	99	94	89	84	79	74	69	64	59	54	49	45	40	35	31	26
28	98	93	87	82	76	72	67	61	56	51	46	41	35	30		
26	97	91	86	80	75	69	63	58	52	47	42	37	31			
24	96	90	84	78	72	66	60	55	49	43	37					
22	95	88	82	76	70	64	58	51	46	40						
20	94	87	81	74	68	61	54	48	41							
18	93	85	79	71	65	58	51	45								
16	92	84	77	70	62	55	48									
14	91	83	75	67	59	52										
12	90	82	73	65	57											

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 line.

For dry bulb temperatures below 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 32° F. is taken as that over water, and not as that over ice.

TABLE XIV
DEW-POINT (°F.)
(FOR USE WITH STEVENSON SCREEN)

Dry Bulb	Depression of Wet Bulb																
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°
100	100	99	98	96	95	94	92	91	90	88	87	86	84	83	81	80	78
98	98	97	95	94	93	92	90	89	88	86	85	83	82	80	79	77	76
96	96	95	94	92	91	90	88	87	85	84	83	81	80	78	76	75	73
94	94	93	91	90	89	87	86	85	83	82	80	79	77	76	74	72	71
92	92	91	89	88	87	85	84	83	81	80	78	77	75	73	72	70	68
90	90	89	87	86	85	83	82	80	79	77	76	74	73	71	69	68	66
88	88	87	85	84	83	81	80	78	77	75	74	72	70	69	67	65	63
86	86	85	83	82	80	79	78	76	75	73	71	70	68	66	64	62	60
84	84	83	81	80	78	77	75	74	72	71	69	67	66	64	62	60	58
82	82	81	79	78	76	75	73	72	70	68	67	65	63	61	59	57	55
80	80	79	77	76	74	73	71	69	68	66	64	62	60	58	56	54	52
78	78	77	75	74	72	71	69	67	66	64	62	60	58	56	54	52	49
76	76	75	73	72	70	68	67	65	63	61	59	57	55	53	51	48	46
74	74	73	71	69	68	66	64	63	61	59	57	55	53	50	48	45	43
72	72	70	69	67	66	64	62	61	59	57	55	52	50	48	45	42	39
70	70	68	67	65	63	62	60	58	56	54	52	50	47	45	42	39	36
68	68	66	65	63	61	60	58	56	54	52	49	47	44	42	39	36	32
66	66	64	63	61	59	57	55	53	51	49	47	44	41	38	35	32	28
64	64	62	61	59	57	55	53	51	49	47	44	41	38	35	32	28	23
62	62	60	59	57	55	53	51	49	46	44	41	38	35	32	28	23	18
60	60	58	56	54	52	50	48	46	44	41	38	35	32	28	23	19	13
58	58	56	54	52	50	48	46	43	41	38	35	32	28	24	19	13	5
56	56	54	52	50	48	46	43	41	38	35	32	29	25	20	14	7	
54	54	52	50	48	46	43	41	38	35	32	29	25	20	14	8		
52	52	50	48	46	43	41	38	35	32	29	25	20	16	9	0		

TABLE XIV—(contd.)

Dry Bulb	Depression of Wet Bulb																
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°
50	50	48	46	43	41	39	36	33	29	25	21	16	10	2			
48	48	46	44	41	39	36	33	30	26	22	17	12	4				
46	46	44	42	39	36	34	30	27	23	19	13	6					
44	44	42	39	37	34	31	28	23	19	15	8						
42	42	40	37	34	32	28	25	20	16	9	3						
40	40	38	35	32	29	26	22	17	11	8	1						
38	38	35	33	30	26	22	18	15	10	3							
36	36	33	30	27	23	21	16	11	5								
34	34	31	28	25	22	17	13	7									
32	32	29	26	22	19	14	8	1									

Dry Bulb	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°			
30	30	29	27	25	23	22	20	17	15	13	10	7	4	0			
28	28	26	24	22	20	18	16	14	12	9	6	3					
26	25	23	22	20	18	16	14	11	8	5	2						
24	23	21	19	17	15	13	11	8	5	1							
22	21	19	17	15	13	10	7	4	1								
20	19	16	14	12	10	7	4	0									
18	16	14	12	10	7	4	0										
16	14	12	10	7	4	0											
14	12	10	7	4	1												
12	10	7	4	1													

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 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 32° F., is taken as that over water, and not as that over ice.

TABLE XV
DEW-POINT (°F)
(FOR USE WITH ASPIRATED PSYCHROMETER.)

Dry Bulb	Depression of Wet Bulb																
	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 XV—(contd.)

Dry Bulb	Depression of Wet Bulb																
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°
50	48	46	44	44	42	40	37	35	32	29	26	22	17	12	6		
48	46	44	42	40	37	35	32	29	26	22	18	13	8	1			
46	44	42	40	37	35	32	30	26	23	19	14	9	2	0			
44	42	40	37	35	33	30	27	23	19	15	10	8	2				
42	40	38	35	33	30	27	24	20	16	14	9	2					
40	38	35	33	31	28	25	21	19	15	10	5						
38	36	33	31	28	25	23	19	15	10	6							
36	34	31	28	25	23	20	16	11	7	1							
34	32	29	26	23	20	17	12										
32	29	27	23	20													

Dry Bulb	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	29	27	26	23	24	23	21	19	17	15	13	11	8	5	3	0
28	26	25	23	20	22	20	18	16	14	12	10	7	4	1		
26	24	22	21	19	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	17	15	13	11	11	9	6	4	1							
18	14	12	10	8	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											
10	7	5	2	0												

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 line.

For dry bulb temperatures below 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 32° F. is taken as that over water, and not as that over ice.

TABLE XVI

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 XVII

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 XVIII

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°						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	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 True force, Beaufort scale	180 1	180 3	180 4	180 5	180 6	180 7	174 1	178 3	179 4	179 5	179 6	179 7	167 1	176 3	177 4	178 5	178 6	179 7	163 1	174 3	176 4	177 5	177 6	178 7	161 2	172 3	175 4	177 5	177 6	177 7	158 2	171 3	175 4	176 5	176 6	177 7	156 2	171 3	174 4	176 5	176 6	176 7	1
2	True direction, degrees off the bow True force, Beaufort scale	— 0	180 2	180 3	180 4	180 5	180 6	96 1	171 2	175 3	177 4	177 5	178 6	100 1	163 2	171 3	174 4	175 5	176 6	105 1	157 2	168 3	171 4	173 5	174 6	110 1	154 2	165 3	169 4	171 5	173 6	115 2	152 3	163 4	168 5	170 6	172 7	120 2	151 3	162 4	167 5	169 6	171 7	2
3	True direction, degrees off the bow True force, Beaufort scale	0 2	180 1	180 2	180 4	180 5	180 5	24 2	126 1	167 3	172 4	175 5	176 6	44 2	116 2	156 3	166 4	170 5	172 6	62 2	116 2	150 3	161 4	166 5	169 6	75 2	118 3	146 4	157 5	163 6	167 7	86 3	121 3	145 4	155 5	162 6	165 7	96 3	125 4	145 5	154 6	160 7	164 6	3
4	True direction, degrees off the bow True force, Beaufort scale	0 3	0 1	180 1	180 3	180 4	180 5	15 3	32 2	116 1	159 3	169 4	172 5	30 3	56 2	110 2	145 3	159 4	166 5	45 3	73 3	112 3	138 3	153 4	160 5	59 3	85 3	116 3	138 4	150 5	156 6	70 4	97 3	121 4	138 5	148 6	155 7	82 4	104 4	125 5	139 6	147 7	153 6	4
5	True direction, degrees off the bow True force, Beaufort scale	0 4	0 3	0 1	180 1	180 2	180 4	13 4	21 3	43 2	112 2	152 3	164 4	27 4	40 3	68 3	108 3	137 3	152 4	39 4	56 4	82 3	110 3	130 4	144 5	52 4	70 4	93 4	115 5	131 6	142 7	64 4	82 4	102 5	119 6	131 7	141 6	75 5	92 5	109 6	123 7	133 6	141 6	5
6	True direction, degrees off the bow True force, Beaufort scale	0 5	0 4	0 3	0 2	180 1	180 2	13 5	17 4	25 3	49 2	102 2	144 3	25 5	33 4	47 4	71 3	103 3	130 4	37 5	48 4	63 4	85 4	107 4	125 5	49 5	61 5	77 5	95 6	112 7	125 6	60 6	73 5	88 5	103 6	117 7	127 6	71 6	84 5	98 6	110 7	121 6	130 7	6
7	True direction, degrees off the bow True force, Beaufort scale	0 6	0 5	0 4	0 3	0 2	— 0	12 6	15 5	20 4	28 4	47 3	83 2	24 6	29 5	38 5	51 4	71 4	97 4	36 6	43 6	54 5	68 4	85 4	103 5	47 6	56 6	68 6	80 6	95 7	109 6	58 6	68 6	79 7	91 6	103 7	114 6	69 7	79 6	90 7	100 7	110 7	119 7	7
8	True direction, degrees off the bow True force, Beaufort scale	0 7	0 6	0 6	0 5	0 4	0 3	12 7	14 6	17 6	21 5	30 4	45 3	23 7	27 7	33 6	41 5	53 4	69 4	34 7	40 7	47 6	57 5	69 4	84 5	45 7	53 7	61 7	71 6	82 5	94 4	56 8	64 7	73 7	82 7	93 7	102 7	67 8	75 7	84 7	93 7	102 7	109 8	8
9	True direction, degrees off the bow True force, Beaufort scale	0 8	0 8	0 7	0 6	0 5	0 4	11 8	13 8	15 7	18 6	22 5	30 4	22 8	25 8	30 7	35 6	43 5	53 4	33 8	38 8	44 7	51 6	59 5	70 4	45 9	50 8	57 8	65 7	73 6	82 5	56 9	62 8	69 8	76 7	84 6	93 5	66 9	73 8	80 8	87 7	94 6	102 5	9
10	True direction, degrees off the bow True force, Beaufort scale	0 9	0 9	0 8	0 7	0 6	0 6	11 9	12 9	14 8	16 7	19 6	23 5	22 9	24 9	28 8	32 7	37 6	44 5	33 9	37 9	41 8	47 7	53 6	60 5	44 10	49 9	53 9	60 8	66 7	74 6	54 10	60 9	66 9	72 8	78 7	85 6	65 10	71 9	77 9	83 8	89 7	96 6	10
11	True direction, degrees off the bow True force, Beaufort scale	0 10	0 10	0 9	0 8	0 8	0 7	11 10	12 10	13 9	15 8	17 7	20 6	22 10	24 10	26 9	29 8	33 7	38 6	33 10	36 10	39 9	43 8	48 7	54 6	44 11	47 10	51 10	56 9	62 8	68 7	54 11	58 10	63 10	68 9	73 8	79 7	65 11	69 10	74 10	79 9	85 8	91 7	11
12	True direction, degrees off the bow True force, Beaufort scale	0 11	0 11	0 10	0 9	0 9	0 8	11 11	12 11	13 10	14 9	16 8	18 7	22 11	23 11	25 10	28 9	31 8	35 7	32 11	35 11	38 10	41 9	45 8	49 7	43 12	46 11	50 11	54 10	58 9	63 8	54 12	57 11	61 11	66 10	70 9	75 8	64 12	68 11	72 11	77 10	81 9	86 8	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

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

TABLE XVIII—(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°						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	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 True force, Beaufort scale	156 2	171 3	174 4	176 5	176 6	176 7	157 2	170 3	174 4	175 5	175 6	176 7	157 2	170 3	173 4	175 5	175 6	176 7	158 2	170 3	173 4	175 5	175 6	176 7	159 2	171 3	174 4	175 5	175 6	176 7	162 2	171 4	174 4	175 5	176 6	176 7	164 2	172 4	175 4	176 5	176 6	177 7	1
2	True direction, degrees off the bow True force, Beaufort scale	120 2	151 3	162 4	167 5	169 6	171 7	125 2	152 3	161 4	166 5	169 6	171 7	130 2	153 3	162 4	166 5	169 6	171 7	135 3	154 4	162 4	167 5	169 6	171 7	139 3	156 4	163 5	167 5	169 6	171 7	145 3	159 4	164 5	168 6	170 6	172 7	150 3	162 4	166 5	170 6	171 7	172 7	2
3	True direction, degrees off the bow True force, Beaufort scale	96 3	125 3	145 4	154 5	160 6	164 6	105 3	129 3	144 4	154 5	160 6	164 7	112 3	133 4	146 4	155 5	160 6	164 7	121 3	139 4	150 5	157 6	161 6	164 7	128 3	143 4	153 5	158 6	162 7	165 7	134 4	148 4	156 5	160 6	164 7	166 8	142 4	152 5	159 6	163 6	166 7	168 8	3
4	True direction, degrees off the bow True force, Beaufort scale	82 4	104 4	125 4	139 5	147 6	153 6	92 4	113 4	129 5	141 5	148 6	154 7	101 4	120 4	134 5	143 6	150 6	155 7	111 4	126 5	138 5	146 6	152 7	156 7	119 4	132 5	143 6	149 6	154 7	158 8	127 4	139 5	147 6	153 7	157 7	160 8	135 5	145 5	152 6	156 7	159 8	162 8	4
5	True direction, degrees off the bow True force, Beaufort scale	75 5	92 5	109 5	123 5	133 6	141 6	85 5	102 5	116 5	128 6	136 6	143 7	95 5	110 5	122 6	132 6	139 7	145 7	105 5	118 5	129 6	137 6	143 7	148 8	114 5	126 6	135 6	142 7	147 8	151 8	123 5	133 6	141 7	146 8	150 8	154 8	131 6	140 6	146 7	151 8	154 8	157 9	5
6	True direction, degrees off the bow True force, Beaufort scale	71 6	84 5	98 6	110 6	121 6	130 7	82 6	94 6	106 6	117 7	126 7	133 7	92 6	104 6	114 7	123 7	131 8	137 8	102 6	112 6	122 7	129 7	136 8	141 8	111 6	121 7	129 7	135 8	140 8	145 9	120 6	129 7	136 7	141 8	145 9	149 9	129 6	136 7	142 8	147 8	150 9	153 9	6
7	True direction, degrees off the bow True force, Beaufort scale	69 7	79 6	90 6	100 6	110 7	119 7	79 7	89 7	99 7	108 7	117 8	124 8	89 7	99 7	108 7	116 8	123 8	129 8	99 7	108 7	116 8	123 8	129 9	134 9	109 7	117 8	124 8	130 8	135 9	139 9	118 7	126 8	132 8	136 9	141 9	145 10	128 7	134 8	139 8	143 9	147 10	150 10	7
8	True direction, degrees off the bow True force, Beaufort scale	67 8	75 7	84 7	93 7	102 7	109 8	77 8	86 8	94 8	102 8	109 8	116 8	88 8	96 8	103 8	110 9	117 9	123 9	98 8	105 8	112 9	118 9	124 9	129 9	107 8	114 8	120 9	126 9	131 10	135 10	117 8	123 9	128 9	133 10	137 10	140 11	126 8	132 9	136 9	140 10	143 10	146 11	8
9	True direction, degrees off the bow True force, Beaufort scale	66 9	73 8	80 8	87 8	94 8	102 8	76 9	83 9	90 9	97 9	104 9	110 9	87 9	93 9	100 9	106 9	112 10	116 10	97 9	102 9	109 9	114 10	119 10	124 10	106 9	112 9	117 10	122 10	127 10	131 11	116 9	121 10	126 10	130 10	134 11	137 12	125 9	129 10	134 10	138 11	141 11	144 12	9
10	True direction, degrees off the bow True force, Beaufort scale	65 10	71 9	77 9	83 9	89 9	96 9	75 10	81 10	87 10	93 10	99 10	104 10	86 10	91 10	97 10	102 10	108 10	112 10	96 10	101 10	106 10	111 10	116 11	120 11	105 10	110 10	115 11	119 11	123 11	127 12	115 10	119 11	124 11	128 11	131 12	134 12	124 10	128 11	132 11	135 12	138 12	141 12	10
11	True direction, degrees off the bow True force, Beaufort scale	65 11	69 10	74 10	79 10	85 10	91 10	75 11	80 11	85 11	90 11	95 11	100 11	85 11	90 11	95 11	99 11	104 11	108 11	95 11	100 11	104 11	109 11	113 12	116 12	104 11	109 11	113 12	117 12	121 12	125 12	114 11	119 12	123 12	126 12	129 12	132 12	123 11	128 12	131 12	134 12	137 12	139 12	11
12	True direction, degrees off the bow True force, Beaufort scale	64 12	68 11	72 11	77 11	81 11	86 11	74 12	79 12	83 12	87 12	92 12	96 12	84 12	88 12	93 12	97 12	101 12	106 12	94 12	98 12	103 12	106 12	110 12	114 12	104 12	108 12	112 12	115 12	118 12	121 12	114 12	118 12	121 12	124 12	127 12	130 12	123 12	127 12	130 12	133 12	135 12	137 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

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 XVIII—(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°							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	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 True force, Beaufort scale	164	172	175	176	176	177	167	173	175	176	177	177	169	174	176	177	177	178	172	176	177	178	178	178	174	177	178	178	178	179	177	179	179	179	179	179	180	180	180	180	180	180	1
2	True direction, degrees off the bow True force, Beaufort scale	150	162	166	170	171	172	155	164	169	171	172	174	160	167	171	173	174	174	165	170	173	174	175	176	170	174	175	176	176	177	175	177	178	178	178	178	180	180	180	180	180	180	2
3	True direction, degrees off the bow True force, Beaufort scale	142	152	159	163	166	168	148	157	162	165	168	170	155	161	166	168	170	172	160	166	169	171	172	174	168	171	173	174	175	176	173	175	176	177	177	177	180	180	180	180	180	180	3
4	True direction, degrees off the bow True force, Beaufort scale	135	145	152	156	159	162	142	151	156	160	164	165	150	157	161	164	166	168	158	163	166	168	170	171	166	169	171	172	173	174	173	174	175	176	176	177	180	180	180	180	180	180	4
5	True direction, degrees off the bow True force, Beaufort scale	131	140	146	151	154	157	140	146	152	156	158	161	148	154	158	161	163	165	156	160	163	166	167	168	164	167	169	170	172	172	172	173	174	175	175	176	180	180	180	180	180	180	5
6	True direction, degrees off the bow True force, Beaufort scale	129	136	142	147	150	153	138	144	149	152	156	158	147	151	155	158	160	162	155	159	161	163	166	167	164	166	168	169	170	171	172	173	174	175	175	175	180	180	180	180	180	180	6
7	True direction, degrees off the bow True force, Beaufort scale	128	134	139	143	147	150	137	142	146	150	152	155	146	150	153	156	158	160	154	157	160	162	163	165	163	165	167	168	169	170	171	172	174	174	174	175	180	180	180	180	180	180	7
8	True direction, degrees off the bow True force, Beaufort scale	126	132	136	140	143	146	135	140	144	147	150	153	145	148	151	154	157	158	154	156	159	160	162	164	162	164	166	167	168	169	171	172	173	174	174	174	180	180	180	180	180	180	8
9	True direction, degrees off the bow True force, Beaufort scale	125	129	134	138	141	144	135	138	142	145	148	150	144	147	150	152	155	156	154	155	157	159	161	163	162	164	165	166	168	168	171	172	173	173	174	174	180	180	180	180	180	180	9
10	True direction, degrees off the bow True force, Beaufort scale	124	128	132	135	138	141	134	137	141	143	146	149	144	146	149	151	154	156	153	155	156	158	160	162	162	163	164	165	167	168	171	172	173	173	173	174	180	180	180	180	180	180	10
11	True direction, degrees off the bow True force, Beaufort scale	123	128	131	134	137	139	134	137	140	142	145	147	143	146	148	150	152	154	153	155	156	158	160	161	162	163	164	165	166	167	171	171	172	173	173	174	180	180	180	180	180	180	11
12	True direction, degrees off the bow True force, Beaufort scale	123	127	130	133	135	137	134	136	138	141	143	145	143	145	147	149	150	152	153	154	156	157	159	160	162	163	164	165	166	167	171	171	172	172	173	173	180	180	180	180	180	180	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

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).

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 the velocity of a centimetre per second.

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

The unit of **Force**, in the C.G.S. system, is the force which produces 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 the 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.

INDEX

	Page		Page
Abnormal compass deviation	84	Barometer, mercury, Gold slide for ..	7
Abnormal refraction	73	Barometer, mercury, position, setting	
Abnormal rises of sea level and waves ..	80	up and care of	7
Absolute thermometer scale	20	Barometer, mercury, reading of ..	9
Accidents to instruments	95	Barometer, millibar, corrections to ..	6
Aerolites	87	Barometer, millibar, corrections with	
Agents, Merchant Navy	95	Gold slide to	7
Aguaie	79	Barometer scales, graduation of ..	3
Alidade	31	Barrier ice	59
Altitude corrections for mercury barometers	4, 6	Bay ice	59
Altitude corrections for aneroid barometers	11	Beaded lightning	64
Alto cumulus	44	Beaufort scale of wind force	35
Alto cumulus castellatus	44	Beaufort weather notation	39
Alto cumulus lenticularis	44	Berg	59
Alto stratus	45	Bergy bits	59
Anchor-ice	59	Beset	61
Anemometer, cup	29	Black ice	59
Anemometer, use at sea of	38	Blink, ice and land	61
Aneroid Barometer	11	Boring	61
Appearance of the sky (Beaufort		Bourdon tube	29
Notation)	40	Brash	59
Arcs, auroral	81	Brocken Spectre	72
Arcs, pulsating	81	Bucket method of obtaining sea surface	
Aspirated psychrometer	26	temperature	27
Astronomical phenomena	86	Bulletins	94
Atlantic Weather Bulletins	94	Calving	61
Atlases, current	94	Canvas bucket	27
Atlases, ice	95	Capillarity in mercury barometers ..	3
Atlases, meteorological	94	Care of instruments :—	
Attached thermometer	3	Aneroid barometer	11
Attached thermometer scale, Gold slide		Barograph	13
Aureole	71	Mercury barometer	8
Aurora	81	Thermometers	21
Aurora, forms of	81	Cargo, care and ventilation of ..	27
Aurora, connections with magnetic		Centigrade thermometer scale ..	20
storms	82	Chain or beaded lightning	64
Aurora, observation of	83	Change or tendency of barometer ..	15
Aurora, permanent	83	Characteristic of barometric tendency ..	15
Aurora, regions of occurrence of ..	81	Circumzenithal arc	68
Aurora, seasonal and diurnal frequency		Cirrocumulus	44
of	83	Cirrostratus	44
Aurora, relation to solar activity ..	83	Cirrus	43
		Clock and chart for barograph, thermo-	
Backing	37	graph and hygrograph	14
Ball lightning	64	Close pack	59
Balloons, measurement of cloud height		Cloud amount, estimation of ..	50
by	31	Cloud forms	43
Balloons, measurement of upper winds		Cloud height, estimation of ..	49
by radar	32	Cloud height, measurement by balloon	
Balloons, measurement of upper winds		of	31
by visual observation of	31	Cloud, iridescent	72
Balloons, pilot	31	Cloud, mother of pearl	73
Bands, auroral	82	Cloud, noctilucant	78
Bar	5, 117	Cloud searchlight	31
Barogram	13	Cloud types	43
Barograph	13	Clouds, code for	47
Barometer, aneroid	11	Clouds, heap	43
Barometer, care of	8	Clouds, height of	49
Barometer, change or tendency of ..	15	Clouds, high	48
Barometer, inch, corrections to ..	3	Clouds, layer or sheet	43
Barometer, Kew Pattern marine ..	1	Clouds, low	47
Barometer, mercury	1	Clouds, middle	48
Barometer, mercury, errors of ..	10	Clouds, observations of	47
		Coloration of the sea	79

INDEX—*contd.*

	Page		Page
Coloration of the sky, daytime	76	Fog	41
Coloration of the sky, night	77	Fog and visibility scale	41
Coloration of the sky, twilight	77	Fog-bow	71
Comets	89	Föhn	44
Commonwealth Scheme for Marine Meteorology	93	Fractocumulus	45, 46
Compass deviation, abnormal	84	Fractonimbus	45, 46
Consolidated pack	59	Fractostratus	45
Conversion of inches to millibars	7	Frost smoke	61
Conversion of thermometer scales	20	Gegenschein	91
Corona, auroral	82	Glacier ice	60
Corona, solar, during eclipse	86	Glory	72
Coronae formed by sun or moon	71	Gold slide	7
Corposants	65	Gravity correction for barometers	4, 6
Corps of Voluntary Marine Observers ..	92	Green flash (or ray)	74
Corrections to millibar barometer, with Gold slide	7	Growler	60
Corrections to millibar barometer, with tables	6	Hair hygrograph	30
Corrections to aneroid barometer readings	11	Halo, circumscribed	68
Corrections to inch barometer	3	Halo, circumzenithal arc	68
Counterglow	77	Halo, colour of	66
Crack	61	Halo complex	66
Crepuscular rays	73	Halo cross	70
Cumulonimbus	46	Halo, general remarks	65
Cumulus	46	Halo of 22°	68
Cup anemometer	29	Halo of 46°	68
Current charts	94	Halo, lower contact arc to 22° halo ..	68
Current meter	58	Halo, mock moon	68
Current observations	58	Halo, mock sun	68
Curtains, auroral	82	Halo, mock sun (or moon) ring	69
		Halo, observations of	67
Debate	61	Halo, paraselenae	68
Dew point	24	Halo, parhelia (22° halo)	68
Diffused patches, auroral	82	Halo, parhelic circle	69
Distant reading thermograph	29	Halo phenomena	65
Diurnal frequency of aurora	83	Halo, rare and unusual	69
Diurnal variation of pressure	15	Halo, sun pillar	69
Draperies, auroral	82	Halo, upper contact arc to 22° halo ..	68
Drift ice	59	Haze	41
Dry and wet bulb thermometers	21	Humidity, relative	23
Dustfall at sea	79, 80	Humidity tables	23
Dust, meteoric	87	Hummock	60, 61
Dust, volcanic	72, 79, 80	Hydrograph, hair	30
Dyne	5, 117	Hygrometer	21
		Hygrometric observations—application in care and ventilation of cargo ..	27
Earth shadow	77	Ice anchor	61
Earthquakes, submarine	80	Iceberg	60
Eclipses	86	Ice blink	61
Engine room intake temperature	28	Ice edge	61
		Ice field	60
Fahrenheit thermometer scale	19	Ice foot	60
Fan-aspirated psychrometer	26	Ice observation	59
Fast ice	59	Ice stream	60
Fata Morgana	73	Ice tongue	60
Fireballs	87	Inch barometer, corrections to	3
Fjord ice	60	Inches, conversion to millibars	7
Flaming aurora	82	Index correction, aneroid barometer ..	11
Flash, green	74	Index correction, inch barometer	3
Flaw	61	Index correction, millibar barometer ..	6
Floc	60	Index scale, Gold slide	7
Floeberg	60	Instruments, accidents to	95
		Instruments, supply and return of	95

INDEX—*contd.*

	Page		Page
Intake temperature	28	Mother of pearl cloud	73
International Convention for Safety of Life at Sea, 1948	96	Mush	60
International exchange of information	95	Muslin and thread	21
International Meteorological Organisation	95	Nimbostratus	45
International weather code	94	Nip	61
Irisation	44	Noctilucent cloud	78
Iridescent cloud	44, 72	Novae or new stars	90
"Irish pennant"	vii		
Kew Pattern marine barometer	1	Observers, Corps of Voluntary Marine	92
Land blink	61	Oil damped barograph	15
Landfast ice	59	Open pack ice	60
Land floe	60	Open scale barograph	15
Landslides, submarine	80	Open water	61
Lane	61	Optical haze	76
Latitude correction for barometers	4, 6	Pack ice	60
Latitude scale, Gold Slide	7	Pancake ice	60
Lead	61	Parallax error when reading barometer	10
Lenticular altocumulus	44	Parallelogram of wind forces	38
Level ice	60	Parhelia	68
Lightning	64	Parhelic circle	69
Lightning, ships struck by	65, 84	Past weather, coding of	41
Log, meteorological	92	Phenomena	63
Lunar coronae	71	Phenomena, astronomical	86
Lunar eclipses	86	Phenomena, general remarks	63
Lunar halos (<i>see</i> Halo phenomena).		Phenomena, meteorological	64
Lunar rainbow	71	Phenomena, methods of observation	63
Magnetic storms	82, 83, 84	Phenomena, miscellaneous	79
Magnetic storms, connection with aurorae	82	Phenomena, radar	84
Mammato cumulus	46	Phenomena, radio	84
Marine Observer	95	Phosphorescence	79
Megadyne	5	Phosphorescence, "milky sea"	79
Merchant Navy Agents	95	Phosphorescent wheel	79
Merchant Shipping Act, 1932	96	Pillar, sun	69
Mercury in steel (distant reading) thermograph	29	Pilot balloons	31
Meteoric dust	87	Plankton	79
Meteorites	87	Polar ice	60
Meteorological charts	94	Pool	62
Meteorological log	92	Port Meteorological Officers and Agents	95
Meteorological Officers, Port	95	Precipitation, Beaufort notation	40
Meteorological phenomena	63	Precipitation, detection by radio methods	33
Meteorological services for shipping	94	Present weather, coding of	41
Meteors	87	Pressure area	62
Meteors, appearance and speed of	87	Pressure ridge	62
Meteors, frequency of	88	Pressure variation, diurnal	15
Meteors, height of	88	Protectors for air and sea thermometers	20
Meteors, observation of	88	Psychrometers, wet and dry bulb	21
Meteors, showers of	88	Psychrometers, ventilated	26
Meter, current	58	"Pumping" in a mercury barometer	11
Milky Sea	79		
Millibar barometers, correction of	6	Radar phenomena	84
Millibars, explanation of	5, 117	Radar, use for measurement of upper winds	32
Mirage	73	Radio, methods for detection of storms, precipitation, etc.	33
Miscellaneous phenomena	79	Radio phenomena	84
Mist	41	Radio-sonde	32
Mistral	44	Rafting	62
Mock suns and moons	66, 68, 69	Rainbows	70
Moon, coloured	78	Rainbows, abnormal	71
		Rainbows, Fog-bow or Ulloa's Ring	71
		Rainbows, lunar	71

INDEX—contd.

	Page		Page
Rainbows, solar	70	Sun, mock	66, 68, 69
Rainbows, white	71	Sun pillar	69
Raingauge	30	Sun, prominences	87
Ray, green	74	Sunspots	86
Rays, auroral	82	Supernumerary and secondary rainbows	70
Rays, crepuscular	73	Supplementary ships	93
Réaumur thermometer scale	20	Supply of instruments to ships	93
Refraction, abnormal	73	Sweating	27
Relative humidity	23	Swell	37
Return of instruments from ships	95	Swell, distinction between sea and	51
Ribbons, auroral	82	Swell, origin and travel of	54
Rotten ice	60		
Safety of Life at Sea, International		Tabular berg	61
Convention, 1948	96	Temperature, effect of local heating	25
St. Elmo's fire	65	Temperature, correction for barometers	4, 6
Sallying	62	Temperature of attached thermometer	9
Scintillation	75	Temperature, engine room intake	28
Scirocco	44, 78	Temperature, sea surface	27
Screen, Stevenson	24	Temperature, wet bulb	21
Screwing	62	Tendency or change of pressure	15
Scud	45	Thermograph	29
Sea	51	Thermograph, distant reading	29
Sea bar	62	Thermograph, sea	28
Sea coloration	79	Thermometers	19
Sea ice	60	Thermometers, dry and wet bulb	21
Sea level, abnormal rises of	80	Thermometers, Scales	19
Sea smoke	62	Thermometers, screen	24
Sea temperature	27	Thermometers, sea	27
Searchlight, cloud	31	Thermometers, Stevenson screen	24
Selected ships	93	Thread, muslin and	21
Selected ships, equipment for	93	Tidal waves	80
Sferic reports	33	Tide crack	62
Shelf ice	59	Trochoid	52
Shooting stars	87	Tropical storms	97
Shore-lead	62	Twilight	75
Sky, appearance of (Beaufort notation)	40	Twilight, abnormal	76
Sky coloration, daytime	76	Twilight arch, primary	77
Sky coloration, night	77	Twilight arch, secondary	77
Sky coloration, twilight	77	Twilight, astronomical	75
Slide, Gold	7	Twilight, civil	75
Sling psychrometer	26	Twilight, duration	75
Sludge or slush	61	Twinkling (of a star)	75
Smoke pollution	76		
Solar corona during eclipses	86	Ulloa's Ring (Fog-bow)	71
Solar coronae	71		
Solar eclipses	86	Veering	37
Solar halos (<i>see</i> Halo phenomena).		Ventilation of cargo	27
Solar rainbow	70	Virga	45
Spectre, Brocken	72	Visibility	41
Standard synoptic hours	93	Visibility, measurement at sea	42
Star scintillation or twinkling	75	Visibility scale (Washington 1947)	41
Stevenson screen	24	Volcanic dust	80
Storms, magnetic	82, 83, 84	Volcanic eruptions	72, 78, 80, 87
Storms, precipitation, etc., detection by		Voluntary Observing Fleet	92
radio methods	33	Voluntary Observing Fleet, atlases for	94
Storms, tropical	97	Voluntary meteorological work at sea	92
Stratocumulus	45		
Stratus	45	Water sky	62
Submarine earthquakes and landslides	79, 80	Water smoke	62
Sunbeams	73	Waterspouts	65
Sun, bright eruptions	84	Wave recorder	51
Sun, coloured	78	Waves	51
Sun, corona	86	Waves, abnormal	80
Sun, eleven year cycle	83, 86		

INDEX—*contd.*

	<i>Page</i>		<i>Page</i>
Waves, below sea surface	53	Wheel, phosphorescent	79
Waves, definition of speed, length, period and height	51	Whirling or sling psychrometer	26
Waves, distinction between sea and swell	51	White horses	52
Waves, groups of	53	White water	79
Waves, importance of observations ..	57	Wind, error when reading barometer ..	11
Waves in shallow water	54	Wind force and direction, measurement of	37
Waves, observations and measurement from a moving ship	55	Wind force, Beaufort scale	35, 36
Waves, observations from Ocean Weather (or stationary) Ships ..	57	Wind parallelogram of velocities	38
Waves, origin and travel of swell ..	54	Wind speed, apparent	38
Waves, profile of (Trochoid)	52	Wind, upper, measurement by radar of ..	32
Waves, swell	54	Wind, upper, measurement by visual observations and balloons of	31
Waves, tidal	80	Winter ice	61
Weather notation, Beaufort	39	World Meteorological Organisation ..	95
Weather, past and present, code for ..	41	Working	62
Wet bulb thermometer	21		
Wet bulb thermometer, reading during frost of	23	Young ice	61
Wet bulb thermometer reading, effect of wind upon	26		
Wet bulb thermometer, reading higher than dry bulb	23	Zodiacal band	91
		Zodiacal light	90