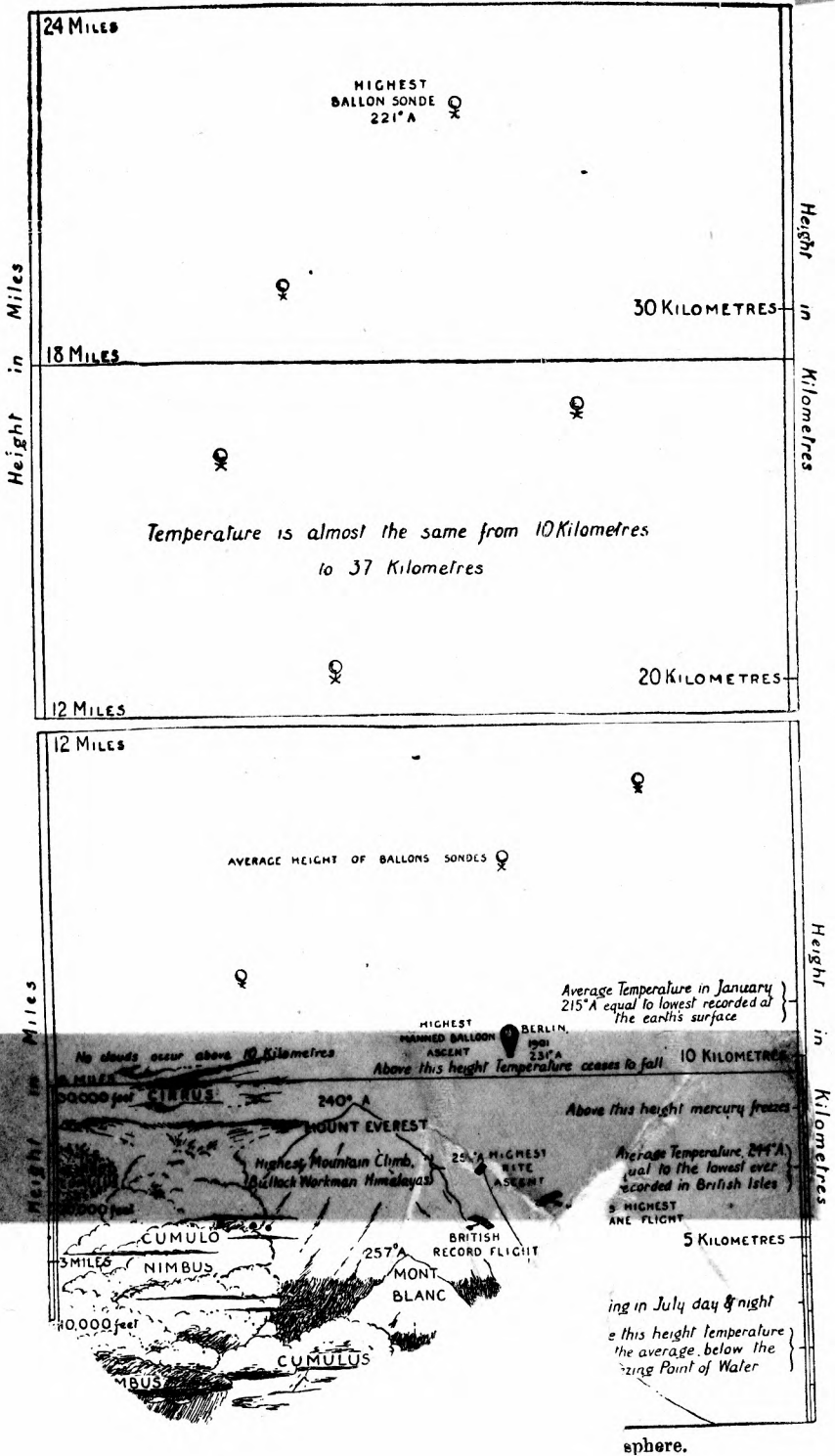


FRONTISPIECE.

The Exploration of the Atmosphere.



sphere.

M.O. 218. (2nd Edition.)

METEOROLOGICAL OFFICE.

THE MARINE OBSERVER'S HANDBOOK.

SECOND EDITION.

1918

Issued by the Authority of the Meteorological Committee.



LONDON :
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GRAFTON STREET, DUBLIN.

To the Captains and Officers of the Ships observing for the Meteorological Office.

After sixty years of work we remain learners about the weather over the ocean; and, as in 1854 when the work on the present plan began, so in 1914 it is upon the careful observations of Seamen that we must rely for the material for further advances towards a knowledge of its laws.

Not that we have learned nothing. Within those sixty years the general characteristics of the revolving storm of tropical latitudes and of its milder relative the cyclonic depression of temperate latitudes have been made out, though their ultimate causes are still obscure. We know at least what the greater fluctuations of barometric pressure mean for the Seaman, and where he is likely to find them. There are minor fluctuations, too, which we know about and which have a meaning, often a very incisive one, but we still have many questions to ask about currents in the water of the ocean, or in the air over it, their variations and their relations to ice, fog and other conditions.

We have also learned the average distribution of pressure, temperature and weather over all oceans, and that has led to another advance by compelling us to regard the whole atmosphere as one, really and not only in name; so that marine meteorology, land meteorology, polar meteorology with its ice and snow, and the study of the upper air have become for all practical meteorologists simply aspects of the study of the atmosphere, of the meteorology of the globe.

Our next step is to bring all these aspects into visible co-operation, and the various observations into juxtaposition. So in presenting to you a new version of the instructions for the guidance of marine observers, drawn up by one of your colleagues and of mine, we have not hesitated to ask you to think with us in terms of the meteorology of the globe, certain that the laws of weather for the sea cannot be disentangled from those for the land and the sky.

The best expression for the obligation which I feel after your sixty years of co-operation with this Office is to appeal once more to your scientific interest, and ask you to continue to give us observations with all possible accuracy. But it is not science only which prompts one to make that appeal. On the sea enterprise is hardly distinguishable from competition or rivalry; and, other things being equal, that ship will certainly be most successful in peace or war whose officers know how to make the most of fair weather and the best of foul weather. He knows best who has learnt how to utilise the experience of others as well as his own.

In the matter of weather, it is the task of this Office to do what it can to make the experience of all available in the most useful form for all, and it is on that ground that the continued appeal to Seamen is based.

METEOROLOGICAL OFFICE
LONDON.

11th December, 1914

W. S. SHAW,
Director.

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THE MARINE OBSERVER'S HANDBOOK.

INTRODUCTORY NOTICE TO CAPTAINS OF SHIPS.

The Meteorological Office was instituted in the year 1854 as a department of the Board of Trade for the purpose of promoting and collecting trustworthy observations for the study of weather from British ships on all navigable seas as part of an international scheme for obtaining a more accurate knowledge of the meteorology of the globe, and more especially of supplying information as to the kind of weather which had been experienced and therefore might be experienced again on any of the trade routes or on exploring expeditions. The work of the Office has been extended in many directions, and since 1854 the carrying trade of the world has been greatly modified by the substitution of steam for sail. But the weather is still a subject not only of interest but of importance to seamen. The use of a vessel for dividend-earning purposes still depends upon the capacity of her officers to make the most of favourable weather and to make the best of bad weather. While wind has to some extent lost in importance, ocean currents, fog, and ice, have gained. The constitution of the Office has also been altered. It is still, however, dependent upon funds provided by Government which are administered by a Director and Committee appointed by H.M. Treasury. Its original purpose has been maintained throughout, and it still remains one of the principal objects of the institution to collect trustworthy observations from the sea and to return the information thus collected in a form useful to seamen. A special division of the Office in charge of the Marine Superintendent is maintained for this purpose; the provisions for securing it remain practically unaltered and are as follow :—

The Director of the Meteorological Office is authorised to lend instruments which are of first-rate character, and

have been properly verified, to Captains who are willing to keep a Meteorological Log for the Office.

The instruments supplied are :—

One barometer; four ordinary thermometers, with a screen; one sea water thermometer; three hydrometers.

In some cases a rain gauge is added to the equipment.

A Meteorological Log Book and an Original Note Book for recording the observations are also supplied. The Note Book, formerly called the *Rough Book*, becomes the property of the Observer.

The Meteorological Log Book and the Original Note Book will be sent to Captains who undertake to make such observations. Application may be made to the Director, or to the Marine Superintendent.

Various publications of the Office are presented to Observers.

The Office is specially desirous of obtaining recent particulars as to the position of ice, or other information that can be utilised in keeping the Meteorological Charts up to date.

The following gentlemen are the agents at the respective ports, and to them application should be made by captains at those ports :—

Cardiff	...	...	Capt. J. Weir, Examiner of Masters and Mates, Mercantile Marine Office.
Dundee	...	...	Capt. J. A. S. Chalmers, Examiner of Masters and Mates, Mercantile Marine Office.
Glasgow	...	...	Messrs. D. McGregor and Co., 57, Bothwell Street.
Greenock	...	...	Messrs. D. McGregor and Co., 33, Cathcart Street.
Hull	...	...	Capt. T. R. Marshall, Examiner of Masters and Mates, Mercantile Marine Office.
Liverpool	...	...	Commr. F. M. Sergeant, R.D., R.N.R., Senior Examiner of Masters and Mates, and Secretary, Board of Trade Office, Canning Place East.

Southampton	...	Sir A. A. Walker, Bart., R.N.R., Senior Examiner of Masters and Mates for London and Southampton, Mercantile Marine Office.
South Shields	...	Capt. W. Forrest, Examiner of Masters and Mates, Mercan- tile Marine Office.
Sunderland	...	Capt. C. Robson, Examiner of Masters and Mates, Mercan- tile Marine Office.

A set of instruments is kept in working order at the Office in London, and at each Agency, for inspection by Captains and Officers; and intending observers can get from the Marine Superintendent at the Meteorological Office, or from an Agent, any further information that they may require on the subject.

CLASSIFICATION AND DESCRIPTION OF REGISTERS.

The forms of Return, which are issued to Marine Observers who are willing to co-operate with the Meteorological Office, for the record of observations required principally in connexion with the work of the Marine Division, may be classed and described as follows :—

The Meteorological Log.—A book ruled to contain, for a period of four months, entries under the headings : Date; Latitude and Longitude; Course and Distance; Total Compass Error and Ship's Head, followed by four hourly observations of Wind: Direction and Force; Barometer, and Attached Thermometer; Wet and Dry Bulb Thermometers; Observation of Clouds and Proportion of Sky Clouded; Weather, and Fog Intensity; Waves, Swell, and Sea Surface Temperature; also Estimates of drift due to current experienced between Noon and Noon or other intervals of time; Specific Gravity of Sea Water at least once daily; and remarks of importance relating to phenomena observed, with the times of occurrence; Changes of Wind, &c. For the keeping of the full Meteorological Log instruments are supplied by the Office.

Short Meteorological Log.—An abbreviated Log-book similar to the foregoing, which is ruled to contain observations taken at Noon and Midnight only, is

4 *Classification and Description of Registers.*

intended for the use of Captains and Officers who are willing to help in the work of the Office, but who cannot undertake to keep the full Log of four hourly observations, for which verified instruments are lent by the Office.

In such cases it is important that the instruments employed by the observer, whether the property of himself or of the owners of his vessel, should be described as fully as possible; and, when practicable, that their readings should be compared with instruments on board ships which have been supplied by the Office or with standards which are available at certain ports. In the Short Log the columns for the Specific Gravity and Cloud observations are omitted. The book is ruled to contain sixty-six days' observations.

Meteorological Registers.—*Forms 121, 122, and 138.*—Forms 121 and 122 are ruled for the entry of observations, similar to those for which provision is made in the Short Meteorological Log, but taken at 8 a.m., and 8 p.m.

Form 121 is spaced to contain records for a period of thirteen days, and is issued principally for the collection of the latest information of value to navigators which may be utilised at once in the compilation of the Monthly Meteorological Charts of the North Atlantic and Mediterranean. Form 122, which is spaced to contain records for a period of twenty-one days, is employed for the collection of data used mainly in connexion with the preparation of the corresponding Charts of the Indian Ocean.

Form 138 (Radio-telegraphy) is issued to the captains of Liners from which reports are transmitted to the Meteorological Office from the North Atlantic by wireless telegraphy. The reports are utilised, when possible, in the preparation of the Daily Weather Charts and Weather Forecasts issued by the Office. This Service, however, is in abeyance during hostilities.

The Form is intended primarily to serve as a record of observations taken for transmission to the Office. In conjunction with a carbon duplicate of the coded message, it is used for checking the data received by telegram, and for amplifying daily synoptic charts of the North Atlantic which are issued weekly. It is ruled to contain the following entries :—

Control Observations at 4 a.m., and 3 p.m., following statement of Ship's Position; Barometer—Uncorrected Reading; Attached Thermometer; Correction from Table; Corrected Reading; Wind: True Direction, and Force.

Final Observations at 7 a.m. and 6 p.m., similar to the above following statement of Ship's Position, but including Temperature of Air; Temperature of Wet Bulb; Sea Disturbance, 0 to 10; Temperature of Sea Surface; Remarks:—Recent particulars of the position of Ice, &c. Mercury barometers are lent to the captains of a limited number of steamships, not otherwise provided with this description of instrument, from whom reports are received by radio-telegraphy.

PART I.—DESCRIPTION OF INSTRUMENTS
REQUIRED FOR KEEPING THE FULL
METEOROLOGICAL REGISTER OR LOG.

CHAPTER I.

The Barometer.*

Without special precautions aneroid barometers do not afford readings of sufficient accuracy for scientific purposes; a marine mercury barometer of the Kew pattern should therefore be used for measuring the pressure of the atmosphere.

In all mercury barometers of the Kew pattern issued by the Meteorological Office the glass tube is considerably contracted for the greater part of its length not only in order to prevent unsteadiness of the mercury column or “pumping,” as this is called; but also to strengthen the tube, and to lessen the weight of mercury.

The tube is furnished with an “air trap” to prevent air working into the space at the top of the mercury column. The air trap consists of a small funnel or “pipette” which is introduced between the cistern and the wider portion of the tube (*see* Fig. 1).

By means of this arrangement any air entering the tube becomes imprisoned at the shoulder A, and therefore cannot interfere with the efficiency of the instrument.

In Marine barometers of this pattern a part of the contracted portion of the tube is further constricted with the object of reducing the pumping caused by the labouring of a vessel in a seaway. In Fig. 1, a Meteorological Office barometer is shown suspended from a bulkhead; a principal section of the tube, in which A indicates the air trap, and C, a specially contracted portion of the capillary tube, is also shown.

THE MOST SUITABLE POSITION FOR THE BAROMETER.

The barometer should hang where it can swing freely, so as always to take up an exactly vertical position; it

* From *A Barometer Manual for the use of Seamen*, M.O. Publication, No. 61.

should be carefully protected from injury; out of the reach of unauthorised persons; and fixed in a conve-

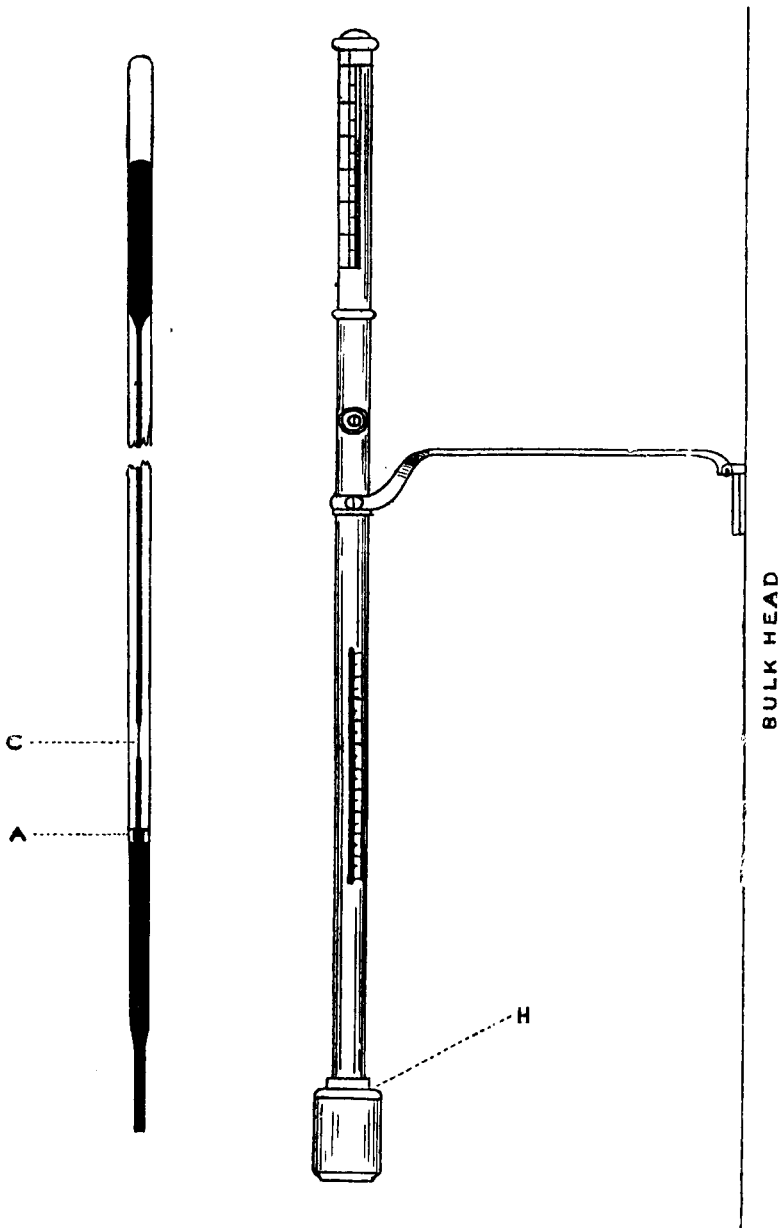


FIG. 1.

nient place for observing, if possible with the light coming from behind the observer, and where it is not liable

to considerable changes of temperature, and therefore away from the influence of sunshine or the direct heat of fires or lamps.

HANDLING THE INSTRUMENT.

In handling barometers it should be remembered that they are delicate and expensive instruments. The result of rough treatment is breakage; and for scientific purposes, observations with an instrument that has been repaired, and not verified by comparison with an instrument the error of which is known, may prove useless.

On no account should a barometer or other instrument belonging to the Meteorological Office be sent to an optician for repair or an attempt be made to repair the instrument on board the ship. All damaged instruments should be returned either direct to the Meteorological Office or to an Agent for the Office at ports where there are such Agencies.

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

Whenever a barometer has to be unshipped and placed in its box, first lift the instrument out of the bracket, and bring it gradually into an inclined position, to allow the mercury to flow very gently up to the top of the glass tube, avoiding any sudden movement which would cause the mercury to strike the top of the tube with violence, as the absence of air there makes the force of the blow little different from that of a solid rod of metal, that 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 not, on any account, be subjected to jars or concussions. In ships of war barometers should, therefore, be always unshipped when heavy guns are being fired.

Experience has shown the advisability of giving directions for packing barometers. If the instrument is to be sent by rail or other conveyance, and is thus liable to be handled by persons unacquainted with its construction, it should, after having been placed in its box as directed, be enclosed in a packing case with two or three inches of soft elastic packing all round it, such as hay, straw, shavings, tow, or paper-cuttings. To avoid concussion, the lid of the case should not be nailed down, but always fastened with screws. The address label should be pasted on the end of the case which is next the cistern of the barometer before the lid is screwed down, and it should be marked "Glass and fragile instruments. Keep this box lying flat, or carry it this end upwards." If two or more barometers be packed together, the cisterns should all be placed at this marked end of the case. Barometers should be sent by passenger train, or by whatever route or conveyance affords the means of transit least likely to lead to rough usage. Transshipment or change of conveyance should be avoided if possible.

When the tube of a barometer is broken the mercury should be emptied into a bottle before the instrument is packed, otherwise the mercury will attack the brass work.

METHOD OF READING THE BAROMETER.

Note.—In the following pages 10 to 16 instructions are given for using the mercury barometer as hitherto supplied by the Office and graduated in inches. Before the readings from any ship can be co-ordinated with those from other vessels or compared with those shown on charts, they have to be corrected for temperature, and allowance has to be made for the height of the barometer above the sea and for the latitude in which the observation was made. For this purpose the tables printed on pp. 119 to 121 must be used. Two scales are now engraved on barometers issued by the Office: one graduated in inches of mercury, the other in pressure units on the C.G.S. system, and with these the process of correction and reduction can be greatly simplified. The instructions applicable in this case are given on pp. 20 to 28.

Observers are requested to use the millibar scale for the entries in the logs, and forms, of the Meteorological Office.

To facilitate accurate reading of the barometer, a small movable scale called a "vernier," so named from its inventor Pierre Vernier (A.D. 1630), is attached to the instrument as shown in Fig. 2. The general principle of this contrivance is that a given length of the vernier, equal to a certain number of divisions of the fixed scale, is divided into one more, or one less, than that number of divisions. In standard barometers the fixed scale is divided into inches, tenths, and half-tenths, each of which last is therefore $\cdot 050$ of an inch. Twenty-five divisions of the vernier are made to coincide with twenty-four of the smallest divisions of the fixed scale; therefore a space on the scale is larger than a space on the vernier by the twenty-fifth part of $\cdot 050$, that is to say by $\cdot 002$ of an inch.

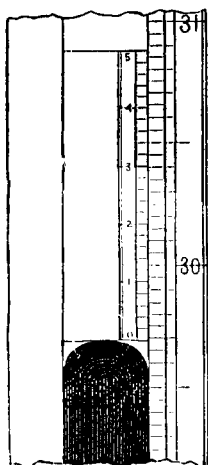


FIG. 2.

The vernier is moved by a rack and pinion which ends in a milled head. To set the vernier for reading, turn the milled head of the pinion so as to bring the lower edge of the vernier exactly on a level with the top of the mercury column. When set properly, the front edge of the vernier, the top of the mercury, and the back edge of the sliding piece, must be in the line of sight, which line will thus just touch the middle and uppermost point of the convex or curved surface of the mercury in the tube. Great care should be taken to acquire the habit of setting the vernier with the eye exactly on a level with the top of the mercury, that is, with the line of sight at right angles to the tube, which, while the observation is being

made, should hang freely in a truly vertical position. The instrument should not be disturbed by being held or even touched; because any inclination will cause the column to rise in the tube. Fig. 3 is a graphical representation of the incorrect results arising from errors of parallax.

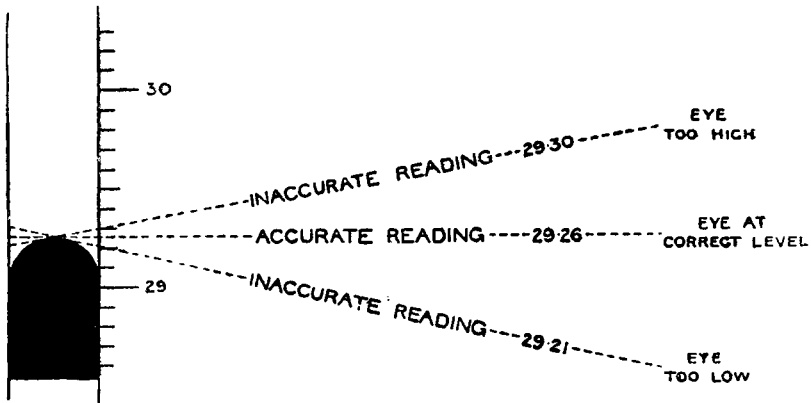


FIG. 3.

A piece of white paper placed behind the tube to reflect the light assists in setting the vernier accurately, and at night a lamp, preferably a candle lamp, may for this purpose be held so as to throw a strong light on the paper.

The mode of reading off the height, when the vernier has been set, may be learned from a study of the diagrams, Figs. 4 and 5 (p. 12), in which A B represents part of the scale, and C D the vernier, the lower edge of which, D, has been brought to coincide with the top of the mercury column. The scale is readily understood; B is 29·000 inches; the first line or division above B is 29·050; the second line or division 29·100, and so on. The first thing is to note the scale division just below D, and the next is to find out the division of the vernier which is in one and the same line with a division of the scale. In Fig. 4 the lower edge of the vernier, D, is represented in exact coincidence with scale division 29·5; the barometer therefore reads 29·500 inches. Studying it attentively in this position it will be perceived that while the top C again coincides with a line on the scale, the other divisions of the vernier are more or less separated from the divisions of the scale nearest to them. As was before stated one division of the vernier is ·002 inch smaller than one division of the scale, consequently with the vernier in the position shown in Fig. 4 the division *a* is ·002 inch below

the nearest line, z , of the scale. If, therefore, the vernier be moved upward, so as to place a in a line with z , the edge D would be raised $\cdot002$ inch, and it would read $29\cdot502$, and this would be the height of D on the scale. In like manner it is seen that b on the vernier is $\cdot004$ inch below the line next above it on the scale; c , $\cdot006$ inch below that next above it; d , $\cdot008$ inch from that next above it; and 1, on the vernier, is $\cdot010$ below y on the scale. Hence, if the lines b , c , d , and 1, be moved in succession into line with the divisions next above them D would be raised $\cdot004$, $\cdot006$, $\cdot008$, and $\cdot010$ in succession, and would read $29\cdot504$, $29\cdot506$, $29\cdot508$, and $29\cdot510$. Thus, coincidences of lines on the vernier and the scale at the numbers 1, 2, 3, 4, 5, on the vernier, indicate that D is raised above the scale line next below it by 1, 2, 3, 4, or 5 hundredths, and coincidences at the intermediate lines mark the intermediate even thousandths of an inch.

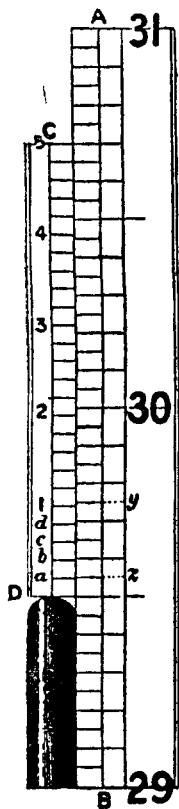


FIG. 4.

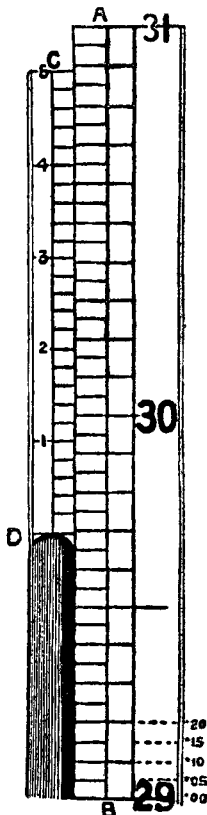


FIG. 5.

The application of this will be seen from Fig. 5. The bottom of the vernier D having been brought into coin-

cidence with the top of the mercury, the scale line just below D is 29·650. Looking carefully up the vernier, the third line above the figure 3 is seen to lie evenly with a line on the scale. The number 3 indicates ·030, and the third subdivision ·006; so that D is ·036 above the scale line next below it, and thus we get—

Reading on scale	...	...	29·650
Reading on vernier	...	...	{ ·030
			{ ·006
Actual reading, or height of mercury	...	...	29·686 inches.

Sometimes two pairs of lines will appear to be coincident, in which case the intermediate thousandth of an inch should be set down as the reading. Thus, suppose coincidences appear corresponding to 29·684 and 29·686, then 29·685, half way between them, should be adopted.

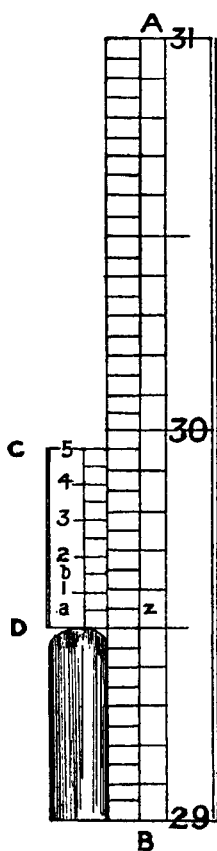


FIG. 6.

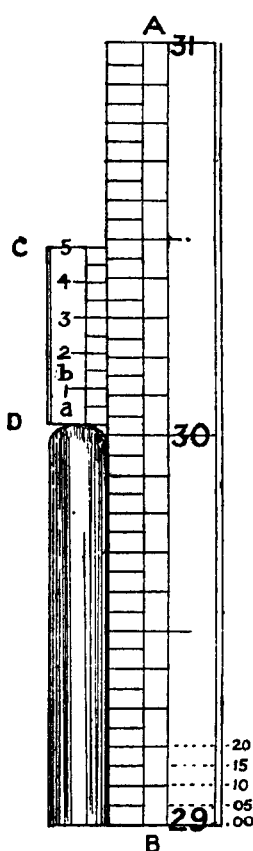


FIG. 7.

The Meteorological Office has issued a barometer for use at sea with a vernier which allows of barometrical readings being taken to the nearest half-hundredth, or '005 of an inch. The divisions of the fixed scale are each '050 inch; nine of these are taken as the length of the vernier, which is, therefore, '45 inch. This length is divided into ten equal parts, consequently each division of the vernier is '045 inch. Hence the difference of length between a division of the scale and one of the vernier is

$$.050 - .045 = .005 \text{ inch.}$$

It is not usual, however, to record the height of the barometer at sea to thousandths of an inch; readings to hundredths are sufficiently accurate in temperate latitudes but within the tropics an accuracy of half-hundredths or '1 millibar (*see* p. 23) should be attempted.

A comparison of Figs. 6 and 7 with Figs. 4 and 5 is sufficient to explain the method of effecting the change. In Figs. 6 and 7, A B represents part of the scale, and C D the vernier, the lower end of which, D, has been brought to coincide with the top of the mercury column. The scale is readily understood. B is 29'00 inches, the first line or division above B is 29'05, the second line or division is 29'10, and so on. First note the scale division just below D, next determine the division of the vernier which is in one and the same line with a division of the scale. In Fig. 6 the lower edge of the vernier, D, is in exact coincidence with 29'50 division on the scale; and the barometer reading is therefore 29'50 inches. It will be seen that the top C again coincides with a line on the scale, but the other divisions of the vernier are separated by increasing amounts from the immediately higher division on the scale. Now one division of the vernier, as stated above, is '005 inch smaller than one division on the scale, and, therefore, with the vernier shown as in Fig. 6, the division *a* on the vernier is '005 below the next higher division *z* on the scale. Hence, if the vernier be moved upward so as to place *a* in a line with *z*, the edge D would be raised '005 inch, and it would indicate 29'505, and this will be the height of D on the scale. Similarly it will be seen that 1 on the vernier is '01 inch below the line next above it on the scale; *b*, '015 inch below that next above it; 2 is '02 inch from that next above it; and 5 on the vernier is '05 below the 30 inch line. Hence if the lines 1, 2, 3, 4, 5 be raised into line with the scale divisions next above them, D will be raised '01, '02, '03, '04, and

·05 inch, in succession; and the barometer readings of 29·51, 29·52, 29·53, 29·54, and 29·55, respectively, would be indicated. Thus coincidences of lines on the vernier and the scale at the numbers 1, 2, 3, 4, 5 on the vernier, show that D is raised above the scale line next below it by 1, 2, 3, 4, or 5 hundredths of an inch. Coincidences at the intermediate lines mark the intermediate half hundredths; but readings to the nearest ·01 will often suffice for the purposes of marine meteorology.

The application of the above explanation will be seen by reference to Fig. 7. The bottom of the vernier D having been brought into a straight line with the top of the mercury, the scale line just below D is 30 inches. Looking carefully up the vernier it will be seen that the line against the figure 3 lies evenly with a line on the scale. The number 3 indicates ·03; hence D is ·03 above the scale line next below it, and thus we get :—

Reading on scale ...	...	...	30·00
Reading on vernier	...	...	·03
<hr/>			
Actual reading, or height of			
mercury	...	...	30·03 inches.

Sometimes two pairs of lines will appear to be coincident as with the 3 line and the shorter line in figure; then, if special accuracy is required, half-way between them is 30·035, and that should be adopted as the reading. For the ordinary purposes of marine meteorology, however, either 30·03 or 30·04 will be sufficiently near.

PUMPING.

If the barometer is pumping at the time of observation the vernier should be set for reading when the mercury, rising and falling in the tube with the heave of the ship, has completed its downward movement. When a mercury barometer is examined on board ship in a sea way, it will be seen that the level is constantly fluctuating. This phenomenon is known as “pumping.” Three separate causes may be operative in various degrees to produce this effect. The mobility of the heavy mercury comes in in two ways: first on account of the heave of the ship, and secondly on account of the rocking of the instrument. Besides these, there is the effect of the wind on the air pressure in the room where the barometer is hung. An

ordinary barometer with a tube of wide bore is so much affected by pumping that no useful reading is possible in a sea way. With the constricted tube of the marine barometer the effect is sufficiently reduced to make a reading possible, but there is still a residual pumping the cause of which has not yet been fully examined, and which makes the reading difficult and uncertain.

CORRECTIONS OF READINGS OF THE BAROMETER.

Correction for Temperature.—As the column of mercury lengthens when heated and shortens when cooled, because hot mercury is specifically lighter than cold, it is necessary to apply to the readings of the instrument a correction for temperature, to show what the reading would have been at the temperature of 32° F., the standard temperature to which all barometrical readings are reduced. A correction is also required to compensate for the variations of temperature of the brass scale. It is therefore essential to take, and register, a careful reading of the thermometer fixed to the instrument, usually called the “attached thermometer,” whenever an observation of the barometer is made. When the thermometer attached to the barometer is above 28°, the correction, for which a table will be found in Appendix V. (p. 119), must be subtracted, and when at, or below, 28°, must be added.

The readings taken on board ship, where the temperature is usually above the freezing point, will therefore commonly be higher than the values given on charts which show the mean height of the barometer, corrected for temperature; the difference depending on the temperature at which the barometer on board happens to be at the time the reading is taken and the height of the instrument above sea level. For a temperature of 80° and a barometrical reading of 30 inches, the correction, to be subtracted from the observed height, would be .139 in. with the barometer cistern at sea level.

The marine barometer which is issued to observers by the Meteorological Office is so constructed as to obviate the necessity for applying corrections, either for capillarity, which tends to depress the mercury in the tube, or for the varying quantity of mercury in the cistern, which are required for some barometers. A label giving the results of a comparison with a standard is pasted in the case.

Correction for Height.—As the pressure of the air becomes less as we rise above the sea level, a correction of the barometer readings is also required to obtain the pressure at sea level. This amounts to about $\cdot 001$ inch for each foot above the sea, and is always to be added.

The correction for height above sea level in the days of small sailing ships was comparatively unimportant; but with the barometer cistern say 70 feet above sea level as in the largest liners, this correction will be as much as $+ \cdot 08$, and may not be neglected as the table on p. 119 shows. It is, however, advisable, when practicable, to hang the barometer in a position near the centre of gravity of the ship, as then the mercury will oscillate least as the ship pitches or rolls.

Correction for Latitude.—When barometer readings from different parts of the world have to be compared by plotting on a chart, and an accuracy of a hundredth of an inch is required, a correction for gravity also is now applied, because, the earth being a spheroid, the force of gravity varies with the latitude, and places at the equator are at a greater distance from the earth's centre than places at the poles. Barometer readings, therefore, are reduced to standard latitude, for which the parallels of 45° N. and 45° S. have been adopted. The corrections required in this connexion are given in Table III., p. 121.

THE ANEROID BAROMETER.

The Aneroid Barometer, an instrument specially adapted for noting changes in pressure, consists of a circular metallic chamber partially exhausted of air and hermetically sealed. By an arrangement of levers and springs, a hand is worked which indicates the pressure.

This instrument is particularly useful in ships, as it can be placed in a position immediately under the eye of the officer on deck, which, generally speaking, is not a practicable, or advantageous position, for a mercury barometer. The aneroid should be frequently compared with the mercury barometer, and corrected, when necessary, by means of the adjusting screw at the back. Whenever such an alteration of the index error is made, the fact should be clearly stated in the log, or on any other records of observations, as a guide to persons consulting the data in the future.

Readings of aneroids do not require correction for temperature or latitude, but only for height above sea

level and index error. The figure given for the correction of the aneroid barometer of ships in communication with the Meteorological Office is frequently a combined result, and makes allowance for both height and index error.

THE MEASUREMENT OF BAROMETRIC PRESSURE IN PRESSURE UNITS.

In the Daily Weather Report which is issued by the Meteorological Office, barometric pressure is now expressed in units of the C.G.S. (centimetre—gramme—second) system, in which the *bar*, *centibar*, and *millibar* are actual units of *pressure*.

The inch, being a unit of length, requires a tiresome numerical calculation in order to convert barometric readings into a real estimate of pressure, and it is pressure that has to be expressed. For the purpose of estimating the probable changes that have taken or may take place in the distribution of atmospheric pressure a measure is wanted of the force requisite to move a given mass of air; just as a measure is needed for estimating the power which is required to drive a vessel of a given tonnage a given length or distance in a given time.

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.

The Second is the universal unit of time.

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

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

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

The unit of Pressure, in the C.G.S. system is the dyne per square centimetre; but as this unit is exceedingly small a practical unit of atmospheric pressure is substituted, which is one million times as great: the megadyne per square centimetre. This unit is equivalent to a pressure of 29.53 inches, or 750.1 millimetres of mercury, at

the freezing point of water in latitude 45° , and is the normal air pressure at 106 meters above the sea. For expressing this unit the name *bar* has been adopted by meteorologists. It is the hundredth and thousandth parts of the *bar*: the *centibar* and *millibar* respectively, which are adopted as working pressure units in the C.G.S. system.

The relation between the centibar and the commoner units, the inch and millimetre of mercury is shown in the following table:—

EQUIVALENTS IN MILLIMETRES, AND CENTIBARS, OF INCHES OF MERCURY AT 32° F. AND LATITUDE 45° .

Mercury Inches.	Mercury Millimetres.	Centibars.	Mercury Inches.	Mercury Millimetres.	Centibars.
28.0	711.2	94.8	29.5	749.3	99.9
28.1	713.7	95.2	29.6	751.8	100.2
28.2	716.3	95.5	29.7	754.4	100.6
28.3	718.8	95.8	29.8	756.9	100.9
28.4	721.4	96.2	29.9	759.5	101.3
28.5	723.9	96.5	30.0	762.0	101.6
28.6	726.4	96.9	30.1	764.5	101.9
28.7	729.0	97.2	30.2	767.1	102.3
28.8	731.5	97.5	30.3	769.6	102.6
28.9	734.1	97.9	30.4	772.2	102.9
29.0	736.6	98.2	30.5	774.7	103.3
29.1	739.1	98.5	30.6	777.2	103.6
29.2	741.7	98.9	30.7	779.8	104.0
29.3	744.2	99.2	30.8	782.3	104.3
29.4	746.8	99.6	30.9	784.9	104.6

Barometers for the Mercantile Marine, which are issued by the Meteorological Office, are now fitted with two scales. On one side of the tube and of the vernier the scale is graduated as formerly, to read to half-hundredths of an inch; on the other side the graduation is in centibars and millibars and can be read to tenths.

Attached thermometers are graduated in centigrade degrees from the Absolute zero of temperature, which is 273° centigrade below the freezing point of water or -459° on the Fahrenheit scale. This zero represents, so far as our present knowledge goes, the temperature at which the whole of the heat of any substance whatever would have been converted into some other form of energy. The

principal advantages of the absolute scale for meteorological work is that all negative values are avoided, and all calculations of the pressure and density of air are reduced to simple proportion.

A diagram illustrating the graduation of a Kew pattern barometer in millibars and of its attached thermometer in centigrade degrees from the Absolute zero is given on page 21.

INSTRUCTIONS FOR THE USE OF A MERCURY BAROMETER
OF THE KEW PATTERN GRADUATED IN MILLIBARS,
WITH THE ATTACHED THERMOMETER IN THE ABSOLUTE
SCALE, AS ISSUED TO MARINE OBSERVERS BY THE
METEOROLOGICAL OFFICE.

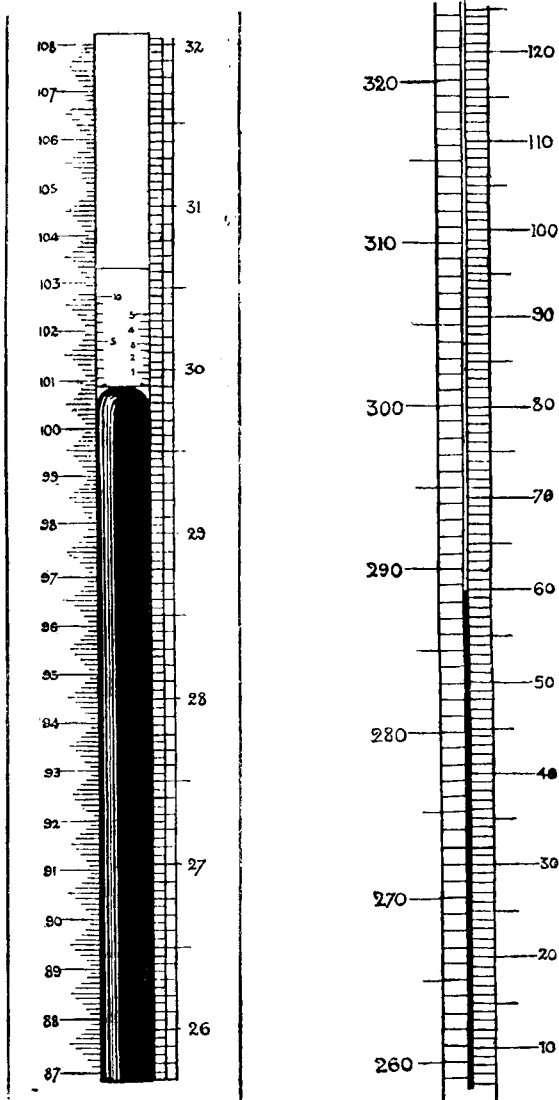
Adapted from M.O. 2 (1914).

The Graduation of the Barometer.

Two scales are engraved on the barometers which are now being issued to marine observers, one reading in pressure-units which are called *millibars*, the other in "inches," but all barometer values reported to the Meteorological Office should be *in millibars*. The pressure-units are arrived at from theoretical considerations, and are those most suited for meteorological calculations. One of the principal reasons for their introduction into the daily weather service of this country is that their use is a step towards the general adoption of a system of units which may become common to all nations, thus doing away with the waste and confusion which at present arise from the use of "inches" in English-speaking countries and "millimetres" elsewhere. The millibar was used some years ago in an important publication of the Carnegie Institution of Washington upon the atmosphere, and it has now been adopted by the International Commission for Scientific Aeronautics for the international publication of the results of the investigation of the upper air by means of kites and balloons. The system has been in use in the Meteorological Office since 1907 for the upper air, since 1911 for the data for the observatories, and since January,

GRADUATION OF KEW PATTERN BAROMETER AND ITS
ATTACHED THERMOMETER.

The latter with graduation in degrees of Fahrenheit
added for comparison.



Centibars. Inches.

Temperature Temperature
in Centigrade Fahrenheit.
Degrees from
Absolute Zero.

FIG. 8.

1914, in the weather charts published in the Weekly Weather Report. Since January 1st, 1914, the Weather Bureau of the United States has adopted it for daily charts of the Northern Hemisphere, which are printed on the reverse side of its Daily Weather Report. The Royal Meteorological Society has decided to use it for the expression of the series of pressure normals for the British Isles which it is now preparing.

The use of the pressure-units introduces a great simplification in work on the meteorology of the upper air, which is now assuming practical importance in consequence of progress in aviation. To the telegraphic observer the new scale offers the advantage that there is less risk of error in reading the vernier scale or in rounding off the final reading before coding the reports. The corrections are also somewhat simpler to apply. If the scale on the instrument is rather too closely divided for comfortable reading the use of a lens will obviate the difficulty.

The units on the absolute scale are related to one another as follows :—

$$\begin{aligned} 10 \text{ millibars} &= 1 \text{ centibar} \\ 10 \text{ centibars} &= 1 \text{ decibar} \\ 10 \text{ decibars} &= 1 \text{ bar.} \end{aligned}$$

The millibar is adopted as the working unit in the Daily Weather Service (*see* p. 18). The scale of millibars is related to the conventional scale of mercury inches as follows :—

$$\begin{aligned} \text{Normal pressure for British Isles,} \\ 29\cdot92 \text{ mercury inches} &= 1013\cdot2 \text{ millibars.} \\ \text{Highest recorded pressure for the British Isles,} \\ 31\cdot11 \text{ mercury inches} &= 1053\cdot5 \text{ millibars.} \\ \text{Lowest recorded pressure for the British Isles,} \\ 27\cdot33 \text{ mercury inches} &= 925\cdot5 \text{ millibars.} \\ 1 \text{ millibar} &= \cdot029 \text{ mercury inch.} \end{aligned}$$

Thus one-tenth of a millibar corresponds with $\cdot003$ mercury inch, which may be taken as the limit of accuracy to which it is possible to read a barometer under favourable working conditions.

To take an Observation.

(1.) *Attached thermometer.*—Observe and note in the appropriate column of the register the temperature of the

thermometer attached to the barometer. The temperature should be read on the scale graduated from about 265° to 305° . Sufficient accuracy will be attained if the temperature be noted to the *nearest whole* degree.

The reading of the attached thermometer should be noted before setting and reading the barometer as changes in temperature due to the presence of the observer are likely to affect the thermometer more quickly than the mercury in the tube.

(2.) *Setting the vernier scale.*—(See p. 10.)

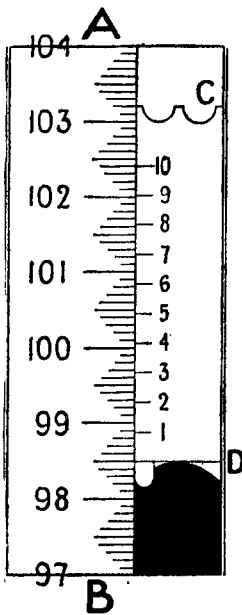


FIG. 9.

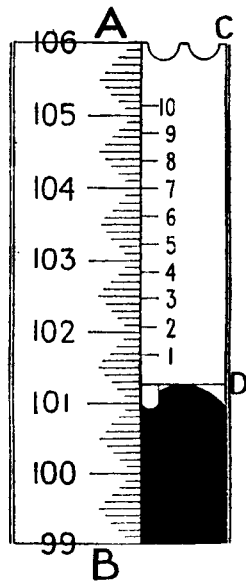


FIG. 10.

(3.) *Reading the scale.*—The operation of reading consists of two parts :

First. Note the value of the scale division *next below* the zero division on the vernier marked D in Figs. 9 and 10. The scale is graduated in *millibars*, and numerical values in *centibars* are figured along it (10 millibars = 1 centibar). In order to assist the eye when determining the value of a division, the millibar graduations are of unequal length. In Fig. 9, D is supposed to be in the same straight line with the fifth (the long) division above the scale division numbered 98, in other words with the graduation 985 millibars. In Fig. 10 the graduation

next below D is the second above the graduation numbered 101; its value is therefore 1,012 millibars.

Second. Look along the vernier for a division which is in one and the same straight line with a scale division. The value of this division on the vernier gives the decimal place. In Fig. 9 the vernier division 0 is exactly coincident with a scale division; the reading of the barometer is therefore 985.0. In Fig. 10 the vernier division 7 is exactly opposite a scale division; the barometer reading is therefore 1012.7.

If the vernier has not been shifted between two observations, it is advisable to check the previous reading before proceeding to a fresh setting.

CORRECTION AND REDUCTION TO SEA-LEVEL OF MILLIBAR BAROMETERS.

Note.—Barometers graduated to read in millibars are provided with an attached thermometer graduated according to the absolute scale of centigrade degrees (*see* p. 21) and the references to temperature in the following instructions are to the readings on that scale. In quoting the temperature the degree mark is omitted and instead of it a small “a” follows the number. Thus 273a on this scale corresponds with the freezing point of water, that is 0° C or 32° F, and 283a corresponds with 10° C or 50° F. A step of 10a in temperature is the same as a step of 18° F.

Standard temperature as shown on the Certificate.—The barometer will have been certified as *correct* in *latitude* 45° at a certain *temperature* which we call the *standard temperature*. The certificate means that when the temperature has the specified value, the barometer reading will give the true value of the pressure in *millibars* at the *level of the barometer cistern* in the specified latitude.

Example.—Barometer M.O. A.2074. The standard temperature is 286.5 a, that is in latitude 45° the barometer reads correctly at 286.5 a which is the same as 56.3° F.

With this information it is easy to make allowance for difference of latitude and difference of temperature; it is also easy to allow for height above sea-level in a similar manner and so put the observer in the position to compare his readings with a synoptic weather-chart or with the normal for the locality, provided that the height above sea-level is not greater than those at which ships' barometers are commonly fixed.

Fiducial temperature.—If the latitude is not 45° the reading will not be correct at the standard tempera-

ture, but there will be a temperature at which the reading would be correct if it were so chosen that the latitude correction would just balance the temperature correction. We call this temperature, at which the readings of the barometer need no correction, the *fiducial temperature* for the barometer in the particular latitude. For a station-barometer with fixed latitude the fiducial temperature remains the same, but at sea the fiducial temperature is different for the different positions of the ship in latitude.

To allow for the height of the barometer above sea-level the fiducial temperature can be adjusted because, in the ordinary circumstances in which the barometer is used at sea, the allowance to be made for 100 ft. of height lies between 3·3 mb. and 3·9 mb., and a correction of 3·6 mb. for 100 ft. would be sufficiently accurate in most cases.

Correction and Reduction.—The process of correction and reduction to sea-level is therefore as follows :—

(1) *To determine the fiducial temperature for the latitude at which the barometer is read, use the following table :—*

Latitude	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°
Subtract from the Standard Temperature.	15	15	14	13	11·5	9·5	7·5	5	2·5	0
Latitude	90°	85°	80°	75°	70°	65°	60°	55°	50°	45°
Add to the Standard Temperature.	15	15	14	13	11·5	9·5	7·5	5	2·5	0

Example.—Barometer M.O. A.2074. Standard temperature, the fiducial temperature in latitude 45°, is 286·5 a. To find the fiducial temperature in latitude 52° add 3·5 a (2·5 a for latitude 50°; and 1 a for the additional 2°): fiducial temperature required is 286·5 a + 3·5 a, that is, 290 a.

(2) *To adjust the fiducial temperature in order to make allowance for the height above sea level.*

Increase the fiducial temperature by 1a for every 5 ft. or 1·5 metres of height.

Example.—Barometer M.O. A.2074 is set at 52·5 ft. (16 metres) above sea level.

Its fiducial temperature is therefore increased by 10·5 a from 290 a to 300·5 a for 52° latitude.

(3) *Having obtained the adjusted fiducial temperature, to correct the barometer reading for the difference between the actual temperature as read on the attached thermometer (absolute scale) and the adjusted fiducial temperature.*

(a) When the attached thermometer reads *higher* than the adjusted fiducial temperature—

Subtract from the reading 1 millibar for every 6 a in the difference “actual – adjusted fiducial.”

The proportional parts are as follow :—

Difference : actual—										
adjusted fiducial ...	1a	2a	3a	4a	5a	6a	7a	8a	9a	10a
Millibars ...	·2	·3	·5	·7	·9	1·0	1·2	1·4	1·5	1·7

(b) When the attached thermometer reads *lower* than the adjusted fiducial temperature—

Add to the reading 1 millibar for every 6 a in the difference.

The proportional parts are the same as before.

Example.—Barometer M.O. A.2074, 16 metres above sea-level in latitude 52° N., reads 1017·6; attached thermometer 292·4 a.

To find the true pressure in millibars—

The adjusted fiducial temperature (2) is 300·5 a

uncorrected reading 1017·6

Correction for defect of actual—adjusted fiducial

(292·4 – 300·5),—8·1a add 1·4

Corrected reading 1019·0

The reading is now ready for plotting on a synoptic chart, but when a high degree of accuracy is required, the calculation should be carried out to the tenth of a degree to avoid the accumulation of error, and the following points must be attended to.

SUPPLEMENTARY CORRECTIONS FOR SPECIAL ACCURACY.

(4) **Proportional adjustment of correction.**—

The correction as set out in (3) is in reality a *fractional part* of the pressure and ought therefore to be adjusted proportionally for different points in the range of atmospheric pressure. The adjustment is very simple: add

1 per cent. to the correction for each 10 millibars above 1,000, and subtract 1 per cent. for each 10 millibars below.

One per cent. only begins to be appreciable when the whole correction is about 10 mb., and the additional correction for proportional adjustment is only necessary on quite exceptional occasions.

Example.—Barometer M.O. 2000 with fiducial temperature 306 a in latitude 20° gave a reading of 920 mb. at 290 a (the lowest observed reading of a cyclonic depression).

Temperature correction	...	add	2·7 mb.
Proportional adjustment			
(for 80 mb.)—8%...		subtract	·216
Adjusted correction	...	add	2·5

True pressure ... 922·5 mb.

(5) **Correction for scale error.**—This can be provided for by the table of Kew corrections which gives the standard temperature at different points of the scale. A properly graduated scale ought to have the same standard temperature throughout its range. If correction for standard temperature in different parts of the scale is necessary, it can be worked by the table of (3).

Example.—Barometer M.O. 2015 had standard temperature 286·5 a at 1000 mb. but 280 a at 900 mb.

Find the correction for scale to the reading in Example 4.

Take the standard temperature at 920 mb. to be 281·5 a or 5 a less than for standard conditions.

That is equivalent to reducing the fiducial temperature by 5 a, which involves a correction of ·8 mb. to be subtracted from the reading.

(6) **Summary.**—The process may be recapitulated and summarised as follows:—

Barometer M.O. A.2074, 16 metres (52·5 ft.) above sea-level in latitude 52° N., reads 1017·6 with attached thermometer 292·4 a.

Standard temperature (fiducial temperature in latitude 45°), by the certificate the same at all points of the scale	...	...	286·5 a
Fiducial temperature in latitude 52° add...			3·5 a
For adjusted fiducial temperature at 16 metres add	...	...	10·5 a
			<hr/>
			300·5 a

For adjusted fiducial—actual ($300\cdot5 - 292\cdot4$) = $8\cdot1a$
 add $1\cdot4$ mb. to $1017\cdot6$ mb.

Corrected reading 1019·0 mb.

Proportional adjustment 2 % of $\cdot4$ mb. (negligible).

Scale error—nil.

(7) The marine observer is advised to have fixed up in the immediate neighbourhood of his barometer a card showing the adjusted fiducial temperature of his barometer for each degree of latitude. He can compile it for himself by the instructions given under (1) and (2). To correct a reading he has then only to consider the difference between the fiducial temperature and the actual temperature at the time of reading simply *adding* $\cdot1$ mb. to the reading for every $\cdot6$ of a degree by which the adjusted “fiducial” exceeds the “actual,” or *subtracting* $\cdot1$ mb. for every $\cdot6$ of a degree if the difference is the other way.

THE SEA BAROMETER.

At the Meteorological Office a new dial has been introduced for aneroid barometers intended for use at sea, of which a

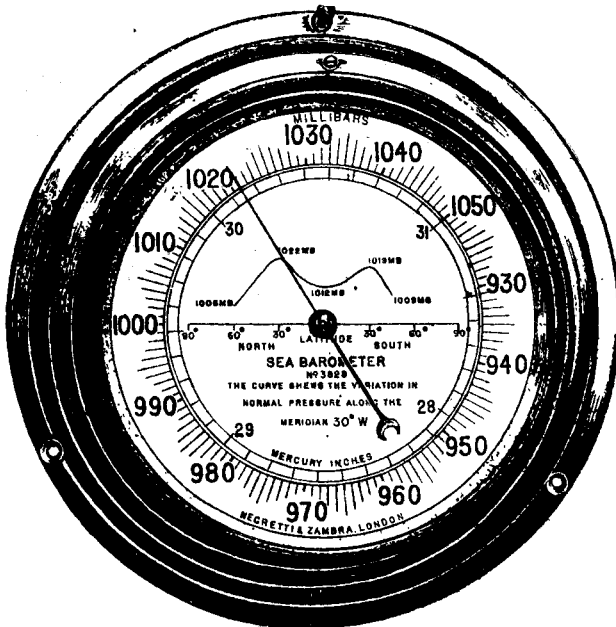


FIG. 11.

representation is given in Fig. 11. The graduations are shown in “millibars” 1,000 millibars (100 centibars) being the “standard atmosphere” in the C.G.S. (centimetre, gramme, second) system of units. On the barometer dial,

graduation in inches and in millimetres is also shown, and it will be seen that the pressure of 100 centibars corresponds very nearly with that of $29\frac{1}{2}$ ins. or 750 millimetres. The dial shows a range from below 93 centibars ($27\frac{1}{2}$ ins.) to 105 centibars (31 ins.), and so covers the whole range of pressure that is likely to be experienced at sea level in any part of the world. For the convenience of sailors, on the special form of instrument which is called a *sea barometer*, and which is figured here, a curve is given which indicates the *mean annual pressure* in certain degrees of latitude along the meridian of 30° West.

This meridian goes over sea from the Arctic to the Antarctic, and crosses the "Icelandic low," the "highs" of the tropics of Cancer and Capricorn, and the deep low of the higher southern latitudes. Similar variations are to be found in other oceans, so that the variations which are indicated by these marks on the dial are a guide to the average values which the mariner may expect. These values should enable him to judge first whether the instrument is in reasonable adjustment, or, secondly, whether the season of his voyage is a normal one so far as pressure is concerned.

THE BAROGRAPH.

A portable "Barograph" (Fig. 12), which is an aneroid barometer provided with a lever recording variations of pressure on a revolving drum, is in some respects a more valuable supplement to the mercury barometer on board ships than the aneroid of the ordinary form. It is not only useful in enabling an observer to detect casual errors in the readings of the mercury barometer but also gives a continuous record of barometric pressure for reference. Barograms, moreover, register minor fluctuations of atmospheric pressure which are seldom noticeable in the action of the mercury barometer, and without the uninterrupted evidence furnished by a sensitive self-recording instrument, are rarely detected.

Attention has been directed on several occasions by the Meteorological Office to the association of these minor fluctuations of pressure disclosed by the barogram, which are aptly described as the "embroidery" of the trace, with occurrences of rain, hail or snow showers, usually accompanying a squall. This joggle in the trace concurrent with showers, and not infrequently with a

transient increase of wind, is an interesting feature in barographic records, showing as it does the close connexion that exists between variations in barometrical pressure, however slight, and weather changes.

The action of the Barograph, briefly, is as follows :— The circular metallic chamber (C), consisting of a series of vacuum metal boxes with elastic lids, is connected with the revolving drum (D) by means of a lever (L) carrying a pen (P) filled with specially prepared ink. The rotation of the drum is effected by means of clockwork contained in the drum which is designed to complete a revolution in seven days.

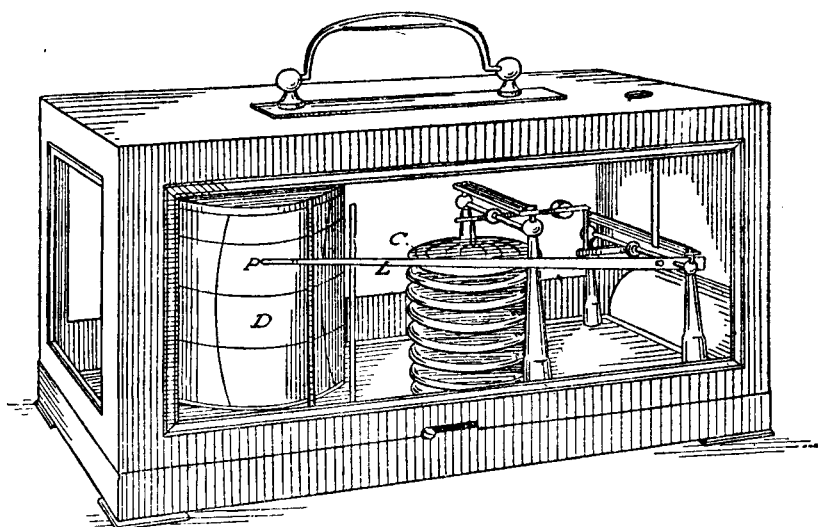


FIG. 12.

The variation in the volume of these vacuum boxes, caused by changes in atmospheric pressure, is transmitted through the lever to the pen, which registers the changes in a continuous line on a printed chart fitted round the drum (Fig. 12).

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

The setting of the Barograph to time presents some difficulties, because ship's time changes from day to day during a passage, while the timepiece of the instrument, if in proper order, will keep the time at which it is origin-

ally set. Thus, if the pen is set correctly for ship's time in longitude 75° W., the instrument will continue to show the time for that longitude for the whole week, and at the end of the week may be as much as five hours slow or fast of ship's time. It is therefore recommended that the pen be set to show Greenwich Mean Time correctly, and it should then continue to show that time however the position of the ship may change.

A time mark, showing Greenwich Mean Noon, should be made each day. If, however, for any special reason the observer sets the pen mark to ship's time on the chart at the beginning of the week he should mark ship's noon on the chart each day. In any case the plan adopted in this connexion should be clearly stated on the back of the chart. The records of the instrument, or *traces* as they are termed, should be examined carefully by the observer from time to time, in order that inaccuracies caused by the pen pressing too closely on the chart may be discovered. The pen should press sufficiently on the chart to leave a clear uninterrupted trace. The records should be compared frequently, or when an opportunity occurs, with the readings of a reliable mercury barometer corrected for instrumental error and temperature, and the result noted on the back of the chart. Should it be found, however, that the difference between the Barograph and the Barometer readings is large the pen of the former should be reset.

A fine clear line should be traced by the pen of the Barograph; if a thick line is produced it may be due to rough or badly sized paper, to bad ink, or to a foul pen. If the pen requires cleaning it should be carefully cleansed with a brush and as carefully dried. An implement such as a knife should on no account be used for this purpose.

The Barograph, when used on board ship, may either be carried in a cradle slung on gimbals, the cradle being secured; or suspended from the deck above. It should be located in a position where it will be least affected by concussion, vibration, or movement of the ship. During gun firing the pen's point should be moved from the paper.

CHAPTER II.

Thermometers, Hydrometer, and Rain Gauge.

THE THERMOMETER.

This instrument shows increase or decrease of temperature but is not sensibly affected by changes of the pressure of the air. It consists of a glass tube of very small bore, closed at one end, and united at the other to a bulb, which is commonly filled with mercury. Thermometers intended for use in very cold climates are filled with spirit instead of mercury, which would freeze and solidify at the low temperatures of the Polar regions, whereas spirit would not freeze. Mercury freezes at a temperature of about -38.2° Fahr. = -39° Cent.; spirit (pure alcohol) becomes a thick liquid at -130° Fahr., and solidifies into a white mass at -202° Fahr. Almost all substances expand when they are heated, and contract when they are cooled, but they do not all expand equally. Mercury expands more than glass, and so when the thermometer is heated the mercury in the bulb expands, and that portion of it which can no longer be contained in the bulb rises in the tube, in the form of a thin thread. The tube being very minute, a small expansion of the mercury in the bulb, which it would be difficult to measure directly, becomes readily perceived as a thread of considerable length in the tube. When the instrument is cooled the mercury shrinks, and the thin thread becomes shorter, as the mercury subsides towards the bulb. By observing the length of the thread of mercury in the tube, as measured by the graduation on the scale at its side, or marked on the tube, the thermometer shows the temperature of the bulb at the time, which thus indicates the temperature of the surrounding air, or of any liquid in which the bulb is immersed.

The indications of a thermometer are recorded in degrees, the scale for which is obtained as follows. There are two fixed points on the scale according to which thermometers are graduated, viz., that at which ice melts, and that at which water boils under standard pressure. In the thermometers in ordinary use in England, the distance between these two points is divided into 180 parts, or degrees. When surrounded by melting ice an accurate

thermometer on this scale indicates thirty-two degrees (32°) and at the boiling point of water, when the pressure is 29.92 inches of mercury, the reading is two hundred and twelve degrees (212°). This graduation was adopted by Fahrenheit, a native of Danzig, in the year 1721. Other graduations were devised about twenty years later; one by Celsius, a professor at Upsala, in 1742; and another by Réaumur, a French physicist, at about the same period. Celsius suggested that the boiling-point be called zero, and the freezing-point 100° . In the modern Centigrade scale, which is an adaptation of the Celsius, and in general use at the present time in most Continental countries, the freezing-point is taken at zero, and the boiling-point at 100° . Réaumur framed a scale somewhat similar to the Centigrade but divided the interval between the freezing and boiling points into eighty divisions. This scale, which at one time was commonly employed on the Continent, is now almost obsolete.

The Absolute scale is yet another measure of temperature that has been introduced, based on the researches of the late Lord Kelvin, the late Dr. J. P. Joule and others, who found the absolute zero of temperature to be 273° Centigrade below the freezing-point of water, or -459° on the Fahrenheit scale. This zero of temperature is based on the doctrine of the dissipation of energy, heat having for a long time previously been recognized as a form of energy. It represents, so far as our present knowledge goes, the temperature at which the whole of the heat of any substance whatever would have been converted into some other form of energy. The principal advantage of the Absolute scale for meteorological work is that all negative values are avoided.

In order to convert readings of the Centigrade scale to those of the Fahrenheit: double the Centigrade number, diminish this by one-tenth of itself and add 32. To convert from Fahrenheit to Centigrade: subtract 32 from the former, increase the remainder by one-ninth of itself and take the half.

In Appendix V. Table IV., the conversion of Centigrade degrees into degrees Fahrenheit is given; and in Table V. the conversion of Fahrenheit degrees into Centigrade. For the conversion of temperature readings of the Fahrenheit and Centigrade scales to the Absolute scale Table VI. is furnished.

The usual range of a thermometer in the shade in the open air, in England, is about sixty degrees, viz., from 20° to 80° . In very hard frosts the temperature of the air sometimes falls below 20° , and on very hot summer days it rises above 80° . If the instrument is exposed directly to the rays of the sun, the mercury will rise much higher, and at night, if exposed to radiation to a clear sky, may fall many degrees below what would be due to the temperature of the surrounding air. It is therefore necessary to take precautions for protecting the instrument from the direct rays of the sun, or from exposure to the clear sky at night, in order to obtain a correct indication of the temperature of the air.

THE HYGROMETER.

This instrument measures the humidity of the air. There are several kinds of hygrometer, but the easiest to make and to manage consists of a pair of thermometers placed near each other. It is known as Mason's Hygrometer. One of these thermometers is fitted with a single thickness of fine muslin or cambric fastened lightly round the bulb, and this coating is kept damp by means of a few strands of cotton wick, which are passed round the glass stem close to the bulb so as to touch the muslin, and have their lower ends dipping into a receptacle of water placed close to the thermometer. This thermometer will usually show a temperature lower than that shown by the other thermometer which is near it, the amount of the difference, commonly called the *depression* of the wet bulb, being dependent on the degree of dryness of the air.

A thermometer fitted in the manner described above is called a *wet-bulb* thermometer, to distinguish it from the ordinary thermometer, which has its bulb uncovered and is known as a *dry-bulb*.

The depression of the wet-bulb thermometer is caused by the evaporation from the moistened covering of the bulb. When the humidity of the atmosphere is very great, during, or just before rain, or when fog is prevalent or dew is forming, there is little or no evaporation, and the two thermometers read very nearly alike, but at other times the wet-bulb thermometer reads lower than the dry, because the water dries off or evaporates from the muslin coating, in which process it passes into the state of invisible vapour, and absorbs heat from the mercury

in the bulb of the thermometer, which consequently indicates a lower temperature. As the air becomes less humid the evaporation is greater, and the fall of temperature of the wetted bulb is also greater, and accordingly the difference in readings between the dry- and the wet-bulb is then also greater. The difference sometimes amounts to 15 or 20 degrees in England, and to more in some other parts of the world, but at sea the difference seldom exceeds 10 degrees.

To ensure correct records of the temperature and humidity of the air, the dry- and wet-bulb thermometers should be placed in a screen, the sides of which are protected from the sun and rain by "jalousies" or louveres, that is, narrow sloping boards overlapping each other, but with spaces between, so as to let in the air freely. Fig. 13.

The annexed engraving shows the form of screen used for exposing the dry and wet bulb thermometers on board ship; the screen should be fixed in a suitable position about five feet above the upper deck, in the open air, but protected from sun, rain, and spray, and as free as possible from radiation or warm currents of air from cabins, engine and boiler rooms, stoke hold and funnel.

A single thickness of fine muslin or cambric should, as before mentioned, be fastened round the bulb of one thermometer, and a few strands of cotton wick passed round the glass stem immediately above the bulb* (*see a*, Fig. 13), touching the muslin; they should be long enough to reach two or three inches below the lowest part of the bulb, in order that their lower ends shall be immersed in a small vessel of water. By this arrangement the water is slowly conducted by capillary action to the bulb, from which evaporation takes place.

The glass, or other small holder of water should be as far as possible from the dry thermometer, as in Fig. 13. Either distilled or rain water should be used, or, if this be not procurable, the softest fresh water available, to avoid the deposit of lime, or other impurity on the bulb. Even rain water is not entirely free from impurities, containing as it does alkalis, salts, &c., which in time form a thin coating on the bulb. Should any incrustation be found on the bulb when the muslin and wick is changed, it should be scraped off with a sharp pen-knife. When needed, the vessel should be replenished with water,

* The strands should be formed into a loop or "bight" in their middle, and their ends passed round, above the bulb, and through the bight.

after, or some little time before observing; because observations are incorrect if made before the mercury in the wet-bulb has fallen to the temperature it would acquire after sufficient exposure to the air.

Should the divisions of the scale of a thermometer become indecipherable, a little black oil paint rubbed gently with a finger into the graduations cut in the tube will render them quite distinct; but before the instrument is again used the paint should be allowed to dry.

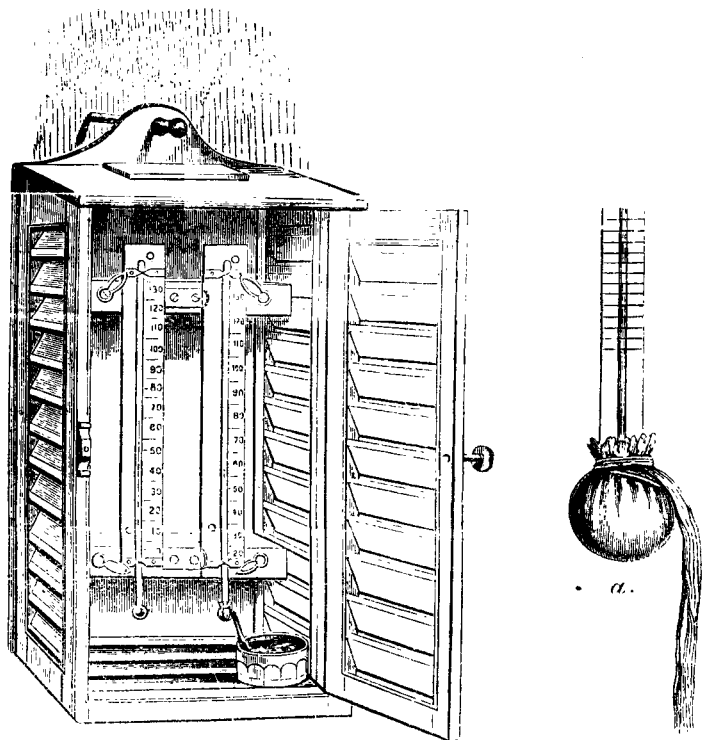


FIG. 13.

The muslin and wick should be well washed before being applied, and occasionally while in use. Both should be changed once a month or oftener when necessary. The times of changing the muslin should be recorded in the Log. Accuracy depends much on the care taken to ensure cleanliness, also on a proper supply of fresh water. The temperature of evaporation is a very important observation, therefore it requires special care. It should be borne in mind that observations of the Wet-Bulb Thermometer are impaired by the presence of salt water on the cambric, therefore in the event of such impregnation taking place through spray, or by any other

means, the cambric, or muslin, and wick should be cleansed, or renewed. Care should also be taken when reading the Dry-Bulb Thermometer that water be not adhering to the bulb.

During frost, when the muslin is thinly coated with ice, the readings are still valid, because evaporation takes place from a surface of ice as freely as from that of water, but if the muslin be dry, and there be no coating of ice, it must first be wetted, and then allowed time to freeze, before the thermometer is read.

Maximum and Minimum Thermometers are not usually supplied to ships, but the following directions may be useful when they are included in the instrumental outfit.

MAXIMUM THERMOMETER.

Suspend the instrument in a nearly horizontal position, the bulb end slightly depressed. Owing to the tube being greatly constricted just above the bulb, when the mercury expands with a rise of temperature, it is forced past this constriction up the stem; but when a subsequent fall of temperature causes a contraction of the mercury, the thread breaks at the constriction, so that the upper end remains in the position to which it was forced, thus registering the highest temperature attained. After reading, set the instrument by holding it bulb downwards, and shaking it.

MINIMUM THERMOMETER.

Suspend the instrument in a position similar to that of the maximum thermometer. In the most serviceable form of instrument, which is a spirit thermometer having a small metallic index in the stem, the index is drawn back towards the bulb when the temperature falls. When the temperature subsequently rises, the spirit expands; and, flowing past the index, does not displace it. The end of the index remote from the bulb will therefore indicate the lowest temperature that has been reached.

The thermometer is set by sloping it, bulb uppermost, until the index runs down to the end of the column of spirit.

Owing to the volatility of alcohol, a little will, in course of time, evaporate from the column and condense at the sealed end of the tube. Hence it is necessary to compare a spirit thermometer from time to time with a mercurial thermometer of known accuracy. Should the two not read alike, the upper end of the spirit thermometer should

be examined closely, and if any spirit be apparent there, it should be shaken down.

The maximum and minimum thermometers also should be exposed in a louvred screen, in as suitable a position as the screen containing the dry and wet bulb thermometers. Preferably a larger screen than the latter should be adopted in order that all four instruments may have an exactly similar exposure. The instruments should be set only once during the 24 hours, a suitable hour would be 8 p.m.

When observing, the thermometers should not be touched by hand until the readings have been recorded.

SEA SURFACE TEMPERATURE THERMOMETER.

When an ordinary thermometer is used for surface temperature observation it should be protected by a metal case having a water-tight space at the bottom which will hold sufficient water to surround the bulb.

A thermometer, specially adapted for sea surface temperature observation, may be issued to marine observers. The tube of this instrument is enclosed in a glass shield and is further protected by a cylindrical metal case, which completely covers all but the graduated portion of the thermometer and its lower end, where three oblong apertures in the case give access to water when the instrument is immersed.

This partly detached end of the metal case, which is water-tight, forms a reservoir, so that when the instrument is lifted out of the draw bucket, a sufficient quantity of the water to cover the bulb can be retained until the temperature has been read.

The thermometer is graduated on the Fahrenheit scale, from 26° to 95° .

To the upper end of the cylinder a large serviceable ring is attached.

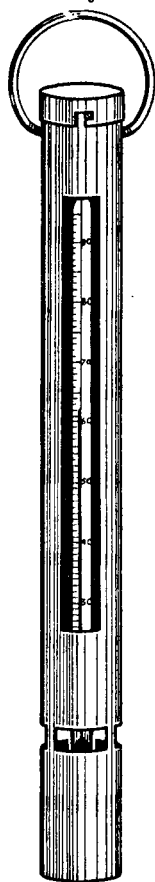


FIG. 14.

READING THERMOMETERS.

As the mercury thread and scale of the thermometer are not in the same plane, errors of parallax (*see* p. 11) will be made unless the observer is careful to place his eye at the same level as the end of the mercury column.

In order to obtain satisfactory results from the observations of the dry and wet bulb thermometers, the values must be known with accuracy; hence the observer should, when reading these instruments, estimate fractions of a degree to the nearest *tenth*.

The thermometers should be read as rapidly as is consistent with accuracy, in order to avoid the changes of temperature due to the presence of the observer. When observing by artificial light with a bull's-eye or candle lantern, care must be taken not to allow the heat from the lantern to vitiate the observations. A pocket electric torch will be found to provide the most suitable means of illumination.

THE THERMOGRAPH.

A self-recording thermometer, or thermograph, may be employed with advantage on board ship for obtaining a continuous record of temperature, which, if studied in connexion with the record of a barograph for the same period, will demonstrate the close relation existing between the fluctuations in temperature and pressure respectively.

The instrument will be found, after the observer has had a little experience with it, a valuable aid in foretelling changes in weather conditions. For instance: a marked rise in temperature, detected by a glance at the thermogram, if associated with a shift of wind to an equatorial quarter, will frequently give warning of the approach of an atmospheric disturbance before the barometer has commenced to fall.

In most thermographs the thermometer consists of a slightly curved metal tube filled with spirit (Bourdon tube). One end of this is fixed rigidly to the instrument while the other is attached to the system of levers which actuates the recording pen.

From the nature of the case thermographs for meteorological use must be exposed out of doors, preferably in a louvered screen. and hence it is necessary to clean and oil their bearings much more frequently than is the case with barographs.

The instrument may be set by comparing its indications with the reading of a standard mercury thermometer placed beside it in the screen. The setting should only be attempted at times when the temperature is constant or changing slowly, and only when the pen is near the middle of its range. As the thermometer is in thermal contact with the body of the instrument (which takes an appreciable time to alter in temperature) it is apt to be somewhat sluggish when the changes of temperature are rapid.

The readings of the thermograph require frequent checking by comparison with standard instruments. A convenient plan is to place a standard maximum and a standard minimum thermometer in the screen with the instrument and to read and set these at regular hours, time marks being made at the hours of reading. It should be borne in mind that in cases when the trace shows that the extreme was of very short duration the sluggishness referred to above may cause a considerable difference between the reading of the standard and that of the recorder.

HYDROMETER.

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

The indications depend upon the well-known principle, that any floating body displaces a quantity of the fluid which sustains it, equal in weight to the weight of the floating body itself. According therefore, as the specific

gravities of fluids differ from each other, so will the quantities of the fluids displaced by any floating body, or the depth of its immersion, vary, when it is floated successively in each.

The true specific gravity of a sample of sea-water is the relation of its weight to the weight of an equal volume of pure water at a standard temperature, namely, 277 a (4°C. , or 39.2°F.):

A hydrometer will show the zero of its scale when it floats in distilled water at that temperature or in any sample of water or other liquid of the same specific gravity. If the specific gravity, or the density of water be increased, as it is by the presence of salts in solution, the hydrometer will rise; if on the contrary the density or specific gravity be diminished as by a sufficient rise of temperature, the hydrometer would carry the zero of its scale under water. The scale is so prepared as to indicate successive increases of density up to 4 per cent., or 40 in the thousand parts. The graduations thus extend from 0 to 40; the latter corresponding to the mark on the scale which will be level with the surface when the instrument is placed in water, the specific gravity of which is 1.040. In recording observations, the last two figures only—being the figures on the scale—are written down. As indicated in the following illustration, Fig. 16, there has recently been introduced a hydrometer of more open scale, which has a range of from 15 to 35, instead of from 0 to 40, as in Fig. 15. This change will facilitate reading, and serve nearly every purpose for observations on board ship.

The instrument is used on board ship to show the relative density of different parts of the ocean. It may float at 40 or even higher in some parts of the Suez Canal, where the water is exceedingly salt. On the north-western side of the North Atlantic; in the regions of Doldrums, Bay of Bengal, and Black Sea; and in the vicinity of the mouth of a large river; the hydrometer will sink much deeper owing to the comparative freshness of the water. The water employed for taking the specific gravity of the sea should be drawn in a canvas bucket from over the ship's side, forward of all ejection pipes, and its temperature immediately observed and recorded, so that by its aid the specific gravity may be reduced to that which it would be at the temperature of 59°F. as explained below. The hydrometer should be slightly spun in the centre of the bucket; when it has lost all up-and-

down motion; and before the turning motion has entirely ceased, the scale can be read.

Whenever the temperature of the water tested differs from 59° , a correction to the reading is necessary, for the expansion or contraction of the glass, as well as for the temperature of the water itself, in order to reduce all observations to one generally adopted standard. Tables have been constructed for this purpose.



FIG. 15.



FIG. 16.

When using the hydrometer, it should be scrupulously clean, all dust, smears, or greasiness, being got rid of by wiping the instrument with a clean soft cloth, before and after use.

The density of sea-water depends upon its temperature, and upon its salinity. A more accurate method, therefore, of estimating the density of the sea, in a given locality, is by determining, by chemical analysis, the saltiness of a sample of sea-water, and converting this salinity determination into specific gravity, by means of tables prepared for the purpose.

The salinity of a sample of water is the total weight in grams of solid matter dissolved in 1,000 grams of water. This solid matter is made up of a number of different salts; more than three-fourths consists of sodium chloride or common salt. Although the salinity of the sea varies somewhat in different localities, times, and seasons, because its degree of saltiness depends upon the removal from or addition to it of fresh water, by evaporation, precipitation, and drainage from the land, nevertheless the ratio of the different salts is substantially constant. The constituents of sea-water, and their relative proportions are set forth in the accompanying table :—

Sodium Chloride (Common Salt)	27.213	per 1,000	Parts of Water.
Magnesium Chloride	3.807	"	"
Magnesium Sulphate	1.658	"	"
Calcium Sulphate (Gypsum) ...	1.260	"	"
Potassium Sulphate	0.863	"	"
Calcium Carbonate and Residue	0.123	"	"
Magnesium Bromide	0.076	"	"
	<hr/>		
	35.000		
	<hr/>		

The average specific gravity of the North Atlantic is expressed as 1.02664, and a hydrometer of the Meteorological Office of the old pattern, if immersed in a sample of water of this specific gravity at a temperature of 60° Fahr., would show a scale reading of 26.7, provided it had no instrumental error.

The new pattern of instrument, however, which is referred to the maximum density of pure water, and graduated to read correctly at standard temperature of 59° F., would, if immersed in a sample of water of the same specific gravity at that temperature, show a scale reading of 25.6; provided the hydrometer had no instrumental error.

The weight of salt in 1,000 parts of water of specific gravities from 1.025 to 1.028 is as follows :—

Specific gravity at 60° F.	1.025	1.026	1.027	1.028
Specific gravity at 59° F. referred to the maximum density of pure water.	1.024	1.025	1.026	1.027
Salts per mille ...	33.765	35.049	36.343	37.637

THE RAIN GAUGE

A rain gauge, suitably fitted for use on steamships, is lent to a restricted number of marine observers.

The instrument, Fig. 17, which is a 5-inch gauge of the Snowdon pattern, is thus described in "The Seaman's Handbook of Meteorology"* (page 165). It consists of a cylindrical funnel (*f*) having a rim 4 inches deep to the edge of which a stout brass ring (*r*) is firmly fixed; a vertical cylinder, with closed base (*c*), and shoulder (*s*), upon which the lower edge of the funnel-cylinder rests when in position; and a can (*n*), which rests on the bottom of the lower cylinder.

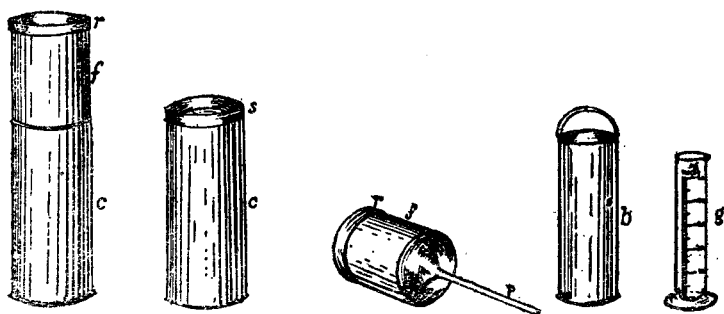


FIG. 17.

Precipitation is directed from the funnel to the can by means of a pipe (*p*) attached to the former, reaching almost to the bottom of the latter. The brass ring, the inside measurement of which is exactly 5 inches in diameter, is bevelled on the outside so as to form a knife edge upon which no rain can rest.

The rim of the cylinder being 4 inches deep, the loss of precipitation by splashing is prevented and its collection when in the form of snow facilitated.

With the exception of the ring the instrument is made entirely of copper.

The rain collected is measured by pouring it into a measuring glass which is graduated to indicate either millimetres or hundredths of an inch.

The measuring glass (*g*) will hold ten millimetres or two-fifths of an inch of rainfall, an amount which corresponds with 4.54 oz. when collected in the gauge (5-inch) described.

The quantity of precipitation collected by a rain gauge depends to some extent upon its exposure; in order, there-

* "The Seaman's Handbook of Meteorology." A companion to the "Barometer Manual for the Use of Seamen." Issued by the Authority of the Meteorological Committee, 1914. Price Two Shillings.

fore, that the gauge may be free, when in action, from the sheltering effects of deck houses, skylights, deck furniture, &c., provision is made for hoisting it to a suitable height above the deck, where, under all but exceptional conditions of wind and sea, it will also be exempt from spray.

The special arrangements for doing this are as follow :—

The instrument is attached to an iron frame, Fig. 18, *a*, by two bands (*b b*) which encircle the cylinder, two tubes (*t t*) forming the sides of the frame.

A two-pronged fork of bar iron (*p p*) has an eye (*e*) formed in the bend of the bar, for use in securing an iron halyard block or gin (*g*) to the fork and the fork to the stay.

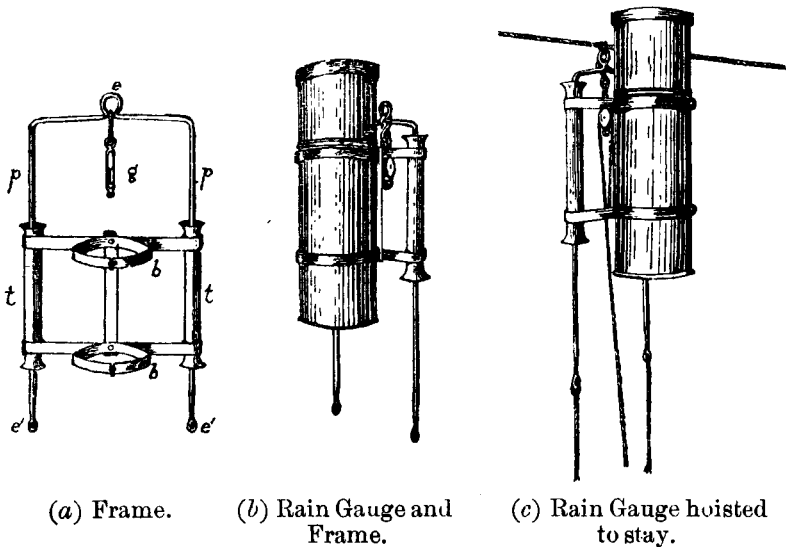


FIG. 18.

In Fig. 18, *b*, the rain gauge is shown attached to its frame.

In the eyes (*é é*) at the end of each prong of the fork a 1-inch steel wire rope is spliced, to serve as guides to the gauge, also as guys when necessary.

The fork is lashed to the stay, at a suitable distance from mast or funnel, at a height of from 20 to 30 feet above the deck; the two guides are rove through their respective tubes and set up to eye-bolts or other suitable fixtures on deck, perpendicular.

The rain gauge is hoisted to the stay by a halyard, one end of which is seized to the lower cross bar of the

frame, the other end being rove through the block pendant from the eye of the fork, and led to the deck. The operation resembles that of hoisting a masthead lamp: the prongs of the fork running into the tubes, which form the sides of the frame, in a similar manner.

When the frame is hoisted close up to the stay, the rim of the gauge will be above it; thus the instrument will have a free exposure, Fig. 18, *c*.

Should the gauge require steadying when it is in its position and the guides are set up taut, the latter should be released, carried outward and re-set up rather nearer the ship's side.

PART II. — OBSERVATIONS OF WIND, SEA DISTURBANCE, CLOUDS, WEATHER, OPTICAL PHENOMENA.

CHAPTER III.

Wind and the Beaufort Scale of Wind Force; Sea Disturbance.

WIND DIRECTION.

The direction of the wind is given by the quarter from which the wind blows. For meteorological purposes, the geographical or true direction is required. It is the practice on the ships of the Navy for all directions to be logged according to the magnetic compass in degrees from 1° to 360° ; but on merchant ships the true direction has come to be regarded as the most convenient, and the practice of reckoning from 1° to 360° is becoming general. The column in the meteorological log should accordingly be carefully headed. For the study of the upper air, directions are given in degrees from north, but the use of the cardinal points and their combinations is still in vogue for wind directions.

VEERING AND BACKING.

One point needs attention with regard to the change of wind direction which is described as "veering" and "backing."

There appears to have been some uncertainty in former years as to the meaning of the words as applied to the changes in the direction of the wind in the Southern Hemisphere. At the International Conference of Directors of Meteorological Institutes and Observatories, held at Innsbruck in 1905, a question was raised in this connexion. The Conference having ascertained the rule in use at the British Meteorological Office agreed that the same should be recommended for general adoption by passing the following resolution :—" That Meteorologists in the Southern Hemisphere, as in the Northern Hemisphere, are requested—without regard to other weather phenomena—to employ the term 'backing,' whether at an observing station or on board ship, exclusively to denote a change in direction against the hands of a watch, *i.e.* : W-S-E-N.; and the term 'veering' for changes in the opposite direction, with the hands of a watch, *i.e.*, W-N-E-S."

WIND FORCE.

Wind force is expressed numerically on a scale from 0 to 12. This scale, with a statement explanatory of the respective wind conditions to which the numbers refer, was originally suggested by Captain, afterwards Admiral, Sir Francis Beaufort, in the year 1808, for use on board ships of the British Royal Navy. Although more especially applicable to the full-rigged frigate of that date, the scale soon came into general use, not only in the Royal Navy, but also in the Mercantile Marine. Since Admiral Beaufort's time, however, so many changes have taken place in the build, rig, and tonnage, of sea-going vessels and steam has so largely superseded sail as the means of propulsion, that a new specification of the Beaufort numbers, with criteria for estimating wind forces on board steamships, has been devised at the Meteorological Office, and adopted officially.

The two specifications of the Beaufort numbers are as follow :—

Admiral Beaufort's Scale of Wind Force

0 Calm	...	Just sufficient to give steerage way.
1 Light air	...	With which a well-conditioned ship of war of
2 Light breeze	...	Admiral Beaufort's time (1800—1850), with
3 Gentle breeze	...	all sail set, would go in smooth water, and
4 Moderate breeze	{	"clean full," from
		{ 1 to 2 knots.
		{ 3 to 4 knots.
		{ 5 to 6 knots.
5 Fresh breeze	...	{ Royals, &c.
6 Strong breeze	...	{ Single-reefed topsails and topgallant sails.
7 Moderate gale...	...	{ 7. Topsails, jib, &c.
8 Fresh gale	...	{ 8 Reefed upper topsails and
9 Strong gale	...	{ courses.
		{ 9 Lower topsails and courses.
10 Whole gale	...	{ 10 Lower maintopsail and reefed
		{ foresail.
11 Storm	...	Which would reduce her to storm-stay-sails.
12 Hurricane	...	Which no canvas could withstand.

* These modifications are made to meet the requirements of double topsails, introduced since Admiral Beaufort's time.

FOR SHIPS RIGGED WITH DOUBLE
TOPSAILS.*

{ 6 Topgallant sails.
7. Topsails, jib, &c.
8 Reefed upper topsails and
courses.
9 Lower topsails and courses.
10 Lower maintopsail and reefed
foresail.

New Alternative Specification.

Admiral Beaufort's Numbers.	Average of Velocity	Limits of Velocity	Equivalent pressure in pounds upon a circular disc one square foot in area.	Description of Wind.	Mode of estimating on board Sailing Vessels.	Criteria for Steamships.
	in statute miles per hour.					
0	0	Less than 1	Less than .01	Calm	...	—

Special consideration is required for the specification of the scale for use on board steamships. For this purpose it is recommended that as opportunity occurs use be made of the equivalents given in Col. 2. Thus, when the ship is running in a calm at 15 knots, the wind felt in an exposed position on board will be a moderate breeze, which, according to the table, is force 4 on the Beaufort scale, and, if a similar breeze is felt when the ship is running at 15 knots *right before the wind*, the actual speed of the wind will be 30 knots, 7 on the Beaufort scale, according to the table of equivalents.

Other opportunities occur from time to time for comparing the speed of the wind with the speed of the ship. A hand anemometer may be employed if used judiciously and if proper allowance be made for the motion of the ship.

1	2	1 to 3	.01 to .04	Light breeze	Sufficient wind for working ship.
2	5	4 " 7	.05 " .16		
3	10	8 " 12	.17 " .44		
4	15	13 " 18	.45 " .96	Moderate breeze	Forces most advantageous for sailing with leading wind and all sail drawing.
5	21	19 " 24	.97 " 1.75		
6	27	25 " 31	1.76 " 2.88	Strong wind	Reduction of sail becomes necessary even with a leading wind.
7	35	32 " 38	2.89 " 4.43		
8	42	39 " 46	4.44 " 6.45	Gale force	Considerable reduction of sail necessary even with wind quartering.
9	50	47 " 54	6.46 " 9.00		
10	59	55 " 63	9.01 " 12.16	Storm force	Close reefed sail when running; or hove-to under storm sail.
11	68	64 " 75	12.17 " 15.97		
12	Above 75	—	15.98 and above	Hurricane	No sail can stand even when running.

Velocity Equivalents of the Beaufort Numbers.

The question of the velocity equivalents of the Beaufort numbers is one which has claimed much attention. From the nature of the case the estimates of different observers, and even the estimates of one and the same observer under different circumstances, must vary considerably.

A careful comparison of the Beaufort estimates with the wind velocities recorded simultaneously by anemometers belonging to the Office, made in the course of the inquiry relating to the Beaufort Scale of Wind Force (Official M.O. 180), showed that the most probable equivalent hourly velocity for expressing individual estimates in miles per hour or *vice versa* agrees very closely with the results calculated by the formula

$$V = 1.87 \sqrt{B^3}$$

where V is the wind velocity expressed in miles per hour and B the Beaufort number.

The relation between the wind pressure and the Beaufort numbers is given by the corresponding formula

$$P = .0105 B^3$$

where P is the pressure in pounds per square foot.

The velocity and pressure equivalents calculated from these two formulæ have been included in the table on pp. 48, 49.

The following table is used in the Meteorological Office for converting estimates on the Beaufort scale into velocities in statute miles per hour or *vice versa* :—

Beaufort Number.	Corresponding Limits of Velocity.		
	Statute Miles per hour.	Metres per second.	Feet per second.
0	Less than 1	Less than 0.3	Less than 2
1	1-3	0.3-1.5	2-5
2	4-7	1.6-3.3	6-11
3	8-12	3.4-5.4	12-18
4	13-18	5.5-7.9	19-27
5	19-24	8.0-10.7	28-36
6	25-31	10.8-13.8	37-46
7	32-38	13.9-17.1	47-56
8	39-46	17.2-20.7	57-68
9	47-54	20.8-24.4	69-80
10	55-63	24.5-28.4	81-93
11	64-75	28.5-33.5	94-110
12	Above 75.	33.6 or above.	Above 110

Insert on p. 51 of Marine Observers Handbook
SCALE OF SEA DISTURBANCE.

Scale	Description	Height of Waves, Crest to Trough.
0	Calm	0
1	} smooth sea	less than 1 foot
2		1-2 feet
3	slight sea	2-3 "
4	moderate sea	3-15 feet
5	rather rough sea	5-9 "
6	rough sea	6-12 "
7	high sea	12-20 "
8	very high sea	20-30 "
9	precipitous sea	30 feet and above

CHARACTERISTIC OF SWELL.
PROVISIONAL DESCRIPTION OF SCALE.

FOR INTERNATIONAL COMMISSION.	ABBREVIATED FOR AIR SERVICE.
No swell.	No swell.
Slight swell.	Slight swell.
Moderate swell.	Moderate swell.
Rather rough swell.	Heavy swell.
Rough swell.	
Heavy swell.	Very heavy swell.
Very heavy swell	
Abnormal swell.	

1	}	No Swell
2		
3		slight swell
4		moderate swell
5		rather rough swell
6		rough swell
7		heavy swell
8		very heavy swell
9		abnormal swell.

NOTE. Great care should be taken to enter into their proper columns the scale numbers and direction of ^{swell} corresponding. If confused, write "confused" in the direction column, stating the chief direction or directions, thus "Confused NE and SE", "confused SW" etc.

The formulæ upon which the relation between the wind velocity, the "pressure" which the wind exerts upon a circular disc exposed to it, and the Beaufort numbers are here put together by way of summary.

For the units which have been hitherto in common use among British Meteorologists—

$$\begin{aligned} P &= \cdot 003 V^2 \\ P &= \cdot 0105 B^3 \\ V &= 1\cdot 87 \sqrt{B^3} \end{aligned}$$

Where B is the Beaufort number; V is the corresponding velocity, in miles per hour; and P is the corresponding pressure in pounds per square foot.

For the C.G.S. system of units, the relations are as follow :—

If *F* is the force in kilodynes upon a disc one square metre in area facing the wind, and *V* the velocity in *metres per second*—

$$\begin{aligned} F &= 72 V^2 \\ F &= 50\cdot 3 B^3 \\ V &= 0\cdot 836 \sqrt{B^3} \end{aligned}$$

OBSERVATION OF SEA DISTURBANCE.

The following scale has been adopted for estimating Sea Disturbance.

Scale.	Description.	Height of waves in feet from crest to trough.	Condition of Surface.
0	Calm ...	—	Glassy.
1 } 2 }	Smooth ...	—	Rippled.
3 } 4 }	Slight to moderate.	Under 5 feet ...	Rocks buoy or small boat.
5 } 6 }	Rough to very rough.	5 to 10 feet ...	Furrowed.
7 } 8 }	High to very high.	{ 11 to 15 feet ... { 16 to 35 feet ...	Much disturbed ; deeply furrowed.
9 } 10 }	Phenomenal	36 feet and above...	Rollers with steep fronts.
			Precipitous ; tower- ing.

NOTE.—In connexion with the relation of the wind velocity to the Beaufort numbers, a Naval Officer has pointed out that there appears to be a cube root relation for the Sea Disturbance scale adopted by the Meteorological Office; and suggests the following formula: $H = .05 C^3$; where H is the height and C the corresponding scale number. The formula is shown below to be approximately in agreement as regards the several numbers of the scale with the arbitrary scale recommended for use at sea by the Meteorological Office.

Scale No.	Height in Feet.		Scale No.	Height in Feet.	
	Originally recommended.	Calculated from the formula.		Originally recommended.	Calculated from the formula.
0	0	0	5 }	5-10	{ 6.25
1	—	.05	6 }		{ 10.8
2	—	.40	7	11-15	17.1
3	} Under 5 {	1.35	8	16-35	25.6
4		3.20	9 }	36 +	36.4 +
			10 }		

OBSERVATIONS OF WAVES AND SWELL.

The application of the theory of wave motion to the experience of ships at sea is a subject which is at once important and interesting. The development of the theory of water-waves is due mainly to Sir George Gabriel Stokes, one of Newton's successors in the chair of Natural Philosophy at Cambridge, and in the Office of President of the Royal Society. He was for many years a member of the Meteorological Council and in that capacity drew up some notes for the observation of waves at sea upon which the present memorandum is based.

Wave Motion. Waves and Swell.

By way of preface it may be said that the term "wave motion" used here is intended to refer to what is known technically as a train of waves, that is to say, to a succession of undulations following each other with obvious regularity, although, comparing one set with another, trains may differ in the height of the individual waves of which they are composed, or in the shape of the waves as they advance, or in the rapidity with which they travel, or in the distance between the advancing crests.

Experience very soon leads us to distinguish between the trains of *waves* raised within the region of action of persistent strong winds frequently reaching the height and extent of long rollers, but having their surfaces ruffled by subsidiary wavelets or varying in the steepness of shape of the masses of water which are apparently advancing, and the regular undulation of the water which may occur in an otherwise smooth sea and is the characteristic phenomenon of a *swell* or, as it is sometimes called, a *ground swell*.

For the purpose of classification the former are called waves and the latter swell, and it is to these two classes that this memorandum refers. There are other examples of wave motion in water; for instance, the so-called solitary wave that runs along a canal abreast of a propelled vessel, or the tidal wave that runs up estuaries, or the standing waves in rivers running over obstacles in its bed. With these we are not at present concerned.

Results deduced from the theory of Wave Motion.

The theory of wave motion, to which reference has been made, establishes by calculation a numerical relation between the length of the wave, that is the distance between consecutive crests, the velocity with which it travels, and the depth of the water, and thus explains the difference of behaviour of the waves of the deep sea, which pass onward with practically no change over immense distances, and that of the same waves when they get into shoal water, where they become gradually steeper and ultimately reach the shore as breakers.

There is also a relation common to all types of wave motion when waves follow one another in trains, whether in water or in air or in the ether, and connects the length of the wave L , with the velocity of its travel V , and the period or time of oscillation T , of the particles which are affected by successive waves. The relation is a simple one, namely

$$L = VT$$

an equation of constant application in wave motion.

To appreciate its meaning we must remember that in a typical wave such as a deep sea wave, the visible motion is not the bodily transference of a mass of water. It is "energy" which travels along the water, not the water.

itself. According to the theory the surface water affected by deep sea waves, as might be indicated by a cork floating on the surface, describes a vertical circle, during the passage of a single wave it moves just as far forward and backward as it moves up and down; so, as successive waves pass by, it describes its circle over and over again but makes no actual advance; the periodic time or "period" of the wave is the time a single particle would take to complete any one of its circles; but since, as soon as one of its circuits is completed it begins another, it is evident that while the circuit is being completed the crest of the wave will have moved forward one "wave length," and hence the relation between wave length, period and velocity of travel, is easily arrived at. The circular motion of water in waves was originally computed by theory, but it has been amply confirmed by experience.

It is not only the surface layer that moves when a train of waves passes; the whole depth is affected but not equally so. For deep sea waves the accepted representation of the relation of the motion of the sub-surface water to that of the surface layer is set out in the theory of the trochoid wave, according to which every particle of water in a vertical line is in a similar position with regard to the description of a circular orbit during the passage of the wave as the particle in the surface; but the diameter of the circular orbit is smaller, and smaller the deeper the layer. An approximate rule is that the diameter of the orbit is *halved* at a depth of *one-ninth* of a wave length, and halved again for every additional ninth. Thus while we must regard a moving train of waves as consisting of motion of the water throughout the whole depth, the motion will be practically inappreciable at a depth approaching the length of the most impressive of ocean waves of this type.

The profile at any depth of a wave such as that described above wherein the separate particles describe circles while the whole system of motion passes onward is a curve known as a *trochoid*, and the use of the trochoid as a means of describing and explaining the phenomena of deep water waves is known as the *trochoid theory of deep sea waves*. In further explanation, an extract from the chapter on the subject by the late Sir W. H. White in his *Naval Architecture* is given here as an appendix.

For waves in shallow water the motion is more complex, the orbits of the particles no longer have the simplicity of circles, but the general character of the motion has

been calculated and the results arrived at are confirmed by the effects observed of the scour of waves in harbours.

Height of Waves.

It may be noticed that nothing has been said about the height of the waves and, indeed, the height of a wave is of very secondary influence in its transmission; it does not come into the calculations. The primary and unvarying characteristic of a wave which becomes a member of a train of waves is its period; that as a rule remains persistent; the velocity and the wave length also remain unchanged as long as the waves travel in deep water, but are varied when the depth of water becomes comparable with the wave length. Meanwhile the height increases if the originating cause persists. It decreases if the waves spread out into widening seas, but the laws of transmission are not altered thereby.

At present we know little of any numerical relation between the heights of waves and the force of the wind, or other cause, which produces them. We are sure that the waves are produced by wind and we may reasonably suppose that the first effect of a wind upon water is to raise wavelets of irregular sizes. The wavelets have a certain rate of travel depending on the length of the wave, and when a slight disturbance is once set up that travels with approximately the same speed as the wind, wavelet and wind will travel together, and the disturbance will be reinforced by the following, or accompanying, wind, until a series of high waves or rollers is formed. Hence we may conclude that to raise a high sea a long "fetch" of wind is required, and a velocity of travel of the waves not very different from that of the wind.

Direction of Motion of Waves. Group velocity.

The direction of a train of waves cannot be changed so long as they travel in deep water, but a shelving shore retards the shore end of a wave and gradually brings the whole wave into line with the shore itself.

But a series or "train of waves," forming a high sea, once set up, will travel forward, though the wind may drop, and they may pass onward to great distances over what may be called smooth seas, and ultimately appear as rollers and breakers on shores far distant from the region where they were formed. The formation of swell is thus explained. The swell originating in waves produced in

a region of strong winds becomes a means of communication more rapid than the speed of a ship. It may thus become a mode of wireless telegraphy intimating the existence of long stretches of wind at a distance.

In considering the velocity of propagation of a disturbance represented by a train of water waves, it is important to note that the velocity of each individual wave of the train is not the same as the velocity of propagation of the disturbance as a whole. Progressive waves on water are observed to occur in groups, each of which is composed of waves of large height in the middle of the group, and of gradually diminishing height towards the front and rear. Between successive groups of waves occurs a region of comparatively still water.

If attention be concentrated on the individual waves of a group, it is found that they move forward through the group, springing up at the rear, increasing in height as they approach the middle and gradually subsiding as they recede from the middle and move to the front, until eventually they are successively lost in the still region in front of the group.

New waves arise in the rear of the group as rapidly as they die out in front, so that the general appearance of a group of waves is transmitted continuously without change. The velocity of the individual waves is given by the formula in Appendix I., and is tabulated below.

Wave length in Deep Sea.	Wave period.	Velocity of transmission of individual Waves in Deep Sea.		Velocity of transmission of the Disturbance or "Group" in Deep Sea.	
Feet.	Seconds.	Feet per Second.	Nautical Miles per Hour.	Feet per Second.	Nautical Miles per Hour.
25	2.2	11.3	6.7	5.7	3.4
50	3.1	16.0	9.5	8.0	4.8
75	3.8	19.6	11.6	9.8	5.8
100	4.4	22.6	13.4	11.3	6.7
150	5.4	27.7	16.4	13.9	8.2
200	6.3	32.0	19.0	16.0	9.5
300	7.7	39.2	23.2	19.6	11.6
400	8.9	45.2	26.8	22.6	13.4
500	9.9	50.6	30.0	25.3	15.0
600	10.9	55.4	32.8	27.7	16.4
700	11.8	59.8	35.4	29.9	17.7
800	12.6	63.8	37.8	31.9	18.9
900	13.3	67.7	40.1	33.9	20.1
1,000	14.1	71.4	42.3	35.7	21.2

Observation shows, however, that the group as a whole has also a definite velocity of propagation, and it thus appears that the velocity of the individual waves is greater than that of the group in which they occur. Sir G. G. Stokes, Professor Osborne Reynolds, and others have treated this subject mathematically. Sir G. G. Stokes was the first to determine the relation between the velocity of travel of the disturbance or group of waves and the velocity of the individual waves of which the group or disturbance is composed. In the case of deep-sea waves, the relation is simply

$$U = \frac{1}{2} V$$

where U = velocity of group,
and V = velocity of wave.

In other words the individual waves travel twice as fast as the group but constantly die out in front of the group.

Consequently, in calculating the distance to which the wave-disturbance due to bad weather may be expected to extend in a given time, half the velocity of the individual waves should be used. For example, suppose that waves 200 feet long are observed to be moving eastwards in mid-ocean. The corresponding wave velocity V is given in the table as 19 nautical miles per hour. Assuming that this velocity is maintained unchanged, the rate of travel of the disturbance or rough sea (U) will be $9\frac{1}{2}$ miles per hour, so that in 12 hours the disturbance will arrive at a point 114 nautical miles further to the east.

Hence in considering the transmission of disturbances to great distances from the region of origin we have two aspects to bear in mind, first the travel of the "group" which marks the limit which the disturbance has reached and secondly the travel of the waves which form part of the group and go twice as fast as the group. It is the component waves which may be the subject of observation on board ship.

Swell.

When the cause of disturbance is persistent the disturbance travels onward and over the region which has become affected there proceeds a regular succession of deep sea waves which travel with the velocity set out in the table and which constitute what is ordinarily known as a swell.

The swell which is thus transmitted from a great distance may often be observed while the surface is affected by waves due to the wind in the more immediate neighbourhood. The swell and the waves may be of different origin and the direction of motion of the two may be quite independent one of another. In these circumstances the effect upon the ship is the result of superposing the two separate effects. This process may be complicated to any extent. When there are only two trains of waves affecting the ship it is generally easy to identify them but in other cases the motion becomes confused and cannot be analysed into its constituent wave groups.

The study of the relation of the swell to the locality of the strong wind which may be regarded as the cause of disturbance is a subject of some interest. An example was worked out by Sir G. Stokes in a letter to Captain H. Toynbee, Marine Superintendent of the Office. It was contributed by the Meteorological Office to the memoir prepared by Sir J. Larmor and is here reproduced from that work.

Observatory, Armagh,
12 September, 1878.

I have been rather going about of late or I would have written to you before this at greater length.

Before I got your letter containing the heights of the barometer, I had plotted the places of the ships, and drawn my conclusions. I send you a copy of the plotting.

I have represented swells by parallel pencil lines in the direction of the ridges. Perpendicular to these I have drawn pencil lines in the direction from which the swell came.

I have also corrected the apparent periods for the motion of the ship by the data furnished by Captain Watson.

In the following table the first column gives the date; the second the ship's speed in knots per hour; the third the angle between the ship's course and the direction from which the swell came; the fourth the apparent period, the fifth the true period as corrected for the motion of the vessel; the sixth the velocity of propagation—V.W.—of an individual wave-crest; the seventh the distance run—D.R.—(by the waves) in a day, in knots, taken, in accord-

ance with theory at half the velocity of propagation of the individual waves.*

Date.	V. S.	—	A. P.	T. P.	V. W.	D. R.
3rd, 6.0 p.m. ...	12	28°·5	6·7	9·25	27·9	335
4th, 10.5 a.m. ...	10	57°·5	6·6	8·06	24·4	297
4th, 1.5 p.m. ...	10	57°·5	8·5	10·01	30·8	362
4th, 5.5 p.m. ...	5	17°·5	13·4	14·83	44·7	537
Later ...	5	17°·5	13·8	15·23	45·9	556

The observation at Lat. 43° 33' N. Long. 50° 44' W. mentions a *confused* sea from different quarters, together with a very regular swell from W.N.W., this was at 6 p.m. on the third. This disturbance appears to have subsided, for it is said afterwards "the sea kept smooth until 8 a.m." on the fourth, which was at a place about 140 knots from the former. The roughness on the third appears accordingly to belong to a distinct disturbance from that of which the very heavy swell afterwards mentioned formed a part. The *regularity* of the swell on the third indicates that it had travelled a considerable way from the place of its birth, which must have been somewhere along a line drawn to W.N.W. from the ship's position on the third at 6 p.m. I shall accordingly dismiss without further notice the disturbance on the third. As neither height nor period of the swell at all came up to what was afterwards met with, the disturbance which produced the W.N.W. swell was evidently far less severe, though of course, for aught we can tell, it *may* have belonged to a very severe disturbance, of which it formed an outlying part.

I come now to the grand disturbance, beginning with the observation of 2 a.m. on the fourth.

The S.S.W. swell which was encountered, beginning with 8 a.m. on the fourth, indicates a heavy disturbance somewhere in a direction drawn S.S.W. from the then place of the ship, a disturbance in which the wind was from S.S.W., and which was supported and increased by the wind for some considerable time.

If this disturbance were cyclonic in character, as is probable, and is fully confirmed by the subsequent observations, the ship being considerably to the E.N.E. of the part of the ocean where the disturbance was produced, the

* In accordance with Sir G. G. Stokes' theory of wave-groups, *Math. and Phys. Papers*, vol. v, p. 362.

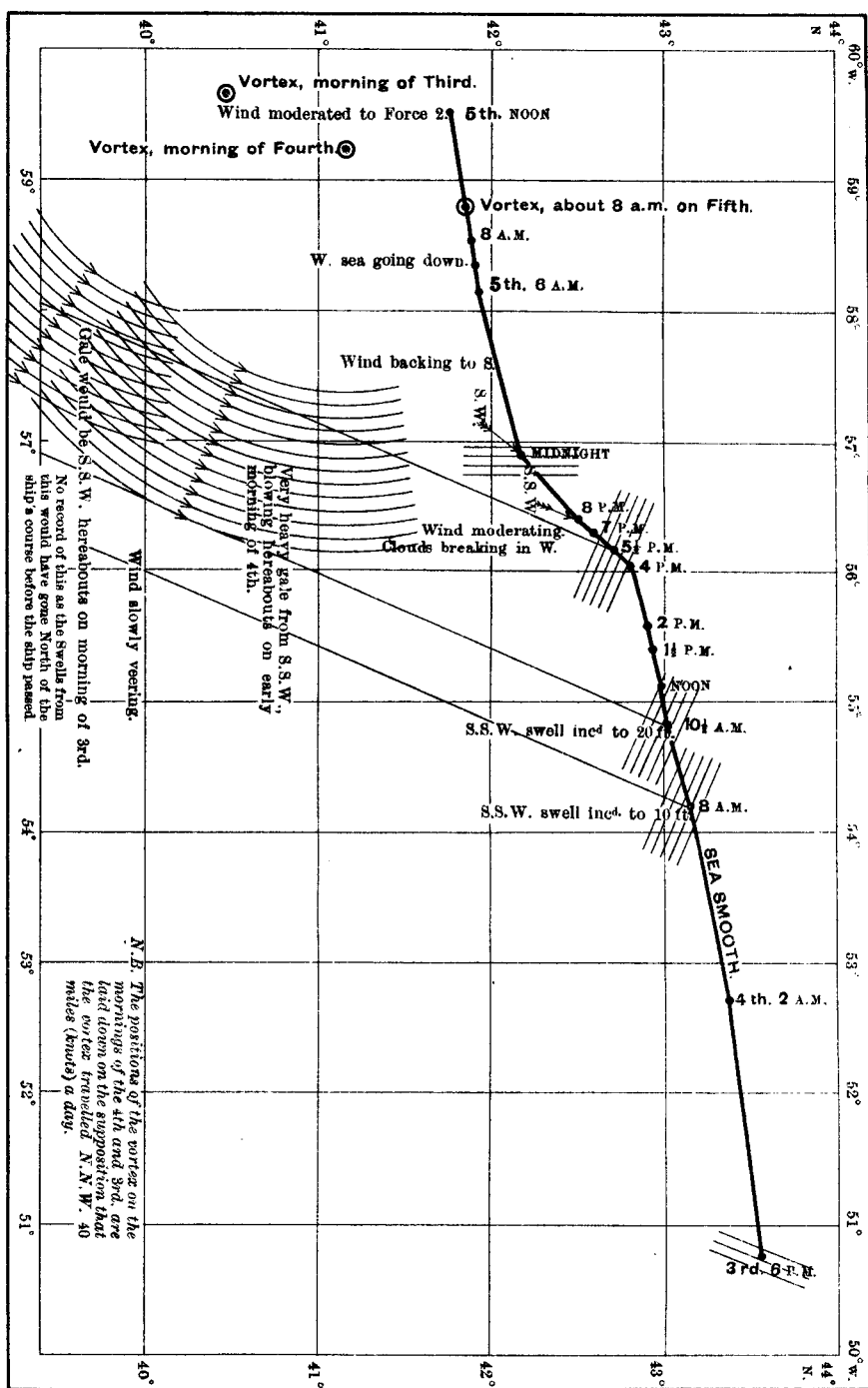
wind at the place of the ship might be expected to be more to the south, say south, which is just what was observed.

Later on the swell increased both in height and in period, up to 5.30 p.m., when it was at its maximum, and was of very unusual magnitude.

This magnificent swell indicates a severe and long continued action of a S.S.W. wind on a region lying S.S.W. of the place of the ship at that time. The increase of the swell observed from 4 a.m. to 5.30 p.m. I take to be due, not so much to an alteration of conditions with the time, as to the ship's change of place, her westerly course bringing her into a region where she got into wave-shot of a more severe part of the cyclone.

The ship's W.S.W. course took her gradually out of the region of wave-shot of the portion of cyclone where the wind was S.S.W. and within wave-shot of the region where the wind was westerly. The progress of the cyclone, which in this portion of the ocean would be travelling in a direction N.N.W. or thereabouts, would contribute to the same result. This accounts for the "westerly sea running fast," which was experienced about midnight.

The wind which had been S., and had veered to S.W., about 4 a.m., backed to S., and became more severe. The ship was now nearing the vortex. At 7 a.m. the westerly sea was noted as going down. The heaviest westerly sea would now lie south and also east of the ship. For a heavy sea requires a wind which is lasting as well as strong, I mean lasting as regards the same disturbance, *i.e.*, agitating the same portion of the ocean, or better still following the disturbance at about the same rate as the disturbance itself progresses. Hence considering the portion of a cyclone where the wind blows west or nearly so, though near the vortex the wind may be stronger than a little further out, still in the latter region the water would be longer under the influence of the westerly gale, and therefore a heavier sea would be raised than nearer the vortex, in spite of the westerly wind being not quite so severe. Also if we mark the region where the wind is westerly, the westerly seas will of course increase from the west to the east of that region, and will travel further to the east, as a westward swell, into a region where the wind is no longer westerly. The same of course, *mutatis mutandis*, applies to the seas excited by any other portion of the wind-system



Storm-Diagram constructed from meteorological log of S.S. "Algeria,"
Captain W. WATSON, March 3-5, 1878.

The change of the ship's place therefore accounts for the subsidence of the westerly swell.

The ship was now very near the vortex; but as the account given by the wind by no means seems equal to the production of such a severe S.S.Wly. swell as had been encountered, it is probable that between the night of the third and morning of the fourth,—at which time the heavy swells experienced at 5.30 p.m. on the fourth may be deemed to have been under the influence of the powerful S.S.W. wind which gave them birth,—and the early morning of the fifth, the violence of the cyclone had a good deal subsided.

The sudden shift of wind, the whirling motion of the clouds, and the immediate change in the character of the clouds observed when the wind had shifted, show that the vortex was passed, at a very short distance, about half-past eight on the morning of the fifth.

This is confirmed by the indications of the barometer, which had been steadily going down till about that hour, when it began to rise.

The described shift of wind shows that the ship had passed a *little* to the *south* of the vortex.

What is said of the motions of the clouds about the vortex accords very well with Mr. Clement Ley's conclusion that the line of vortex is not vertical but slopes upwards in the direction of the progress of the cyclonic disturbance.

On second thought I send you my drawing, such as it is, rather than taking the trouble to copy it. I should be glad to have it again, but of course if you think it worth while to take a copy of it, you can get one of the staff to make it, or rather to make a better plotting of the course of the ship.

I think this example shows how much may be learned by combining good observations of swells with the ordinary observations of other elements.*

* Further considerations on the forms of ocean rollers, and on their necessarily irrotational character, are included in the Appendices added in 1880 to the reprint of the Memoir of 1847, "On the Theory of Oscillatory Waves," *Math. and Phys. Papers*, vol. i., cf. pp. 224, 228, 320.

Recent statistics of navigation give the average period of N. Atlantic waves as 12 seconds; the longest waves hitherto recorded were 2,800 ft. long and had a period of 23 secs. On the generation of waves by wind, see Kelvin, *Phil. Mag.* 1871, and two papers by v. Helmholtz, *Sitz. Berlin Akad.* 1889-90. At the end of the latter, reprinted in *Wied. Ann.* xli. pp. 641-62, Helmholtz's observations on sea-waves at Cape Antibes are discussed

Further notes on Wave Motion as affecting ships.

This example is only one instance of what can be learned from a study of waves. Another will be found in what follows, based upon the well-known fact that every ship afloat has its own period of oscillation for rolling motion, and a roll becomes dangerous when the apparent period of the waves coincides with the period of the natural roll of the ship.

Professor Clerk Maxwell in his book on the "Theory of Heat" says :—

"If we observe what goes on in the substance at a given place when the wave passes that place, and if we suddenly transport ourselves a certain distance forward in the direction of propagation of the wave, then, after a certain time, we shall observe exactly the same things occurring in the same order in the new place, when the wave reaches it. If we travel with the velocity of the wave, we shall therefore observe no change in the appearance presented by the wave as it travels along with us. This is the characteristic of a wave of permanent type." By "a wave of permanent type" is meant a wave that continues its oscillatory motion undisturbed by any counteracting wave motion.

It has been found that the degree of motion in the water constituting a wave declines rapidly with depth below the surface; and the rate of diminution of motion depends upon the ratio of depth to the length of wave. At a depth equal to one wave length, the motion, whether horizontal or vertical, is less than a five-hundredth part of what it is at the surface, so that the water at that depth may under such conditions be regarded as practically undisturbed.

The motion associated with the largest ocean waves is therefore inappreciable even at moderate depths.

When waves come under the influence of a shelving beach their troughs become flatter and the crests steeper in front and more sloping behind, until at last the crest topples forward and breaks on the shore.

Writing upon the subject of swells and the rollers of Ascension* Stokes remarked :—"I am glad to find that the evidence which you have obtained from the examination of ships' logs supports the view which I have long entertained as to the cause of the rollers."

* The following quotation from a paper "On a method of determining the *Periods* and *Dimensions* of Waves," prepared by Mr. Froude for the use of H.M.S. "Challenger," will explain the remark :—

" There is one element as regards the rollers which I should be very glad to get hold of, but which (though the easiest of all to observe) does not appear to have been regarded, doubtless because people were not aware of the interest which attaches itself to it, and that is the periodic time. It is of interest not only as regards the light it helps to throw on the origin of the rollers, but also as indicating the largest period of disturbance we have to guard against, and thereby possibly helping to avert a repetition of a disaster like that of the foundering of the "*Captain*," in the event of the construction of an ironclad of some hitherto untried pattern. Captains of ships, or residents on islands, could easily give us the information, only they don't know that anyone cares for it.

Instructions for observing Waves.

Sir G. G. Stokes summarises the observations required as follows :—

" From a Ship at Sea.

" (1) The apparent periodic time observed as if the ship were at rest.

" (2) The *true* direction from which the waves come; also the ship's *true* course and speed per hour.

" (3) A measure or estimate of the height of the waves.

" (4) The depth of the sea, if it is known, but at any rate the position of the ship as near as possible, either by cross-bearings of land or any other method, so that the depth may be got from charts or other sources."

" From a Ship at Anchor.

" (1) The periodic time.

" (2) The *true* direction from which the waves come.

" (3) A measure or estimate of the height of the waves.

" (4) The depth of the water where she is anchored.

" It is well known that the behaviour of a ship in a seaway is in a high degree dependent on the relation which the *Period* of the waves bears to the *Period* in which the ship naturally continues to oscillate when she has been artificially set in motion in still water. Without tracing the consequences of this relation in full detail, it may be broadly stated that the deepest rolling which a given ship can exhibit, occurs when she is exposed (broadside on) to a series of waves, the *Period* of which is the same or nearly the same as her own; and that under these circumstances her rolling may be, and generally will be, very deep indeed, even though when broadside on to waves of a different *Period* she has seemed almost insensible to their effect."

“ For an Observer on Shore.

“ The same as for the ship at anchor, with the depth near the rock over which the swell passes instead of near the ship.”

In connexion with the foregoing summary Mr. Froude has given valuable information, which in effect is as follows :—

The apparent period of a wave is the interval of time which elapses between the transit of two successive wave-crests past an observer's position on board a vessel under way; the wave-crest is the highest line along the wave's ridge.

But the interval which elapses between the transits of two consecutive wave-crests past an observer thus situated is greater or less than the true period according to the distance travelled by the vessel in the interim, and the relative direction in which she is moving either from or towards the waves under observation. A correction must therefore be applied to the apparent periodic time in order to find the true period; and for this reason it is necessary for the observer to note the true direction from which the waves are coming; also the true course of the vessel, and her speed.

The apparent speed may be determined by noting the time the crest takes to traverse a measured distance between two positions on the ship. This measurement requires two observers, one to give a signal and the other to note the interval of time.

The true speed of the waves may then be estimated from their apparent speed, as primarily deduced from observations by adding or deducting the speed of the vessel towards or from them, as the case may be. By applying the correction thus obtained, the true wave length and wave period may be found.

The height of a wave is its elevation from trough to crest. The length of a wave or wave-length is the shortest distance between two successive crests. A “ long ” wave in the technical sense is thus used to indicate a member of a group of waves which follow each other with a great distance between the crests. It has no reference to the extent of the crest.

Stokes gave the following method for observing the periodic time by an observer on shore, which also holds good on board ship, only the direction towards which the wave is moving, as well as the course and speed of the ship, must be recorded at the same time.

“ The observation requires no more apparatus than a common watch with a second hand. A single person can observe very well, but it is more satisfactory when two work in concert, as one can then keep his eye on the rock (or ship) while the other keeps his eye on the watch, when the time draws near when the crest of the wave is about to reach the rock (or ship). In that case the second notes and writes down the time when the first calls out ‘ Now.’ ”

“ Waves usually come in sets followed by a comparative lull, during which observations might be uncertain, and great care should be taken not to observe any of the uncertain waves. The periodic time of several sets should be taken when possible, though three or even two sets would give a good result; being very careful to note the direction towards which the wave is moving, and the course and speed of the ship, when the observation is taken at sea. With these data the observed periodic time can be corrected for the ship’s motion when the observations are received in England.

“ A word or two may be useful as to the mode of observation. I found it better to observe when the waves reached a particular rock, than when their ridges, seen edgeways as they entered a small bay, were in a line with an object on shore. A rock should be selected, if possible, in sufficiently deep water for the waves not to break before they reach it. If the form of the coast permit of the observer stationing himself so as to get a side view of the waves as they approach the rock, so much the better, as the observer can then see their ridges as they approach the rock, and is better prepared to note the exact moment when they reach it. If the watch used has a gaining or losing rate of sufficient magnitude to be sensible in the observation, its gain or loss in a certain time should also be recorded. The time (second or half second alone) of transit of each wave of such sets as seem worth keeping should be recorded, and the time of day when the observations were made. In the case of remarkable swells the observation should be repeated at intervals of a few hours, as the gradual alteration of periodic time is a matter of interest.”

“ It is desirable to observe the *height* of the waves as well, and in case of shoal water the *depth of the sea* should be recorded. I do not know any very satisfactory way of determining the height of waves at sea, especially of long swells; the best seems to be that adopted by the late Captain Owen Stanley, R.N., as shown in the following

paragraph, quoted from a letter of his in the Report of the British Association for 1848, Part II, page 38.

“ ‘ For measuring the height of waves I adopted a plan recommended to me by Mrs. Somerville, which I have tried for 10 years with success. When the ship is in the trough of the sea, the person observing ascends the rigging until he can just see the crest of the coming wave on with the horizon, and the height of his eye above the ship’s water line will give a very fair measure of the difference of level between the crest and hollow of a sea. Of course in all these observations the means of a great many have been taken, for even when the sea is apparently most regular there is a change in the height of individual waves.’ ”

Captain Owen Stanley gives a table in which he shows that the distance between the crests of various waves which he measured, ranged between 33 and 57 fathoms, which the sailor must bear in mind is called *wave length*. In nautical terms a long wave is one which has a long crest, and the above would be considered as its breadth.

Captain Owen Stanley’s observations were taken when his ship was before the wind, and Stokes considers that in such a case, when the centre of the ship was in the trough of the sea, her ends would be buoyed up, so that the height of a wave by the above method would be very sensibly underestimated. He goes on to say :—

“ To carry out this method for long low swells the observer would have to climb down outside the ship, unless one of the cabin windows happened to be just of the right height. As to pitching; the observer can choose his station where there is no sensible motion up or down, except (in the case of long waves) of the ship as a whole.

“ Rolling, if there be much, is more difficult to manage, for he cannot see from the middle line of the ship (except when the crests are above, not below the deck) when the ship is in the trough, unless he be at the bow or the stern, and then the least pitching would vitiate his height.

“ I hardly expect to get more than a fair estimate of the height; but on the other hand it is not of much interest to know the height more than approximately.

“ For observing the height from shore much must depend upon circumstances. Supposing rollers break on a shelving beach, I should say ascend till the crests of the waves, just as they begin to break, are in a line with the horizon, and take the height of the eye above the average height of the water at the water’s edge.

“ It would be desirable to direct special attention to very long swells, even though they should not be con-

spicuous as to height. I have myself observed, in a heavy swell on the north coast of Ireland, a periodic time of 17 seconds, the calculated wave length for which in deep water is 247 fathoms. Low swells of such great length would hardly perhaps attract attention, unless the observer were specially on the look-out for them; but it is just these very long swells that I take to be the origin of the rollers.

“ You may perhaps want to have an idea *how* deep the water must be in order that it may be regarded as ‘ deep ’ in relation to waves.

“ Practically the water is ‘ deep ’ when the depth equals half the wave length. I do not know what the periodic time of the rollers at Ascension and St. Helena may amount to at the greatest. Mr. Froude told me that he once observed periods of from 18 to 23 seconds in Torbay. For 23 seconds the wave length in deep water is 452 fathoms, the half of which, or 226 fathoms, would therefore be the depth of practically ‘ deep ’ water for such a wave length, and in which case the depth of the sea need not be recorded. Hence you see that for such *very* long waves the bottom begins to tell even at depths much beyond ordinary soundings. In many such cases the depths would probably be known approximately from published charts.

“ It would be difficult to recognise at all low swells of 400 or 500 fathoms length out at sea, especially as there would be generally shorter waves as well, which from a ship would appear much more conspicuous. But in crossing a bank the long swells would mount up, while the shorter waves would be unaffected, as for them we should still have practically ‘ deep ’ water.

“ There would therefore be a special interest in the observation of the periodic time of heavy swells over the Agulhas bank and in similar localities.”

All who have crossed the Agulhas bank and seen how the sea was comparatively smooth in deep water, but high on the edge of the bank, must feel the force of these remarks. We learn from Sir George Gabriel Stokes that the low swells of deep water, which have long periodic times, cause high rollers when they come into shallow water. The navigator who records “ occasional N.Wly. swells ” at the equatorial verge of the Atlantic S.E. Trade, will now know that if their periodic time be great, which is suggested by using the word “ occasional,” however low they may appear (and they are often so low as only

to be detected by a slight pitching motion in the ship going to the north-west), they are probably on their way to cause the Ascension rollers.

Careful observations on the plan indicated in the foregoing paragraphs are welcomed as a useful addition to the ordinary observations of a ship's meteorological log.

Visibility.

In order that normal visibility in various localities of the several oceans and seas may be ascertained, reliable observations of visibleness are required on all oversea routes. Such observations should be recorded in the "Remarks" column of the Meteorological Log Book; but data, other than those of vouched-for accuracy, should on no account be noted.

The records wanted in this connexion are:—the light or headland to which an observation refers—(if the former, not the glare of the lights); the height of the observer's eyes above sea level; the time, and the true bearing of the aforementioned object when first seen; the time and the true bearings when nearest; the estimated distance when first seen; the estimated distance when nearest. If a light, its range of visibility (taken from the Chart) and the state of the weather, by Beaufort notation, should be noted.

The following scale of visibility, that has been constructed for general use, is based on the assumption that, the atmosphere being free from fog, a Lighthouse, Light-Vessel, or Light of the third, or higher, order, elevated to a height of at least 35 feet above sea level, will be visible to the unaided eyes of normal sight when viewed from a height of 40 feet or more, or *vice versâ*, at a distance of at least 14 nautical miles.

A total number of 547 special observations are employed in the construction of the scale.

<i>Scale of Visibility.</i>			No. of
Scale.	Miles Visible.		Observations.
4	...	30-17	363
3	...	16-9	144
2	...	8-3	40
1	...	2 and under	—

Total No. of Observations ... 547

APPENDIX I. TO CHAPTER III.

Stokes's Formulæ for Reducing Observations of Waves.

From "Remarks to accompany Monthly Charts of Meteorological Data for Nine ten-degree squares." M.O. Publication 27, p. 567.

For the sake of those who are willing to reduce their own observations, it may be well to give the formulæ required.

The first thing is to obtain the apparent period. In commencing the observation of a series of waves the observer cannot prophesy how it will turn out, so that the series noted in the first instance will be of very unequal merit. A few of the best should be selected for permanent record and reduction; the rest may be thrown away. Those series are best which contain the greater number of waves which have come in fairly regular succession, for the observation is only vitiated by pushing it beyond this. If there be $n+1$ waves in a series, a fair value of the apparent period may be got by dividing the interval of time between the transit of the first and last waves of the series by n , the number of wave intervals. But in this way only the two extreme waves are utilized, and it is more accurate to give each its due weight. The rule for this is simple: supplying 60, 120, &c., for the minutes passed over in recording in the first instance the seconds only of the times of transit, write the time in seconds of transit of the first wave under that of the last, that of the first but one under that of the last but one, and so on till the middle is reached. Take the differences: if n be odd, multiply them, beginning at the middle, by 1, 3, 5, &c.; sum the products, and divide by $\frac{1}{6} n(n+1)(n+2)$. If n be even so that there is a middle wave which is left out, multiply the products by 1, 2, 3, &c., sum, and divide by $\frac{1}{12} n(n+1)(n+2)$. The result in either case will be the most probable value of the apparent period derived from the series.

We must next correct for the ship's motion, so as to get the true period from the observed period. It will be convenient to write down in the first instance the known formulæ for the velocity of propagation, &c., of periodic waves when the height is moderate compared both with the length of the waves (*i.e.*, distance from crest to crest) and the depth of the water, a condition practically fulfilled in nature, except when waves are on the point of breaking on shore.

If V be the velocity of propagation, l the length, T the true period, then in all cases—

$$l = VT \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If h be the depth of the water, g the force of gravity, e the base of the Napierian logarithms, π the ratio of the circumference to the diameter of a circle—

$$V^2 = \frac{gl}{2\pi} \left(e^{\frac{2\pi h}{l}} - e^{-\frac{2\pi h}{l}} \right) / \left(e^{\frac{2\pi h}{l}} + e^{-\frac{2\pi h}{l}} \right) \quad . \quad . \quad . \quad (2)$$

For observations at sea, when the depth will usually be as good as infinite, (2) becomes,

$$V^2 = \frac{gl}{2\pi} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Let v be the velocity of the ship, θ the angle between the ship's course and the direction in which the waves are travelling. Then $v \cos \theta$ will be the ship's velocity resolved in the direction in which the waves are travelling, and $V - v \cos \theta$ will be the velocity of the waves relatively to the ship. If then P be the apparent period,

$$VT = (V - v \cos \theta) P \quad . \quad . \quad . \quad . \quad . \quad (4)$$

For a ship at sea we may regard the depth as practically infinite in making the correction for the ship's velocity, and when she is at anchor there is no correction to make. Hence, instead of (2) we may use the simpler form (3); and eliminating V and l between (1), (3), (4), we find

$$gT^2 = (gT - 2\pi v \cos \theta) P,$$

whence

$$T = \frac{P}{2} + \sqrt{\left(\frac{P}{2}\right)^2 - \frac{2\pi v \cos \theta}{g} P} \quad . \quad . \quad . \quad (5)$$

giving the true period T in terms of the observed period P .

As it would be a needless refinement to use the local value of g in correcting for the ship's motion, we may put for g its mean value 32.14, referred to feet and seconds, and we must of course express v in feet per second. We have

$$\log \frac{2\pi}{g} = 1.2913.$$

The true period having been obtained, the observer can calculate if he pleases the length and velocity from (1) and (2), or if the depth be great, from (1) and (3), and compare the results with any direct observations he may have taken of those elements. When the depth is considerable we have

$$V = \frac{gT}{2\pi} \quad . \quad . \quad . \quad . \quad (6). \quad l = \frac{gT^2}{2\pi} \quad . \quad . \quad . \quad . \quad (7).$$

In this calculation it might be well to take for g its actual local value as given by the expression

$$g = 32.09 (1 + 0.0051 \sin^2 L)$$

where L is the latitude.

When the depth is small enough to make the influence of the bottom sensible, the calculation, though less simple, is not very troublesome. The results may be got by the method of trial and error, or else successive substitution, from (1) and (2), the latter being put for convenience under the form—

$$e^{\frac{2\pi h}{l}} = \cot \phi, \quad V^2 = \frac{gl}{2\pi} \cos 2\phi.$$

APPENDIX II. TO CHAPTER III.

Waves in the open Ocean. Trochoid Waves.

From the "*Manual of Naval Architecture*," by the late Sir W. H. White, K.C.B., F.R.S.

Suppose QR, Fig. 19, to be a straight line, under which the large circle whose radius is OQ is made to roll. The length QR being made equal to the semi-circumference, the rolling circle will have completed half a revolution during its motion from Q to R; and if this length QR and the semi-circumference QR_1 are each

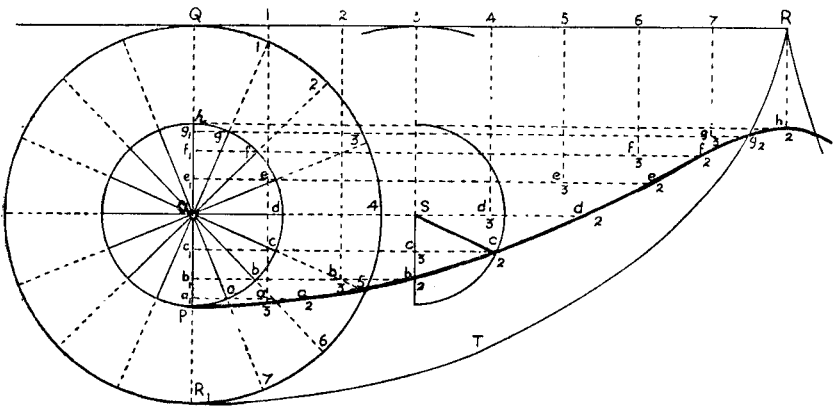


FIG. 19.

divided into the same number of equal parts (numbered correspondingly 1, 2, 3, &c., in the diagram), then obviously, as the circle rolls, the points with corresponding numbers on the straight line and circle will come into contact successively, each with each. Next suppose a point P to be taken on the radius OR_1 of the rolling circle; this will be termed the "tracing point," and as the circle rolls, the point P will trace a curve (a trochoid, marked P, a_2 , b_2 , c_2 h_2 in the diagram) which is the theoretical wave profile from hollow to crest, P marking the hollow and h_2 the crest. The trochoid may, therefore, be popularly described as the curve traced on a vertical wall by a marking-point fixed in one of the spokes of a wheel, when the wheel is made to run along a level piece of ground at the foot of the wall; but when thus described, it would be inverted from the position shown in Fig. 19.

To determine a point on the trochoid is very simple. As the rolling circle advances, a point on its circumference (say 3) comes into contact with the corresponding point of the directrix-line QR; the centre of the circles must at that instant be (S) vertically below the point of contact (3), and the angle through which the circular disc and the tracing arm OP have both turned is given by $QO3$. The angle POc , on the original position of the circles, equals $QO3$; through S draw Sc_2 parallel to Oc , and make Sc_2 equal to Oc ; then c_2 is a point on the trochoid. Or the same result may be reached by

drawing cc_3 horizontal, finding its intersection (c_3) with the vertical line $S3$, and then making c_2c_3 equal to cc_1 . In algebraical language, this may be simply expressed. Take Q as the origin of co ordinates, QR for axis of abscissae (x)—

Let radius $OQ=a$,

„ $OP=b$,

Angle $QO3=\theta$

and x, y co-ordinates of point c_2 on trochoid.

Then

$$x=c_1 c_2=c_1 c_3+c_2 c_3 \\ =a\theta+b \sin \theta ;$$

$$y=c_1 Q=O P+O c_1 \\ =a+b \cos \theta$$

The tracing arm (OP) may, for wave motion, have any value not greater than the radius of the rolling circle (OQ). If OP equals OQ , and the tracing point lies on the circumference of the rolling circle, the curve traced is termed a *cycloid*, and corresponds to a wave on the point of breaking. The curve R_1TR , in Fig. 19 shows a cycloid, and it will be noticed that the crest is a sharp ridge or line (at R), while the hollow is a very flat curve.

A few definitions must now be given of terms that will be frequently used hereafter. The *length* of wave is its measurement (in feet usually) from crest to crest, or hollow to hollow— QR in Fig. 19 would be the half-length. The *height* of a wave is reckoned (in feet usually) from hollow to crest; thus in Fig. 19 for the trochoidal wave, the height would be Ph —twice the tracing arm. The *period* of a wave is the time (usually in seconds) its crest or hollow occupies in traversing a distance equal to its own length; and the velocity (in feet per second) will, of course, be obtained by finding the quotient of the length divided by the period, and would commonly be determined by noting the speed of advance of the wave crest.

Accepting the condition that the profile of an ocean wave is a trochoid, the motion of the particles of water in the wave requires to be noticed, and it is here the explanation is found of the rapid

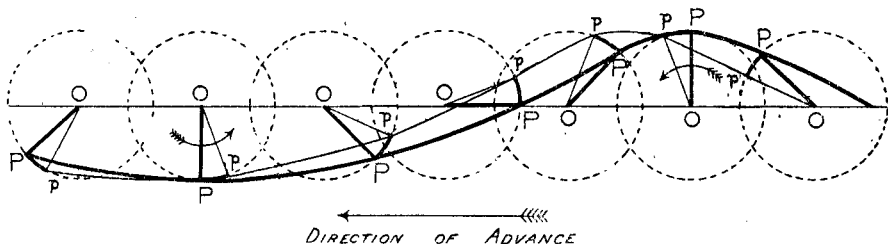


FIG. 20.

advance of the wave form, while individual particles have little or no advance. The trochoidal theory teaches that every particle revolves with uniform speed in a circular orbit (situated in a vertical plane which is perpendicular to the wave ridge), and completes a revolution during the period in which the wave advances through its own length. In Fig. 20 suppose $P, P, P, \&c.$ to be particles on

the upper surface, their orbits being the equal circles shown ; then for this position of the wave the radii of the orbits are indicated by OP , OP , &c. The arrow below the wave profile indicates that it is advancing from right to left ; the short arrows on the circular orbits show that at the wave crest the particle is moving in the same direction as the wave is advancing in, while at the hollow the particle is moving in the opposite direction. It need hardly be stated again that for these surface particles the diameter of the orbits equals the height of the wave. Now suppose all the tracing arms OP , OP , &c. to turn through the equal angles POp , POp , &c. ; then the points p , p , p , &c. must be corresponding positions of particles on the surface formerly situated at P , P , &c. The curve drawn through p , p , p , &c. will be a trochoid identical in form with P , P , P , &c., only it will have its crest and hollow further to the left ; and this is a motion of advance in the wave form produced by simple revolution of the tracing arms and particles (P). The motion of the particles in the direction of advance is limited by the diameter of their orbits, and they sway to and fro about the centres of the orbits. Hence it becomes obvious why a log dropped overboard, as described above, does not travel away on the wave upon which it falls, but simply sways backward and forward. One other point respecting the orbital motion of the particles is noteworthy. This motion may be regarded at every instant as the resultant of two motions—one vertical, the other horizontal—except in four positions, viz. : (1) when the particle is on the wave crest : (2) when it is in the wave hollow ; (3) when it is at mid-height on one side of its orbit ; (4) when it is at the corresponding position on the other side. On the crest or hollow the particle instantaneously moves horizontally, and has no vertical motion. At mid-height it moves vertically, and has no horizontal motion. Its maximum horizontal velocity will be at the crest or hollow ; its maximum vertical velocity at mid-height. Hence uniform motion along the circular orbit is accompanied by accelerations and retardations of the component velocities in the horizontal and vertical directions.

The particles which lie upon the trochoidal upper surface of the wave are situated in the level surface of the water when at rest. The disturbance caused by the passage of the wave must extend far below the surface, affecting a great mass of water. But at some depth, supposing the depth of the sea to be very great, the disturbance will have practically ceased ; that is to say, still, undisturbed water may be conceived as underlying the water forming the wave ; and reckoning downwards from the surface, the extent of disturbance must decrease according to some law. The trochoidal theory expresses the law of decrease, and enables the whole of the internal structure of a wave to be illustrated in the manner shown in Fig. 21.* On the right-hand side of the line AD the horizontal lines marked 0, 1, 2, 3, &c. show the positions in still water of a series of particles which during the wave transit assume the trochoidal forms numbered respectively 0, 1, 2, 3, &c. to the left of AD . For still water every unit of area in the same horizontal plane has to sustain the same pressure ; hence a horizontal plane would be termed a surface or subsurface of "equal pressure," when the water is at rest. As the wave passes, the trochoidal surface corresponding to that horizontal

* This diagram we borrow from Mr. Froude's paper on "Wave Motion" in the Transactions of the Institution of Naval Architects for 1862 ; it was one of the first constructed, and is therefore reproduced.

plane will continue to be a subsurface of equal pressure; and the particles lying between any two planes (say 6 and 7) in still water will, in the wave, be found lying between the corresponding trochoidal surfaces (6 and 7).

In Fig. 21 it will be noticed that the level of the still-water surface (O) is supposed changed to a cycloidal wave (O), the construction of which has already been explained; this is the limiting height the wave could reach without breaking. The half-length of the wave AB being called L, the radius (CD) of the orbits of the surface particles will be given by the equation—

$$CD=R=\frac{L}{\pi}=\frac{7}{22} L \text{ (nearly).}$$

All the trochoidal subsurfaces have the same length as the cycloidal surface, and consequently they are all generated by the motion of a rolling circle of radius R; but their tracing arms—measuring half

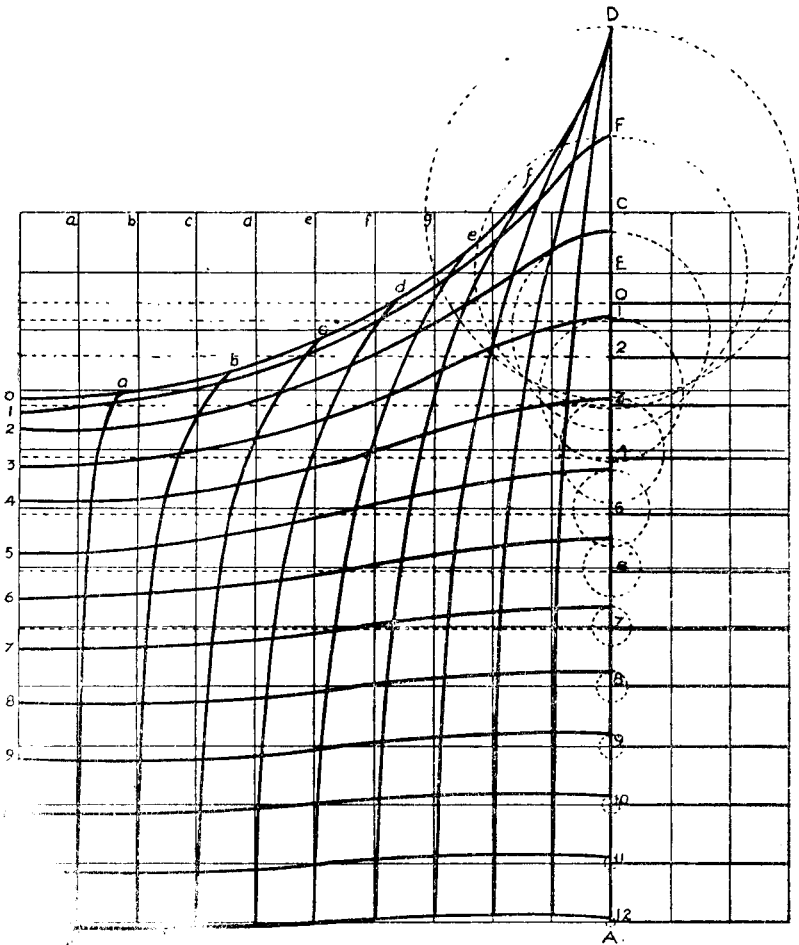


FIG. 21.

the heights from hollow to crest—rapidly decrease with the depth (as shown by the dotted circles), the trochoids becoming flatter and flatter in consequence. The crests and hollows of all the subsurfaces are vertically below the crest and hollow of the upper wave profile. The heights of these subsurfaces diminish in a geometrical progression, while the depth increases in arithmetical progression; and the following approximate rule is very nearly correct. The orbits and velocities of the particles of water are diminished by *one-half*, for each additional depth below the mid-height of the surface wave equal to *one-ninth* of a wave length. For example—

Depths in fractions of a wave length below	} 0, $\frac{1}{9}$, $\frac{2}{9}$, $\frac{3}{9}$, $\frac{4}{9}$, &c.
the mid-height of the surface wave	
Proportionate velocities and diameters	... 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, &c

Take an ocean storm wave 600 feet long and 40 feet high from hollow to crest: at a depth of 200 feet below the surface ($\frac{2}{3}$ of length), the subsurface trochoid would have a height of about 5 feet; at a depth of 400 feet ($\frac{4}{3}$ of length) the height of the trochoid—measuring the diameter of the orbits of the particles there—would be about 7 or 8 inches only; and the curvature would be practically insensible on the length of 600 feet. This rule is sufficient for practical purposes, and we need not give the exact exponential formula expressing the variation in the radii of the orbits with the depth.

It will be noticed also in Fig. 21 that the centres of the tracing circles corresponding to any trochoidal surface lie above the still-water level of the corresponding horizontal plane. Take the horizontal plane (1), for instance. The height of the centre of the tracing circle for the corresponding trochoid (1) is marked E, EF being the radius; and the point E is some distance above the level of the horizontal line 1. Suppose r to be the radius of the orbits for the trochoid under consideration, and R the radius of the rolling circle; then the centre (E) of the tracing circle (*i.e.*, the mid-height of the trochoid) will be above the level line (1) by a distance equal to $\frac{r^2}{2R}$. Now R is known when the length of the wave is known; also r is given for any depth by the above approximate rule. Consequently, the reader will have in his hands the means of drawing the series of trochoidal subsurfaces for any wave that may be chosen.

Columns of particles which are vertical in still water become curved during the wave passage: in Fig. 21 a series of such vertical lines is drawn (see the *fine* lines a, b, c, d , &c.); during the wave transit these lines assume the positions shown by the strong lines (a, b, c, d , &c.) curving towards the wave crest at their upper ends, but still continuing to inclose between any two the same particles as were inclosed by the two corresponding lines in still water. The rectangular spaces inclosed by these vertical lines (a, b, c, d , &c.) and the level lines (0, 1, 2, &c.) produced are changed during the motion into rhomboidal-shaped figures, but remain unchanged in area. Very often the motions of these originally vertical columns of particles have been compared to those occurring in a corn-field, where the stalks sway to and fro, and a wave form travels across the top of the growing corn. But while there are points of resemblance between the two cases, there is also this important difference—the corn-stalks are of constant length, whereas the originally vertical

columns become elongated in the neighbourhood of the wave crests, and shortened near the wave hollows.

These are the chief features in the internal structure of a trochoidal wave, and in the following chapter* they will be again referred to in order to explain the action of waves upon ships. It is necessary, however, at once to draw attention to the fact that the conditions and direction of fluid pressure in a wave must differ greatly from those for still water. Each particle in the wave, moving at uniform speed in a circular orbit, will be subjected to the action of centrifugal force as well as the force of gravity; and the resultant of these two forces must be found in order to determine the direction and magnitude of the pressure on that particle.

APPENDIX III. TO CHAPTER III.

Observations by Lieutenant Paris.

During the years 1867-70 a French naval officer, Lieutenant A. Paris, recorded a succession of carefully made observations upon the state of the sea, while serving on board the corvette *Dupleix* and the frigate *Minerve* during a passage to the Far East and while cruising in the China Seas and Western Pacific. Lieutenant Paris published the results of his investigations in the "Revue Maritime et Coloniale" in 1871. In this paper the author states that the *height* of the wave increases somewhat rapidly with an increase of wind and, when the wind drops, diminishes more rapidly than any other element in wave motion. He found the *length* of the wave to be very variable; with an increasing wind the increase in length was at first inconsiderable, but afterwards it increased more rapidly than the height. The *speed* of the wave he considered to be the least variable of the elements of wave motion and *with* the length was preserved longest after the wind had dropped and the sea had become a swell.

Lieutenant Paris mentions that the relation of the speed of the wind to that of the wave increases fairly rapidly in proportion to the strength of the breeze; and he bases his conclusions in this connexion upon the results of observations of waves that for the most part were unaffected by preceding wind or by local conditions, all records of swell and of deep sea waves having been discarded for this purpose.

The reliable data remaining after these eliminations—in all only thirty-one observations—were arranged in four groups and the average speed of the wind and that of the wave was ascertained for each group.

The results are shown in the following table, in reference to which the author expresses the opinion that these indicate that in

* Chapter VI. of "Manual of Naval Architecture," by Sir W. H. White, K.C.B., F.R.S.

the open sea the speed of the wave is proportionate to the square root of that of the wind.

Assignment of speed.	Average speed of the Waves.		Average relation of the speed of the Wind to that of the Wave.	Average relation by square root of the speed of the Wind to the speed of the Wave.	Number of Days of observations forming each group.
	Metres per sec.	Feet per Sec.			
Speed of waves included between 8 and 11 metres (26·25 and 36·09 feet).	9·6	31·5	0·63	0·25	8
Speed of waves included between 11 and 14 metres (36·09 and 45·93 feet).	12·5	41·0	0·99	0·27	8
Speed of waves included between 14 and 15 metres (45·93 and 49·22 feet).	14·6	47·9	1·26	0·29	8
Speed of waves above 15 metres (49·22 feet).	16·4	53·8	1·32	0·28	7

In any attempt to determine the relation between the height of waves and the force of the wind we are met, however, by difficulties not alluded to by Lieutenant Paris; for when estimating the effect of wind force upon sea disturbance it must be borne in mind that winds from a polar quarter have a greater effect in raising the sea than is the case with winds from an equatorial quarter. Moreover sea disturbance is reduced by the fall of rain and hail, especially by the latter, and is increased by the opposition of current and tide to the wind's direction.

* * The following papers on waves may be referred to:—W. Froude; On a method of determining at sea, by simple observation, the periods and dimensions of waves.

Lieutenant Paris, French Navy; Observations sur l'état de la mer recueillies à bord du Duplex et de la Minerve (1867-70), *Revue Maritime et Coloniale*, Vol. xxxi, 1871.

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CHAPTER IV.

Clouds, Weather and Optical Phenomena.

CLOUDS.

Cloud observations may be considered under three headings, viz. :—

- (1.) Amount.
- (2.) Form.
- (3.) Direction and Velocity of Motion.

AMOUNT OF CLOUD.

The proportion of the sky covered by cloud should be indicated on a numerical scale running from 0, cloudless, to 10, completely overcast; in other words we are required to estimate the number of tenths of the area of the sky which would be covered by the cloud present supposing them moved up to each other so as to form a continuous sheet. The numbers given are to refer solely to the amount of the sky covered and not to the density, height or other quality of the cloud.

If desired the density of the cloud may be indicated by adding suffixes 0, 1, 2 thus, 4₁ indicates that rather less than half the sky is covered by moderately heavy cloud, 7₂ that seven tenths are covered by heavy dark clouds.

In estimating, the observer will do well to sub-divide the sky mentally into quadrants by means of diameters at right-angles to each other. An estimate (on the scale 0—10) is then formed for each quadrant separately, and the figure finally entered in the register is the mean of the four numbers so obtained.

The direction of the dividing diameters should be selected to give convenient sub-divisions of the prevailing cloud canopy.

Fog must be regarded as a cloud at sea surface level, and 10 must accordingly be entered for the amount of cloud on days when the sea lies under its pall. Some uncertainty arises in the case of mists, or when the sky is obscured by a very thin haze. Supposing that more definite cloud forms are entirely absent, the observer is

occasionally confronted by the problem whether he should enter the amount of cloud as 0 or 10. In all such cases appropriate notes should be made in the "remarks" column of the register.

CLOUD FORMS.

Luke Howard, whose classification of cloud forms is the basis of the system now in use, distinguished three principal cloud forms, viz. :—

- (1.) Cirrus cloud (of fibrous or feathery appearance, mare's tails).
- (2.) Cumulus cloud (having rounded tops).
- (3.) Stratus cloud (arranged in horizontal sheets or layers).

Many forms intermediate between these primary types are found to occur, and these are specified by compounding the names of the primary types. As the observation of cloud forms became more common it was found desirable to increase the number of types and to agree on definitions for them. The International Meteorological Committee accordingly appointed a sub-committee to prepare and publish an international cloud atlas in which the following classification of clouds into 10 main types has been adopted.* Some examples are given in Appendix VI., and an indication of the height of clouds is also given in the frontispiece.

(1.) **Cirrus (Ci.).**—Delicate clouds of fibrous texture, taking the form of feathers, generally of a white colour. At times the cloudlets are detached, at others they are joined up into continuous masses. Occasionally cirrus clouds are arranged in belts which cross a portion of the sky in "great circles" and by an effect of perspective, converge towards one point or two opposite points of the horizon. (Cirro-stratus and Cirro-cumulus often contribute to the formation of these belts.)

(2.) **Cirro-Stratus (Ci-St.).**—A thin whitish sheet, at times completely covering the sky and only giving it a milky appearance (it is then sometimes called cirro-nebula), or at others, presenting, more or less distinctly, a formation like a tangled web. This sheet often produces halos around the sun or moon.

(3.) **Cirro-Cumulus (Ci-Cu.).**—Small globular masses or white flakes without shadows, or having very slight shadows, arranged in groups and often in lines. (French *Mouton*, German *Schäfchenwolken*.)

* The International Atlas of Clouds is unfortunately now out of print.

(4.) **Alto-Cumulus (A.-Cu.).**—Largish globular masses, white or greyish, partially shaded, arranged in groups or lines, and often so closely packed that their edges appear confused. The detached masses are generally larger and more compact (changing to strato-cumulus) at the centre of the group; at the margin they form into finer flakes (changing to cirro-cumulus). They often spread themselves out in lines in one or two directions.

N.B.—The title cumulo-cirrus is suppressed as giving rise to confusion.

(5.) **Alto-Stratus (A.-St.).**—A thick sheet of a grey or bluish colour showing a brilliant patch in the neighbourhood of the sun or moon, and which without causing halos, may give rise to coronae. This form goes through all changes similar to those shown by cirro-stratus, but by measurements made at Upsala its altitude is one half less.

N.B.—The title strato-cirrus is suppressed as giving rise to confusion.

(6.) **Strato-Cumulus (St.-Cu.).**—Large globular masses or rolls of dark cloud, frequently covering the whole sky, especially in winter and occasionally giving it a wavy appearance. The layer of strato-cumulus is not as a rule very thick and patches of blue sky are often visible through the intervening spaces. All sorts of transitions between this form and the alto-cumulus are noticeable. It may be distinguished from nimbus by its globular or rolled appearance.

(7.) **Nimbus (Nb.).**—A thick layer of dark clouds, without shape or form and with ragged edges from which continued rain or snow is falling. Through the openings in these clouds an upper layer of cirro-stratus or alto-stratus may almost invariably be seen. If the layer of nimbus separates up into shreds, or if small loose clouds are visible floating at a low level, underneath a large nimbus, they may be described as *fracto-nimbus* ("Scud," of sailors).

(8.) **Cumulus (Cu.) (Wool-pack or Cauliflower Cloud).**—Thick cloud of which the upper surface is usually dome-shaped and exhibits protuberances while the base is horizontal. These clouds appear to be formed by a diurnal ascensional movement which is almost always noticeable. When the cloud is opposite the sun, the surfaces facing the observer have a greater brilliance than the margins of the protuberances. When the light falls aslant, these clouds show deep shadows. When on the contrary they are on the same side as the sun, they appear dark with bright edges. Occasionally the upper surface of cumulus cloud though mammalated is not dome-shaped. This form is characteristic of areas of high pressure.

The true cumulus has clear superior and inferior limits. It is often broken up in strong winds and the detached portions undergo continual changes. These may be distinguished by the name *fracto-cumulus*.

(9.) **Cumulo-Nimbus (Cu.-Nb.). The Thunder cloud; Shower Cloud.**—Heavy masses of cloud rising in the form of mountains or turrets or anvils generally having a sheet or screen of fibrous appearance above (false cirrus), and underneath, a mass of cloud similar to "nimbus." From the base there usually fall local showers of rain or of snow (occasionally of hail or soft hail). Sometimes the upper edges have the compact form of cumulus, forming into massive peaks round

which the delicate "false cirrus" floats, and sometimes the edges themselves separate into a fringe of filaments similar to that of the cirrus cloud. This last form is particularly common in spring showers. The front of thunderclouds of wide extent frequently presents the form of a large bow spread over a large portion of the sky which is uniformly brighter in colour.

(10.) *Stratus* (St.).—A uniform layer of cloud which resembles a fog but does not rest on the ground. The complete absence of details of structure distinguishes stratus from other more compact forms of cloud. If the cloud layer is broken up into irregular shreds by wind or by mountains, it may be distinguished by the name *fracto-stratus*.

In view of the almost infinite diversity which cloud phenomena present, the observer must not expect to be able to assign without hesitation all clouds to one or other of the types described. If he is unable to classify the clouds seen, he should note the fact in the register.

If abbreviations be used for the names of the cloud types those given above should be employed.

Several different cloud forms will frequently be present simultaneously. In such cases the direction of motion of each type should be observed and noted in the register. The directions of motion of different clouds observed at one and the same time may differ very materially.

A GUIDE TO THE CLASSIFICATION OF CLOUD FORMS IS GIVEN AS APPENDIX VI.

Attention is also directed to the following details :—

Undulated clouds.—It often happens that the clouds show regular striae, parallel and equidistant, like waves on the surface of water. This is mostly the case with the cirro-cumulus, strato-cumulus (roll cumulus), &c. It is important to know the direction of these striae. When two distinct systems are apparent, as is often seen in clouds separated into globular masses by striae in two directions, the directions of these two systems should be noted. As far as possible, these observations should be taken of striae near the zenith so as to avoid errors caused by perspective.

The point of radiation of the upper clouds.—These clouds often take the form of narrow parallel lines, which by reason of perspective appear to issue from a given point on the horizon. The "point of radiation" is the name given to the point where these belts or their prolongations meet the horizon. This point on the horizon should be indicated in the same manner as the direction of the wind, N., N.N.E., &c.

WEATHER.

The state of the weather is recorded in letters of the Beaufort Notation which are as follow :—

Letters to indicate the State of the Weather.

b	Blue Sky.	q	Squalls.
c	Clouds (detached).	r	Rain.
d	Drizzling rain.	s	Snow.
e	Wet a r without rain.	t	Thunder.
f	Fog.	u	Ugly or threatening appearance of the weather.
g	Gloom.	v	Visibility. Objects at a distance unusually visible.
h	Hail.	w	Dew.
l	Lightning.	z	Haze.
m	Mist.		
o	Overcast Sky.		
p	Passing showers.		

NOTE.—A dot (·) under any letter augments its signification ; thus, *r* heavy rain ;

r very heavy rain ; but to express the intensity of the fog the scale should be

:

used. A figure preceeding a letter shows how many hours that style of weather had prevailed since last observation : thus, 4 *r* means four hours' rain ; 2½ *l* means two and half hours of vivid lightning, &c., &c. It is well

to bear in mind that *w*=dew, but *d*=drizzle, and *e*=wet without rain ; *p*=passing showers of rain, and *q*=squalls, but *s*=snow.

Appearance of sky.—The letters—*b*, *c*, *o*,—are intended to refer only to the amount of cloud visible, and not to its density, form, or other quality. They have gradually come to be regarded as corresponding to the following cloud amounts in the scale 0–10 :—*b*=0 to 3, *bc* or *cb*=4 to 6, *c*=7 or 8, *o*=9 or 10. The letters *g* and *u*, which stand respectively for gloomy and threatening (ugly), should be used when appropriate to indicate the general appearance of the sky.

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

Unless otherwise stated, it is assumed that the letter *p* refers to showers of rain. Snow or hail showers may be noted thus, *sp*, *hp* ; showers of mixed hail and rain thus, *rhp*. No separate letter is given for sleet ; the combination *rs* is generally used.

Fog, f ; Mist, m ; Haze, z.—These three words are used to indicate a deterioration of the transparency of the

Insert on p 82.

Weather Notation

b	blue sky (not more than one quarter clouded)	o	overcast
bc	sky partly clouded (one half covered)	p	passing showers
c	generally cloudy (three quarters covered)	q	squalls
d	drizzle or fine rain	r	rain
e	wet air without rain falling	rs	sleet; ie rain & snow together
f	fog	s	snow
g	glaze	t	thunder
h	hail	u	lightly threatening appearance
l	lightning	v	unusual visibility
m	mist.	w	dew
		x	hoar frost
		z	dust haze; the turbid atmosphere of dry weather

These letters refer only to amount of cloud. They are regarded as equivalent to the following cloud amounts, scale 0-10; b = 0-3; bc = 4-6; c = 7-10; e = 9 and 10

It is well to bear in mind that w = dew but not drizzle and e = wet air without rain; p = showers of rain, and q = squalls but s = snow; z = dust haze but not fog.

Insert on p 83.

SCALE OF FOG INTENSITY.

Scale	Description
8 f	Objects visible at 0 metres but not at 25 metres or 27 yards
7 f	25 or 27 yards . . 50 . . 53 .
6 f	50 . . 53 . . 100 . . 109 .
5 f	100 . . 153 . . 200 . . 219 .
4 f	200 . . 219 . . 500 . . 547 .
3 f	500 . . 547 . . 2000 . . 1 1/2 nautical miles
2 f	2000 . . 1 1/2 nautical miles . 7000 . . 3.8 . .
1 f	7000 . . 3.8 . . 20,000 . . 10.8 . .

lower layers of the atmosphere caused by solid or liquid particles, and in ordinary literature the choice of the particular term employed is almost at the discretion of the writer.

“Mist” and “fog” both refer properly to surface cloud; when either is experienced there will be little or no difference between the readings of the dry bulb and wet bulb thermometers. A slight fog is sometimes called a haze, but it is better to restrict the use of the word haze to the obscurity due to smoke, dust, or other cause, when the air is dry and there is considerable difference between the dry bulb and wet bulb readings.

Endeavours have been made to draw a distinction between “mist” as a cloud on the surface which wets objects exposed to it, and “fog” as being one in which objects remain dry. The distinction is, however, not a practical one; having regard to the established usage of travellers on land and sea. Fog seems always to imply hindrance to shipping and thus the word may be used to denote the obscurity of the atmosphere regarded not from the point of view of the meteorologist, but from that of the navigator. The same cloud may be a “fog” for a person who is enveloped in it, but a “mist” for a person looking at it from a distance. The distinction is an important one in the practical applications of meteorology and fog should therefore be understood to mean surface cloud regarded from the point of view of interference with navigation.

A numerical scale of five steps of fog intensity, based on this criterion, was adopted in an inquiry into the occurrence and distribution of fog in the London area during the winter 1902-3. The following is a reproduction of this scale as modified by subsequent experience:—

Description.	Scale.	On Sea.	On River.
No Fog or Mist ..	0 f.	Horizon clear	Horizon clear.
Slight Fog or Mist	1 f.	Horizon invisible, but lights and landmarks visible at working distances.	Objects indistinct, but navigation unimpeded.
Moderate Fog ...	2 f.	Lights, passing vessels and landmarks generally indistinct under a mile. Fog signals are sounded. Ships lights and vessels invisible at $\frac{1}{4}$ mile or less.	Navigation impeded, additional caution required.
	3 f.		
	4 f.		
Thick Fog ...	5 f.		Navigation suspended.

When the obscurity does not interfere with navigation it may be identified as mist, and thus mist may be regarded, in a sense, as slight fog and fog as thick mist.

Wet Fog.—A fog in which water is deposited copiously on exposed surfaces should be noted by means of the letters *fe*.

Visibility.—*v*. This letter is used to indicate unusual transparency of the atmosphere, whether the sky be cloudy or not.

OPTICAL ATMOSPHERIC PHENOMENA.

The following instructions for observing optical atmospheric phenomena are translated, from the instruction drawn up by the late Professor J. M. Pernter and incorporated in the Handbook issued by the Austrian Meteorological Department. They received the approval of the International Conference of Directors of Meteorological Institutions which met at Innsbruck in 1905.

There are a large number of optical phenomena which not only arrest the attention of observers on account of their beauty, but also are more or less closely connected with the weather; they are of importance for both reasons, and observers are recommended to note them carefully.

Halo. Solar Halo; Lunar Halo.—Many different kinds of halo have been observed (*see* fig. 22*). The most common is the halo of 22° —a large ring, CIBG, round the sun or moon, having a radius of very nearly 22° (of a great circle). When of no great intensity the ring appears white, but when it is more strongly developed we may easily recognise the fact that the edge nearest the sun is red—a very pure red—and that orange, yellow, and, under very favourable circumstances, green, follow on, as we go outwards. The latter colour is always rather faint and whitish, and the blue is almost always so faint that it is not recognised as blue. Violet is never recognisable. The ring thus appears white on its outer edge.

A ring of about twice the radius, halo of 46° ; Fig. 22, VXYZ, occurs more rarely. Its luminosity is much less than that of the halo of 22° ; the arrangement of the colours, if visible, is the same.

Occasionally a colourless white ring, which passes through the sun parallel to the horizon, may be recognised. This is called the horizontal circle or mock sun ring. The latter name has been given to it because the mock suns described below lie on or near it. It is represented in the figure by the circle CDFEB, in which the portion

* Fig. 22 is a representation of the so-called Danzig phenomenon, as seen, drawn, and described by the well-known astronomer Hevel. The date of the observation is shown at the head of the figure. This figure is a facsimile of the original in Hevel's Publication (*see* Hellmann, "Neudrucke, Meteorologische Optik," p. 57).

BC, which passes through the sun, is omitted. This is frequently the case, but there are many cases on record in which the portion passing through the sun was distinctly visible.

A fourth ring is exceedingly rare ; it is white, and has a radius of about 90° ; it is known as the halo of 90° . In the diagram two

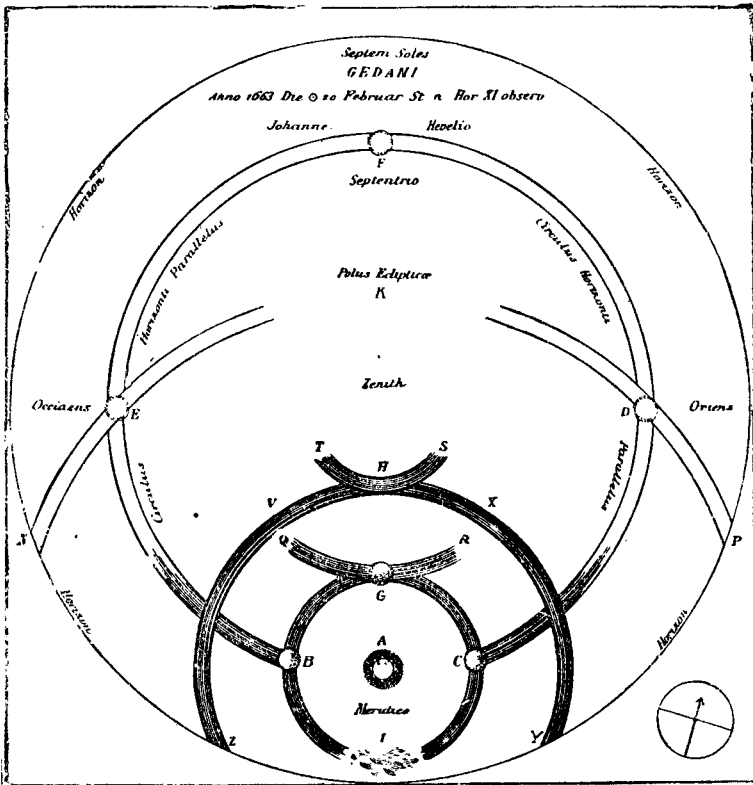


FIG. 22.

portions of it, NE and DP, are visible; if produced they would pass through K. It is obvious that this halo can never be seen in its entirety in our latitudes, for this would require the sun to be in the zenith.

It should be mentioned that the rings are frequently incomplete in the cases of the three first-mentioned halos also ; at times only small portions of them can be seen.

There are a number of other halo phenomena which, from their method of formation, can only be seen as arcs. Among these are the so-called *arcs of contact*, of which two are shown in the figure. Both of them are arcs of upper contact, RGQ belonging to the halo of 22°, THS to that of 46°. Arcs of lower contact may occur in

connexion with both these rings, but they are very rare. The arcs of upper contact appear with their convex sides turned towards the sun, as shown in the figure. Contact arcs appear occasionally at the sides of the halos of 22° and 46° , but they are as rare as the arcs of lower contact. The arcs of upper contact are very luminous at the points of contact, which have occasionally been described as "mock suns." The colour effects are often brilliant, red being turned towards the sun, *i.e.*, on the convex edge of the halo. The coloration of the arc of upper contact of the halo of 46° is frequently exceedingly brilliant. The ends of the arc of upper contact of the halo of 22° are frequently bent downwards.

A large number of other rings and arcs have been observed on rare occasions, and are generally described as "irregular"; observers who are fortunate enough to see such irregular bows are requested to sketch and describe them carefully, and, if possible, to measure their angular distance from the sun.

Of all halo phenomena, mock suns (parhelia) and mock moons (paraselenae) are probably the most admired. These terms are used to describe luminous, or even brilliant images of the sun which are seen most frequently at or near the intersection of the halo of 22° with the white mock sun ring (B and C, fig. 22). Very rarely mock suns are seen at or near the intersection of this ring with the halo of 46° . The mock suns of this halo are always very faint, and their colouring is indistinct; mock suns belonging to the halo of 22° are, on the other hand, both frequent and very luminous, and their colours are brilliant. Red is on the side nearest the sun, with yellow, green, and blue following in order. Blue is generally indistinct, and violet is usually too faint to be distinguished. As a rule a long and pointed white tail, occasionally attaining a length of 20° , extends from the mock suns along the mock sun ring (*see* fig. 22).

The mock suns of the ring of 90° (D and E, fig. 22) have been observed on a few occasions only since Hevel's day.

Not infrequently mock suns are seen without any of the rings being observed.

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

Other mock suns, besides those which have been mentioned, are occasionally seen. Observers are requested to sketch and describe carefully what they see, should they happen to observe one of these. If possible they should determine its position by measurement.

Other very beautiful halo phenomena are afforded by *sun pillars*, which are most easily observed at sunrise or sunset. These frequently extend about 20° above the sun and generally end in a point. At sunset they may be entirely red, but as a rule they are of a blinding white and show a marked glittering. If the sun is high in the heavens, white bands may appear vertically above and below him, but these are not very brilliant and often they are very short. Occasionally these white columns appear simultaneously with a portion of the white mock sun ring, and so form another very remarkable phenomenon, *viz.*, the cross (Fig. 23).

Plate 1A.

SOLAR HALOS OBSERVED AT ABERDEEN.

Reproduced from sketches by G. A. Clarke, Aberdeen Observatory.



Solar Halo of 22° radius, May 27, 1912. Complete circular halo, with arc of contact. Semi-major axis of the ellipse of which the arc of contact forms a part was about 29° .



Solar Halo of 22° radius, March 5, 1908, with arc of contact, mock sun ring, and mock suns (parhelia).

Frequently parts only of the rings and arcs are visible, having apparently no connexion with one another, thus lending a very peculiar appearance to the sky; not infrequently these arcs intersect obliquely, which increases the strangeness of the appearance.

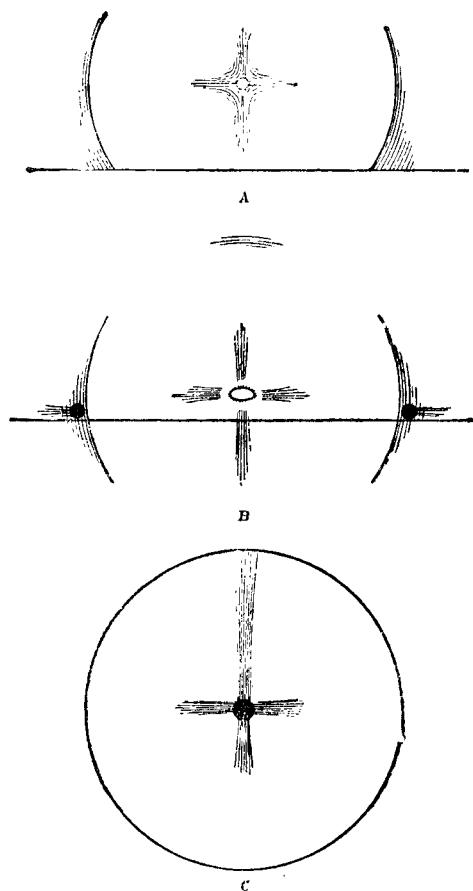


FIG. 23.

Many other halo phenomena are known to occur, but the space which can be devoted to the subject in a book of instructions to observers is limited, and they cannot all be described here. All halo phenomena should be sketched and described, and, if possible, photographed.

Halos only occur in presence of cirrus clouds or of light ice fog; they are produced by refraction and reflection of the rays of the sun or moon by ice crystals. The sun has been assumed as the source of light in all the phenomena described. This has been done solely for the sake of brevity; precisely similar though rather less brilliant appearances may be produced by moonlight.

Coronae. Solar Corona; Lunar Corona.—Coronae are seen most frequently round the moon. As their diameter is generally considerably smaller than that of the halo of 22° they are very near the luminary and can thus only be seen around the sun under favourable circumstances. No doubt they occur round the sun as frequently as round the moon; they may be observed by making use of a reflector or of a smoked glass to reduce the intensity of the light.

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

The size of the diameter of the ring is not an infallible criterion for distinguishing between halos and coronae, for a corona may be quite as big as a halo. Bishop's ring* has furnished a well-known example of such a corona. The criteria which the observer should apply to distinguish the two sets of phenomena are not the diameters of the rings, but the sequence of colour and the presence of the brown-red of the aureole.

As coronae are diffraction phenomena they occasionally show the sequence of colour two or three or even four times over. This can never be the case with a halo. Observers are requested to note carefully the colours which they can identify and also the order in which they follow one another from the inside to the outside of the ring.

In a foggy atmosphere (especially on mountains) an observer, standing with his back to the sun, will sometimes see a coloured ring of light round the shadow cast upon the fog by his own head. This appearance has been variously called "glory," "Ulloa's ring," "Brocken spectre," &c.

Green and red patches are occasionally seen in cirrus clouds, at a great distance from the sun or moon. They have no apparent connexion with coronae and may even occur when no corona is visible. Frequently a number of these patches may be seen along a line passing through the sun. This phenomenon is known as "irisation." The most important point to note is the (angular) distance between the sun (or moon) and the patches showing irisation.

Rainbow.—The erroneous assumption that all rainbows show the same sequence of colours and have the same radius has caused the careful study of this phenomenon to be much neglected. It has been shown that the colours of a rainbow as well as their extent

* In the year following the eruption of Krakatoa (1883) and again in 1903 after the eruption of Mount Pelée, a brownish red ring of over 20° diameter was frequently seen with a clear sky. It was proved to be an unusually large corona.

and the position of the greatest luminosity are very variable and depend on the size of the drops producing the bow. It is very desirable that greater attention be given again to this subject. If we note (1) the sequence of colours seen in the primary bow commencing with the red, (2) the colour which shows the maximum luminosity, and (3) which colour band is the widest, we can in most cases calculate the size of the drop producing the bow. This can be done with greater certainty if the observer also pays attention to the supernumerary bows which frequently appear on the inner side of the primary bow, and (1) notes the sequence of colours in them, and (2) states whether the bows are continuous with the primary bow and with one another.

Observation should also be made of the secondary bow which appears outside the primary bow at a distance of about 12° from it. This bow is of less importance, if the primary bow is visible.

Coloration of the Sky.—A cloudless sky appears to be blue, but it may show all possible gradations between a deep blue and a whitish-blue shade. It is desirable to note the gradations of colour according to the scheme; deep blue, light blue, and pale blue. Such observations give information regarding the purity of the air, and may also be used as indications of coming weather.

The most beautiful colours are seen at dusk. When the sky is cloudless, the colour and form of the first "purple light" is worth attention. It is approximately parabolic in shape and appears at a considerable elevation above the point where the sun disappeared soon after sunset.* It varies in colour between pink and violet. Observers are also invited to note the colouring of the western sky and the appearance of the "second purple light" which develops after the disappearance of the first. The time of disappearance of the second light is also of importance. If "Alpenglühén" and "after glow" are associated with the sunset, the phenomena should be noted.

The coloration of the clouds at sunset is often very beautiful and very striking, and is therefore frequently noted, although the phenomena observed when the sky is clear are more important.

AURORA.

Displays of Aurora seen in the higher latitudes of the great ocean highways do not exhibit the full luminous splendour which may be witnessed in more northern parallels, yet the meteor not infrequently appears in great brilliancy and grandeur; charming the beholder, and inspiring a feeling of wonder, if not of awe.

In the Meteorological Logs contributed by captains and officers of ships to the Meteorological Office numerous observations of the phenomenon have been recorded from time to time. The Meteorological Office, while inviting

* All these remarks apply also to sunrise but in the reverse order.

further contributions upon the subject, takes this opportunity of requesting observers to supplement their notices of Aurora with details as to the following points, to which scientific enquiry might be directed :—

- (1) The angular altitude of the summit of an arch.
- (2) The orientation of the arch or arches.
- (3) The lateral motion of the streamers, whether from right to left or left to right. Does the individual streamer move sideways, or do fresh streamers arise to one side of the former?
- (4) As a rule streamers are parallel to the dipping-needle; it should be noted if any streamers are curved.
- (5) Can stars be seen immediately under the base of streamers?
- (6) It should be noticed if the arches always move from north (magnetic) to south. And if so, whether it is by a motion southward of the individual streamers or by new streamers appearing to the south of the old ones.
- (7) The formation of corona by streamers should be carefully watched and noted.
- (8) Special notice should be taken of the behaviour of the compass when Aurora presents the appearance of a luminous curtain.

The precise way in which Aurora comes to exist is still a matter of dispute, but it is now almost universally believed to be an electrical phenomenon. Auroral light is supposed to be the visual effect accompanying the passage of electrical discharges of some kind through the earth's atmosphere. Auroral forms are difficult to classify owing to their great variety and the rapid changes they go through.

The chief types are :—

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

Arcs present themselves in many forms. The simplest consists of an approximately circular segment of uniform or nearly uniform light, whose lower ends may extend like those of a rainbow right down to the horizon. An arc may, however, be made up of brighter

and less bright narrow concentric arcs in juxtaposition; or it may consist of an innumerable number of short rays side by side, their lengths being in some cases approximately parallel to one another, in other cases radial, or nearly so, to the arc which they form. The arc is often elliptical or irregular in form, and there may be several arcs of different shapes visible simultaneously. In regular-shaped arcs the summit, or highest point above the horizon, is usually in or not far out of the observer's magnetic meridian—*i.e.*, the vertical plane in which the compass needle lies—the arc being directed roughly magnetic east and west. It is, however, not at all uncommon for the summit to be considerably out of the magnetic meridian, and in high latitudes the summit has been observed in almost every possible magnetic azimuth. The observer in noting the azimuth of the summit should always specify whether his directions are astronomical or magnetic. In measuring the altitude of the summit he should take the lower or concave edge of the arc, as this is usually much the better defined. It is not unusual for arcs to be in visible motion, rising from the horizon towards the zenith or receding from it; and it may be impossible to do more than note approximately the greatest and least altitudes attained.

When an arc extends right down to the horizon it is worth recording the number of degrees between the ends measured along the horizon. The sky immediately under the concave border of an arc often appears dark. It is somewhat doubtful whether this is merely an effect of contrast. The existence or non-existence of this 'dark segment' should be noted, and if it exists care should be taken to state whether stars can be seen through it.

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

Rays often occur in close juxtaposition, the combination going to form an arc or a band. But they also occur separately. They often extend from the upper or convex border of an arc towards the zenith. The apparent length of rays often alters very rapidly. The ray seems suddenly to dart towards the zenith and retire from it. This characteristic has led to the description of auroral phenomena as 'merry dancers.' What exactly happens it is impossible to say. Assuming aurora to be an electrical phenomenon, the total length of a particular line of electrical discharge may suddenly alter, or the length may remain unchanged, but the intensity of the current may suddenly increase so much as to render visible a portion of the discharge route previously invisible. In some cases rays group themselves into a sort of fan-shaped appearance. Sometimes there is a single large fan, made up of rays which may point towards a common centre, or may be more or less parallel; in other cases there may be several apparently independent fan-shaped bundles of rays.

Auroral Draperies or Curtains are one of the most impressive forms, but are seldom seen except in fairly high latitudes. The drapery may appear single or multiple, and the lower border may be nearly straight or very sinuous. These draperies seem often in rapid

motion, and observers in high latitudes have described the appearance seen as they approach and pass overhead. When directly overhead they are said to narrow to a streak, just as a vertical sheet of light would seem to do as one passed immediately under it.

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

Patches of Aurora often resemble the higher clouds, and it is sometimes doubtful whether what the observer is looking at is really aurora or merely illuminated cloud. Observers have asserted that what has been seen as cirrus before sunset, or in early twilight, has later been seen as a patch of aurora, and that what has appeared as a patch of aurora in the early morning has been seen as cirrus after dawn. It is thus desirable that observers should keep an eye on cloud forms at times of aurora, and make notes of any phenomena likely to throw light on the alleged connection between aurora and cirrus.

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

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

Spectroscopic examination of auroral light shows that the brighter part is made up of rays of definite wave length. The majority at least of these rays are identical with those seen when electrical discharges pass in tubes containing highly-rarefied atmospheric gases. One of the rays, which is especially characteristic of aurora, was for long rather a puzzle, as it differed from any of the rays given out by nitrogen, oxygen or hydrogen. It has, however, been identified by Sir W. Ramsay with a very bright ray given out by one of the new constituents of the atmosphere which he has discovered. Accurate measurements of the wave lengths of auroral light are of considerable interest, but they are difficult to make, even by trained physicists, owing to the comparative faintness of the light and the rapid changes usually in progress.

Intensity and Visibility of Auroral Light.—The intensity varies within wide limits. An aurora may be so faint as to be visible only to the keenest eyesight, and there may be electric discharges which would be visible as aurora to beings endowed with keener eyesight than man. In Arctic regions aurora is said to be sometimes so bright that it compares with full moon light as the electric light does with gas light. The estimate made of the brightness is often largely dependent on whether the moon is visible or not. It is thus important, when recording any estimate of brightness to describe the circumstances under which the observation was made. On moonless nights a statement that print of definite size can be read at a specified distance by a normal-sighted eye is probably the simplest way in which information can be conveyed.

Even the brightest aurora becomes invisible when the sun rises, and in fact aurora is seldom seen until the sun is at least 5° below the horizon. It is thus difficult to be certain as to the hour of the day at which are best developed the electric currents whose tracks are seen as aurora after sunset. But aurora, as an optical phenomenon, has been found at most stations where careful observations have been made—with the possible exception of some in Greenland and Northern Canada—to have its greatest development from one to three hours before midnight. In some cases aurora has been visible during the same 24 hours over a large part of one, if not both, hemispheres; but in such a case the brilliancy of the display at any particular place seems largely dependent on the local time.

Variations throughout the Year.—A complication arises from the action of sunlight. In high latitudes it is never dark in summer, and then aurora is invisible. Near the equator the length of the day is comparatively independent of the season, but aurora is a very rare occurrence in latitudes much under 40° . In most of Northern Europe, and in North America between 40° and 60° N. latitude, aurora is most frequent near the equinoxes. In higher latitudes the maxima of frequency near the equinoxes seem to disappear, being replaced by a single maximum of frequency near mid-winter. It is doubtful whether there is a real difference according to the latitude in the season of greatest frequency of the electrical phenomena to which aurora is due, or whether the apparent difference is not simply a matter of the different conditions of visibility.

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

At places to the south of the zone of maximum frequency aurora is usually seen in the north, but in very high northern latitudes it is usually seen in the south. In intermediate latitudes aurora is seen sometimes in the north, sometimes in the south. It is thus desirable to make it quite clear from which horizon the altitude of auroral arc is measured.

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

Variation from Year to Year.—Aurora is much more often seen in some years than others. There seems to be a fairly well marked 11-year period, coincident, or nearly so, with the sun-spot period. There seems no doubt that in temperate latitudes aurora are very decidedly more numerous in years of many than in years of few sun-spots. In Greenland and some other Arctic regions the connection between sun-spot and aurora frequency appears, however, to be different from that ordinarily observed elsewhere.

Connexion with Magnetic Storms.—A big auroral display in Great Britain or similar latitudes is always, or nearly always, accompanied by a big magnetic storm and large earth currents. The magnets at observatories are disturbed from their normal positions, and sometimes kept in nearly constant oscillation whilst telegraph wires are traversed by large currents which sometimes seriously interfere with the dispatch of messages for several hours on end. It is thus desirable during bright auroral displays to keep an eye on the compass, and to remember that deviations larger than 1° from the normal position are sometimes experienced during magnetic storms, even in the south of England. The amplitude of displacement of the compass needle during magnetic storms increases as we go north or approach the magnetic pole. Displacements of 4° or 5° , or even more, from the normal have been recorded in North America.

While, however, in moderate latitudes auroral displays are nearly always accompanied by a more than ordinarily disturbed state of the compass needle, this connexion is by no means so nearly invariable in higher latitudes, where aurora and magnetic disturbances are both much more common. Several observers have reported that in Arctic regions aurora frequently occurs without any special magnetic disturbance, and that there is no very clear connexion between the two phenomena unless the apparent movements of the aurora are exceptionally large and rapid, or the changes of brightness unusually great.

When auroral draperies are observed in motion, it is especially desirable to watch the compass needle, as several Danish observers in Greenland have observed motions on such occasions which are strongly suggestive of the passage of electric currents in a vertical direction in the space occupied by the drapery.

Height of Aurora.—Many attempts have been made to determine the height of aurora above the ground. Calculations have been made from simultaneous observations of the angular altitude of the summits of arcs obtained with theodolites at different stations. For various reasons none of the results can be accepted without some reserve. The calculated heights from observations in temperate latitudes have been mostly of the order of 100 miles, some have been considerably less, others very considerably more. In Arctic regions the heights calculated have frequently been a comparatively few miles; observers have even described aurora as visible below the summits of mountains of no very great altitude.

Sound.—It has been asserted by observers that during aurora in the Arctic a distinct sound is sometimes heard, resembling that produced when electricity is discharging from points, and this belief seems pretty widely distributed amongst the natives in these regions. Any trustworthy case of the kind would be of interest. To check the effects of imagination, co-operation is desirable between two observers, one closing his eyes and listening, the other noting whether any special optic effects occur when the former observer signals that he hears something.

Theories.—Aurora, as already stated, is now generally believed to be due to electric currents in the earth's atmosphere, but opinions differ widely as to what causes these currents. The following are amongst the best known recent theories :—

Hertzian Waves.—Nordmann supposes that Hertzian waves—*i.e.*, waves of the type first observed by Hertz, and now used in wireless telegraphy—are set up by electrical disturbances in the sun, travel through space to the earth's atmosphere, and there give origin to electric currents and thence aurora. These waves travel with the velocity of light.

Cathode Rays.—When electricity passes in a vessel nearly exhausted of air, a discharge known as cathode rays proceeds from the negative pole, or cathode. These rays travel in straight lines, unless deflected by a magnet, and cause bright phosphorescence when they fall upon glass. The cathode rays consist of very small ions, or carriers of negative electricity, which travel with a velocity which, in extreme cases, may approach that of light, but is usually considerably less. Professor Birkeland believes the ultimate cause of aurora to be cathode rays emanating from the sun. Employing a magnetic sphere enclosed in a vacuum vessel, to represent the earth, and sending electric discharges through the surrounding space, he has succeeded in producing a number of phenomena strikingly suggestive of many of the forms of actual aurora.

Repulsion of Light.—Many years ago the late Professor Clerk-Maxwell, of Cambridge, concluded on theoretical grounds that light proceeding from any luminous body must exert a repulsion on surrounding bodies, the action increasing enormously in importance as the body repelled is reduced in size, down at all events to a certain very low limit. In bodies of finite size the calculated repulsion is infinitesimal as compared to gravity, but of late years refined experiments have proved that it actually exists, and follows to all appearance the exact laws foretold by Maxwell.

The theory has been advanced by Arrhenius that negatively-charged particles, much bigger than ordinary ions, are driven away through the sun's atmosphere by this repulsion of light, travel through space, and cause aurora in the earth's atmosphere. The time taken to travel from the sun depends on the size and density of the particle. For the most likely size, Arrhenius has calculated the time as slightly under two days.

There are difficulties in the way of accepting any of the above theories, but there may be a good deal of truth in one or in all of them. There is no reason why electrical disturbances should not be propagated from the sun to the earth in more than one way. If Hertzian waves are the vehicle, the disturbance would reach the earth's atmosphere simultaneously with any light caused by the disturbance at the sun. Aurora being visible only after sunset, it is

clear that the electrical current in the earth's atmosphere, if originating in the sun, must be due to something which either travels much more slowly than light, or else produces, when it reaches the earth's atmosphere, some electrical condition which persists to a greater or less extent for a good many hours.

Our knowledge of electrical phenomena has been advancing very rapidly of late years, and it is by no means improbable that before many years have elapsed we shall have reached something like definite knowledge of the cause or causes to which aurora is due.

THE ZODIACAL LIGHT.

The Zodiacal Light is a soft faint light, usually white, which may be seen in the tropics on any clear night, rising cone shaped above the western horizon after sunset, and above the eastern horizon before sunrise; except when the moon is past her first quarter and has not waned to her last, when it is masked by the light from the satellite. Even in latitudes of the temperate zones it is visible after twilight, when the sky is sufficiently clear, on winter or spring evenings or just before daybreak in the summer or autumn. It cannot be seen on summer or autumn evenings in temperate latitudes of either hemisphere because it extends from the sun, and lies approximately in the plane of the ecliptic. Therefore the course of the latter, in north temperate latitudes being in the south-west, and in south temperate latitudes in the north-west, is, during these seasons, so near the horizon that the light is extinguished by the thickness of the atmosphere through which, in order to be visible, it would have to pass. Near the Equator, when weather conditions are favourable, the Light may be seen equally well in all months of the year, as the ecliptic in Equatorial regions is always well above the horizon.

Various explanations have been offered to account for the Zodiacal Light not one of which is wholly convincing, and the results of observations of its spectrum have been conflicting. Some astronomers have expressed the opinion that it is caused by a sort of lens shaped luminous appendage surrounding the sun; consisting, probably, of incandescent gas extending beyond the Earth's orbit, nearly in the plane of the ecliptic. More recent observations of the phenomenon have led to the belief that it is due to the reflection of solar light from a swarm of bodies, minute and possibly meteoric, which revolve about the sun, the attenuated edge of which extends beyond the orbit of our planet.

The nature of the matter from which the Zodiacal Light emanates has not in fact been discovered, and so little is known in other respects in regard to it that careful observations in suitable latitudes would be useful. By those who desire to contribute information in this connexion a keen watch should be kept between sunset and sunrise for the appearance of the Light, especially when in tropical latitudes; and the time and extent of its visibility noted.

It is confined for the most part within the limits of the Zodiac; and those who are familiar with the principal stars and the constellations should have no difficulty in describing, when seen, the place it occupies from time to time in the heavens: its breadth, extent and path; also its degree of brilliance, taking the light of the Milky Way, in definite positions, or that of well known nebulæ as criteria.

Associated with the Zodiacal Light is another phenomenon which has puzzled astronomers, to which has been applied the term *Gegenschein* from a German word, the meaning of which may be expressed in English as *counter-glow*.

It is a faint light which is seen in the sky after sunset exactly opposite the sun when that luminary is considerably below the horizon. It varies in distinctness but is, as a rule, so faint that even the light of the Milky Way suffices to drown it. When observed, its exact altitude should be measured and noted, the ship's position stated, also the apparent time at ship, as well as the mean time at Greenwich.

METEORS OR SHOOTING STARS.

During the night watches the seaman has many opportunities for obtaining useful observations of meteors or as they are commonly called *shooting stars*. He can probably recall having seen in the sky at times one of these visitors to our atmosphere so bright that it has illumined the whole heavens.

By those who watch for their appearance several meteors may, as a rule, be seen on a clear night in the course of an hour. Usually they occur singly, but occasionally they are seen in swarms and the display on such occasions is impressive. Less frequently the passage of a meteor is followed by a report similar to that accom-

panying the discharge of ordnance; and more rarely the aerolite is seen to fall to the earth.

Aerolites, as these meteoric visitors to our earth are called, have been subjected to crucial examination by chemists and mineralogists, and have been found to contain no new chemical element; but the combination of the elements of which they are composed differs from any known on earth, so that they must have their origin outside the earth.

It is known that in the regions of the universe, which we call *space*, countless minute bodies are constantly revolving about the sun in various orbits; and that as the earth moves around our luminary they frequently pass through the higher regions of our atmosphere and become luminous by friction. Heat is but a ~~form~~ of motion, as was proved by Lord Kelvin (then Sir William Thomson), who, by placing a thermometer in front of a swiftly moving body, found that the mercury of the instrument rose one degree when passing through the air at the rate of 125 feet per second. At higher velocities he found that the increase of temperature was larger, being in proportion to the square of the velocity.

The so-called *shooting star*, then, as has been shown, is merely an incandescent aerolite.

Observations of ordinary meteors, although of interest, are not as a rule of scientific value; it is otherwise as regards those that form part of the meteoric showers that occur at certain periods. The most remarkable of these recur in November and are called *Leonids*, because their *radiant point* is in the constellation of *Leo*. The radiant point is that position in the heavens at which the meteors of a shower would be found to meet if their apparent paths were drawn on a celestial globe, and continued backwards. It is the radiant point of the meteors that an observer should endeavour to ascertain; but failing that he might trace their paths among the stars by the luminous streaks they leave in their wake.

Professor Adams, the famous mathematician and astronomer, found by an elaborate calculation that the November meteoric showers are due to the earth's encounter with a swarm of particles which follow Tempel's comet in its orbit. This comet was first seen, as a faint telescopic object, by an astronomer named Tempel, at Marseilles in December, 1865.

The *Perseids*, which derive their name from the constellation *Perseus*, in which their radiant point is situ-

ated. belong to another well known meteoric shower, and may be looked for in August.

It has been remarked by an eminent authority upon the subject of meteorites, Mr. W. F. Denning, that the direction of the air currents at an altitude of ten to fifteen miles, which by balloon ascents has been found to be towards the east or south-east, accords exactly with that of the majority of meteoric trains at fifty and sixty miles above the earth's surface.

COMETS.

Observations of Comets, to be of any value, should include angular distances, measured with a sextant, between the comet and at least two but preferably three stars of the first or second magnitude; the respective names of which should, of course, be stated. The position of the ship at the time of observation, referred to the Greenwich meridian, should also be entered.

CORPOSANTS OR ST. ELMO'S FIRES.

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

PART III.

CHAPTER V.

Instructions for keeping the Original Note Book, the Meteorological Logs and the Meteorological Registers.

To make the following Instructions as clear as possible they commence with the introductory pages of the Meteorological Log in their order, and then deal in the same way with the columns of the Form of Log, which are numbered from left to right at the bottom of each page. It will be seen that each column of the Original Note Book bears the number of that in the Meteorological Log which contains the same observations.

PARTICULARS RESPECTING SHIP, CAPTAIN, KEEPER OF LOG, AND BEAUFORT'S NOTATIONS FOR WIND FORCE AND WEATHER; ALSO SEA DISTURBANCE.

The upper part of this page should be filled in by the observer. Beaufort's notations explain themselves; they save a certain amount of writing and help to ensure uniformity. They are alluded to again on pages 46, 51, and 83.

FORM OF LOG.

The Specimen Sheet of Log shows four days correctly filled up; it is given for the guidance of new observers.

The columns will be remarked upon in the order of their numbers. They are similarly numbered in the Original Note Book, so that the remarks will refer to either book. It is advisable to take the space of the first day in each Log and Original Note Book for the remarks on the correction to be applied to the direction of the wind, cloud, sea, &c., and the position of the barometer and thermometers, &c., as in the specimen pages of Log and Original Note Book.

COLUMNS 1 AND 2.—DAY AND HOUR.

The name of the month may be written, or its number given in Roman numerals, as shown in Specimen Sheet of Log.

The day is reckoned in civil time, commencing at midnight; the hour in apparent time at ship. The day of the month should be entered as in Specimen Sheet of Log. The Log Book is ruled for an observation every fourth

hour, which on all ordinary circumstances is sufficient; during hurricanes or other exceptional weather, the space of two or more days may be taken for one if required. It is very desirable that observations should be entered for all the four-hourly periods, since the regular omission of any one such period renders it impossible to utilize the others for certain discussions, though an occasional omission is of little importance.

The Original Note Books are also ruled for four-hourly observations, but two-hourly lines are given for the winds. If the observer wishes to record observations for every two hours, he must take two days of the Original Note Book for one day's observations, and alter the hours accordingly.

Copying from the Original Note Book into the Log will be made easier if the four days from one opening of the Original Note Book be copied into one opening of the Log.

COLUMNS 3, 4, 5, AND 6.—LATITUDE, LONGITUDE, AND CURRENT.

The ship's position at noon, and oftener when convenient, both by observation and dead reckoning is required. When near land the position by cross-bearings should be recorded every four hours. It is hoped that the Captain will himself calculate the Current each day, as no one can decide so well as he can, as to whether the positions are sufficiently trustworthy for the purpose; if they are not trustworthy, the fact should be recorded in the space where the current would otherwise be entered. If he can estimate the current more frequently than each 24 hours, it should be recorded in the Remarks Column, No. 25.

COLUMNS 7 AND 8.—TRUE COURSE AND DISTANCE BY LOG.

In discussing the observations the position is made out for every four hours, but as very few observers give the latitude and longitude so frequently, the course and distance between each set of Meteorological Observations will give much more correct results than can be arrived at by interpolating between the noon positions.

COLUMN 9.—TOTAL COMPASS ERROR.

This column is for recording the Variation and Deviation combined. The compass error required is that of the

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compass by which the directions of wind, clouds, &c., are ascertained. For the purposes of Meteorology the true direction of the wind, clouds, &c., is required, so that if this is not the direction given in the log the observer must give the total compass error, or the data for finding it, on each course, so that the true direction of each observation can be deduced.

COLUMN 10.—SHIP'S HEAD BY THE SAME COMPASS AS THE WIND.

The direction of the ship's head is needed with each record of the wind *in those logs in which the wind's true direction is not entered.*

COLUMN 11.—DIRECTION OF WIND.

The direction of the wind should be given to the nearest point. An entry should be made at the commencement of the Log, stating whether the direction recorded is referable to the true meridian, or subject to total compass error, or to variation only. The apparent direction of the wind, as shewn by a vane on board of a vessel moving through the water, will be the true direction only when the wind is either right ahead or right astern, especially in fast steamers; but experienced seamen can generally estimate the true direction by watching the direction from which the wave tops or the lowest clouds move. This observation is asked for at the time of observing, and not an estimate of the direction since the last observation. If, however, a squall is blowing at the time of observing, the direction and force which existed before the squall should be entered in the Direction and Force columns. It is particularly requested that the direction, force, and duration of squalls, with any other important remark respecting them, such as how the wind changed during the squall, &c., be entered in the Remarks, and if these changes are too numerous, that their general character be noted. It is also of consequence that the exact time of any important change in direction or force of wind should be recorded in Column 24.

COLUMN 12.—FORCE OF WIND.

The force of wind must be estimated according to the Beaufort's scale (new specification) given on pp. 48 and 49.

**COLUMNS 13 AND 14.—BAROMETER AND ITS ATTACHED
THERMOMETER.**

Next to the direction and force of wind, the readings of the barometer are most important. Unfortunately they are not always carefully taken in fine weather, though to the meteorologist they are just as important then as when the weather is unsettled. Occasional readings of the ship's barometer should be noted in the log, more especially at times of high and low readings. A mercurial barometer is preferred, but if the ship's instrument is an aneroid its readings should be recorded at least once in every 24 hours. By doing this, a table of corrections for the ship's barometer or aneroid can be deduced, and observations of the instrument will become very valuable if the barometer lent by the Meteorological Office should get out of order.

The number of the instrument and the height of its cistern (or lower end) above the sea level (at least at the beginning and end of each passage) must be entered in the upper part of the column, and any change in its position or in the height of the cistern should be recorded in the Remarks Column; of course, the height of the cistern is affected by a change in the ship's draught of water. Captains are also requested to state in the column for Remarks whether their barometers "pump" much, *i.e.*, whether the quicksilver rises and falls when the ship has much motion, so as to prevent their getting a correct reading, and to state how much they pump. In such cases the reading entered in the Register should be the lowest point of the oscillation. The attached thermometer must always be read and recorded before the barometer is read.

Special care is necessary with barometer observations in tropical regions as the natural fluctuations of pressure are so small there, that they are easily lost in errors of reading.

**COLUMNS 15 AND 16.—DRY AND WET BULB
THERMOMETERS.**

The numbers of the instruments in use should be entered at the heads of the columns, and every change of instrument during the voyage should be recorded in the "Remarks" Column. At the commencement of the voyage the position of the screen containing these instruments should be plainly stated, and any changes in its position and surroundings recorded. The thermometers

should be read to tenths of a degree, which are easily estimated by the eye. Readings below zero should be preceded by the minus sign, thus, -15° ; the minus sign must be repeated with each observation that is below zero.

COLUMN 17.—CLOUDS.

Column 17 is devoted to the names of the clouds. The direction from which the *lower clouds* come is not needed, unless it differs much from that of the wind, in which case a special entry should be made in the Remarks. Figures to indicate their apparent speed might be adopted, such as (0) stationary, (1) slow, (2) moderate, (3) fast.

The direction *from* which the *upper clouds* are moving should be recorded. It is an observation which is of exceptional value but it is exceptionally difficult. The relative motion of clouds past other clouds, or any movable object, is so deceptive that the apparent motion should not be recorded.* The apparent speed of an upper cloud might be represented by a figure following the direction from which it is moving, thus (0) stationary, (1) slow, (2) moderate, (3) fast. Example, $\overset{\text{Ci.}}{\text{N.W.}}$ (1); which means that Ci. was coming slowly from N.W.

It is particularly requested that the contractions which are given on pages 79 to 81 should always be used, as any other contractions are liable to mislead. It adds to the certainty of what is meant if the Observer separates the abbreviated name of one cloud from that of the next by a vertical line, as shown in Specimen Sheet of a Log.

COLUMN 18.—AMOUNT OF CLOUD.

Proportion of sky clouded, or amount of cloud. It is represented by figures, 0 meaning "No clouds," and 10 "Completely clouded." When there is a large amount of any particular form of upper cloud the fact may be recorded in the Remarks.

COLUMN 19.—WEATHER.

The weather reported should be that which exists at the time of observation, and not an estimate of what has been

* The only means of obtaining an accurate result is by localising a distinctive cloud, by a vertical sextant angle, and compass bearing; repeating the process after a lapse of at least ten minutes; but if possible a longer period.

Insert on p. 105.

Column 12. Weather. The column is only to be used for weather at the time of observation. The direction of rain, hail, snow or fog should be entered into the REMARKS column.

Column 19a. Fog intensity and Visibility. The appropriate figure should be entered into this column adding 'V' for visibility or 'f' for fog intensity. Neglect of this precaution may lead to confusion in using the observation.

since the last observation; except in the case of fog, rain, snow, or hail, when their initial letters should be preceded by a figure showing the number of hours that they have lasted during the time elapsed since the previous observation.

Any important facts respecting the weather which cannot be shown in Column 19 should appear in the Remarks, such as the kind of lightning, with the direction in which it is seen, or the accompanying thunder heard; also the direction, duration, and force of squalls, with any veering or backing of wind with which a squall may be associated. When squalls are numerous their general character should be explained in the Remarks. The occurrence of Sleet, and Soft Hail or "Graupel" should also be recorded in the Remarks. When haze or mist does not seem to be the result of moisture, but to be caused by dust, or in some other way, the fact should be noted.

Some observers have been led into the mistake of using d where they should use w for dew.

h " " " m " haze or mist.

s " " " p " showers.

s " " " q " squalls.

It therefore seems well to remark that when the first letter of a word has already been appropriated, another has been taken. In the case of showers p alludes to their passing or temporary nature.

COLUMN 19A.—FOG INTENSITY.

The intensity of fog observed should be estimated by means of the criteria and scale given on page 83, and the appropriate number should be entered in this column.

COLUMNS 20 AND 20A.—DIRECTION FROM WHICH WAVES OR SWELL ARE MOVING.

This should be given by the same compass as the direction of the wind. If, besides the waves produced by the existing wind, there are swells from other quarters, they should also be noted in the columns allotted. In cases where the columns will not contain the important facts relating to the sea, they should be entered in the Remarks. The direction of the waves is usually only given in general terms, such as Wly., S.Wly., &c.

COLUMNS 21 AND 21A.—DISTURBANCE OF SEA.

This should be expressed by figures 0 to 10, according to the scale given on page 51.

COLUMN 22.—SURFACE TEMPERATURE OF THE SEA.

The number of the thermometer in use must be entered at the head of the column, and any change during the voyage should also be recorded in the Remarks. The water must be drawn in a bucket direct from the sea, not pumped; and in steamers it should be drawn forward of the ejection pipe. A canvas bucket should be used, and the thermometer should be immersed for three minutes; it should then be read directly after it is taken out of the bucket whilst the bulb is still in the water held in its metal case. The reading should be taken to tenths of a degree.

COLUMN 23.—SPECIFIC GRAVITY OF SEA SURFACE.

It is a rather difficult observation when the ship has much motion, or the surface of the water in the bucket is exposed to much wind. A large well-filled bucket answers the purpose well, and the hydrometer should be slightly spun in the centre; it soon loses all up and down motion, and the scale can be read before the turning motion has entirely ceased. The water for trying the specific gravity should also be drawn over the side in a bucket, and its temperature taken and recorded at the same time as the specific gravity is obtained.

The hydrometers supplied by the Meteorological Office are of glass; they should be perfectly clean and dry before use. The number of the instrument in use should be recorded at the head of the column, and any change during the voyage should be noticed in the Remarks.

Observers are not expected to give the specific gravity of the sea more than once a day (at noon), except when in the neighbourhood of current ripples, on each side of lines of foam, &c., &c. In cases of extreme motion it is better to omit the observation than to give a doubtful one.

COLUMN 24.—TIME OF REMARK.

As it is impossible to confine each remark to the line of the hour to which it refers, the time relating to each remark should be written before it, for which purpose this column is given. The time is very important in the case of a change in direction or force of wind, and, by stating the hour when a ship arrives in or leaves port, the positions of the four-hourly observations can be calculated. Both of these entries add much to the value of a log.

COLUMN 25.—REMARKS.

This column should contain any important facts which cannot be recorded in the other columns, even though they may not at first sight appear to be related to Meteorology.

They should include :

The direction from which upper clouds are moving, also the direction from which the lower clouds come when they do not move with the wind, stating whether they move fast or slow, also anything very remarkable in the position or appearance of clouds.

Extra observations of the barometer, wind, &c., during tropical revolving storms, or other exceptional weather, carefully stating the hour. In such cases the space of several days may be taken for one, and, if thought requisite, the Remarks may extend across the whole Log.

The description of Lightning and its bearing. The appearance of Corposants, their position and duration, whether they flit about or remain steady; Aurora, Zodiacal Light; Meteors, remarking whether they all come from, or go to, one part of the heavens; what is that part of the heavens; whether they usually leave trails behind them, what is their usual brightness (as compared with that of known stars); and any other remarks which may be suggested by their appearance.

Waterspouts and any facts connected with their formation, rotation, track as related to the wind, and disappearance. Temperature of rain just fallen, and that of the air by the dry bulb at the same time, making sure that the bulb is dry.

Halos, Red Fog, Dust, Submarine Earthquakes.

Tide Ripples, Discoloured or Luminous parts of the sea, Ice, Seaweed, Drift Wood, Wreckage, Derelicts, &c., &c.

Land or Sea Birds, Insects, or other creatures of land or sea, and the direction towards which they are travelling. For instance, Whales, Black Fish, Porpoises, &c.; also fish, such as Albacores, Bonitos, Dolphins, Flying Fish, Sharks, and especially shoals of Herrings, Mackerel, Pilchards, &c., giving the temperature of the sea they are in.

Well-confirmed Hydrographical Notes, such as bearings, soundings, &c., which are omitted from, or do not agree with the latest Admiralty charts. The

times of high water on full and change days, and amount of rise and fall, direction of tides and currents, &c., when they are not already known.

A simple plan for preserving any organisms, animal or vegetable, is to not more than half-fill the bottle containing the bodies with sea-water, and it should then be filled up with whatever spirit is convenient. This will kill the organisms, and sufficiently preserve them until they can be properly examined.

Photographs of meteorological phenomena of any kind are specially invited.

Navigators who have much experience of particular routes are requested to devote a few pages at the end of the log to remarks on wind, weather, currents, tides, best routes at the various seasons of the year, &c., &c.

RAIN.

The rain gauge should be lowered to the deck at 8 a.m. each day, whatever weather conditions may have prevailed during the previous twenty-four hours.

The water collected in the can provided for the purpose should be carefully poured into the graduated measuring glass, and the amount measured entered in the Remarks column. In the event of the can overflowing, the overflow should be measured and included in this amount.

In reading, the bottom of the meniscus or curved surface of the water, should be accepted at the true height of its column; and in order to avoid errors arising from parallax, care should be taken to hold the measuring glass so as to bring the meniscus on a level with the eyes.

When spraying has occurred since the previous observation, the water collected should be tasted, and if found to be brackish a remark to that effect should be noted.

The measuring glass must be kept scrupulously clean. When snow has been collected or when the rain in the gauge is frozen, a measured quantity of hot water should be added, and when the snow or ice has melted, and the contents of the gauge has been measured, the amount less the quantity added, should be registered as the catch.

WET AIR WITHOUT RAIN.

When moisture emanating from a humid atmosphere, which includes fog, has been collected, the amount should be measured, registered, and a note added intimating that the precipitation took the form of 'c.'

Meteorological Log kept on board a *P. & O. Steamship.*

Captain _____ from *London* to *Australia.*

DATE.		Latitude.		Longitude.		Course and Distance.		Total Compass Error.	Ship's Head.	Wind, at the time of observation.		Barometer.* No. 12		Thermometers.			
Year 1915.		Observed.	Dead Reckoning.	Observed.	Dead Reckoning.	Each four hours.		Of Compass used for Wind, being Variation and Deviation combined.	By same Compass as Wind.	Direction. State if true, or subject to Compass Error, or only to Variation.	Force 0 to 12.	Height of Cistern above Sea 42 feet.		Dry Bulb.	Wet Bulb.		
Month II.						True Course.	Distance by Log.					Uncorrected Reading. Mb.				Att. Therm. Absolute Scale.	
Day. Civil Time.	Hour.	The D.R. position is needed daily, in addition to that by Observation, but it should be the result of careful calculation, in order to give any value to the estimation of the current.															
14																	
	4					All Bearings, Courses, Directions of Wind, Sea, Swell, Currents, etc.. given TRUE throughout ;											
	8					except Ship's Head, Ship's Barometer Mercury, B.T. Pattern, in Commander's Cabin											
	NOON	{ At Anchor off Tilbury. }				8 ft. below M.O. Bar. Readings given daily at Noon. In Inches, for comparison.											
	4	{ Current in last hours mls. }				Various	—		—	N.W.	4	979.0	279	39.6	36.8		
	8					by	—	15° W.	—	W.N.W.	5	985.9	278	39.7	36.3		
	MIDT.					Pilot's	—	16°	—	N.W.	6	993.3	278	40.5	37.5		
15																	
	4					Orders.	—	16½°	250°	N.W. by W.	5	998.5	277	38.3	36.0		
	8					238°	48		254°	W.N.W.	5	1004.5	280	42.5	39.5		
	NOON	{ 49 39 N. 3 22 W. }				238°	48		254°	W.N.W.	4-5	1009.2 (29.81)	284	45.0	40.4		
	4	{ Current in last 24 hours Tidal streams ms. }				236°	48		252°	N.W. by W.	5	1013.6	285	46.8	42.0		
	8					236°	48		252°	N.W.	4	1016.7	283	46.2	42.7		
	MIDT.					208°	48	17°	225°	W.	2	1019.8	282	47.0	3.2		

Hour.	Clouds.		Weather.		Sea Surface.					Remarks.		
	The direction from which the upper clouds are moving, and also that of the lower clouds when they do not move with the wind, should be noted when determinable.		According to Beaufort Notation.	Fog Intensity. 0 to 5	Waves.		Swell.		Temp. by No.			Spec. Grav. by No.
	Names.				Direction from.	Disturbance. 0 to 10	Direction from.	Disturbance. 0 to 10				
	Upper.	Lower.								Also record when Confused.				1431	70
Here give any important Remarks as to phenomena, with the times of their occurrence; especially the times of Changes in Direction and Force of Wind, as well as the Direction, Veering or Backing, Force and Duration of Squalls; the direction from which upper clouds are moving; the Position of Ice and of Derelicts. Also note the hour at which the Ship arrives in or leaves Port. (See "Marine Observer's Handbook" for further particulars.)												
4	Attached Thermometer is read in Absolute Scale.											
8	(Rain Gauge emptied and readings observed at 8 a.m. daily. Height above sea 90 feet.											
NOON	NOON Instruments placed in position.											
4	Cu. | St.	9	o		N.W.	2	—	0	38'0	0'35	Hove up and proceeded from Tilbury. Fresh breezes, cloudy. Bar rising rapidly.	
8	Ci.-Cu.	St.	8	c		W.N.W.	2	S.S.W.	2	42'0		
MIDT.	St.-Cu.	8	cp		N.W.	4	S.W.	2	43'6	10'0	Some passing squalls with little rain. MID. Short choppy sea; horizon clear.	
4		St.-Cu.	8	cp		N.W. by W.	4	W.S.W.	3	41'8	3'0	Stopped off Nab light. Pilot left.
8	Ci.	St.-Cu.	5	cb		W.N.W.	5	W.S.W.	3	46'0	6'0	Sky clearing. Rainfall by Gauge 0.6 mm.
NOON	Ci.	Cu. St.-Cu.	6	cb		W.N.W.	5	W.S.W.	3	47'7	28	NOON Fresh breeze.
4	Ci.	Cu.	4	bc		N.W. by W.	4	W.	4	47'5		
8	Ci.	Cu.	3	b		N.W.	3	W.	4	48'0	8'20	Ushant Lt. 146°, 19 m. Wind backing to W., falling light. St. slowly from W.S.W.
MIDT.		St.-Cu.	3	b		W.	1	W.S.W.	4	48'6	MID.	Stars very brilliant.

1909.

MONTH.		TOTAL COMPASS ERROR.	WIND.		BAROMETER. M.O. 1070.		TEMP. OF AIR. Ther. No. 8100.	WEATHER.	SEA SURFACE.				TEMP.
XI.			Direction. By Compass.	Force. 0 to 12.	Uncorrected Reading.	Att. Ther.			WAVES.		SWELL.		
CIVIL TIME.									Direction From. By Compass.	Distur- bance. 0 to 10.	Direction From. By Compass.	Distur- bance. 0 to 10.	
Day.	Hour.												
27th	Noon												
	Midt.												
28th	Noon	8° E.	E. by S.	3	1014.0	302	85	bc	E. by S.	2	S.E.	2	82
	Midt.		E.S.E.	4			79.5	bc	E.S.E.	4	S.E.	4	81
29th	Noon	9° E.	E. by N.	3	1014.0	302	86.8	bc	E. by N.	2	E.S.E.	3	81
	Midt.		E.N.E.	3			79.3	bc	E.N.E.	2	E.	3	80
30th	Noon	9° E.	E. by S.	3	1015.7	302	80.8	cb	E. by S.	3	E.S.E.	3	79
	Midt.		E.	5			76.3	bc	E.	4	N.E. } S.E. }	4	78
XII.													
1st	Noon	10° E.	E.N.E.	4	1017.7	302	79.5	bc	E.N.E.	3	N.E. by E.	3	78
	Midt.		N.E.	4			79.5	bc	N.E.	2	N.E.	2	—
2nd	Noon	10° E.	N.N.E.	3	1018.4	300	79.5	cb	N.N.E.	2	Confused N.W., S.E., N.E.	3	79.5
	Midt.		—	—									
3rd	Noon	10° E.	Calm.	0									
	Midt.		W.N.W.	4				or					
4th	4 8 Noon	a.m. a.m. 9° E.	N.W. N. N.E.	4 4 4	1005.9	300	83	bv	N.N.E.	3	—	0	75.5
	4 Midt.	p.m.	S.E.	6									

13447

NOON.		REMARKS.
Lat. S.	Long. E.	
Obs.	At	
D.R.	D.R.	
Obs.	Obs.	
D.R.	D.R.	2.30 p.m. Left Aola Bay.
Current in	Guadalcanar. Hours.	6 to 7 p.m. Rounded E. end of Guadalcanar. Observed an almost total eclipse of moon.
..... Miles.		Moderate Ely. winds, cloudy, passing showers.
Obs. ....12... 3...	Obs. 159...40...	8 a.m. 2 m. W. of Rennell Isle.
D.R. ....12... 4...	D.R. 159...41...	Current between Guadalcanar and Rennell Isle, <u>E.N.E. 10 miles in 10 hours.</u>
Current in	Hours.	
..... Miles.		Brilliant weather.
Obs. ....15...10...	Obs. 158...25...	
D.R. ....15...12...	D.R. 158...37...	Brilliant weather.
Current in	24..... Hours.	
.....N. 80 W.....	11... Miles.	Fine, clear weather.
Obs. ....18...16...	Obs. 157...13...	2 to 4 a.m. Ci.-Cu. moving slowly from W.S.W.
D.R. ....18...14...	D.R. 157...11...	8 a.m.—Noon. Sky becoming overcast with Ci.-St.
Current in	24..... Hours.	From Noon, 29th, until 5 a.m., as shown by good stellar observations, current was <u>E.S.E. 5 miles in 17</u>
.....S.E.....	3... Miles.	<u>hours</u> : thence to Noon, westerly.
Obs. ....21...43...	Obs. 155...43...	9.15 a.m. Passed 3 miles E. of Obsery. Cay, Kenn Reef.
D.R. —.....	D.R. —.....	Current from Noon to 9.30 a.m. (21½ hours), S. 52° W., 26 miles.
Current in	Hours.	3.30 p.m. Passed ¾ mile E. of Wreck Reef. Current from Kenn to Wreck Reef, <u>S. 66° W. 7 miles in</u>
..... Miles.		<u>5½ hours.</u>
Obs. ....25...13...	Obs. 154...11...	2.30 a.m. Heavy rain squalls for half an hour. Wind E.N.E. to N.N.E., 3.
D.R. ....24...59...	D.R. 154...27...	10 a.m. Heavy rain squall for ¾ hour.
Current in	last 20½... Hours.	9 to 11 a.m. Wind very variable N.E., N., N.W., force 4 to 2.
..... S. 49 W.....	21... Miles.	2 to 4 p.m. Variable light breezes and calms.
		9 to 10 p.m. Heavy rain. Midt. Arrived at Moreton Bay.
Obs.	Obs.	
D.R.	D.R.	Noon. Left Brisbane for Sydney. Calm; fine.
Current in	Hours.	3 p.m. Cleared Cape Moreton.
..... Miles.		6 p.m. to Midt. Rain; wind W.N.W., 4.
Obs.	Obs.	2 a.m. Off Cape Byron. Rain cleared.
D.R.	D.R.	
Current in	Hours.	2 p.m. Off Smoky Cape. Light N.E. breeze. Weather b.v.
..... Miles.		3.30 p.m. Wind veered to S.E. rapidly freshened to force 6.

METEOROLOGICAL OFFICE, LONDON.

MONTHLY METEOROLOGICAL CHARTS OF THE NORTH ATLANTIC & MEDITERRANEAN.

In order that the latest information of value to Navigators may be inserted in the monthly issues or in the supplementary weekly editions of the Meteorological Chart of the North Atlantic and Mediterranean, Commanders are strongly urged to supply, with the Meteorological Observations, recent particulars of the position of ice, or other matters, on this Form, and to forward it by post at the earliest opportunity. Postage need not be prepaid in the case of forms posted in the United Kingdom or a British Colony.

Steamship

Captain

METEOROLOGICAL OBSERVATIONS.

Year 1914.			Ship's Position.		Current in 24 hours Dir ^m . Rate.	Temp. Sea Surface.	Total Com- pass Error.	Wind.		Barometer.		Pressure Sea Level in mb.*	Thermometers.		Weather.	Fog 0 to 5.	Sea Disturb- ance 0 to 10.	REMARKS. Information relating to duration of Rain, Hail, Snow, and Sleet is especially valued.
Month.	Day.	Hour.	Latitude. N.	Longitude. W.				Direction by Compass.	Force 0 to 12.	Uncorrected Reading.	Att. Ther.		Temp. of Air.	Temp. of Wet Bulb.				
February	25	8 a.m. 8 p.m.	51 27 50 14	7 49 10 32	Noon. —	44 51	18 W. 20 W.	N.N.W. W.S.W.	3 5	1011.0 1012.5	286 285		45 49	43 44	bc c	0 0	2 5	MILLIBAR BAROMETER.
"	26	8 a.m. 8 p.m.	49 4 47 57	13 5 15 36	Noon. —	52 54	20 W. 20 W.	S.W. W.S.W.	5 6	1006.9 1014.7	287 287		51 54	50 52.5	ogr ofe	0 3	5 6	1.30 a.m. Came in continuous light to moderate rain.
"	27	8 a.m. 8 p.m.	46 49 45 48	18 1 20 12	Noon. —	55 54	22 W. 24 W.	S.W. S.W.	6 6	1014.5 1015.3	289 291		55 55	53 52	o bc	0 0	6 6	Noon-4 p.m. Showers of light misty rain, 10-20 min. duration.
"	28	8 a.m. 8 p.m.	44 46 43 36	22 14 24 29	Noon. —	54 55	25 W. 25 W.	W.N.W. W.N.W.	7 5	1019.8 1031.5	289 287		52 54	47 50	b o	0 0	7 6	Occasional squalls, force 8.
March	1	8 a.m. 8 p.m.	42 22 41 9	26 50 29 13	Noon. S. 58° W. 10	56 57	26 W. 25 W.	N.N.W. S.E.	2 4	1034.2 1032.7	289 287		57 56	51 52	b b	0 0	2 4	
"	2	8 a.m. 8 p.m.	39 59 38 49	31 37 33 47	Noon. N. 38° W. 13	58 61	25 W. 24 W.	S. x E. S. x E.	7 7	1028.4 1025.6	289 290		58.5 60	55.5 58	o oge	0 0	6 6	7.45 a.m. Sighted Corvo Is. bearing S. 50 E., 19 m.
"	3	8 a.m. 8 p.m.	37 41 36 27	35 49 37 56	Noon. N. 52° E. 7	63 64	24 W. 23 W.	S.W. S.S.W.	3 4	30.34 30.42	63 67		61.5 63	61 61	odm cb	2 0	5 5	INCH BAROMETER.
"	4	8 a.m. 8 p.m.	35 10 33 59	40 6 42 11	Noon. Nil.	64 65	23 W. 20 W.	S.S.W. S.S.W.	5 6	30.31 30.28	65 67		64 65	62 63	c cge	0 0	5 6	Heavy dew throughout night.
"	5	8 a.m. 8 p.m.	32 49 31 31	44 13 46 14	Noon. —	67 67	20 W. 18 W.	S.S.W. N.W.	6 3	30.27 30.26	68 69		66 67	65 64	oge c	0 0	5 3	
"	6	8 a.m. 8 p.m.	30 7 28 43	48 15 50 29	Noon. —	67 69	18 W. 17 W.	N.N.W. N. x W.	2 2	30.26 30.36	69 69		68 67	63.5 63	bc c	0 0	2 2	Passing small patches of Gulf weed.
"	7	8 a.m. 8 p.m.	27 17 25 56	52 49 55 9	Noon. N. 78° W. 5	70 72	17 W. 14 W.	N. x W. E.	2 3	30.36 30.26	71 72		70 71	63 65	bc cb	0 0	2 3	Passing large quantities of Gulf weed. Halo round moon.
"	8	8 a.m. 8 p.m.	24 37 23 14	57 28 59 42	Noon. N. 20	71 75	13 W. 9 W.	E.S.E. E.S.E.	3 4	30.33 30.32	72 75		72 75	65 68	c b	0 0	3 3	
"	9	8 a.m. 8 p.m.	21 49 20 29	61 53 64 3	Noon. N. 54° E. 13	75 77	7 W. 5 W.	E.S.E. E	3 3	30.29 30.30	76 78		76 77	71.5 73	bc cp	0 0	3 3	

REPORT UPON THE POSITION OF ICE, &c.

Approximate positions of ice observed.

Date.	When first seen.		When last seen.		REMARKS. (If field ice is observed, give estimate of its extent.)
	Latitude.	Longitude.	Latitude.	Longitude.	

* For the correction and reduction of readings to Sea Level and for conversion tables to millibars, see *Marine Observer's Handbook*, Chapter I.

OBSERVATIONS OF VISIBILITY AT SEA.*

Date.	Light or Headland (if the former not the glare).	Height of eye above sea level.	Time and True bearing when first seen.	Time and True bearing when nearest.	Distance when first seen.	Distance when nearest.	Range of visibility.	Weather of Beaufort Notation.	Remarks.

Millibar Barometer—Standard Temperature 285.3a. @ 1000 mb.

* These observations are needed for use in the construction of a table of visibility for reference on board H.M. Ships.

Barometer, Mercury or Aneroid—Mercury { Too high — }
 Error? { Too low .005 } at 30.0 ins. When and where last compared? London, Dec. 1912. Height above Sea Level, 35 ft.
 Maker of instrument and No. (if any) 122 Adie

Signature of Observer _____ Rank _____

METEOROLOGICAL OFFICE, LONDON.

MONTHLY METEOROLOGICAL CHARTS OF THE INDIAN OCEAN.

In order that the latest information of Value to Navigators may be inserted in each monthly issue of the Meteorological Chart of the Indian Ocean Commanders are strongly urged to supply recent particulars of all matters that may be considered of use in the compilation of the Chart, on this Form, and to forward it by post at the earliest opportunity. Postage need not be prepaid in the case of forms posted in the United Kingdom or a British Colony.

Steamship

Captain

METEOROLOGICAL OBSERVATIONS.

Year 1914.			Ship's Position.		Current in 24 hours Dir ⁿ . Rate.	Temp. of Sea Surface.	Total Com- pass Error.	Wind.		Barometer.		Thermometers.		Weather.	Fog 0 to 5.	Sea Disturb. ance. 0 to 10.	REMARKS. Information relating to duration of Rain, Hail, &c., is especially valued.
Month.	Day.	Hour.	Latitude. N.	Longitude. E.				Direction by Compass.	Force 0 to 12.	Uncorrected Reading.	Att. Ther.	Temp. of Air.	Temp. of Wet Bulb.				
March	18th.	8 a.m. 8 p.m.	Rangoon River		Noon.	81·2	1° E.	S.S.W.	3	30·181	84·3	82·8	79·4	bcl	0	1	8.15 p.m. Left Pilot Station.
"	19th.	8 a.m. 8 p.m.	14 34 13 9	93 58 91 41	Noon.	80·4 80·9	3° E.	N.N.E. "	3 3	30·209 30·149	80·8 82·3	80·7 81·0	77·7 75·7	bc b	0 0	1 2	
"	20th.	8 a.m. 8 p.m.	11 32 10 0	89 15 87 4	Noon. Nil.	81·3 83·0	2° E.	" N.E. by E.	2 4	30·139 30·074	82·7 85·3	83·6 83·8	76·2 78·5	bc bcl	0 0	2 3	Lightning to Southward.
"	21st.	8 a.m. 8 p.m.	8 29 6 39	84 37 82 18	Noon. N. 32° W. 8	83·0 83·3	2° E.	N.E. E.S.E.	2 1	30·069 30·039	83·9 84·1	83·3 83·4	79·1 78·8	bc bl	0 0	1 1	Lightning in West.
"	22nd.	8 a.m. 8 p.m.	6 16 Colombo Harbour	79 56	Noon. —	83·1 —	2° W.	N. by E. S.E.	2 1	30·049 30·037	82·1 84·2	81·4 82·8	78·4 78·1	bc cb	0 0	1 —	11.23 a.m. Arrived Colombo.
"	23rd.	8 a.m. 8 p.m.	"		Noon. —	— —	2° W.	Calm W.S.W.	0 1	30·061 30·031	81·3 84·9	— 84·1	— 75·7	cb b	0 0	— —	
"	24th.	8 a.m. 8 p.m.	"		Noon. —	— —	2° W.	Calm Calm	0 0	— 30·000	— 84·3	— 84·0	— 79·3	bc b	0 0	— —	8.45 p.m. Left Colombo.
"	25th.	8 a.m. 8 p.m.	7 18 7 50	77 16 74 23	Noon. S. 38° E. 11	83·2 84·0	2° E.	N.N.W. N.	4 2	1014·9 1014·9	301 302	83·2 82·7	78·9 77·8	bc bcl	0 0	3 2	Lightning to N.E.
"	26th.	8 a.m. 8 p.m.	8 23 9 0	71 40 68 53	Noon. Nil.	83·2 83·0	2° E.	N.W. by N. N.	2 3	1016·6 1015·7	301 301	81·8 81·3	77·3 77·9	bc b	0 0	1 2	
"	27th.	8 a.m. 8 p.m.	9 31 10 12	65 59 63 12	Noon. N. 5	83·2 81·9	3° E.	N. by E. N.N.E.	2 2	1017·1 1016·7	301 301	81·8 81·4	76·7 75·6	bc b	0 0	1 1	8.10 p.m. Sea very phosphorescent.
"	28th.	8 a.m. 8 p.m.	10 53 11 19	60 27 57 35	Noon. N. 40° E. 15	80·2 80·2	3° E.	" N.E. by N.	2 3	1017·3 1017·0	300 300	80·8 79·9	76·6 74·2	bc l	0 0	1 3	
"	29th.	8 a.m. 8 p.m.	11 49 12 7	54 47 51 53	Noon. Nil.	79·7 80·2	4° E.	N.E. N.	2 2	1019·0 1017·9	300 301	81·0 80·1	76·1 73·3	bc b	0 0	2 1	

"	30th. "	8 a.m. 8 p.m.	12 29 12 32	48 43 45 58	Noon. N. 36° W. 16	78.9 79.3	4° E.	E. E.	2 2	1019.2 1017.0	300 300	81.7 78.8	76.0 73.9	bc bw	0 0	1 1	
"	31st. "	8 a.m. 8 p.m.	12 53 15 15	43 16 41 53	Noon. Nil.	79.4 79.3	2° E.	S.E. by S. N. by E.	3 2	1017.3 1013.8	300 301	79.6 79.3	74.4 74.9	bc b	0 0	2 1	8 p.m. Current since 6 p.m. S., 4 miles.
April	1st. "	8 a.m. 8 p.m.	17 31 19 47	40 23 39 1*	Noon. S. 30° W. 8	81.4 79.6	1° E.	N. w. by N. N.N.W.	3 4	1013.7 1012.5	300 299	80.5 78.5	74.9 73.8	cb b	0 0	2 4	
"	2nd. "	8 a.m. 8 p.m.	22 2 24 29	37 37 36 9	Noon. S. 26° E. 9	77.0 75.0	0°	N. by W. N. by W.	4 3	1014.1 1014.9	298 296	76.3 70.7	72.2 65.2	cb cb	0 0	3 3	
"	3rd. "	8 a.m. 8 p.m.	26 55 29 5	33 34 32 48	Noon. —	70.5 65.8	1° E.	N.W. N.	5 3	1018.4 1023.3	291 292	66.0 65.8	62.1 61.2	b b	0 0	4 2	Midt. Anchored Suez Bay.
		8 a.m. 8 p.m.			Noon.												
		8 a.m. 8 p.m.			Noon.												
		8 a.m. 8 p.m.			Noon.												
		8 a.m. 8 p.m.			Noon.												

NOTES.

Barometer, Mercury or Aneroid ?

Mercury.

Too high

—

Error ?

Too low

·005

at 30.0 ins.

When and where last compared ?

October, 1910.

Kew.

Height above Sea Level

36

ft.

Maker of Instrument and No. (if any) —

Adie, No. 1161.

Standard Temperature @ 1000 mb. :—285.1a.

Signature of Observer _____ Rank _____

**WEATHER REPORTS BY RADIOTELEGRAPHY
FROM SHIPS.**

Meteorological Registers No. 138.

INSTRUCTIONS FOR OBSERVING AND CODING MESSAGES.

Meteorological Observations to be signalled:—

The Meteorological Observations to be signalled are as follow:—

1. The reading of the barometer at a fixed hour to the tenth of a millibar corrected for index error, latitude, temperature, and height above the sea level (*see* Pages 20 to 28 and Tables, pages 112–115).
2. The wind direction and force at the fixed hour.
3. The fixed hour, and the state of the weather at the fixed hour.
4. The reading of the barometer (corrected), wind direction and force, three hours before the fixed hour.

The observations under 4 are called Control Observations.

Date and position of ship to be signalled.

The number of the day of the month; and the position of the ship, both at the fixed hour and at the hour of the control observation are to be included in the message.

The fixed hours of observation.

The fixed hours are 7 a.m. and 6 p.m. Greenwich Mean Time, and the hours of the control observations are, therefore, 4 a.m. and 3 p.m. respectively.

The address.

The word "Meteorology" is registered with the Marconi Company as a sufficient address.

The message.

The message following the address will give the required information by *four groups of five figures each.*

Times for despatching messages.

So long as the ship is between longitude 10° W. and longitude 30° W. a message should be sent regularly, (1) at 7h. 5m. a.m. G.M.T. reporting the observations at 7 a.m. G.M.T. with the control observations of 4 a.m., and (2) at 6h. 5m. p.m. G.M.T. reporting observations at 6 p.m. G.M.T. with the control observations of 3 p.m.

When the ship is between longitude 10° W. and 15° W. a message should also be sent reporting observations at 1 p.m. with control observations at 10 a.m.

Priority of transmission is accorded to radiotelegrams from British ships sent to the Meteorological Office in accordance with the terms of this Circular.

The Marconi Company will arrange as far as may be practicable for the transmission from ship to ship of the messages sent when a ship is outside her own range from the shore station.

The figure groups.

First group (DDppp).

The day of the month, two figures DD according to Code I.

The position of the ship at the time of the control observation indicated by 1° squares numbered in *three* figures (ppp) according to Code II and the numbered chart included herewith.

Second group (bbbww).

The corrected reading of barometer to the tenth of a millibar at the time of the control observation, three figures (bbb), in accordance with Code III.

The wind direction and force at the time of the control observation (two figures, ww, Code IV).

Third group (PPPHX).

The position of the ship at the fixed hour (three figures, PPP, Code II).

The fixed hour (one figure, H, Code V).

The state of the sky at the fixed hour (one figure, X, Code VI).

Fourth group (BBBWW).

Corrected reading of barometer at the fixed hour, three figures, BBB, according to Code III.

Wind direction and force at the fixed hour, two figures, WW, according to Code IV.

Example of message.

The following is an example of the information compiled for the message reporting an observation at 7 a.m. G.M.T., the control observation having been made at 4 a.m. G.M.T. :—

Address.	Day of the Month.	Position at 4 a.m.	Barometer at 4 a.m.	Wind direction and force at 4 a.m.
Meteorology	31	Lat. 51° N., Long. 15° W.	1016·6	S.W. 6.
Coded as, Meteorology	31351		16657	

Position at 7 a.m.	Fixed hour of Observation.	Weather at 7 a.m.	Barometer at 7 a.m.	Wind direction and force at 7 a.m.
Lat. 51° N., Long. 16° W. ...	7 a.m. ...	Overcast ...	1014·9	S. 7.
36174			14945	

N.B.—In view of the necessity for the messages reaching the Meteorological Office in time for use in connexion with the daily weather service, the coded message must be despatched as follows :—

For a 7 a.m. observation not later than 7.5 a.m. G.M.T.

For a 6 p.m. observation not later than 6.5 p.m. G.M.T.

Note :—

The message is to be sent *promptly* at 7h. 5m. a.m., or 6h. 5m. p.m., G.M.T., as the case may be.

If the control observation has been omitted, insert 999 instead of the position of the ship at the time of the control observation, and *omit* the second group, *e.g.*, "Meteorology 31999 36174 14945;" decoded :—

31st March. No control observation, Lat. 51°, Long. 16°, 7 a.m.
Overcast. Bar., 1014.9. Wind, S., 6 or 7.

Telegraph forms and books with carbon paper are provided for entering the coded messages. The original form should be handed to the official in charge of wireless telegraphy. The books of carbon copies should be returned to the Meteorological Office, London, S.W., with the schedule of original observations. Postage from British or Colonial ports need not be prepaid.

Specimen of Coding.

The observations as coded are shown in facsimile below.

M.O. FORM 103.

METEOROLOGICAL REPORTS BY RADIOTELEGRAPHY, 8TH, 7.A.M.

From S.S. —			TO METEOROLOGY.	
DD ppp	bbb ww	PPP HX	BBB WW	
08325	18393	33573	21702	

Signature of Officer _____

The corresponding messages at subsequent hours are as follow :—

8th. 6 p.m.	08375	17901	38562	28100
9th. 7 a.m.	09534	27167	55478	27167
9th. 6 p.m.	09574	25767	58462	22762

These are the coded messages representing the observations set out in the specimen Form 138.

THE ADJUSTMENT OF FIDUCIAL TEMPERATURE FOR

Latitude N. or S.	Height in Feet of Barometer								
	0	5	10	15	20	25	30	35	40
°	a.	a.	a.	a.	a.	a.	a.	a.	a.
0	-15.2	-14.2	-13.2	-12.2	-11.2	-10.2	-9.2	-8.2	-7.2
2	15.1	14.1	13.1	12.1	11.1	10.1	9.1	8.1	7.1
4	15.0	14.0	13.0	12.0	11.0	10.0	9.0	8.0	7.0
6	14.8	13.8	12.8	11.8	10.8	9.8	8.8	7.8	6.8
8	14.6	13.6	12.6	11.6	10.6	9.6	8.6	7.6	6.6
10	14.2	13.2	12.2	11.2	10.2	9.2	8.2	7.2	6.2
12	13.8	12.8	11.8	10.8	9.8	8.8	7.8	6.8	5.8
14	13.4	12.4	11.4	10.4	9.4	8.4	7.4	6.4	5.4
16	12.8	11.8	10.8	9.8	8.8	7.8	6.8	5.8	4.8
18	12.3	11.3	10.3	9.3	8.3	7.3	6.3	5.3	4.3
20	11.6	10.6	9.6	8.6	7.6	6.6	5.6	4.6	3.6
22	10.9	9.9	8.9	7.9	6.9	5.9	4.9	3.9	2.9
24	10.1	9.1	8.1	7.1	6.1	5.1	4.1	3.1	2.1
26	9.3	8.3	7.3	6.3	5.3	4.3	3.3	2.3	1.3
28	8.5	7.5	6.5	5.5	4.5	3.5	2.5	1.5	-0.5
30	7.6	6.6	5.6	4.6	3.6	2.6	1.6	-0.6	+0.4
32	6.6	5.6	4.6	3.6	2.6	1.6	-0.6	+0.4	1.4
34	5.7	4.7	3.7	2.7	1.7	-0.7	+0.3	1.3	2.3
36	4.7	3.7	2.7	1.7	-0.7	+0.3	1.3	2.3	3.3
38	3.7	2.7	1.7	-0.7	+0.3	1.3	2.3	3.3	4.3
40	2.6	1.6	-0.6	+0.4	1.4	2.4	3.4	4.4	5.4
42	1.6	-0.6	+0.4	1.4	2.4	3.4	4.4	5.4	6.4
44	-0.5	+0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
46	+0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5
48	1.6	2.6	3.6	4.6	5.6	6.6	7.6	8.6	9.6
50	2.6	3.6	4.6	5.6	6.6	7.6	8.6	9.6	10.6
52	3.7	4.7	5.7	6.7	7.7	8.7	9.7	10.7	11.7
54	4.7	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7
56	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7
58	6.6	7.6	8.6	9.6	10.6	11.6	12.6	13.6	14.6
60	+7.6	+8.6	+9.6	+10.6	+11.6	+12.6	+13.6	+14.6	+15.6

ANEROID

* This table printed above is applicable only to circumstances permit. Without special precautions accuracy for plotting on synchronous charts, but in alone are available it should be noticed that they that only the correction for error of instrument, as to the actual reading. In this correction the allowance provided that the position of the instrument in the ship was given.

One barometer only should be used throughout a hitherto been in use, the error of which is known at the however, for some cogent reason, to substitute another should be made on Form 138 to this effect, and the reporting the index error of the instrument.

LATITUDE AND HEIGHT ABOVE SEA LEVEL.

Cistern above Sea Level.								Latitude N. or S.
45	50	55	60	65	70	75	80	
a.	a.	a.	a.	a.	a.	a.	a.	°
-6.2	-5.2	-4.2	-3.2	-2.2	-1.2	-0.2	+0.8	0
6.1	5.1	4.1	3.1	2.1	1.1	-0.1	+0.9	2
6.0	5.0	4.0	3.0	2.0	1.0	0.0	1.0	4
5.8	4.8	3.8	2.8	1.8	0.8	+0.2	1.2	6
5.6	4.6	3.6	2.6	1.6	0.6	0.4	1.4	8
5.2	4.2	3.2	2.2	1.2	-0.2	0.8	1.8	10
4.8	3.8	2.8	1.8	0.8	+0.2	1.2	2.2	12
4.4	3.4	2.4	1.4	-0.4	0.6	1.6	2.6	14
3.8	2.8	1.8	0.8	+0.2	1.2	2.2	3.2	16
3.3	2.3	1.3	-0.3	0.7	1.7	2.7	3.7	18
2.6	1.6	-0.6	+0.4	1.4	2.4	3.4	4.4	20
1.9	0.9	+0.1	1.1	2.1	3.1	4.1	5.1	22
1.1	-0.1	0.9	1.9	2.9	3.9	4.9	5.9	24
-0.3	+0.7	1.7	2.7	3.7	4.7	5.7	6.7	26
+0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	28
1.4	2.4	3.4	4.4	5.4	6.4	7.4	8.4	30
2.4	3.4	4.4	5.4	6.4	7.4	8.4	9.4	32
3.3	4.3	5.3	6.3	7.3	8.3	9.3	10.4	34
4.3	5.3	6.3	7.3	8.3	9.3	10.3	11.3	36
5.3	6.3	7.3	8.3	9.3	10.3	11.3	12.3	38
6.4	7.4	8.4	9.4	10.4	11.4	12.4	13.4	40
7.4	8.4	9.4	10.4	11.4	12.4	13.4	14.4	42
8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	44
9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	46
10.6	11.6	12.6	13.6	14.6	15.6	16.6	17.6	48
11.6	12.6	13.6	14.6	15.6	16.6	17.6	18.6	50
12.7	13.7	14.7	15.7	16.7	17.7	18.7	19.7	52
13.7	14.7	15.7	16.7	17.7	18.7	19.7	20.7	54
14.7	15.7	16.7	17.7	18.7	19.7	20.7	21.7	56
15.6	16.6	17.6	18.6	19.6	20.6	21.6	22.6	58
+16.6	+17.6	+18.6	+19.6	+20.6	+21.6	+22.6	+23.6	60

BAROMETERS.

mercury barometers, which should be used whenever aneroid barometers do not give reading of sufficient those cases in which readings of aneroid barometers require no correction for temperature or Latitude, and notified by the Meteorological Office, should be applied for height above sea level has already been included, has not been changed since the figure for the correction

voyage; and that barometer the instrument that has Meteorological Office. Should it be considered necessary, instrument for taking the barometer readings, a note earliest opportunity should be taken of ascertaining and

CORRECTION OF BAROMETER READINGS FOR AND ADJUSTED

Attached Thermo- meter.	ADJUSTED FIDUCIAL															
	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295
a.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
271	+1.5	+1.7	+1.9	+2.0	+2.2	+2.4	+2.6	+2.7	+2.9	+3.1	+3.2	+3.4	+3.6	+3.8	+3.9	+4.1
272	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9
273	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8
274	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6
275	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4
276	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2
277	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1
278	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9
279	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7
280	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6
281	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4
282	0.3	-0.2	0.0	0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2
283	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0
284	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9
285	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7
286	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5
287	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4
288	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2
289	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0
290	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9
291	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7
292	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5
293	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3
294	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2
295	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0
296	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2
297	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3
298	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5
299	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7
300	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9
301	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0
302	3.8	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4	1.2
303	3.9	3.8	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5	1.4
304	4.1	3.9	3.8	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7	1.5
305	4.3	4.1	3.9	3.8	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9	1.7
306	4.4	4.3	4.1	3.9	3.8	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0	1.9
307	4.6	4.4	4.3	4.1	3.9	3.8	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2	2.0
308	4.8	4.6	4.4	4.3	4.1	3.9	3.8	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4	2.2
309	5.0	4.8	4.6	4.4	4.3	4.1	3.9	3.8	3.6	3.4	3.2	3.1	2.9	2.7	2.6	2.4
310	-5.1	-5.0	-4.8	-4.6	-4.4	-4.3	-4.1	-3.9	-3.8	-3.6	-3.4	-3.2	-3.1	-2.9	-2.7	-2.6

DIFFERENCE BETWEEN "ATTACHED THERMOMETER"
FIDUCIAL TEMPERATURE.

TEMPERATURE.

296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	Attached Thermo- meter.
mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	in.
+4.3	+4.4	+4.6	+4.8	+5.0	+5.1	+5.3	+5.5	+5.6	+5.8	+6.0	+6.2	+6.3	+6.5	+6.7	271
4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	6.2	6.3	6.5	272
3.9	4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	6.2	6.3	273
3.8	3.9	4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	6.2	274
3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	275
3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	5.5	5.6	5.8	276
3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	5.5	5.6	277
3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	5.5	278
2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	279
2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	5.0	5.1	280
2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	5.0	281
2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	282
2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	283
2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	284
1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	285
1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	286
1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	287
1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	288
1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	289
1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	290
0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	3.2	291
0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	3.1	292
0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	2.9	293
0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	2.7	294
+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2.6	295
0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	296
-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	297
0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	298
0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	299
0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	300
0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	301
1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	1.4	302
1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	1.2	303
1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	1.0	304
1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	0.9	305
1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	0.7	306
1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	0.5	307
2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	0.3	308
2.2	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.7	0.5	0.3	-0.2	0.0	+0.2	309
-2.4	-2.2	-2.0	-1.9	-1.7	-1.5	-1.4	-1.2	-1.0	-0.9	-0.7	-0.5	-0.3	-0.2	0.0	310

CODES.

Code I. Day of Month. (DD.)

The number of the day of the month with a Zero prefixed to fill up the group if necessary, 01 to 31.

Code II. Ship's position (PPP or ppp).

The position of the ship is indicated by the *number of the 1° square* in which the observations are taken.* The numbers of the degree squares are given in the numbered chart according to the rule :—The first figure shows the 10° square, thus :—

0, 2, 4, 6, 8, are the 10° squares between 40° N. and 50° N., going west from the meridian of Greenwich up to 45° W.

1, 3, 5, 7, 9, are the 10° squares between 50° N. and 60° N., or between 30° N. and 40° N., going west from the meridian of Greenwich up to 45° W.

The second position figure is the last figure in the degree of longitude.

The third position figure is the last figure in the degree of latitude.

Beyond 45° W. of Greenwich the figures repeat as from the meridian of Greenwich.

Code III. Barometer to tenths of a millibar (BBB or bbb).

The reading of the **mercury barometer** is to be corrected for index error, and for temperature, and also for height above sea level. A table of corrections is given overleaf.

If an aneroid barometer be used only the correction notified by the Meteorological Office should be applied. (*See footnote, page 112.*)

The corrected reading is coded for the message by simply omitting the initial 9 or 10 of the reading in millibars: thus a reading of 1014.9 mb. goes into the group as 149, or 999.7 mb. as 997.

Code IV. Wind direction (to 16 points) and wind force (WW or ww).

	Wind force Beaufort Scale.	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.	N.
Light breeze ..	1, 2 or 3	01	07	13	19	25	31	37	43	49	55	61	67	73	79	85	91
Moderate breeze	4 or 5	02	08	14	20	26	32	38	44	50	56	62	68	74	80	86	92
Strong wind ..	6 or 7	03	09	15	21	27	33	39	45	51	57	63	69	75	81	87	93
Gale force ..	8 or 9	04	10	16	22	28	34	40	46	52	58	64	70	76	82	88	94
Storm force ..	10 or 11	05	11	17	23	29	35	41	47	53	59	65	71	77	83	89	95
Hurricane ..	12	06	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96
Calm	0	00	The wind direction is to be referred to true bearings.														

* The 1° Square appropriate to the position of the ship at the time of observation is the one immediately West of the Meridian of the degree of longitude, and immediately North of the parallel of the degree of latitude. A position 51° 55' N., 26° 49' W. should be reported as 51° N., 26° W., code figures 561, and not as 52° N., 27° W. The figures reporting minutes are dropped in all cases, and those reporting degrees are not "thrown up" for the next higher degree if the minutes exceed 30.

METEOROLOGICAL REPORTS BY WIRELESS TELEGRAPHY.

Numbering of one degree squares for indicating the positions of ships at the times of observations.



METEOROLOGICAL OFFICE, LONDON.

Form for Meteorological Observations for Ships reporting by Radio-telegraphy.

Steamship
Captain
Month
June, 1914.

CONTROL OBSERVATION.											FINAL OBSERVATION.													REMARKS. Recent particulars of the position of Ice should be given in this column.							
Hour. G.M.T.	Day of Month.	SHIP'S POSITION.		BAROMETER.				WIND.		SHIP'S POSITION.		Hour. G.M.T.	Weather.	BAROMETER.				WIND.		THERMOMETERS.		Sea Disturb- ance 0 to 10	Temp. of Sea Surface.			Fog 0 to 5					
		Latitude. N.	Longitude. W.	Uncorr. Reading	Att. Ther.	Corr ⁿ . from Table.	Corr. Reading	True Dirn.	Force 0 to 12	Latitude. N.	Longitude. W.			Uncorr. Reading	Att. Ther.	Corr ⁿ . from Table.	Corr. Reading	True Dirn.	Force 0 to 12	Temp. of Air.	Temp. of Wet Bulb.										
	DD	ppp					bbb	ww		PPP		H	X			BBB	WW														
4 a.m.	8th	55	30	12	30	1015.7	285	+2.6	1018.3	N.	6	55	30	13	55	7 a.m.	c	1019.0	284	+2.7	1021.7	N.N.E.	5	51	47	4	50	0	June 11th and 12th, 1914— Between Lat. 50° 6' N., Long. 44° 24' W. and Lat. 48° 22' N., Long. 49° 9' W., passed 14 Icebergs, several growlers and pieces. Saw no field Ice.		
3 p.m.	8th	55	18	17	40	1015.3	285	+2.6	1017.9	N.N.E.	3	55	15	18	51	6 p.m.	bc	1025.7	286	+2.4	1028.1	Calm	0	51	48	2	50	0			
4 a.m.	9th	54	48	23	48	1024.5	285	+2.6	1027.1	W.	3	54	38	25	6	7 a.m.	fe	1024.5	285	+2.6	1027.1	W.	3	51	51	2	49	4			
3 p.m.	9th	54	25	27	40	1023.1	285	+2.6	1025.7	W. by S.	3	54	9	28	58	6 p.m.	bc	1020.3	286	+2.4	1022.7	W.S.W.	4	52	51	2	49	0			
4 a.m.																7 a.m.															
3 p.m.																6 p.m.															
4 a.m.																7 a.m.															
3 p.m.																6 p.m.															
4 a.m.																7 a.m.															
10 a.m.								1 P.M.	O bserva	tions	with	10 A.M.	Control	Observations	between 10°	and 15°	W. Long.														
10 a.m.													1 p.m.																		
10 a.m.													1 p.m.																		
10 a.m.													1 p.m.																		
10 a.m.													1 p.m.																		
	DD	ppp					bbb	ww		PPP		H	X			BBB	WW														

The information to be coded is indicated in the columns in which the letters forming the message groups **DDppp**, **bbbww**, **PPPHX**, **BBBWW** are placed.
 Telegraph forms with carbon paper are provided for entering the coded messages. The carbon copies should be returned by post from the first port of call to the Meteorological Office, London, S.W., with this form. Postage from British or Colonial ports need not be prepaid.

Barometer, Mercurial or Aneroid? Mercurial
 Maker of Instrument and No. (if any) Adie, 229

Standard Temperature 285 a.
 @ 1,000 m.b.

Height above Sea Level 50 ft.

Signature of Observer _____
 Rank _____

Code V. The hour (H).

The only hours to be included in messages are 7 a.m. and 6 p.m. which will be introduced into the groups as 7 or 6.

Code VI. Weather or state of the sky (X).

- | | |
|--------------------------------|------------------|
| 0. Sky quite clear. | 5. Rain falling. |
| 1. Sky quarter clouded. | 6. Snow falling. |
| 2. Sky half clouded. | 7. Haze or mist. |
| 3. Sky three-quarters clouded. | 8. Fog. |
| 4. Sky entirely overcast. | 9. Thunderstorm. |

APPENDIX IV.

CORRECTION OF OBSERVATIONS OF MERCURY BAROMETERS WITH
BRASS SCALES GRADUATED IN MILLIBARS, COMBINED WITH
REDUCTION TO MEAN SEA LEVEL.

I. From the instructions given on pages 24 to 26, construct a table of Fiducial Temperatures in different latitudes for the barometer as mounted in the ship, as follows :—

For S.S. _____ Barometer M.O. 975.

(Standard Temperature at 1,000 mb. = 285a.)

Barometer is 55 ft. above Sea Level ; therefore the Fiducial Temperature adjusted for reduction for that height in Latitude 45° is 296a.

TABLE OF FIDUCIAL TEMPERATURES OF BAROMETER M.O. 975 ON
S.S. _____ IN VARIOUS LATITUDES.

To be set out near the Barometer.

Latitude ...	...	56°	55°	54°	53°	52°	51°	50°	49°	48°	47°	46°
Fiducial Temperature.		302a	302a	301a	301a	300a	300a	299a	299a	298a	297a	297a

Latitude ...	...	45°	44°	43°	42°	41°	40°	39°	38°	37°	36°	35°
Fiducial Temperature.		296a	295a	295a	294a	293a	293a	292a	292a	291a	291a	290a

II. Correct for the difference between the reading of the attached Thermometer and the Fiducial Temperature by means of the following :—

TABLES OF CORRECTIONS FOR TEMPERATURE.

(A.) Actual Temperature *above* the Fiducial Temperature.

Actual Temperature	} - { Fiducial Temperature		1a	2a	3a	4a	5a	6a	7a	8a	9a	10a
Subtract ...	...	...	·2	·3	·5	·7	·9	1·0	1·2	1·4	1·5	1·7 mb.

(B.) Actual Temperature *below* the Fiducial Temperature.

Fiducial Temperature	} - { Actual Temperature		1a	2a	3a	4a	5a	6a	7a	8a	9a	10a
Add ...	...	...	·2	·3	·5	·7	·9	1·0	1·2	1·4	1·5	1·7 mb.

APPENDIX V.

TABLE I.

TABLE of CORRECTIONS to be applied to BAROMETERS with *Brass Scales* extending from the CISTERN to the top of the MERCURIAL COLUMN, to reduce the observation to 32° Fahrenheit.

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

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

TABLE I.—continued.

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

TABLE II.

REDUCTION OF BAROMETRIC READINGS TO MEAN SEA LEVEL.
READING, 30 inches.

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	.066	.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.

CORRECTIONS for reducing BAROMETRIC READINGS 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.	At 30.		At 27.	At 30.		At 27.	At 30.		At 27.	At 30.
0	ins.	ins.	0	ins.	ins.	0	ins.	ins.	0	ins.	ins.
1	-.070	-.078	23	-.049	-.054	46	+.002	+.003	69	+.052	+.058
2	.070	.078	24	.047	.052	47	.005	.005	70	.054	.060
3	.070	.078	25	.045	.050	48	.007	.008	71	.055	.061
4	.070	.077	26	.043	.048	49	.010	.011	72	.057	.063
5	.069	.077	27	.041	.046	50	.012	.013	73	.058	.064
6	.069	.077	28	.039	.043	51	.015	.016	74	.059	.066
7	.068	.076	29	.037	.041	52	.017	.019	75	.061	.067
8	.068	.075	30	.035	.039	53	.019	.021	76	.062	.069
9	.067	.075	31	.033	.036	54	.022	.024	77	.063	.070
10	.067	.074	32	.031	.034	55	.024	.027	78	.064	.071
11	.066	.073	33	.028	.032	56	.026	.029	79	.065	.072
12	.065	.072	34	.026	.029	57	.028	.032	80	.066	.073
13	.064	.071	35	.024	.027	58	.031	.034	81	.067	.074
14	.063	.070	36	.022	.024	59	.033	.036	82	.067	.075
15	.062	.069	37	.019	.021	60	.035	.039	83	.068	.075
16	.061	.067	38	.017	.019	61	.037	.041	84	.068	.076
17	.059	.066	39	.015	.018	62	.039	.043	85	.069	.077
18	.058	.064	40	.012	.013	63	.041	.046	86	.069	.077
19	.057	.063	41	.010	.011	64	.043	.048	87	.070	.077
20	.055	.061	42	.007	.008	65	.045	.050	88	.070	.078
21	.054	.060	43	.005	.005	66	.047	.052	89	.070	.078
22	.052	.058	44	-.002	-.003	67	.049	.054	90	+.070	+.078
	-.050	-.056	45	± 0	± 0	68	+.050	+.056			

TABLE IV.

CONVERSION OF CENTIGRADE DEGREES INTO DEGREES OF FAHRENHEIT.

Centi- grade Degrees.	Tenths of Degrees.									
	0	1	2	3	4	5	6	7	8	9
0										
-39	-88.2	-38.4	-38.6	-38.7	-38.9	-39.1	-39.3	-39.5	-39.6	-39.8
38	36.4	36.6	36.8	36.9	37.1	37.3	37.5	37.7	37.8	38.0
37	34.6	34.8	35.0	35.1	35.3	35.5	35.7	35.9	36.0	36.2
36	32.8	33.0	33.2	33.3	33.5	33.7	33.9	34.1	34.2	34.4
35	31.0	31.2	31.4	31.5	31.7	31.9	32.1	32.3	32.4	32.6
34	29.2	29.4	29.6	29.7	29.9	30.1	30.3	30.5	30.6	30.8
33	27.4	27.6	27.8	27.9	28.1	28.3	28.5	28.7	28.8	29.0
32	25.6	25.8	26.0	26.1	26.3	26.5	26.7	26.9	27.0	27.2
31	23.8	24.0	24.2	24.3	24.5	24.7	24.9	25.1	25.2	25.4
30	22.0	22.2	22.4	22.5	22.7	22.9	23.1	23.3	23.4	23.6
29	20.2	20.4	20.6	20.7	20.9	21.1	21.3	21.5	21.6	21.8
28	18.4	18.6	18.8	18.9	19.1	19.3	19.5	19.7	19.8	20.0
27	16.6	16.8	17.0	17.1	17.3	17.5	17.7	17.9	18.0	18.2
26	14.8	15.0	15.2	15.3	15.5	15.7	15.9	16.1	16.2	16.4
25	13.0	13.2	13.4	13.5	13.7	13.9	14.1	14.3	14.4	14.6
24	11.2	11.4	11.6	11.7	11.9	12.1	12.3	12.5	12.6	12.8
23	9.4	9.6	9.8	9.9	10.1	10.3	10.5	10.7	10.8	11.0
22	7.6	7.8	8.0	8.1	8.3	8.5	8.7	8.9	9.0	9.2
21	5.8	6.0	6.2	6.3	6.5	6.7	6.9	7.1	7.2	7.4
20	4.0	4.2	4.4	4.5	4.7	4.9	5.1	5.3	5.4	5.6
19	2.2	2.4	2.6	2.7	2.9	3.1	3.3	3.5	3.6	3.8
18	-0.4	-0.6	-0.8	-0.9	-1.1	-1.3	-1.5	-1.7	-1.8	2.0
17	+1.4	+1.2	+1.0	+0.9	+0.7	+0.5	+0.3	+0.1	0.0	-0.2
16	3.2	3.0	2.8	2.7	2.5	2.3	2.1	1.9	+1.8	+1.6
15	5.0	4.8	4.6	4.5	4.3	4.1	3.9	3.7	3.6	3.4
14	6.8	6.6	6.4	6.2	6.1	5.9	5.7	5.5	5.4	5.2
13	8.6	8.4	8.2	8.1	7.9	7.7	7.5	7.3	7.2	7.0
12	10.4	10.2	10.0	9.9	9.7	9.5	9.3	9.1	9.0	8.8
11	12.2	12.0	11.8	11.7	11.5	11.3	11.1	10.9	10.8	10.6
10	14.0	13.8	13.6	13.5	13.3	13.1	12.9	12.7	12.6	12.4
9	15.8	15.6	15.4	15.3	15.1	14.9	14.7	14.5	14.4	14.2
8	17.6	17.4	17.2	17.1	16.9	16.7	16.5	16.3	16.2	16.0
7	19.4	19.2	19.0	18.9	18.7	18.5	18.3	18.1	18.0	17.8
6	21.2	21.0	20.8	20.7	20.5	20.3	20.1	19.9	19.8	19.6
5	23.0	22.8	22.6	22.5	22.3	22.1	21.9	21.7	21.6	21.4
4	24.8	24.6	24.4	24.3	24.1	23.9	23.7	23.5	23.4	23.2
3	26.6	26.4	26.2	26.1	25.9	25.7	25.5	25.3	25.2	25.0
2	28.4	28.2	28.0	27.9	27.7	27.5	27.3	27.1	27.0	26.8
1	30.2	30.0	29.8	29.7	29.5	29.3	29.1	28.9	28.8	28.6
-0	+32.0	+31.8	+31.6	+31.5	+31.3	+31.1	+30.9	+30.7	+30.6	+30.4

TABLE IV.—*continued.*

CONVERSION of CENTIGRADE DEGREES into DEGREES of FAHRENHEIT.

Centi- grade Degrees.	Tenths of Degrees.									
	0	1	2	3	4	5	6	7	8	9
0										
+0	+32°0	+32°2	+32°4	+32°5	+32°7	+32°9	+33°1	+33°3	+33°4	+33°6
1	33°8	34°0	34°2	34°3	34°5	34°7	34°9	35°1	35°2	35°4
2	35°6	35°8	36°0	36°1	36°3	36°5	36°7	36°9	37°0	37°2
3	37°4	37°6	37°8	37°9	38°1	38°3	38°5	38°7	38°8	39°0
4	39°2	39°4	39°6	39°7	39°9	40°1	40°3	40°5	40°6	40°8
5	41°0	41°2	41°4	41°5	41°7	41°9	42°1	42°3	42°4	42°6
6	42°8	43°0	43°2	43°3	43°5	43°7	43°9	44°1	44°2	44°4
7	44°6	44°8	45°0	45°1	45°3	45°5	45°7	45°9	46°0	46°2
8	46°4	46°6	46°8	46°9	47°1	47°3	47°5	47°7	47°8	48°0
9	48°2	48°4	48°6	48°7	48°9	49°1	49°3	49°5	49°6	49°8
10	50°0	50°2	50°4	50°5	50°7	50°9	51°1	51°3	51°4	51°6
11	51°8	52°0	52°2	52°3	52°5	52°7	52°9	53°1	53°2	53°4
12	53°6	53°8	54°0	54°1	54°3	54°5	54°7	54°9	55°0	55°2
13	55°4	55°6	55°8	55°9	56°1	56°3	56°5	56°7	56°8	57°0
14	57°2	57°4	57°6	57°7	57°9	58°1	58°3	58°5	58°6	58°8
15	59°0	59°2	59°4	59°5	59°7	59°9	60°1	60°3	60°4	60°6
16	60°8	61°0	61°2	61°3	61°5	61°7	61°9	62°1	62°2	62°4
17	62°6	62°8	63°0	63°1	63°3	63°5	63°7	63°9	64°0	64°2
18	64°4	64°6	64°8	64°9	65°1	65°3	65°5	65°7	65°8	66°0
19	66°2	66°4	66°6	66°7	66°9	67°1	67°3	67°5	67°6	67°8
20	68°0	68°2	68°4	68°5	68°7	68°9	69°1	69°3	69°4	69°6
21	69°8	70°0	70°2	70°3	70°5	70°7	70°9	71°1	71°2	71°4
22	71°6	71°8	72°0	72°1	72°3	72°5	72°7	72°9	73°0	73°2
23	73°4	73°6	73°8	73°9	74°1	74°3	74°5	74°7	74°8	75°0
24	75°2	75°4	75°6	75°7	75°9	76°1	76°3	76°5	76°6	76°8
25	77°0	77°2	77°4	77°5	77°7	77°9	78°1	78°3	78°4	78°6
26	78°8	79°0	79°2	79°3	79°5	79°7	79°9	80°1	80°2	80°4
27	80°6	80°8	81°0	81°1	81°3	81°5	81°7	81°9	82°0	82°2
28	82°4	82°6	82°8	82°9	83°1	83°3	83°5	83°7	83°8	84°0
29	84°2	84°4	84°6	84°7	84°9	85°1	85°3	85°5	85°6	85°8
30	86°0	86°2	86°4	86°5	86°7	86°9	87°1	87°3	87°4	87°6
31	87°8	88°0	88°2	88°3	88°5	88°7	88°9	89°1	89°2	89°4
32	89°6	89°8	90°0	90°1	90°3	90°5	90°7	90°9	91°0	91°2
33	91°4	91°6	91°8	91°9	92°1	92°3	92°5	92°7	92°8	93°0
34	93°2	93°4	93°6	93°7	93°9	94°1	94°3	94°5	94°6	94°8
35	95°0	95°2	95°4	95°5	95°7	95°9	96°1	96°3	96°4	96°6
36	96°8	97°0	97°2	97°3	97°5	97°7	97°9	98°1	98°2	98°4
37	98°6	98°8	99°0	99°1	99°3	99°5	99°7	99°9	100°0	100°2
38	100°4	100°6	100°8	100°9	101°1	101°3	101°5	101°7	101°8	102°0
+39	+102°2	+102°4	+102°6	+102°7	+102°9	+103°1	+103°3	+103°5	+103°6	+103°8

TABLE V.

CONVERSION of DEGREES of FAHRENHEIT into CENTIGRADE DEGREES.
To convert to the ABSOLUTE SCALE add 273° to the Centigrade reading.

Degrees of Fah.	Tenths of Degrees.											
	0	1	2	3	4	5	6	7	8	9		
°												
32	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	31
33	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.1	1.1	30
34	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	29
35	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.2	28
36	2.2	2.3	2.3	2.4	2.4	2.5	2.6	2.6	2.7	2.7	2.8	27
37	2.8	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.2	3.3	3.3	26
38	3.3	3.4	3.4	3.5	3.6	3.6	3.7	3.7	3.8	3.8	3.9	25
39	3.9	3.9	4.0	4.1	4.1	4.2	4.2	4.3	4.3	4.4	4.4	24
40	4.4	4.5	4.6	4.6	4.7	4.7	4.8	4.8	4.9	4.9	5.0	23
41	5.0	5.1	5.1	5.2	5.2	5.3	5.3	5.4	5.4	5.5	5.6	22
42	5.6	5.6	5.7	5.7	5.8	5.8	5.9	5.9	6.0	6.1	6.1	21
43	6.1	6.2	6.2	6.3	6.3	6.4	6.4	6.5	6.6	6.6	6.7	20
44	6.7	6.7	6.8	6.8	6.9	6.9	7.0	7.1	7.1	7.2	7.2	19
45	7.2	7.3	7.3	7.4	7.4	7.5	7.6	7.6	7.7	7.7	7.8	18
46	7.8	7.8	7.9	7.9	8.0	8.1	8.1	8.2	8.2	8.3	8.3	17
47	8.3	8.4	8.4	8.5	8.6	8.6	8.7	8.7	8.8	8.8	8.9	16
48	8.9	8.9	9.0	9.1	9.1	9.2	9.2	9.3	9.3	9.4	9.4	15
49	9.4	9.5	9.6	9.6	9.7	9.7	9.8	9.8	9.9	9.9	10.0	14
50	10.0	10.1	10.1	10.2	10.2	10.3	10.3	10.4	10.4	10.5	10.6	13
51	10.6	10.6	10.7	10.7	10.8	10.8	10.9	10.9	11.0	11.1	11.1	12
52	11.1	11.2	11.2	11.3	11.3	11.4	11.4	11.5	11.6	11.6	11.7	11
53	11.7	11.7	11.8	11.8	11.9	11.9	12.0	12.1	12.1	12.2	12.2	10
54	12.2	12.3	12.3	12.4	12.4	12.5	12.6	12.6	12.7	12.7	12.8	9
55	12.8	12.8	12.9	12.9	13.0	13.1	13.1	13.2	13.2	13.3	13.3	8
56	13.3	13.4	13.4	13.5	13.6	13.6	13.7	13.7	13.8	13.8	13.9	7
57	13.9	13.9	14.0	14.1	14.1	14.2	14.2	14.3	14.3	14.4	14.4	6
58	14.4	14.5	14.6	14.6	14.7	14.7	14.8	14.8	14.9	14.9	15.0	5
59	15.0	15.1	15.1	15.2	15.2	15.3	15.3	15.4	15.4	15.5	15.6	4
60	15.6	15.6	15.7	15.7	15.8	15.8	15.9	15.9	16.0	16.1	16.1	3
61	16.1	16.2	16.2	16.3	16.3	16.4	16.4	16.5	16.6	16.6	16.7	2
62	16.7	16.7	16.8	16.8	16.9	16.9	17.0	17.1	17.1	17.2	17.2	1
63	17.2	17.3	17.3	17.4	17.4	17.5	17.6	17.6	17.7	17.7	17.8	0
		9	8	7	6	5	4	3	2	1	0	Degrees of Fah.
	Tenths of Degrees.											

The Centigrade values corresponding with the degrees of Fah., as shown in the right-hand column, require the *minus* sign.

TABLE V.—*continued.*

Conversion of Degrees of Fahrenheit into Centigrade Degrees.
To convert to the ABSOLUTE SCALE add 273° to the Centigrade reading.

Degrees of Fah.		Tenths of Degrees.									
Plus.	Minus.	0	1	2	3	4	5	6	7	8	9
64	0	17.8	17.8	17.9	17.9	18.0	18.1	18.1	18.2	18.2	18.3
65	1	18.3	18.4	18.4	18.5	18.6	18.6	18.7	18.7	18.8	18.8
66	2	18.9	18.9	19.0	19.1	19.1	19.2	19.2	19.3	19.3	19.4
67	3	19.4	19.5	19.6	19.6	19.7	19.7	19.8	19.8	19.9	19.9
68	4	20.0	20.1	20.1	20.2	20.2	20.3	20.3	20.4	20.4	20.5
69	5	20.6	20.6	20.7	20.7	20.8	20.8	20.9	20.9	21.0	21.1
70	6	21.1	21.2	21.2	21.3	21.3	21.4	21.4	21.5	21.6	21.6
71	7	21.7	21.7	21.8	21.8	21.9	21.9	22.0	22.1	22.1	22.2
72	8	22.2	22.3	22.3	22.4	22.4	22.5	22.6	22.6	22.7	22.7
73	9	22.8	22.8	22.9	22.9	23.0	23.1	23.1	23.2	23.2	23.3
74	10	23.3	23.4	23.4	23.5	23.6	23.6	23.7	23.7	23.8	23.8
75	11	23.9	23.9	24.0	24.1	24.1	24.2	24.2	24.3	24.3	24.4
76	12	24.4	24.5	24.6	24.6	24.7	24.7	24.8	24.8	24.9	24.9
77	13	25.0	25.1	25.1	25.2	25.2	25.3	25.3	25.4	25.4	25.5
78	14	25.6	25.6	25.7	25.7	25.8	25.8	25.9	25.9	26.0	26.1
79	15	26.1	26.2	26.2	26.3	26.3	26.4	26.4	26.5	26.6	26.6
80	16	26.7	26.7	26.8	26.8	26.9	26.9	27.0	27.1	27.1	27.2
81	17	27.2	27.3	27.3	27.4	27.4	27.5	27.6	27.6	27.7	27.7
82	18	27.8	27.8	27.9	27.9	28.0	28.1	28.1	28.2	28.2	28.3
83	19	28.3	28.4	28.4	28.5	28.6	28.6	28.7	28.7	28.8	28.8
84	20	28.9	28.9	29.0	29.1	29.1	29.2	29.2	29.3	29.3	29.4
85	21	29.4	29.5	29.6	29.6	29.7	29.7	29.8	29.8	29.9	29.9
86	22	30.0	30.1	30.1	30.2	30.2	30.3	30.3	30.4	30.4	30.5
87	23	30.6	30.6	30.7	30.7	30.8	30.8	30.9	30.9	31.0	31.1
88	24	31.1	31.2	31.2	31.3	31.3	31.4	31.4	31.5	31.6	31.6
89	25	31.7	31.7	31.8	31.8	31.9	31.9	32.0	32.1	32.1	32.2
90	26	32.2	32.3	32.3	32.4	32.4	32.5	32.6	32.6	32.7	32.7
91	27	32.8	32.8	32.9	32.9	33.0	33.1	33.1	33.2	33.2	33.3
92	28	33.3	33.4	33.4	33.5	33.6	33.6	33.7	33.7	33.8	33.8
93	29	33.9	33.9	34.0	34.1	34.1	34.2	34.2	34.3	34.3	34.4
94	30	34.4	34.5	34.6	34.6	34.7	34.7	34.8	34.8	34.9	34.9
95	31	35.0	35.1	35.1	35.2	35.2	35.3	35.3	35.4	35.4	35.5
96	32	35.6	35.6	35.7	35.7	35.8	35.8	35.9	35.9	36.0	36.1
97	33	36.1	36.2	36.2	36.3	36.3	36.4	36.4	36.5	36.6	36.6
98	34	36.7	36.7	36.8	36.8	36.9	36.9	37.0	37.1	37.1	37.2
99	35	37.2	37.3	37.3	37.4	37.4	37.5	37.6	37.6	37.7	37.7
100	36	37.8	37.8	37.9	37.9	38.0	38.1	38.1	38.2	38.2	38.3
101	37	38.3	38.4	38.4	38.5	38.6	38.6	38.7	38.7	38.8	38.8
102	38	38.9	38.9	39.0	39.1	39.1	39.2	39.2	39.3	39.3	39.4
103	39	39.4	39.5	39.6	39.6	39.7	39.7	39.8	39.8	39.9	39.9
104	40	40.0	40.1	40.1	40.2	40.2	40.3	40.3	40.4	40.4	40.5

On this page Centigrade has the same sign as Fahrenheit.

TABLE VI.

TABLE for the CONVERSION of TEMPERATURE READINGS on the FAHRENHEIT and CENTIGRADE SCALES to the ABSOLUTE SCALE.

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

TABLE VII.

PRESSURE VALUES.

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

Mercury Inches.	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09
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	926.1	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
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	1008.8
29°8	1009.1	1009.5	1009.8	1010.1	1010.5	1010.8	1011.2	1011.5	1011.8	1012.2
29°9	1012.5	1012.8	1013.2	1013.5	1013.9	1014.2	1014.5	1014.9	1015.2	1015.6
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

Thousandths of an inch.

Inch.	'001	'002	'003	'004	'005	'006	'007	'008	'009
Millibars ..	'0	'1	'1	'1	'2	'2	'2	'3	'3

TABLE VIII.

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

Milli- bars.	0	1	2	3	4	5	6	7	8	9
	Mercury Inches.									
910	26·87	26·90	26·93	26·96	26·99	27·02	27·05	27·08	27·11	27·14
920	27·17	27·20	27·23	27·26	27·29	27·32	27·35	27·38	27·41	27·44
930	27·46	27·49	27·52	27·55	27·58	27·61	27·64	27·67	27·70	27·73
940	27·76	27·79	27·82	27·85	27·88	27·91	27·94	27·97	28·00	28·03
950	28·05	28·08	28·11	28·14	28·17	28·20	28·23	28·26	28·29	28·32
960	28·35	28·38	28·41	28·44	28·47	28·50	28·53	28·56	28·59	28·62
970	28·65	28·67	28·70	28·73	28·76	28·79	28·82	28·85	28·88	28·91
980	28·94	28·97	29·00	29·03	29·06	29·09	29·12	29·15	29·18	29·21
990	29·24	29·26	29·29	29·32	29·35	29·38	29·41	29·44	29·47	29·50
1000	29·53	29·56	29·59	29·62	29·65	29·68	29·71	29·74	29·77	29·80
1010	29·83	29·86	29·89	29·92	29·94	29·97	30·00	30·03	30·06	30·09
1020	30·12	30·15	30·18	30·21	30·24	30·27	30·30	30·33	30·36	30·39
1030	30·42	30·45	30·48	30·51	30·53	30·56	30·59	30·62	30·65	30·68
1040	30·71	30·74	30·77	30·80	30·83	30·86	30·89	30·92	30·95	30·98
1050	31·01	31·04	31·07	31·10	31·13	31·16	31·18	31·21	31·24	31·27

Differences for tenths of a millibar.

mb.	·1	·2	·3	·4	·5	·6	·7	·8	·9
in.	·003	·006	·009	·012	·015	·018	·021	·024	·027

APPENDIX VI.

ILLUSTRATIONS OF CLOUD-FORMS.

Figure.

1. Threadlike Cirrus in the Zenith. 1907—July.
2. A tuft of “false” Cirrus. 1910—July 6, 16 h. 55 m.
3. Lenticular mass of Cirro-stratus and Cirro-cumulus with Alto-stratus or Strato-cumulus (with dark shadow) underneath and in front.
4. Cumulus. 1907—June 22, 11 h.
5. Top of Cumulo-nimbus. 1907—June 28, 13 h.
6. Lower part of Nimbus. 1907—May 18, 11 h. 33 m.
7. Veil of Cirro-stratus (Cirrus-haze) with Strato-cumulus in front.
8. Strato-cumulus with Alto-cumulus above it. 1909—January 29, 11 h. 45 m.
- 9-12. Sequence of Cloud-Forms. 1907—February 27, between 14 h. 5 m. and 15 h. 20 m.
- 13-16. Sequence of Cloud-Forms. 1909—February 4, between 10 h. 40 m. and 12 h. 50 m.

GUIDE TO THE CLASSIFICATION OF CLOUD-FORMS.

For the assistance of observers a scheme of classification of cloud-forms in accordance with the international classification is reproduced on pp. viii, ix, from notes of a course of lectures in the University of London, 1908. It is based upon the consideration of the question whether the observer sees merely the extended under surface of a high distant layer, or of a layer, high or low, immediately overhead (clouds seen mostly in plan), or sees the general mass of the cloud at a distance in perspective (clouds seen mostly in elevation or profile). The height and vertical thickness of the clouds become important items from this point of view. Estimates of the heights of the various types are taken from the International Cloud Atlas. In practice it will be found that many forms of cloud of the British Isles which are not easily classified fall under the denomination *Strato-cumulus* as being seen partly in plan and partly in elevation or perspective but at no great height. Whether the scheme of classification is sufficiently exclusive to make the identification independent of the distance from which the cloud is seen is not yet ascertained.

EXAMPLES OF CLOUD-FORMS.

Photographs by G. A. Clarke, Aberdeen Observatory.



FIG. 1. Thread-like Cirrus in the Zenith. 1907—July.



FIG. 2. A tuft of "false" Cirrus. 1910 July 6. 16 h. 55 m.



FIG. 3. Lenticular mass of Cirro-stratus and Cirro-cumulus, with Alto-stratus or Strato-cumulus (with dark shadows) underneath and in front. 1906—Nov. 27, 14 h.



FIG. 4. Cumulus. 1907—June 22, 11 h.

EXAMPLES OF CLOUD-FORMS.

Photographs by G. A. Clarke and Dr. W. J. S. Lockyer.



FIG. 5. Top of Cumulo-nimbus. 1907—June 28, 13 h. (G. A. C.)



FIG. 6. Lower part of Nimbus. 1907—May 18, 11 h. 33 m. (W. J. S. L.)

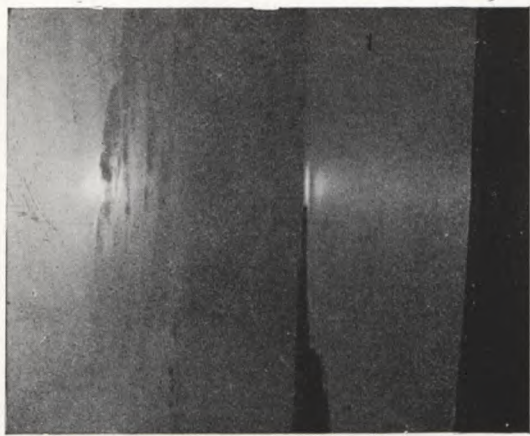


FIG. 7. Veil of Cirro-stratus (Cirrus Haze), with Strato-cumulus in front. (W. J. S. L.)



FIG. 8. Strato-cumulus with Alto-stratus above. 1909—Jan. 29, 11 h. 45 m. (G. A. C.)

[illegible]

1

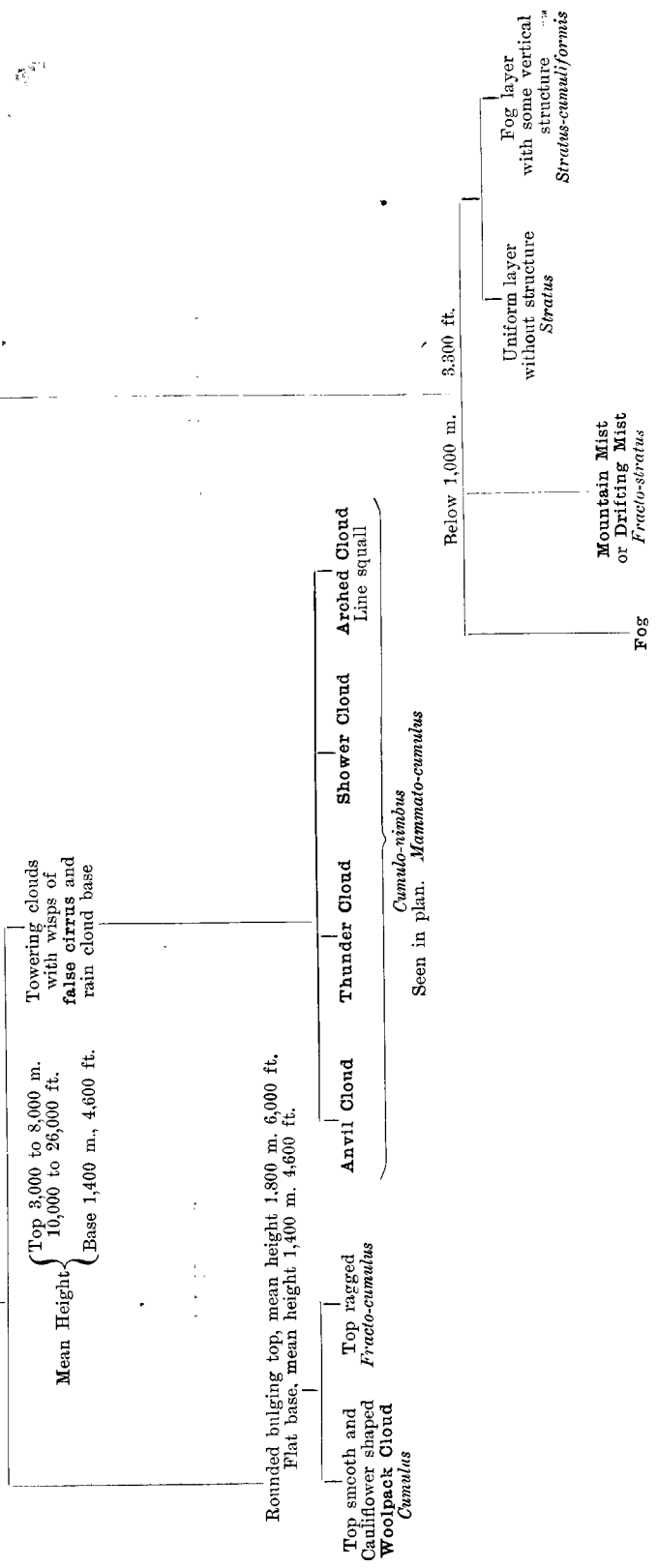
Stratified in a sheet or continuous layer	Stratified in separate but ordered cloudlets forming groups (flocks) in layers, lines, or stripes	Mean Height 9,000 m. 30,000 ft.
Thin veil without shadows (Halo sheet)	Thread or feather clouds Mares' tails <i>Cirrus</i>	
Tangled Web <i>Cirro-stratus</i>	Small Flocks (Fr. Moutons) in groups or lines, no shadows Mackerel Sky <i>Cirro-cumulus</i>	
Thick layer grey or bluish, not rainy (Corona layer) 3,000 m. to 7,000 m. <i>Alto-stratus</i> , 10,000 ft. to 23,000 ft.	Large detached masses with some shadow (Fr. Gros moutons) sometimes contiguous in the middle, with detached small flakes at the edges <i>Alto-cumulus</i>	Height { 10,000 ft. to 23,000 ft. 3,000 m. to 7,000 m.
Shapeless Cloud with ragged edges } Below 2,000 m. or 7,000 ft.	Masses with some vertical structure appearing in rolls or waves sometimes covering the whole sky. Below 2,000 m. or 7,000 ft.	
Rain Cloud with vertical extension <i>Nimbus</i>	Rain Cloud with vertical extension <i>Fracto-nimbus</i>	
Rain Cloud with vertical extension <i>Nimbus-cumuliformis</i>	Roll-cumulus	

CLOUDS SEEN MOSTLY IN ELEVATION OR "PROFILE."

Cloud-Heaps of considerable vertical height.

LOW CLOUDS SEEN IN PLAN OR ELEVATION ACCORDING TO CIRCUMSTANCES.

Fog banks or wreaths, mountain clouds.



SEQUENCE OF CLOUD-FORMS. February 27, 1907.

Photographs by G. A. Clarke, Aberdeen Observatory.



FIG. 9. 14 h. 5 m. Cirrus and Cirro-cumulus.



FIG. 10. 14 h. 10 m. Alto-cumulus.



FIG. 11. 14 h. 20 m. Strato-cumulus.



FIG. 12. 15 h. 20 m. Heavy Strato-cumulus.

SEQUENCE OF CLOUD-FORMS. February 4, 1909.
Photographs by G. A. Clarke, Aberdeen Observatory.



FIG. 13. Cirrus and rippled Cirro-cumulus. 10 h. 40 m.



FIG. 14. Rippled Cirro-cumulus. 11 h. 50 m.



FIG. 15. Cirro-cumulus becoming Alto-cumulus. 12 h. 5 m.



FIG. 16. Alto-cumulus becoming Strato-cumulus. 12 h. 50 m.

NOTE ON THE ILLUSTRATIONS OF CLOUD-FORMS.

The definitions of the typical Cloud-Forms are given in pp. 79 to 81. These definitions are taken from the International Atlas of Clouds which was approved at the International Conference of Directors of Meteorological Institutes and Observatories at Innsbruck in 1905 and published by Gauthier Villars in 1910. It includes a number of carefully selected illustrations of the typical forms reproduced by chromo-lithography, which are intended as a guide to observers as regards the nomenclature of clouds. Copies of the Atlas can be obtained from the Meteorological Office, price 10s.

It was originally intended to make a selection of the illustrations reproduced in the International Cloud Atlas and include copies of them in this volume, but when the Atlas was published it was felt that it would be unjust to the international selection to pick out some and leave others; the international selection must be taken in its entirety as illustrating what the Commission and the Conference meant to be included. Meanwhile it is a matter of common experience that the difficulty of the meteorological observer is not so much in recognising a cloud-form when a typical example occurs as in describing what may be called the every-day sky which is often very composite.

The Meteorological Office has become possessed of a rich collection of beautiful cloud photographs by Mr. G. A. Clarke, of Aberdeen Observatory, showing all kinds of skies, typical and other, for the naming of which the principles of the international classification ought to be an adequate guide. A selection has therefore been made from the photographs included in Mr. Clarke's album and to these names have been given in accordance with the principles of classification laid down in the International Atlas as understood in the Meteorological Office. It is not suggested that the selection includes all the types which an expert meteorologist will recognise.

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The Observer's Handbook. Approved for the use of meteorological observers by the Meteorological Office, the Royal Meteorological Society, the Scottish Meteorological Society, and the British Rainfall Organization. (No. 191.) Issued annually. 3s.

(M) The Computer's Handbook, issued in sections. (No. 223.) The following have been published:—

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Sub-sections II., III. and IV. in one cover. 1s. 3d.

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The Marine Observer's Handbook. (No. 218. 1915.) 3s. (Second Edition 1917.)

A Barometer Manual for the Use of Seamen. A Text Book of Marine Meteorology. With an Appendix on the Thermometer, Hygrometer, and Hydrometer. Fifth Edition, 1916. (No. 61.) 1s.

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(¶) Weather Science. By R. G. K. Lempfert, M.A. T. C. and E. C. Jack. London and Edinburgh. 1912. 6d. (Fcp. 8vo.)

Fishery Barometer Manual. 1887. (No. 3.) 6d. Out of Print, Replaced by the *Seaman's Handbook of Meteorology*, see above.]

Instructions for Meteorological Telegraphy. New Edition, 1914. (No. 2.) Prepared for the use of Observers.

Hints to Meteorological Observers in Tropical Africa, with Instructions for taking Observations, and Notes on Methods of recording Lake Levels. Second Edition, revised 1907. (No. 162.) 9d.

(M) Hygrometrical Tables, based on Glaisher's Tables. 1904. 4s. 6d. [Out of Print.]

(¶) Tables for the reduction of Meteorological Observations, published by the Indian Meteorological Department. 2s.

FORECASTING :—

Aids to the Study and Forecast of Weather.—By W. Clement Ley, M.A. (No. 40. 1880.) 1s. [Out of print]. The subject is now dealt with in *The Seaman's Handbook of Meteorology* (q.v.).

Principles of Forecasting by means of Weather Charts.—By the Hon. Ralph Abercromby, F.R.Met.Soc. Second Edition, Revised, 1885. (No. 60.) [Out of print.]

(M) The Weather Map.—An Introduction to Modern Meteorology. By Sir Napier Shaw, F.R.S., Director. (No. 225i, 1917.) 4d. (Royal 16mo.)

(M) Meteorological Glossary, in continuation of The Weather Map. (No. 225ii, 1917.) 8d. (Royal 16mo.)

(¶) Forecasting Weather.—By W. N. Shaw, Sc.D., F.R.S. Constable and Co., Ltd., 1913. 12s. 6d. (Demy 8vo.)

Note.—Chapters on Atmospheric Pressure distribution and Weather Conditions and Anticipation of Weather by observations at a single station, appear in *The Seaman's Handbook of Meteorology* (q.v.).

TERRESTRIAL MAGNETISM :—

(¶) Studies in Terrestrial Magnetism.—By C. Chree, Sc.D., F.R.S., Superintendent of Kew Observatory. Macmillan & Co., Ltd., 1912. 5s. net. (Medium 8vo.)

2. **Reports of Investigations in Dynamical and Statistical Meteorology and other Memoirs.**

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Report on the Storm of October 13-14, 1881. By Robert H. Scott. F.R.S. (No. 46. 1882.) 1s. 6d. [Out of print.]

Report of an Inquiry into the Connection between Strong Winds and Barometric Differences.—By Robert H. Scott. (Non-Official, No. 1. 1868.) 6d. (8vo.)

Report to the Committee of the Meteorological Office on the use of Isobaric Curves.—By Captain H. Toynbee, F.R.A.S. (Non-Official, No. 3. 1869.) [Out of print.]

Barometric Gradient and Wind Force. Report to the Director of the Meteorological Office by E. Gold, M.A., Fellow of St. John's College, Cambridge, Superintendent of Instruments. (No. 190. 1908.) 2s. 6d. (4to.)

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The Free Atmosphere in the Region of the British Isles. First Report, by W. H. Dines, F.R.S., with an Introduction and Note on the Perturbations of the Stratosphere, by W. N. Shaw, Sc.D., F.R.S., Director. (No. 202. 1909.) 2s. 6d. (4to.)

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The Beaufort Scale of Wind-force. Report of the Director of the Meteorological Office upon an Inquiry, with a Paper by G. C. Simpson, M.Sc., and Notes by Sir G. H. Darwin, K.C.B., F.R.S., W. H. Dines, F.R.S., and Commander Campbell Hepworth, C.B., R.N.R., Marine Superintendent. (No. 180. 1906.) 1s. 6d. (4to.)

Harmonic Analysis of Hourly Observations of Air Temperature and of Pressure at British Observatories. (No. 93. 1891.) 12s. (4to.)

The Trade Winds of the Atlantic Ocean. By M. W. Campbell Hepworth, C.B., Commander, R.N.R., J. S. Dines, B.A., and E. Gold, M.A. (No. 203. 1910.) 3s. (4to.)

(M) AERONAUTICS :—

Report on Wind Structure. (8vo.) (No. 4. 1912–13.) 1s. 6d.

[Nos. 1, 2, and 3 are out of print as separate copies.]

From Reports of the Advisory Committee for Aeronautics.

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