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**M.O. 218. (3rd Edition.)**

[SUPPLEMENT No. 1.]

AIR MINISTRY.

**METEOROLOGICAL OFFICE.**



SUPPLEMENT No 1

TO THE

# Marine Observer's Handbook

(THIRD EDITION).

These corrections, up to January, 1922, should be cut out and pasted into the appropriate pages of the Marine Observer's Handbook, 3rd Edition, 1921.

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The Hollerith Electrical Sorting and Tabulating machine, which was used extensively for working up the last census of population in Great Britain, has been introduced in order to facilitate the computation of mean values from the observations received. Observations in logs are coded into a series of figures which are punched out from specially printed cards. These are stored in geographical order and according to date. When a sufficiently large number of cards have been so punched they are put into the Hollerith machine, which sorts them into the ten degree square in which each set of observations falls. Then, by further sorting, they can be divided into one degree squares, and after that by further sortings they can be grouped according to wind direction and wind force, or for any other element. Another machine can deal in a somewhat similar way with the barometric pressure and the temperature or any numerical values, adding up the sum punched on the cards and recording the number of cards passed through, from which figures are derived the mean pressure and temperature.

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**Cyclone Forms.**—M.O. Form 119 has been introduced for all ships which do not keep a full Meteorological Log, in order that as many observations as possible may be obtained from ships which encounter tropical cyclones. These are supplied on application. They are ruled for observations of the main meteorological elements.

*Page 23—after line 6 insert :—*

In order to keep a check on the index errors of official barometers and to obtain the errors of ships' barometers, both aneroid and mercury, the blue post-card method was devised. These post-cards, M.O. Form 125, accompany every log or form, and should be filled in in port and sent to the Marine Division at the end of each voyage. The index error will then be worked out and forwarded to the ship.

*Page 52—delete lines 14 to 30, and substitute :—*

The following visibility scale has been introduced as from March 1st, 1922, in order to conform to the agreement reached for land observations by the International Meteorological Committee in September, 1921.

## SPECIMEN OF CODED LOG.

## Meteorological Log kept on board ss Port Augusta

DATE		Latitude		Longitude		Current when observed at short intervals	Course and Distance		Total Compass Error	Ship's Head	Wind, at the time of observation	Barometer, No. 1428		Thermometers	
Year	Month	Observed	Dead Reckoning	Observed	Dead Reckoning		Each four hours					Height of Glass above Sea	Dry	Wet	
1920	Oct.														
	10														
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.															
Day	Hour	True Course		Distance by Log		Of Compass used for Wind, being Variation and Deviation combined		By which Compass or Wind		Direction, State if true, or subject to Compass Error, or only to Variation		Uncorrected Reading	Atm. Therm.	Bar. Therm.	Wet Bulb
05	5	4		3											
	4	4		3			S48W 31								
	2	4		3											
	8						" 36								
	3	3		4											
O.M.T.	NOON	3 44	3 35	84 09	84 15		" 37								
(Current in last 24 hours N. 50 E. 8 mile)															
	4														

## Captain Allen from Panama to Auckland

Hour.	Clouds, at time of observation.		Weather, at time of observation.		Sea Surface.						Remarks.
	The direction from which the clouds are coming should be noted when determinable.		Amounting to Barnett's Notation.	Wind, Force or Intensity, by Sea Scale.	Waves.		Swell.		Surf by Sea Scale.	Spec. Gen. by No.	
					Direction from 0 to 180.	Dis- tance from 0 to 10.	Direction from 0 to 180.	Dis- tance from 0 to 10.			
Name.		Time of Day.	Time of Night.	Mark give any important Remarks as to phenomena, with the times of their occurrence; especially the time of Change in Direction and Force of Wind, as well as the Direction, Force or Shaking, Force and Direction of Squalls; the Position of Ice and of Drifts. Also note the hour at which the Ship arrives in her home Port. (See "Master Observer's Handbook" for further particulars.)							
Upper.	Lower.			Also record when Confused.							
4	RR	6R	R	0000	X	20	5	18	4	79	XXO
		St-Cu	10	0		SW	5	SSW	4	79	
8	3R	RR	6	0000	X	18	4	18	4	78	XXO
	Ci-Cu		6	bc		SSW	4	SSW	4	78	
NOON	R5	6R	R	0000	X	18	4	18	4	78	XXO
	A-St	St-Cu	10	0		SSW	4	SSW	4	78.5	

SPECIMEN OF CORRESPONDING  
PUNCHED CARD

4. 8 M. 5TH OCTOBER, 1920.

A.M. Form 789.		12 Square		Day	Water	Sub-Square	Wind Direction	Wind Force	Barometer	Dry Bulb	Wet Bulb	Upper Middle Lower	Weather B.	Sea Direction	Swell Direction	Sea Temperature	Cloud	Mo. Len	Amount
Year	Mo.	1	2																
1920	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9



## Visibility Scale.

### *Specification for Use at Sea.*

- 0 Dense fog.—Objects not visible at 50 yards.
- 1 Thick fog.—Objects not visible at 1 cable.
- 2 Fog.—Objects not visible at 2 cables.
- 3 Moderate fog.—Objects not visible at  $\frac{1}{2}$  mile (nautical).
- 4 Thin fog or mist.—Objects not visible at 1 mile (nautical).
- 5 Visibility poor.—Objects not visible at 2 miles (nautical).
- 6 Visibility moderate.—Objects not visible at 5 miles (nautical).
- 7 Visibility good.—Objects not visible at 10 miles (nautical).
- 8 Visibility very good.—Objects not visible at 30 miles (nautical).
- 9 Visibility exceptional.—Objects visible more than 30 miles\*

*Page 75, line 16—for “ knots ” read “ miles.”*

*Page 75, after line 23 insert :—*

It is requested that the following particulars should be recorded at the end of each passage :—

Was the speed measured by Log or Revolutions ? .....

State of Loading, Light or Deep ? .....

Was the Propeller immersed ? .....

General Remarks as to reliance which may be placed on observations .....

.....

---

The following meteorological office publications and reports are affected by this change of visibility scale and should be corrected accordingly.

1. Western Seaboard W/T Report broad-casted from Poldhu.
2. Provisional International Codes for weather. Reports from Ships at Sea. Form 138A.







3. Meteorological Rough Book. M.O. Form 133.
4. Meteorological Logs. M.O. Form 131.
5. Lighthouse Registers. M.O. Form 135.
6. Cadet's Meteorological Log. M.O. Form 134.
7. Ship's Meteorological Report. M.O. Form 121.
8. Telegraphic Reports from Cross-Channel Steamers, p. 5
9. Observations of Air and Sea Temperature Wind and Weather. M.O. Form 129A.
10. Weather Forecasting in the Eastern North Atlantic and Home Waters for Seamen. M.O. 246.
11. Marine Observer's Handbook. M.O. 218, p. 52.
12. The Seaman's Handbook of Meteorology. M.O. 215, p. 55.
13. The Weather of the British Coasts. M.O. 230, p. 40.

Marine Division,  
Meteorological Office.  
January, 1922.

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1922.

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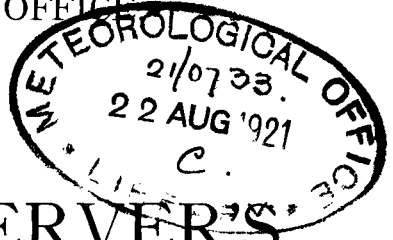
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M.O. 218. (3rd Edition.)

AIR MINISTRY.

METEOROLOGICAL OFFICE



THE

# MARINE OBSERVER'S HANDBOOK.

THIRD EDITION.

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*Issued by the Authority of the Meteorological Committee.*

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# MARINE OBSERVER'S HANDBOOK.

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# THE MARINE OBSERVER'S HANDBOOK.

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## 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. Wireless telegraphy has placed in the hands of the navigator a means of communication whereby he can ascertain weather conditions from ships ahead and around him. By the synoptic method he can thus foretell with some degree of certainty the probable changes of wind and weather in the near future, which enable him to use the high speed of his vessel with greater economy. The constitution of the Office has also been altered, and now expenses are chargeable upon the votes of the Air Ministry estimates. Its original purpose, however, 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, who is a Master Mariner, is maintained for this purpose ; the provisions for securing it remain practically unaltered and are as follows :—

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 copper case for sea surface temperature observations ; two hydrometers.

In some cases a rain gauge and a barograph are 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. Applications 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 :—

Liverpool	...	...	(Port Meteorological Officer) Lieut.-Commander G. ff. H. Lloyd, R.N.R., Dock Office.
Cardiff	...	...	Captain J. Weir, Examiner of Masters and Mates, Mercantile Marine Office.
Dundee	...	...	Captain J. A. S. Chalmers, Examiner of Masters and Mates, Mercantile Marine Office.
Glasgow and Greenock	...	...	Captain I. Hayward, R.D., R.N.R., Senior Examiner of Masters and Mates, Board of Trade Office. Captain W. Ellery, Examiner of Masters and Mates, Board of Trade Office.
Hull	...	...	Captain G. A. Williamson, Board of Trade Surveyor's Office.
Southampton	...	...	Captain F. W. Bate, O.B.E., R.D., R.N.R., Board of Trade Surveyor's Office.



Tyne and Wear District.			Captain W. Forrest, Senior Examiner of Masters and Mates, Mercantile Marine Office, South Shields. Captain A. H. Raymer, R.D., R.N.R., Board of Trade Surveyor's Office, Sunderland.
Hong Kong	...	...	Lieut. Commander Sydney Robinson, R.N., Superintendent Admiralty Chart and Chronometer Depot, Hong Kong.
Melbourne	...	...	The Commonwealth Meteorologist.
Vancouver	...	...	T. S. H. Shearman, Esq., Room 40, Post Office Building.

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 connection 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 or Visibility, Sea, Swell, and Sea Surface Temperature ; also Estimates of Set and Drift, due to current experienced between noon and noon, or at shorter 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, etc. For the keeping of the full Meteorological Log instruments are supplied by the Office.

**How Meteorological Logs are dealt with.**—On the receipt of a Meteorological Log in the Marine Division of the Meteorological Office, it is examined and classified accord-

It is found that with the introduction of this mechanical device for extraction, the necessity for neatness in the entries in logs is even greater than it was in the old system, observers are therefore requested to use every care to facilitate the computers' work in this respect. A sample of a coded log and corresponding card is given on Plate A.

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Meteorological Log kept on board ss Port Augusta

DATE	Latitude		Longitude		Current when determined at short intervals	Compass and Distance		Total Compass Error	Ship's Head	Wind, at the time of observation		Barometer, No. 1428		Thermometers	
	Observed	Dead Reckoning	Observed	Dead Reckoning		Each four hours	By Log			Of Compass used for Wind, being Variation and Deviation combined	By same Compass as Wind	Direction, State if free, or subject to Compass Error, or only to Variation	Force, 0 to 12	Uncorrected Reading	Atm. Therm.
Year 1920															
Month Oct.															
Day															
Civil Time	Hour	The D.R. position is checked daily, in addition to that by Observation, but it should be the result of careful estimation, in order to give any value to the estimation of the current.				Time Consumed	Distance by Log			True.		Height of Clouds above Sea 26 feet.		265.8 265.7	
05	5	1	4	3			548W 31			20	SW	05	1010.7	76	74
009		4								05	SW	5	1014.2	76	73.5
		2	4	3			" 36			18	SSW	04	1012.4	78	74
009		8								04	SSW	4	1016.0	78	74
		3	3	4			" 37			18	SSW	04	1012.9	80	75
009	G.M.T.	NOON	3 44.4 3 30.0		84 09 W 84 15 W					04	SSW	4	1016.5	80	75
		4	(Current in last 2 hours N 50 E 8 mi.)												

Captain Allen from Panama to Auckland

Hour	Clouds, at time of observation		Weather, at time of observation		Sea Surface		Remarks	
	Upper	Lower	Wind	Direction	Waves	Swells	Remarks	Remarks
4	RR	GR	R	0000	X	20 5 18 4	79	XXO
8	RR	GR	R	0000	X	18 4 18 4	78	XXO
NOON	RR	GR	R	0000	X	18 4 18 4	78.5	XXO

SPECIMEN OF CORRESPONDING  
PUNCHED CARD

4 P.M. 5TH OCTOBER, 1920.

A.M. Form 789.											
Year	12	Square	Day	Wet	Sub	Wind	Wind	Barometer	Dry	Wet	Wind
11	11	11	11	11	11	11	11	11	11	11	11
0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9	9	9



## **PART I.—INSTRUMENTS AND INSTRUMENTAL OBSERVATIONS.**

---

### **CHAPTER I.**

---

#### **THE HANDLING OF INSTRUMENTS.**

Meteorological instruments are very delicate to handle, and the packing and transporting cause the breaking of a certain percentage ; these notes on the care and packing of instruments are given in order to impress on all observers the necessity of causing as few replacements as possible.

Instruments are supplied either by the Meteorological Office or its agents, and are delivered by hand to ships. The barometer will be found in its specially designed box, the thermometers and hydrometers in theirs.

Instruments, when not in use, and especially spare instruments that are stowed for perhaps a considerable period, should be inspected occasionally, and the store in which they are placed must have certain requisite qualities. It is of course, essential that no instrument should be placed in a position, where it might be jarred accidentally. Hydrometers especially must be kept in a place that is not liable to become too hot. The scale of these instruments is retained in position by a small quantity of wax, which has been known to melt when the instruments were stowed in a locker that became over hot in the Red Sea.

Any accident to any instrument, even if no apparent damage is done to it, should be reported to the Meteorological Office. The constants of the instrument may well have been altered without any apparent difference in its working.

On no account should a barometer or any other instrument belonging to the Meteorological Office be sent to an instrument maker for repair, or an attempt be made to repair the instrument on board the ship. All damaged instruments should be returned by hand to an agent for the office at ports where there are such agencies; or direct to the Meteorological Office from ports in Great Britain where no such agency exists. Instructions for their return are given on p. 8.

### **The Position for Instruments on Board Ship.**

It is impossible to lay down any fixed rules as to the position selected for instruments on board ship, as the best exposure will vary with different ships. The main points to be observed in deciding on the position for all instruments are as follows :—

They must not be exposed to suddenly varying conditions due to local causes, such as sudden draughts of air or sudden changes of temperature.

They must not be exposed to the direct rays of the sun.

They must be out of the way of unauthorised persons.

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

In addition to these a special point to be observed for the barometer is :—

It should not be too high up in the vessel; to minimise pumping it should be near the centre of gravity.

The thermometer screen requires to be on deck in such a position that it will record the shade temperature and shall be free from spray. In the tropics heat reflection takes place freely from sunny decks and off brightly polished metal. The thermometer screen should be protected as far as possible from this indirect heating.

Hot draughts or even the warm radiation of the hull may cause errors.

The lighting arrangement should be especially carefully considered to make sure that it cannot affect the temperature of the thermometer.

Usually the bridge in a steamer or the poop in a sailing vessel is the most suitable position for the instruments with the exception of the barometer. For the latter the chart-house is often the most convenient position, but this is not always the best owing to its exposed position and its distance from the centre of gravity of the ship.

### **The Shipping and Unshipping of Instruments.**

**The Marine Barometer** is so constructed that it swings on gimbals and so preserves itself nearly erect, even when the ship is rolling. In order to give the instrument swinging room it is supported by a bracket which is securely screwed on to a bulkhead. The height of this arm should be so regulated that the top of the mercury at its highest probable position should be half an inch or so below the Observer's eye. A barometer that is too high is almost certain to cause errors of parallax.

The bracket having been screwed to the bulkhead, the instrument should be carefully lifted 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 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 its bracket, and bring it gradually into an inclined position to allow the mercury to flow very gently up to the top of the glass tube, avoiding any sudden movement which would cause the mercury to strike the top of the tube with violence, as the absence of air there makes the force of the blow little different from that of a solid rod of metal, and it might break the tube. The barometer should then be taken lengthwise and laid in its box. To be carried with safety it should be held with the cistern end



upwards, or lying flat; and it must on no account be subjected to jars or concussions. In ships of war barometers should always be unshipped when heavy guns are fired.

**The barograph** when used on board ship should be carried in a cradle slung fore and aft from the deck above, or a Meteorological Office spring suspension bracket may be used. It should be located in a position where it will be least affected by concussion, vibration or movement of the ship. During gunfire the pen's point should be moved from the paper.

**The Louvred Screen** for the thermometers can be simply secured to a bulkhead or may be attached to the rail. It should, if possible, be fixed at a height of about 5 ft. from the deck, so that it is at a convenient height for reading the thermometers.

The back of the screen should not be in contact with a bulkhead, particularly if of steel or iron, but separated from it by means of battens or chocks so as to leave an air space.

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

**The Thermograph** should be slung in a screen on deck in a similar way to the barograph, in a position such that, while not being under the influence of the heat of the ship, it is not exposed to spray.

**How to Pack Instruments for Return.**—Experience has shown the advisability of giving directions for packing instruments; even with the utmost care breakages occur through mishandling in transit, especially when instruments are sent by rail or are transhipped at ports and are so handled by persons unacquainted with their construction.

Instruments should always be packed in the boxes specially designed for them and carefully enclosed in cotton wool or some soft elastic packing, and the boxes should be marked with a bold label "Glass—fragile instruments."

The address of the Office to which instruments should be consigned is Meteorological Office, Exhibition Road, South Kensington, London, S.W.7

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

A barometer of which the inner glass tube is broken, so that mercury is seen to escape from the instrument, should be sent to the Office by passenger train at owner's risk, but before despatch it is very important that all loose mercury should be emptied from the instrument and from its wooden box ; otherwise the mercury will attack the brasswork of the frame and silvering of the scales, causing much damage en route. The loose mercury should be placed in a strong glass or stone bottle, securely corked and packed carefully inside the box.

If it is desired to forward to the Office a mercurial barometer of which the glass tube is unbroken, special arrangements will be necessary to avoid breakage during transit, so that a letter asking for instructions should **first** be sent to the Office.

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## CHAPTER II.

## THE BAROMETER.\*

The barometer is an instrument with which to measure the weight or pressure of the atmosphere. Two kinds are in use for observations at sea, the mercury and the aneroid.

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.

The principle of the mercury barometer was discovered by Torricelli in 1643; but the instrument was not utilised by seamen until a century had elapsed, and its form had undergone several modifications in the interval. A mercury barometer consists of a glass tube closed at one end, which is filled with pure mercury, all air being carefully excluded; the tube is then inverted, and its open end immersed in a small cistern, also containing mercury, so as to prevent air entering the tube. Great care is taken to exclude the air, as its presence, even in minute quantity, will vitiate the readings of the instrument. The pressure of the atmosphere on the surface of the mercury in the cistern maintains the mercury in the tube at a height which corresponds to that pressure, and measurements with the instrument are made by reading the height of the column in the tube above the surface of the mercury in the cistern. A small hole in the upper part of the cistern, H, Fig. 1, admits access to the superincumbent air; and a washer of leather permits of the atmosphere exerting pressure, but prevents the mercury escaping from the cistern. English instruments are graduated either for mercury inches and decimals of an inch, or for centibars and millibars; the average pressure at sea level in the British Isles being 29·92 in., or 1013·2 millibars, though the highest recorded is 31·11 in. or 1053·5 millibars, and the lowest is 27·33 inches or 925·5 millibars.

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

In all mercury barometers of the Kew pattern issued by the Meteorological Office the glass tube is considerably

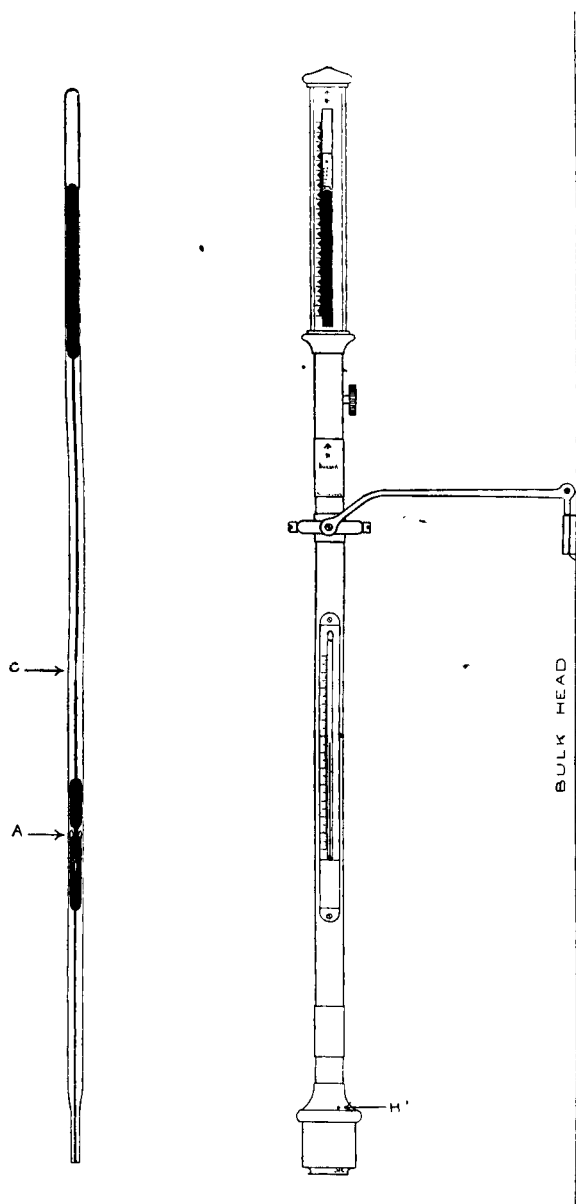


FIG. 1.

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 Measurement of Barometric Pressure in Pressure Units.**

Until quite recently it was the custom to measure the barometer height in inches, that is to say, the weight of the atmosphere being balanced against the weight of a column of mercury, the alteration in the weight of the atmosphere was given in terms of the alteration of the mercury column in length. Meteorology is now being developed along even more scientific lines than formerly, and for the purposes of science it is found that the C.G.S. (centimetre-gramme-second) unit of pressure is not only more truthful but it is more convenient to handle. It is more truthful in that it is not a unit of length but of pressure. This will, perhaps, be more easily understood from considering the following case. If a water barometer were constructed, the height of the column of water that would be required to balance the atmosphere would be about 34 ft. in length and the variation due to a change in pressure of one millibar would not be 0.03 of an inch as it is in the case of a mercury barometer, but would be more in the nature of 0.41 of an inch. The use of the C.G.S. unit is more convenient, since it has been found that to read the barometer to .01 of an inch is barely accurate enough for scientific work, whereas to read to .001 of an inch is not practicable, at any rate at sea. On the millibar scale, however, .1 is a quantity that satisfies our requirements; it is readable and it has a sufficient accuracy.

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 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 in., or 750.1 millimetres of mercury, at the freezing point of water in latitude 45°, and is the normal air pressure at 106 metres 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.

Barometers for the Mercantile Marine, which are issued by the Meteorological Office, were at one time 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. More recent barometers are fitted with millibar scales only.

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

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 p. 14 (Fig. 2). In this diagram the graduation of an inch barometer is also given for comparison.

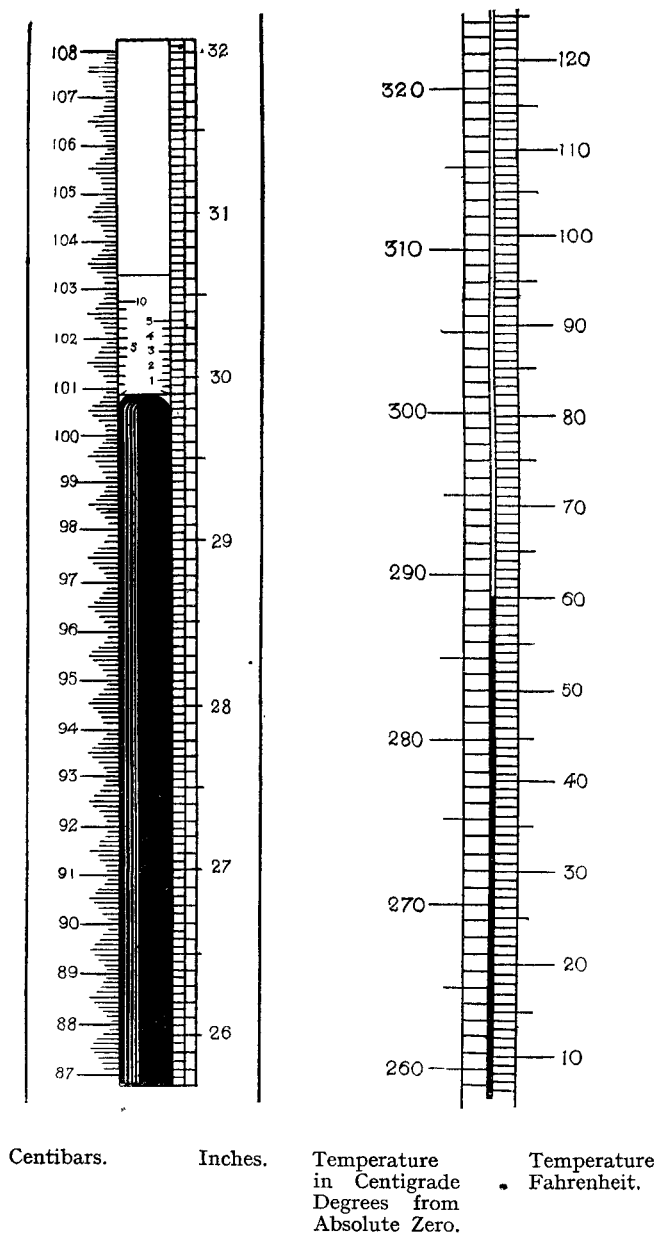


FIG. 2.

**Instructions for Reading a Mercury Barometer of the  
Kew Pattern graduated in Millibars.**

The reading of the attached thermometer should be made before the reading of the barometer, as heat from the presence of the Observer will affect the thermometer more quickly than the barometer. On no account should the barometer be touched before this reading has been taken.

The temperature is read to the nearest whole degree on the scale graduated from about 265a to 305a and is entered in the appropriate column of the register.

After the temperature of the instrument has been read, the barometer may be touched with the hand, but care should be taken to do this as lightly as possible.

Tap gently with the finger until the tapping no longer affects the shape of the mercury surface in the tube. Turn the milled head at the side of the instrument, until the lower edge of the vernier and the lower edge of the sliding piece at the back of the instrument, which moves with the vernier, are in line and appear just to touch the uppermost part of the domed surface of the mercury. If a piece of white paper is placed behind the instrument it assists the eye. Figs. 3 and 4 illustrate this. If the

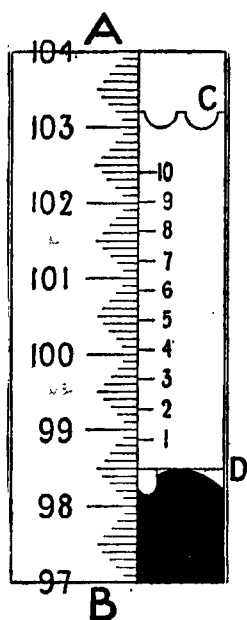


FIG. 3.

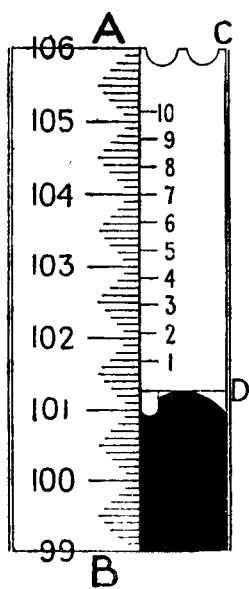


FIG. 4.



eye is not in line with both the bottom of the vernier and the sliding piece at the back, error of parallax will come in, which are illustrated by Fig. 5. The vernier is read in just the same way as that of a sextant. The

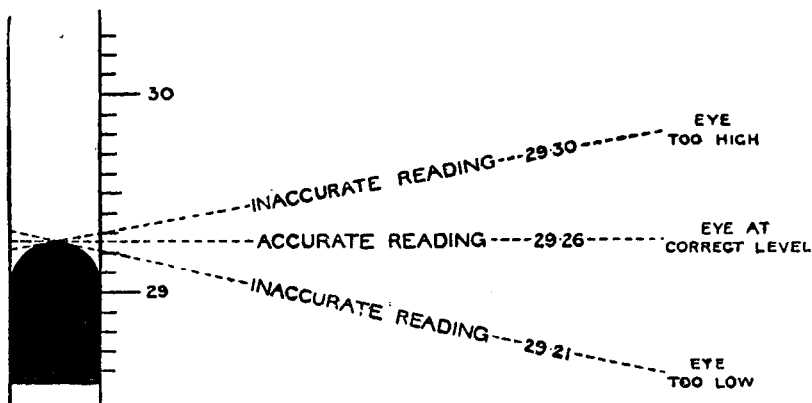


FIG. 5.

reading will be speedily mastered by examining Figs. 3 and 4, that of Fig. 3 being 985.0 millibars and that of Fig. 4 being 1012.7 millibars.

### **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. 13) 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.

The reading of a mercury barometer will give the weight of the atmosphere under certain conditions. These conditions will alter with time and place. The main variations that affect the reading of a mercury barometer are those of

- (a) Temperature ;
- (b) Height above sea level ;
- (c) The value of gravity.

If, however, we reduce our barometer readings for standard values of these factors, then the barometer readings at two places or at two times can be truly compared. To take them in turn :—The temperature of the mercury, which will be the same as that of the whole instrument, will cause the volume of mercury, and thereby its specific gravity, to alter. That will readily be seen, when it is remembered that the mercury in a thermometer expands with heat. The mercury in a barometer will, therefore, rise in the tube with increase of temperature.

As a barometer is taken up above the level of the sea, there is less atmosphere above it ; the weight of the atmosphere is, therefore, by that much the less. So the barometric pressure decreases with increase of height above mean sea level.

The value of the attraction of the earth for any body varies over the earth's surface, owing to the fact that the earth is not a sphere, but has a greater radius at the equator than the poles. So at the equator the weight of a mercury column of given length is less than at the poles. A greater column is, therefore, required to balance the atmosphere, so there the barometer will read too high.

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

With millibar barometers this certificate is put in a slightly different form from that in which it is put with inch barometers. In the latter the index correction is given as so many thousandths of an inch to be added or subtracted from the barometric reading, in the former the *standard temperature* is given ; that is to say, a temperature is calculated at which the reading of the barometer in latitude  $45^{\circ}$  and at mean sea level is comparable with that of any other instrument. If the temperature of the instrument is not at this particular reading, a correction will have to be applied.

If the latitude is not  $45^{\circ}$ , the reading will not be correct at the standard temperature, but there will be a temperature at which the reading would be correct, if it 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 changes with 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.

To make these corrections as simple as possible, tables have been made out and are given on pp. 80-83. They are used as follows :—

The height of the cistern above sea-level having been determined, the table on pp. 80 and 81 is used and the value of the *fiducial temperature* for various degrees of latitude is made out by adding or subtracting the figures given in that table to the *standard temperature*.

These values should be hung up near the barometer, as they will not alter, unless the height of the cistern is changed by an alteration in the draught of the vessel.

Having determined the adjusted fiducial temperature for the suitable latitude, the table on pp. 82 and 83 is used to compare it with the attached thermometer. Enter the table with appropriate attached thermometer reading on the left hand side, and in the column under the appropriate adjusted fiducial temperature will be found the correction in millibars to be applied to the barometric reading.

This table is not absolutely accurate if the barometric pressure is either very high or very low. To correct exceptional readings the rule is "add 1 per cent. of the correction given in the table for each 10 millibars above 1,000 and subtract 1 per cent. for each 10 millibars below."

*Example.*—M.O. Barometer No. 922 has a standard temperature of  $285.0^{\circ}$  at 1,000 millibars. In latitude  $32^{\circ} 39' N$  the reading of the barometer was 1016.9 mb., and of the attached thermometer 293a. The height of the barometer cistern was 42 ft. above sea-level.

Forty-two ft. being about half-way between 40 and 45 ft., from the table on p. 80 we find that for this height in latitude  $32^{\circ} 39'$  to get the adjusted fiducial temperature we must add  $2.4^{\circ}$ , which makes it  $287.4^{\circ}$ .

Then by the table on p. 83 the row marked 293a for the attached thermometer meets the column marked 287a for the adjusted fiducial temperature in  $-1.0$  mb.

The corrected barometer reading is then 1015.9 mb.

### **Slide for Use with Mercury Barometers, reading in Millibars.**

Recently a slide has been devised to be attached to the barometer in order to facilitate these computations.

The slide is intended to serve the purpose of the correction and reduction tables used for obtaining pressure at sea-level from the actual readings of the barometer and thermometer. The corrections are three in number :—

1. The temperature correction.
2. The correction for the variation of gravity with latitude.
3. The reduction to sea-level.

The slide affects the corrections with varying degrees of exactness thus, correction (1) is allowed for exactly under all conditions if we assume that the reading of the attached thermometer really gives the temperature of the instrument; correction (2) is effected exactly only when pressure is nearly 1,000 mb.; and correction (3) is arranged for a mean temperature of the air column of 285a ( $53.6^{\circ}F.$ ). When the mean temperature differs greatly from this value the reduction to sea-level is not exact, especially if the height of the station approaches 100 ft., the maximum height provided for.

The slide, which may be clamped in different positions by means of two milled-head screws, works between the attached thermometer of the barometer and a fixed scale which is graduated unequally according to the latitude of the place of observation. On the slide itself (Plate I.) are two scales; that on the left is a scale of heights from 0 to 100 ft. above mean sea-level, that on the right is a scale of corrections in millibars and tenths, whole millibars being figured and marked either + or —. To use the slide :—

1. Unclamp and move the slide until the figure on the left-hand side of the scale corresponding with the height of the barometer above the level of the sea is in line with the figure on the fixed scale of latitude corresponding with the latitude of the ship.

2. Clamp the slide in position.

3. Note on the right-hand scale of the slide and with the proper sign the reading in millibars opposite the end of the mercury column of the attached thermometer.

4. This reading is the complete correction required, and has merely to be added to or subtracted from the reading of the barometer.

*Example.*—Barometer 1429. Latitude of ship  $50^{\circ}\text{N}$ . Height of cistern of barometer above sea-level, 40 ft.

The Plate shows the slide set in the correct position. The end of the mercury column in attached thermometer is opposite the graduation  $+0.8$  millibar on the slide. Consequently, the correction for temperature, gravity, and reduction to sea-level is  $+0.8$  mb.

Reading of barometer  $= 1,012.4$  mb.

“ “ “ corrected and reduced to sea-level  
 $= 1,012.4 + 0.8 = 1,013.2$  mb.

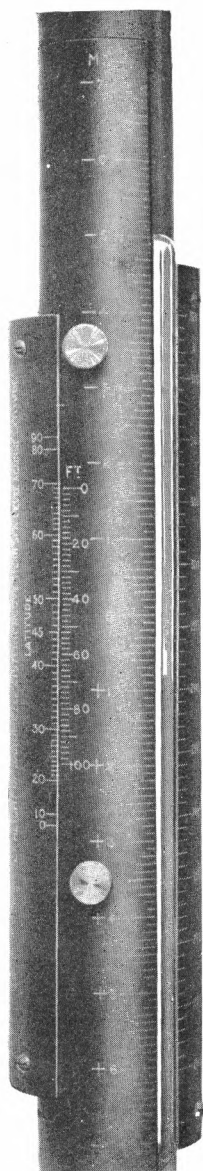
**Note.**—When sailing on an approximately east-west course (as, for example, from the British Isles to North America), sufficient accuracy will be attained if the observer sets the slide to the mean latitude of the voyage; but if sailing on courses where there is more than a small alteration of latitude he should reset the slide accordingly.

### **Instructions for the Use of a Mercury Barometer of the Kew Pattern Graduated in Inches.**

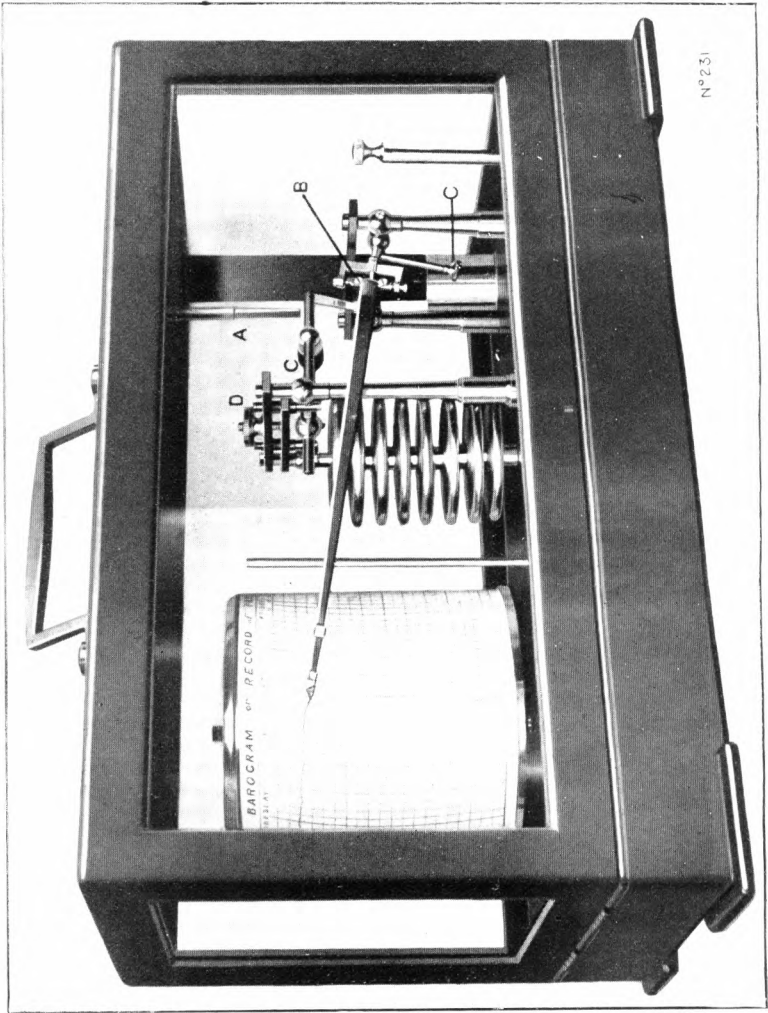
Although it is hoped that the pressure unit (the millibar) will in time entirely supersede the length unit (the inch) for the measurement of all barometric heights, there are still in use so many inch barometers that a very brief description will be given here of the method of reading and correcting them.

Precisely the same precautions have to be observed in setting the instrument as have already been referred to for the millibar barometer (p. 15). The vernier is read in just the same manner also with the exception that the scale being ruled in inches the vernier is divided to read in half-hundredths of an inch, that is to say, to  $.005$  in. The divisions on the fixed scale are each  $.050$  in. 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 should be attempted.

Tables of correction for temperature, height and gravity are given at the end of the book. In addition to these the index correction must not be forgotten. The causes of these corrections have already been explained in the case of the millibar barometer. The corrections in the case of the inch barometer, however, have simply to be added to, or subtracted from the reading.



SLIDE FOR USE WITH MERCURY BAROMETERS READING  
IN MILLIBARS.



THE BAROGRAPH

**Errors in Reading the Barometer.**

The most dangerous error that can be made in reading the barometer is that of making an actual mistake of 10 mb. or 1 mb. The only means of guarding against that is care. After a reading has been entered in the rough book, it should be checked to make sure that no misreading has been made. In making the first reading attention should be concentrated on accuracy in the record of the decimals, in the check reading attention should be concentrated on the tens and units.

*Parallax* has been mentioned on p. 16 ; it is due to insufficient care being taken that the eye is at the same level as the top of the mercury column, when setting the vernier.

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

When a ship is in a seaway, it will be observed that the mercury of the barometer oscillates up and down in the barometer tube ; this is termed *pumping*. This is due to the following causes :—

- (a) The mobility of the mercury being acted on by the heaving of the ship, and her vibration.
- (b) The mercury being acted on by the rocking of the instrument.
- (c) The effect of the wind gusts on the air pressure of the room in which the barometer is hung.
- (d) The variation of atmospheric pressure following the change of height of the ship above mean sea-level due to her vertical motion on the waves.

Of these (a), (c) and (d) are oscillations about a mean position, the mercury being as likely to be high as to be low, while for (b) the oscillation will be always above the true position. For many years this latter was considered to be of such preponderating importance that the cases (a), (c) and (d) could be neglected and accordingly it was impressed on observers that the lowest position should be taken. This decision was incorrect for, though the mean position between highest and lowest reading



will be in excess of the true value, the error will not be so great as that involved in taking the lowest value. In future, observations should, therefore, be recorded for the mean position, to obtain which the vernier should be set by eye midway between the highest and lowest positions of the mercury column. Observers who wish to obtain a more exact mean should take three pairs of readings, in each pair one being of the highest reading obtainable and one of the lowest and the result recorded being the mean of the whole set. Thus, if observations were obtained as follows :—

<i>Highest Reading.</i>		<i>Lowest Reading.</i>
1007·6 mb.	..	1006·5 mb.
1007·5 mb.	..	1006·6 mb.
1007·7 mb.	.	1006·6 mb.

The mean reading would be 1007·1 mb.

An ordinary barometer with a tube of wide bore is so much affected by pumping that no useful reading is possible in a seaway. To obviate this, however, the tubes of marine barometers are constricted ; this lengthens the period of the oscillation of the mercury and thereby damps down the effect of pumping to a large extent. One result of this constriction is that a lag is introduced in the movement of the mercury column, but this is seldom serious.

### **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 of the watch, 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 future.

*Page 23—after line 6 insert :—*

In order to keep a check on the index errors of official barometers and to obtain the errors of ships' barometers, both aneroid and mercury, the blue post-card method was devised. These post-cards, M.O. Form 125, accompany every log or form, and should be filled in in port and sent to the Marine Division at the end of each voyage. The index error will then be worked out and forwarded to the ship.

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 a combined result, and makes allowance for both height and index error.

### The Sea Barometer.

At the Meteorological Office a new dial has been introduced for aneroid barometers intended for use at sea, of which a representation is given in Fig. 6. The

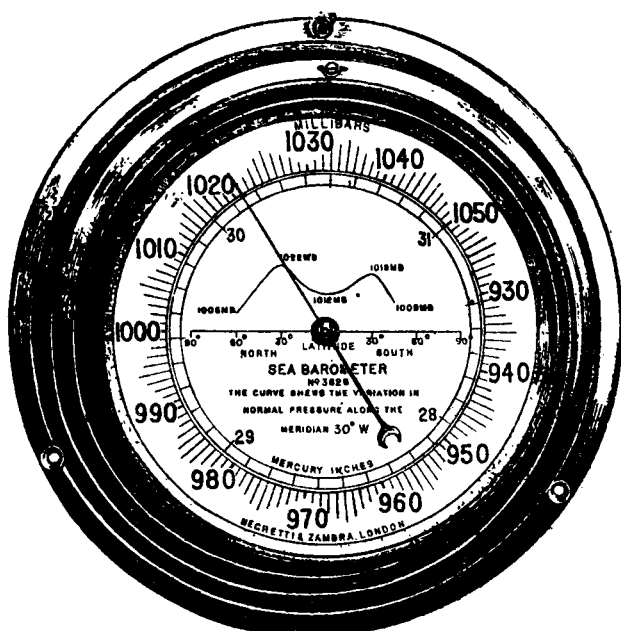


FIG. 6.

graduations are shown in "millibars," 1,000 millibars being the standard atmosphere in the C.G.S. (centimetre, gramme, second) system of units. On the barometer dial, graduation in inches is also shown, and it will be seen that the pressure of 100 centibars corresponds very nearly with that of  $29\frac{1}{2}$  in. The dial shows a range from below 93 centibars ( $27\frac{1}{2}$  in.) to 105 centibars (31 in.), 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 this special form of instrument, a curve is given which indicates the *mean annual pressure* in certain degrees of latitude along the meridian of  $30^\circ$  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 (Plate II.), 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, show 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 connection that exists between weather changes and variations in barometrical pressure.

The action of the barograph, briefly, is as follows :—

The circular metallic chamber, consisting of a series of vacuum metal boxes with elastic lids, is connected with the revolving drum by means of a lever carrying a pen 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.

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.

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 originally set.

The rule should be to keep Greenwich Mean Time throughout the voyage. Time marks should be made each day at noon by ship's clock, when the other meteorological observations are made, and against each time mark should be entered the date and the latitude and longitude. The *corrected* height of the mercurial barometer should also be added.

It should be clearly stated on each barogram that the instrument was set for G.M.T., and the latitude and longitude at noon should be entered after the record has been removed.

For the purpose of making time marks all barographs issued by the Meteorological Office have a small lever termed a time marker which on being depressed moves the pen slightly.

Barograph and thermographs require constant attention and care. The thermograph being of necessity out of doors and so exposed to the moisture in the air, will frequently require to be cleaned.

The following notes are applicable to all self-recording instruments. Friction between the working parts of the apparatus must be avoided as far as possible. The bearings should be cleaned occasionally and oiled with a good clock oil, care being taken to remove excess of oil.

The most serious friction generally occurs between the pen and paper on which it writes. The pen should be well washed from time to time in water or methylated spirit.

A thin, clear trace should be aimed at, for if the trace be thick and blurred many of the smaller variations, which are most interesting meteorologically, become obliterated.

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

Excess of ink should be avoided. Special care must be taken not to let ink come in contact with the metal style which carries the pen, as this will cause the pen to adhere firmly to the style, so that it cannot be removed and cleaned. The ink may also cause the metal to become brittle and break. Should the style be accidentally inked, it should be immediately washed and slightly oiled. The pressure of the pen on the paper should be reduced to the minimum consistent with a continuous trace for which simple contact with the paper will suffice.

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

## CHAPTER III.

THERMOMETERS, HYGROMETER, HYDROMETER,  
AND RAINGAUGE.**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  $-38.2^{\circ}$  Fahrenheit ( $-39^{\circ}$  Centigrade); spirit (pure alcohol) becomes a thick liquid at  $-130^{\circ}$  Fahrenheit, and solidifies into a white mass at  $-202^{\circ}$  Fahrenheit. Almost all substances expand when they are heated, and contract when they are cooled, but they do not all expand equally. Mercury expands more than glass, and so, when the thermometer is heated, the mercury in the bulb expands, and that portion of it that can be no longer contained in the bulb rises in the tube in the form of a thin thread. The tube being very minute, a small expansion of the mercury in the bulb, which it would be difficult to measure directly, becomes readily perceived as a thread of considerable length in the tube. When the instrument is cooled, the mercury shrinks, and the thin thread becomes shorter, as the mercury subsides towards the bulb. By observing the length of the thread of mercury in the tube, as measured by the graduation on the scale at its side, or marked on the tube, the thermometer shows the temperature of the bulb at the time, which 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 ( $32^{\circ}$ ), and at the boiling point of water when the pressure is 29.92 inches of mercury, the reading is two hundred and twelve degrees ( $212^{\circ}$ ). This graduation was adopted by Fahrenheit, a native of Danzig, in the year 1721. Other graduations were devised about 20 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  $100^{\circ}$ . In the modern Centigrade scale, which is an adaption 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  $100^{\circ}$ . Réaumur framed a scale somewhat similar to the Centigrade, but divided the interval between the freezing and boiling-points into 80 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  $273^{\circ}$  Centigrade below the freezing-point of water, or  $-459^{\circ}$  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 use the following rule: Multiply by  $\frac{9}{5}$  and add 32. Similarly, to convert from Fahrenheit to Centigrade: subtract 32 and multiply by  $\frac{5}{9}$ .

In Table VIII. the conversion of temperature readings of the Fahrenheit and Centigrade scales to the Absolute scale is furnished.

The usual range of a thermometer in the shade in the open-air, in England, is about  $60^{\circ}$ , viz., from  $20^{\circ}$  to  $80^{\circ}$ . In very hard frosts the temperature of the air sometimes falls below  $20^{\circ}$ , 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 secured 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

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\* **Radiation** is the process by which heat is transferred from one body to another without altering the temperature of the intervening medium. The earth itself is always radiating into space. During the day normally the earth receives directly from the sun and indirectly from the atmosphere, including the clouds, more radiation than it gives out. At night the reverse is the case (*v.* Meteorological Glossary, p. 330).



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 except in fine, clear weather in the tropics.

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 louvres, so as to let in the air freely.

The annexed engraving (Fig. 7) 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 5 ft. above the upper deck, in the open air, but protected from sun, rain, and spray, and as free as possible from radiation or warm draughts of air from galleys, engine and boiler rooms, stokehold and funnel.

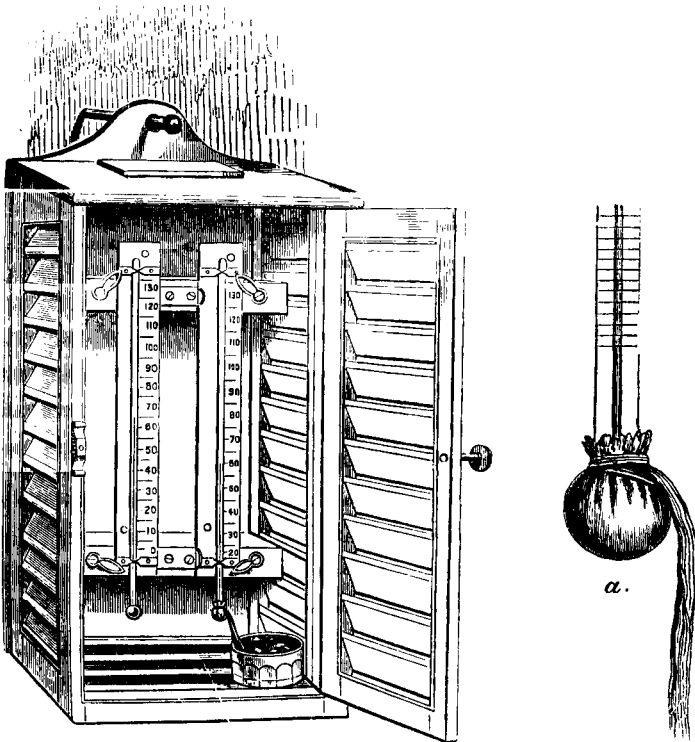


FIG. 7.

A single thickness of fine muslin or cambric should, as before mentioned, be secured 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. 7), 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. 7. 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.

The wet bulb is probably the instrument that needs most careful attention. It has already (p. 29) been explained how the muslin and wick are to be attached to the thermometer bulb. The muslin and wick should be well washed before use in water containing ammonia and occasionally during use. Both should be changed once a month or oftener. The water used should be the purest obtainable, as the effect of the constant evaporation is to cause any impurities to be deposited on the bulb. Should an incrustation be formed on the thermometer, it should be scraped off with a sharp penknife. Should it be thought that spray had reached the instrument the muslin should be at once changed, since the presence of salt in the water will be certain to vitiate the results obtained. The water vessel should be refilled after an observation has been made rather than before, since it takes at least 15 minutes for the instrument to resume its normal position. Care must be taken to see that the muslin is damp but not dripping. The wick must not be allowed to hang down in a bight, or water will drip down from the lowest point of the curve until the reservoir is emptied. If the reading of the wet bulb is above that of the dry, make sure first that there is no error of readings and that there is an excess when the known corrections have been applied. Then see if the moisture has been deposited on the bulb of the dry. If this is the case, wipe the bulb dry and read again after waiting a minute or two for the thermometer to take up the temperature of the air.

If there is no evidence of moisture, make two or three more observations of both instruments at intervals of about two minutes. It will usually be found in that case that the temperature is falling, and that the wet bulb

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\* To secure the strands to the thermometer, take a round turn with the strands middled on the bight and pass the ends through the bight forming a round turn and cow hitch.

eventually falls below the dry, although at first the dry may fall more rapidly than the wet.

In the first of these two cases the peculiarity is due to the fact that the dry bulb is acting as a wet bulb, and is giving a temperature below the true air temperature. This will usually happen when the temperature is rising. In the second case the wet bulb is lagging more than the dry in air in which the temperature is falling, and the wet bulb is reading too high.

The amount by which the temperature of the wet bulb is reduced below that of the dry is found to depend to some extent on the ventilation to which the instrument is exposed. On calm days the observer will frequently be able to reduce the temperature of the wet bulb by a degree or more by fanning it. It is therefore obvious that a screen exposed to the wind will reveal a greater difference than one sheltered behind a deck house.

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 is no coating of ice, it must be first wetted and then allowed time to freeze, before the thermometer is read.

### **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.

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

The sea thermometer and its case should be kept carefully cleaned. It is essential that the bulb of the instrument should be under water at the time of reading, hence the reservoir around the bulb. If it is not covered evaporation will take place from the drops of water adhering to it, and it will tend to act as a wet bulb thermometer.

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

### **Reading Thermometers.**

To avoid errors due to *parallax* (*vide* p. 16) the observer's eye must be at precisely the same height as the top of the mercury column of the thermometer.

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 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 connection 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.

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

From the nature of the case thermographs for meteorological use must be exposed on deck, 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.

The same remarks with regard to the time of setting apply to the thermograph as to the barograph, *q.v.*

### **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 (Fig. 8). It consists of a



FIG. 8.

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 a 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 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, 277a ( $4^{\circ}\text{C.}$ , or  $39\cdot2^{\circ}\text{F.}$ ).

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 of the hydrometer now being issued by the Meteorological Office is graduated from 15 to 35, that is to say, for use in water the specific gravity of which lies between 1·015 and 1·035, which is the range of sea water in almost all parts of the globe, though it may float above this range in parts of the Suez Canal, where the water is extremely salt.

The instrument is used on board ship to show the relative density of different parts of the ocean. 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. This instrument is of great value for ascertaining the change of draught of a ship proceeding to sea from a river, or *vice versa*.

The specific gravity of the sea should be taken in the same water as the sea surface temperature. 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 is read.

It has been defined that specific gravity of a sample of sea water is the relation of its weight to an equal volume of pure water at 277a. Since the volume of water changes with its temperature, it is clear that a correction must be made for temperature, but as glass also changes its volume with changes of temperature, this correction for hydrometers will be modified by this factor. In order to make this correction small the scale on Meteorological Office hydrometers is so arranged that, if the temperature is 288a (59°F.), there is no correction. Table XVI. on p. 99 gives the corrections.

Since the density of sea water depends on its salinity, a more accurate method of determining the specific gravity of a sample is by obtaining its salinity from chemical analysis and then converting this salinity determination into specific gravity by means of a table prepared for this purpose. For this purpose samples are collected and sent to the Board of Agriculture and Fisheries, as it is not practicable to make the chemical analysis at sea.

The hydrometer needs most careful handling to obtain the best results. It is an instrument of which the weight is very nicely balanced and which will, therefore, be made inaccurate by any foreign matter which adheres to it. The hydrometer should be washed occasionally in distilled water and care must be taken that it is always scrupulously clean, all dust smears or greasiness being got rid of by wiping with a clean, soft cloth before and after use. When the ship is in a seaway, it is necessary that the bucket should be hung up and allowed to swing.

Parallax is very likely to occur in reading this instrument and must be watched for. It will be noticed that the surface of the water will be curved up round the stem of the instrument by capillarity. The point of the scale

to be observed is that point which is on a level with the surface of the water, not the highest point to which it is drawn up around the stem. Care should be taken to read the instrument just before the spin has died down and when all up and down motion has ceased.

### The Rain Gauge.

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

The instrument, Fig. 9, which is a 5-in. gauge of the Snowden pattern, consists of a cylindrical funnel (f) having a rim 4 in. 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 (b), which rests on the bottom of the lower cylinder.

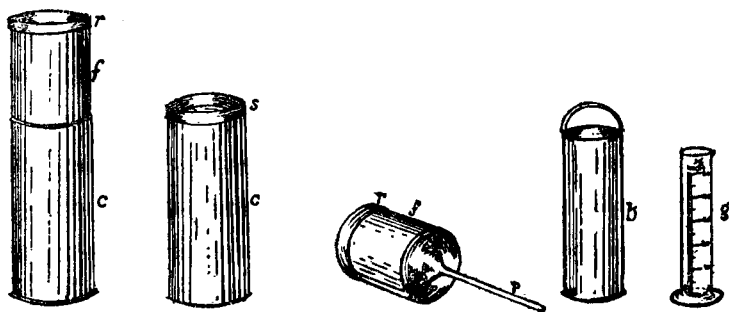


FIG. 9.

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 in. 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 in. deep, the loss of precipitation by splashing is prevented and its collection when in 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 in.) described.



The quantity of precipitation collected by a rain gauge depends to some extent upon its exposure; in order, therefore, that the gauge may be free, when in action, from the sheltering effects of deck houses, skylights, deck furniture, etc., 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 similar to those used for hoisting an oil masthead light.

The instrument is attached to an iron frame, Fig. 10 *a*, by two bands (*bb*) which encircle the cylinder, two tubes (*tt*) forming the sides of the frame.

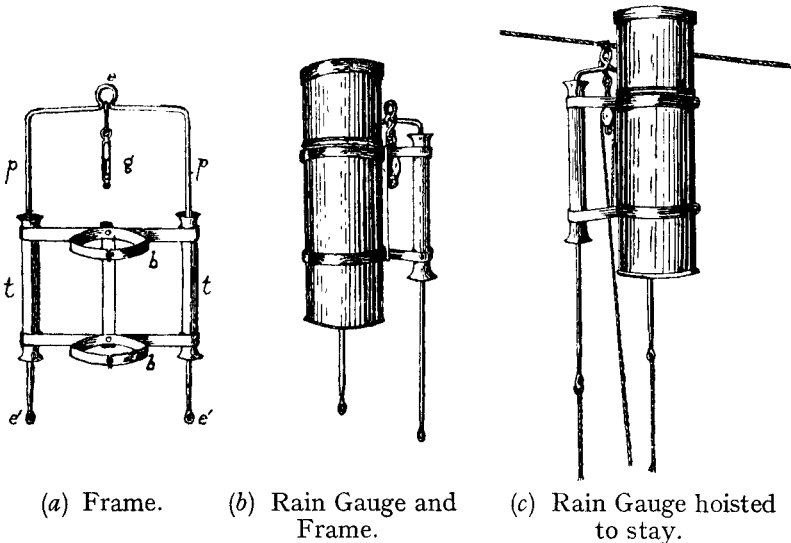


FIG. 10.

A two-pronged fork of bar iron (*pp*) 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.

In Fig. 10 *b*, the rain gauge is shown attached to its frame.

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. 10 *c*).

Should the gauge require steadying when it is in position the guys should be set up rather nearer the ship's side.

It will be noticed that the precipitation in the measuring glass of the rain gauge has not a flat surface but is drawn up at the sides. The scale reading corresponding to the lowest point should be given as the amount of precipitation.

When snow is collected in the rain gauge, it may be melted out by slightly warming the gauge before a fire. An alternative method which is quicker and is useful if snow is falling at the hour of observation is to measure accurately a quantity of hot water, pour it into the gauge to melt the snow, then measure out the total amount of water in the gauge; the result less the quantity of hot water will be the amount of precipitation.

It should be remembered that dew and fog are apt to leave precipitation; this should be measured and recorded.

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## **PART II.—NON-INSTRUMENTAL OBSERVATIONS.**

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### **CHAPTER IV.**

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#### **WIND AND SEA OBSERVATIONS.**

There are certain observations which at present cannot be measured by mechanical means, at any rate at sea. The landsman has the advantage of the sailor in that with the aid of a self-recording anemometer he can obtain a continuous and accurate record of the wind both in direction and force, with a nephoscope he can determine the motion of a cloud; such instruments are not practicable at sea owing to the unsteadiness of the ship. Reliance, therefore, has to be placed on eye observations.

##### **Wind Direction. \***

The direction of the wind is given by the point of the compass from which the wind blows. For meteorological purposes, the true direction is required. The column in the meteorological log should accordingly be carefully headed. If the direction is recorded by the use of cardinal points, endeavour should be made to judge the wind to the nearest point, since for the scientific comparison of the wind observed with the forces which cause it, it is essential that this accuracy should be maintained.

##### **Veering and Backing.**

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

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\* For a discussion of the Causes and Distribution of Wind, *vide* "A Barometer Manual for the use of Seamen," Chapter IV.

“backing,” caused by cyclonic and anticyclonic systems drifting over any place, *vide* “A Barometer Manual for the use of Seamen,” p. 65.)

There is said 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, though seamen spoke of the wind as changing in direction in southern latitudes with the sun, and against the sun in northern latitudes. At the International Conference of Directors of Meteorological Institutes and Observatories, held at Innsbruck in 1905, a question was raised in this connection. 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 specification of the Beaufort numbers is 'as follows :—

## A Combination of Beaufort's Scale and the Modern Specification for use at Sea.

Meteorological Wind Scale.				The Seaman's Wind Scale.			
Beaufort Number.	Average Velocity nautical miles per hour. <i>knots.</i>	Limits of Velocity nautical miles per hour. <i>knots.</i>	Equivalent pressure in pounds upon a circular disc of one square foot.	Seaman's Description of Wind.	Deep Sea Criterion.	Coastal Criterion.	Beaufort Number.
1	2	3	4	5	6	7	8
0	0	Less than 1	Less than .01	Calm.	—	—	0
1	2	1 to 3	.01 to .04	Light air.	Just sufficient to give steering way with the "wind free."*	Sufficient to give good steering way to fishing smacks with the "wind free."†	1
2	5	4 to 6	.05 to .16	Light breeze.	Well conditioned ship with all sail set in smooth water "full and by" will make 2 knots.	Fishing smacks with topsails and light canvas "full and by" make up to 2 knots.	2
3	9	7 to 10	.17 to .44	Gentle breeze.	Ditto, 3 to 4 knots.	Smacks begin to heel over slightly under topsails and light canvas make up to 3 knots "full and by."	3
4	14	11 to 16	.45 to .96	Moderate breeze.	Ditto, 5 to 6 knots.	Good working breeze. Smacks heel over considerably on a wind under all sail.	4
5	19	17 to 21	.97 to 1.75	Fresh breeze.	Ship "full and by" can just carry royals and light staysails.	Smacks shorten sail.	5
6	24	22 to 27	1.76 to 2.88	Strong breeze.	Ship "full and by" can just carry topgallant sails	Smacks double-reef gaff mainsails.	6

7	30	28 to 33	2·89 to 4·43	Mod. gale (half a gale).	Ship "full and by" can just carry whole upper topsails.	Smacks remain in harbour and those at sea lie to.	7
8	37	34 to 40	4·44 to 6·45	Fresh gale.	Ship "full and by" can just carry reefed upper topsails and whole foresail.	Smacks take shelter if possible.	8
9	44	41 to 47	6·46 to 9·00	Strong gale.	Ship "full and by" can just carry lower topsails and reefed foresail.	—	9
10	52	48 to 55	9·01 to 12·16	Heavy gale. (whole gale).	Ship "full and by" can only carry main lower topsail.	—	10
11	60	56 to 65	12·17 to 15·97	Storm.	Ship can only carry storm staysail or trisail.	—	11
12	—	above 65	15·98 and above	Hurricane.	No canvas can stand.	—	12

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

Scale Numbers.

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

The scale numbers are attributed to the wind force at the time of observation by judgment of the observer. For the purposes of the Meteorologist, forces of 8 to 10 only are gales, and what seamen term a moderate gale is called by them a high wind.

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

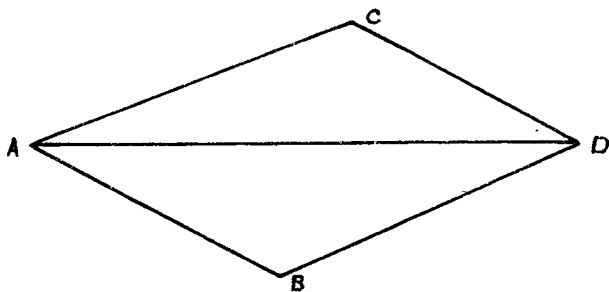
In a steamer the force of the wind may be judged by an experienced observer by the appearance of the sea, remembering that polar winds create more sea than equatorial winds, rain has a smoothing effect, and tides or currents influence the sea surface differently when there is a weather or lee tide or current.

The speed of the ship in a calm, the speed of the ship when the wind is dead aft with same velocity as speed of ship, or the velocity of the wind when the ship is stationary, are the only standards on which the estimate of wind can be based for those who have not sailing ship experience. A hand anemometer, if allowance is made for *all* movements of the ship, may be used with advantage.

\* A modern steel full-rigged ship, with average co-efficient of fineness, deep loaded, with clean bottom.

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

To determine both the velocity and direction of the wind it is found by seamen that the appearance of the surface of the water is of the utmost help. It is not possible to explain in words the criteria for determining the various Beaufort forces by a glance at the waves, but seamen in sailing ships by long practice have learnt to estimate the wind thus with extreme accuracy. The only method of learning thus to read the sea is practice with the aid of one, who is an accurate judge of wind. It should be remembered that, when the wind is dead aft in a steamer, the relation of the ship's speed to the air, through which she is passing, gives a simple means of determining its velocity; but as soon as the wind blows from any direction out of the fore and aft line the problem becomes more complicated. For instance, if the ship is travelling along the line AB with velocity 15 knots, and the wind appears to be coming from the direction DA with velocity 29 knots (Beaufort Scale 7). The true direction of the wind is along CA, and its velocity will be 18 knots. This is most simply got by drawing a figure as below, making BA proportional to 15 and DA proportional to 29 and then measuring DB, which is equal to CA, where ABDC is a parallelogram.



Working it out by trigonometry it is obtained by the formula  $BD^2 = AB^2 + AD^2 - 2 AB \cdot AD \cdot \cos. B.A.D.$  and so the angles from the rule of sines.

**Sea Disturbance.**

The following scale has been adopted for estimating Sea Disturbance :—

<i>Scale.</i>	<i>Description.</i>	<i>Height of Waves, Crest to Trough.</i>
0	Calm .. ..	0
1 } 2 }	Smooth Sea ..	{ less than 1 ft. 1 to 2 ft.
3	Slight Sea ..	2 " 3 "
4	Moderate Sea ..	3 " 5 "
5	Rather Rough Sea	5 " 8 "
6	Rough Sea ..	8 " 12 "
7	High Sea.. ..	12 " 20 "
8	Very High Sea ..	20 " 40 "
9	Precipitous Sea ..	40 ft. and above.

Swell should be denoted by the following provisional characteristics which have been authorised by a commission appointed by the International Maritime Meteorological Conference that met at Paris in 1919.

<i>For Use at Sea.</i>	<i>Abbreviated for Air Service.</i>
No Swell ... ..	No Swell.
Slight Swell .. ..	Slight Swell.
Moderate Swell .. ..	Moderate Swell.
Rather Rough Swell ..	
Rough Swell .. ..	Heavy Swell.
Heavy Swell .. ..	
Very Heavy Swell ..	Very Heavy Swell.
Abnormal Swell .. ..	

These characteristics for swell should be recorded and not a scale of numbers, which have been omitted until these characteristics have been confirmed. Direction of sea disturbance and swell should be observed and recorded. If the swell should present a confused appearance, the word "confused" should be recorded in the direction column together with the chief direction or directions, thus "Confused NE and SE," or "Confused SW."

It will be noticed that the scale for sea disturbance only takes into account the height of the wave, while the characteristics for swell are even more indefinite. The reason for this is that accurately to describe a wave it is necessary to give much more information than can usually be conveniently collected by the officers at sea. The sea disturbance scale and the swell characteristic will afford some useful information, but for those who care to make more thorough observations the following are the main points to be observed as directed by Sir G. G. Stokes :—

**“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.”

**“For an Observer on Shore.”**

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

In connection 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 underway ; 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.

The following method for ascertaining wave heights is described by the late Captain Owen Stanley, R.N., in a letter quoted in the Report of the British Association for 1848, Part II., p. 38, and is probably the best for purposes of Marine Observers :—

"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 waterline will give a 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."

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## CHAPTER V.

## CLOUD AND WEATHER.

**Clouds.**

Cloud observations may be considered under three headings :—

- (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.

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 top).
- (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. (The International Atlas of Clouds is, unfortunately, now out of print.) Some examples are given in Plate IV

**Upper Clouds.**

(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*).

(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 coronæ. 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.

### Lower Clouds.

(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 thunder clouds 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 clouds. 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 facts in the log. If abbreviations be used for the names of the cloud types those given above should be employed.

### **Cloud Motion.**

The direction of motion of clouds should always be stated as the direction from which the cloud is coming. It is best observed by sighting the cloud against a fixed point. At sea such fixed points are difficult to find ; but at night time and when the cloud canopy is broken, stars near the zenith form very suitable fixed points. It should be remembered that the motion of a cloud near the horizon will be distorted by the effect of perspective. This effect will decrease as the zenith is approached. Clouds should not, therefore, be observed for motion that are at a greater zenith distance than  $30^{\circ}$ , unless no observation near the zenith is possible. The speeds of clouds cannot be measured accurately at sea, but the following qualitative scale of velocities should be used :—0 to denote stationary, 1 to denote slow movement, 2 moderate and 3 fast. The method of recording cloud motion that should be adopted is to place the direction of motion underneath the relevant cloud type and a figure of the above scale to denote its

Ci

velocity ; thus ——— 2 means Cirrus Cloud moving from  
NW

north-west at moderate speed, while A-Cu.0 denotes that Alto Cumulus is stationary.

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 log. As far as possible each layer should be observed separately, and its appropriate direction and velocity entered. It is often very difficult to observe the motion of upper cloud without comparing it with the lower. This should never be done. The motion recorded must be the absolute motion of the cloud, not its motion relative to another moving object.

It has been suggested that the following method would give good results :—A cloud is selected, its altitude is measured with a sextant and its bearing by compass. After a lapse of ten minutes the same measurements are again taken. By assuming the height of the cloud according to its type the two positions can be fixed and plotted from either end of a line representing the distance travelled by the ship in the interval between the observation. The line joining the two positions of the cloud so plotted will give the distance that it has travelled in the time.

Attention is directed to the following details :—

*Undulated Clouds.*—It often happens that the clouds show regular striae, parallel and equivalent, like waves on the surface of water. This is mostly the case with the cirro-cumulus, strato-cumulus (roll cumulus), etc. 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 of striae should be taken near the zenith so as to avoid errors of 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., NNE., etc.

### Weather.

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

#### Letters to Indicate the State of the Weather.

†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; <i>i.e.</i> , rain and snow together.
f = fog.	s = snow.
g = gloom.	t = thunder.
h = hail.	u = ugly threatening appearance.
l = lightning.	v = unusual visibility.
m = mist.	w = dew.
	z = dust haze; the turbid atmosphere of fine 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 and 8; o=9 and 10.

It is well to bear in mind that **w** = dew, **d** = drizzle and **e** = wet air without rain ; **p** = passing showers of rain ; **q** = squalls, but **s** = snow ; **z** = dust haze, but **h** = hail ; **v** denotes unusual visibility ; it should be used when *small* objects such as the spars of a lofty vessel are visible at 16 nautical miles and the air is exceptionally clear.

**Precipitation.**—A distinction is drawn on the Beaufort Notation between steady rainfall (**r**), light drizzle (**d**), and passing showers (**p**). The indication of passing showers is useful, and the time of commencement and ending of heavy showers should always be noted. The letter **e** has been added to the Beaufort 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**.

**Visibility and Fog.**—Fog, **f** ; Mist, **m** ; Haze, **z** ; — these three words are used to indicate a deterioration of the transparency of the 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 the use of the word haze should be restricted 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.

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**.

The following scale of Fog Intensity and Surface Visibility has been drawn up by the International Commission for Weather Telegraphy.

#### **Fog and Visibility Scale.**

##### *Specification for use at Sea.*

0. Dense fog.—Objects not visible at 50 yards.
1. Thick fog.—Objects not visible at 1 cable.
2. Fog.—Objects not visible at 2 cables.
3. Moderate fog.—Objects not visible at  $\frac{1}{2}$  mile.
4. Thin fog or mist.—Objects not visible at 1 mile.
5. Hazy. Objects not visible at 2 miles.
6. Horizon not visible from 40 ft (or objects not visible at 4 miles).
7. Horizon only just visible (or objects not visible at 7 miles).
8. Horizon well defined but visibility not exceptionally good (or objects not visible at 20 miles).\*
9. Fog in patches.

The estimation of the state of the atmosphere in regard to visibility is an easier matter for a fixed station on land than it is at sea, because on land a series of objects A, B, C, etc., at known distances from the point of observation can be chosen, and the observer can decide which of the selected objects he can see, and knowing that they are there, those which he cannot see. At sea, so long as he is near land, an observer may see an object at a distance which he can estimate or calculate, and he may know from the chart the distance of other objects which he cannot see, but in the open ocean the only object available is an occasional ship within range of vision.

\* If the visibility is exceptionally good the letter V should be entered in the weather column.



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.

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**.

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Page 52—delete lines 14 to 30, and substitute :—

The following visibility scale has been introduced as from March 1st, 1922, in order to conform to the agreement reached for land observations by the International Meteorological Committee in September, 1921.

### Visibility Scale.

#### *Specification for Use at Sea.*

- 0 Dense fog.—Objects not visible at 50 yards.
- 1 Thick fog.—Objects not visible at 1 cable.
- 2 Fog.—Objects not visible at 2 cables.
- 3 Moderate fog.—Objects not visible at  $\frac{1}{2}$  mile (nautical).
- 4 Thin fog or mist.—Objects not visible at 1 mile (nautical).
- 5 Visibility poor.—Objects not visible at 2 miles (nautical).
- 6 Visibility moderate.—Objects not visible at 5 miles (nautical).
- 7 Visibility good.—Objects not visible at 10 miles (nautical).
- 8 Visibility very good.—Objects not visible at 30 miles (nautical).
- 9 Visibility exceptional.—Objects visible more than 30 miles\*.

which he can estimate or calculate, and he may know from the chart the distance of other objects which he cannot see, but in the open ocean the only object available is an occasional ship within range of vision.

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\* If the visibility is exceptionally good the letter V should be entered in the weather column.

The distance can in that case be estimated by the lapse of time, and run, since she was passed; or perhaps judged by previous experience of the appearance at a distance but the circumstances in which two such vessels would be available, one just gone out of sight and the other visible at a known and suitable distance, are so few that the assignment of visibility to its actual place in the proposed scale is only rarely possible. It is hardly ever desirable to attempt the task by estimating the distance at which the observer can see nothing but water. Scientific observations are only good when they record what is observed, not what is not.

Observers at sea should, therefore, take such opportunities as there are for getting the limiting distances of visibility irrespective of the term-hours for normal observations, for example, the time between a ship happening to come into sight and passing, or between passing and going out of sight, or the time of losing sight of a landmark, the distance of which is known. If no such favourable opportunity offers, it is better not to assign a figure.

In a long steamer the lowest numbers of the scale 0 and 1, can be determined by the length of the ship.

2 and 3 indicate conditions of fog or obscurity of the atmosphere when visibility goes beyond the length of the ship, but is not sufficient for speed, on account of traffic.

4 and 5 indicate conditions when visibility is sufficient to proceed at speed concerning traffic, but when coastal navigation may be difficult.

By the regulations laid down by the Admiralty the distance in nautical miles at which lights are visible in clear weather are calculated on the supposition that the observer's eye is 15 ft. above sea-level, in order that small vessels may see lights at their full calculated range. It is, however, recognised that an observation at 15 ft. above sea-level is not generally convenient in large steamers at the present day. The observer is requested to select a convenient point for this purpose and note in his log for report to this Office the height of the selected point above sea-level, 40 ft. is generally a suitable height, at which height under normal conditions it is possible to see the horizon at about  $7\frac{1}{4}$  miles.

## CHAPTER VI.

## 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. 11\*). The most common is the halo of  $22^\circ$ —a large ring, CIBG, round the sun or moon, having a radius of very nearly  $22^\circ$  (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  $46^\circ$ , Fig. 11, VXYZ, occurs more rarely. Its luminosity is much less than that of the halo of  $22^\circ$ ; 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

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\* Fig. 11 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  $90^\circ$  ; it is known as the halo of  $90^\circ$  In the diagram two

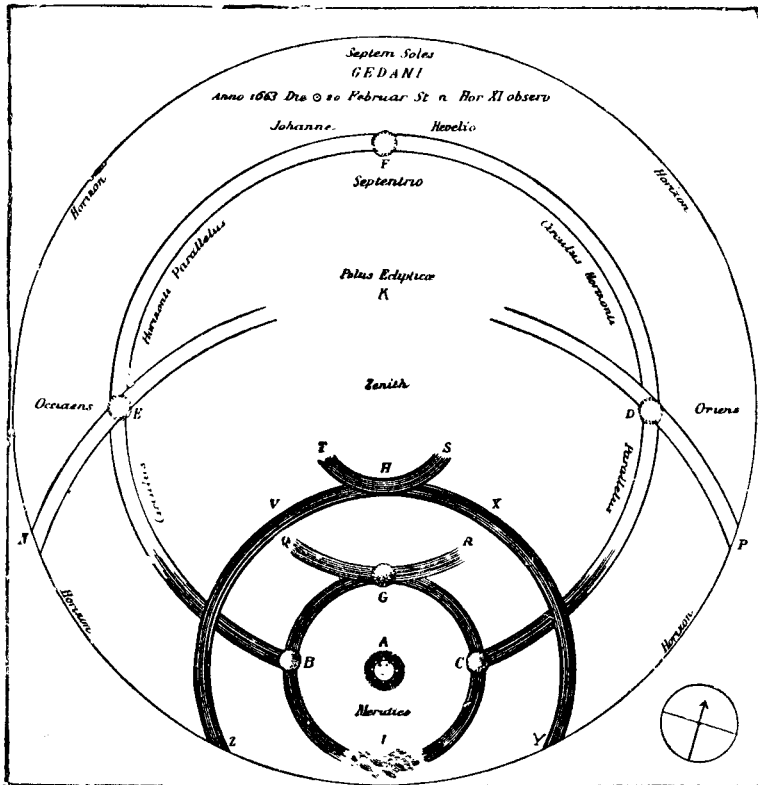


FIG. 11.

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  $22^\circ$ , THS to that of  $46^\circ$ . 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  $22^\circ$  and  $46^\circ$ , 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  $46^\circ$  is frequently exceedingly brilliant. The ends of the arc of upper contact of the halo of  $22^\circ$  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  $22^\circ$  with the white mock sun ring (B and C, Fig. 11). Very rarely mock suns are seen at or near the intersection of this ring with the halo of  $46^\circ$ . The mock suns of this halo are always very faint, and their colouring is indistinct; mock suns belonging to the halo of  $22^\circ$  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  $20^\circ$ , extends from the mock suns along the mock sun ring (*see* Fig. 11).

The mock suns of the ring of  $90^\circ$  (D and E, Fig. 11) 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.*,  $180^\circ$  away from the luminary along the mock sun ring. This is known as the counter sun. Mock counter suns, at about  $60^\circ$  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  $20^\circ$  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. 12).

PLATE III.

SOLAR HALOS OBSERVED AT ABERDEEN.

*Reproduced from sketches by G. A. Clark, Aberdeen Observatory.*



Solar Halo of  $22^{\circ}$  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  $29^{\circ}$ .



Solar Halo of  $22^{\circ}$  radius, March 5, 1903, 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.

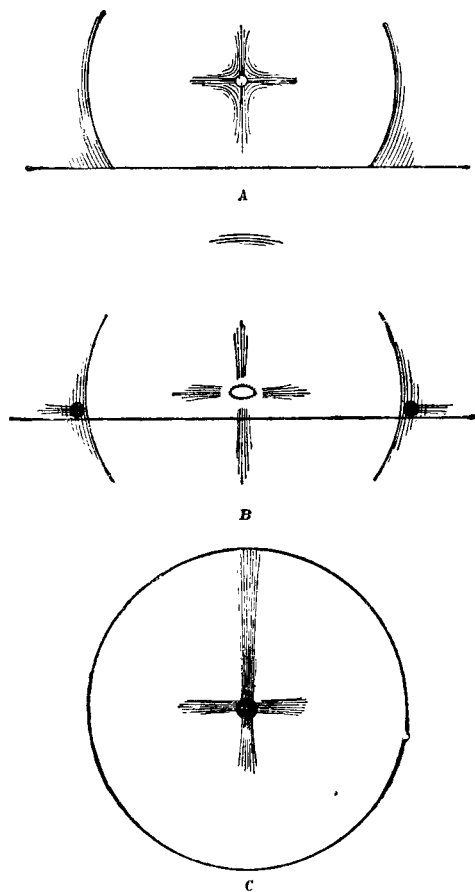


FIG. 12.

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  $22^\circ$  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," etc.

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 and the position of the greatest luminosity are very variable and

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\* 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  $20^\circ$  diameter was frequently seen with a clear sky. It was proved to be an unusually large corona.



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  $12^\circ$  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.

**Mirage.**—The phenomenon termed mirage is caused by the refraction and reflection of light rays through layers of air of different densities. It should be recorded whether the image is inverted or not; whether there are two or more images. When mirage appears it should be noticed if it has any connection with sudden variations in temperature.

**Aurora.**—Auroral displays are often seen in higher latitudes. For the guidance of those who are interested to observe them in detail the following notes are given and information on these lines will be most welcome to the Meteorological Office.

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

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 not far out of the observers' 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 identification with the spectra of known gases is, however, still a disputed question. 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  $5^{\circ}$  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 in the northern hemisphere, 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 the Antarctic several observers have found auroral display to be most numerous in the early morning. 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  $40^{\circ}$ . In most of Northern Europe, and in North America between  $40^{\circ}$  and  $60^{\circ}$  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  $55^{\circ}$  N. in longitude  $60^{\circ}$  W. to fully  $75^{\circ}$  N. in longitude  $90^{\circ}$  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  $40^{\circ}$  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  $1^{\circ}$  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  $4^{\circ}$  or  $5^{\circ}$ , 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 connection 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 connection 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.**—Of recent years many measurements of height have been made in Norway, the earliest by Prof. Störmer, who devised satisfactory means of photographing aurora. Simultaneous photographs are taken as in rangefinding, from two ends of a measured base, usually from 15 to 25 kilometres long, but sometimes a good deal longer. The observers at the two ends are connected by telephone and arrange to direct their cameras at certain stars, which appear in the photographs. The positions of the aurora relative to the stars in the two photographs show a greater or less shift according to the auroral height, which can thus be calculated. Some of the earlier photographs gave a height under 50 kilometres, but doubt is now thrown on these, as the more recent measurements put the lowest edge of the aurora at from 90 to 120 kilometres, the most common heights for it being from 100 to 110 kilometres. For the highest auroral level much more variable results are obtained. Heights exceeding 250 kilometres are sometimes found.

The Norwegian results throw much doubt on the claims that several observers have made that they have seen aurora at much lower levels between themselves and mountains. No one should refrain from publishing an observational result merely because it runs counter to the theoretical views of his contemporaries, but he ought to be prepared for active criticism.

**Sound.**—If aurora never descends below 80 kilometres the presumption is strongly against the accuracy of observers who say that they have heard aurora produce a sound resembling the discharge of electricity from points, which has waxed and waned simultaneously with the fluctuations of luminosity. But the assertion that aurora has been audible has repeatedly been made by observers of some reputation in the Arctic. Thus it is desirable that any report of such an occurrence should not be rejected without investigation.

### **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 nebulae 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 accompanying 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 ft. 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 situated, 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 10 to 15 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 50 and 60 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*.

### Waterspouts and Air Whirls.

These occur more frequently in the tropics than in higher latitudes.

They are accompanied by circular motion of the air, and are formed beneath heavy nimbus cloud.

Observations of these should be made with special attention to the direction of motion of the air, clockwise or counter-clockwise. The position of the spout or whirl should be given as accurately as possible at frequent intervals. Measurements of diameter and height can be made with a sextant. Special attention should be paid to the height at which the spout meets and breaks. If possible the motion of the water descending and ascending should be recorded. At the same time special observations of the Meteorological instruments should be made to notice if they are affected in any peculiar way by the disturbance.

The introduction of rangefinders in some ships will enable observers to obtain a base from which the dimensions of waterspouts, etc., may be found by sextant angles.

**Line Squalls.**

The line squall is a squall of wind, accompanied by rain or hail, associated with a sudden drop of temperature and the passing of a long line or arch of dark cloud. This phenomenon is caused by the meeting of warm and cold winds, the most favourable condition for which being the trough of a "V"-shaped depression. In the northern hemisphere the warmer wind being generally from the south-west, the wind direction will veer as a rule, during the passage of the squall (in the southern hemisphere the reverse, using the international sense of the term, will be the case). During the passage of the squall the barometric pressure will rise with great suddenness about 2 mb., and the temperature will fall from 5° to 10°C or 10° to 20°F. Line squalls are frequently precursors of thunderstorms, and owing to the violent convection and eddying of the atmosphere at the time of meeting of the cold and hot winds are often found to cause waterspouts.

As an instance of these squalls the Pampero of the Argentine and Uruguay may be cited.

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## CHAPTER VII.

## HYDROGRAPHIC OBSERVATIONS.

**Current Determination.**

In order that observers may supply suitable current data it seems particularly desirable that they should know for what purpose these observations are required and how they are dealt with.

The currents shown on the charts published by the Hydrographic Department of the Admiralty were generalised from a very large number of observations taken from logs and documents received by the Meteorological Office from ships of the Mercantile Marine and H.M. ships' logs and remark books. These require revision and it is hoped that this will be done in the near future.

On the receipt of meteorological logs current data are checked; all those which appear to be reliable are converted into 24 hour values and entered into data books for the one degree square of the middle position; *i.e.*, the position to the nearest minute of latitude and longitude midway between the two points fixed by observation between which the current is calculated.

When a sufficient number of observations have been collected, these values are generalised and plotted on charts in the form of current arrows or current roses.

**Determination of Current by differences between Observed Positions and Dead Reckoning.**

It is obvious that the value of a current observation is dependent on the accuracy with which the positions of the ship can be determined. Cross bearings, horizontal angles of well defined and accurately charted terrestrial objects, or good twilight stellar sights are more accurate for this purpose than the determination by sights of the sun near the meridian and prime vertical, especially if the run of the ship between the two observations is long.

The current, if carefully determined between noon and noon is valuable, but the current determined at shorter intervals between *reliable fixes* is more so, being less subject to error and variation; for the current is not likely often to run in the same direction over a long distance such as that covered by a fast ship in a day's run, particularly when passing near the junctions of ocean currents as off Cape Guardafui, Cape Delgado, the Tail of the Newfoundland Banks, or when crossing the separating line of the Equatorial and Counter Equatorial Currents.

Currents determined at short intervals should be checked with the noon to noon result and all should be entered in their respective columns.

It is desired, when possible, that the speed of the ship through the water should be ascertained by two different methods, as this will increase the accuracy of the estimation of the day's run. It is suggested that for deep ships the revolutions of the propeller should be one of these. The methods adopted should be stated in the log.

By the method of computation of current from the difference between observed and D.R. positions all factors not allowed for in the D.R. are attributed to current. It is, therefore, essential that variation and deviation of the compass should be frequently and carefully determined and allowed for and that leeway and any other possible disturbing factors should be estimated and applied.

If the true courses steered and the distances run through the water with times of alteration of course and speed are given it will facilitate checking.

### **The Determination of Surface Set and Drift by Bottles, etc.**

Another method of determining drift is by setting bottles afloat which are returned to the Meteorological Office, if recovered, with a note of the position of their recovery. A stout sheet of white paper, with the following clearly written upon it, should be placed in a bottle carefully ballasted to float in sea water with not more than a quarter of its volume above the surface, tightly corked and sealed.

“ This bottle was thrown overboard from S.S. ——— in latitude ———, longitude ———, at ——— G.M.T. on ——— 19——.

The finder is requested to post this paper to The Director, Meteorological Office, Air Ministry, London, by whom the cost of postage will be returned.

The finder is also requested at the same time to state the exact position and date at which the bottle was found.

(Signed) Captain S.S. ———.”

Drift bottles have been picked up after travelling many thousands of miles.

The drift of a small object like a bottle gives no indication of the current below the surface. There may be currents running beneath the surface in different directions to that of the surface, and it is important that these should be known.

The values for current determined by the difference of observed position and D.R. probably gives set acting on the ship at a depth of more than half her draught.

To navigators making a land fall the value of the current observation is of the greatest importance, but it often happens that with the additional work of the ship when approaching or leaving port these are not recorded. Current determined between the last celestial fix (checked for error of chronometer after arrival) of the passage and the first reliable terrestrial fix after making the land, is essential; and currents determined between terrestrial fixes when coasting are much desired.

### **The Determination of Sub-Surface Current.**

These observations are seldom possible in ships of the Mercantile Marine, but cable ships when stationary may be in favourable circumstances to make them. Currents below the surface may be measured by a ship at anchor or riding to a cable by means of a current meter, of which instrument many good patterns are made. The Ekman Current Meter has been used with success. This apparatus consists of a form of submarine log and compass with vane combined. When lowered to the required depth the propeller is set in motion by

means of a messenger ; and can be stopped in the same manner. The velocity is indicated by means of a dial. The direction by compass is shown by a number of shot which roll along the needle and drop off its point into receptacles corresponding to the points of the compass.

In addition to current observations there is much other hydrographic information that, though not used in the Meteorological Office, will be forwarded to the proper quarter if sent to the Director.

Most important of this information is the reporting of the positions of uncharted rocks, shoals, etc. It must be impressed on observers in reporting such information that accurate positions are essential, to plot the sounding. The data for its reduction to L.W.O.S. should be sent in, as it is most necessary that all computations should be checked thoroughly. A sounding is useless for charting purposes unless its position can be fixed accurately, but all indications of shoal water which is uncharted should be reported.\*

Information should also be sent in on the following points :—

Inaccurately charted positions, additions to foreign harbour works, discrepancies of the character and range of lights from those given in the Admiralty Light Lists, discrepancies of sound signals and submarine sound apparatus.

Tidal observations, submarine tremors, and abnormal sea waves.

Any danger to shipping, as ice, wreckage, derelicts, etc.

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\* Such information will be forwarded to the Hydrographer of the Navy through the Superintendent for Naval Meteorological Services.

### PART III.—METEOROLOGICAL LOGS.

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#### CHAPTER VIII.

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#### INSTRUCTIONS FOR KEEPING THE ORIGINAL NOTE BOOK AND THE METEOROLOGICAL LOG.

Between pp. 74 and 75 will be found a specimen of a Meteorological Log, and at the beginning of every log is given a specimen for the guidance of observers. At the bottom of each page the columns will be found numbered from left to right. These numbers correspond to those given to the various columns of the original note book, and in this chapter the columns are referred to by these numbers.

Inside the cover of the log, will be found a space set aside for information as to the position of the instruments, and on the fly-leaf is made an entry of the names of the ship and the observers.

Any information which affects the observations throughout the whole voyage should be written across the space of the first day as in the specimen sheet.

It should be remembered that a blank space is better than an uncertain observation that is not clearly marked as doubtful.

**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 the specimen. The day is reckoned in civil time starting at midnight. The hour is intended for apparent time at ship, as this will not always be correct, the amount that the clock is fast or slow of G.M.T. at ship's noon should be entered daily. A note should be made of the number of minutes the clock is put forward or back with the time that the correction is made. Zone time may be used with advantage.

The log book is ruled for an observation every fourth hour, which in all ordinary circumstances is sufficient. During hurricanes or other exceptional weather the space of two or more days may be taken if required, the appropriate corrections being made in the hour column.





Figure 13. -

# Meteorological Log kept on board R.M.S. Somme

DATE.		Latitude.		Longitude.		Current when determined at short intervals.	Course and Distance.		Total Compass Error.	Ship's Head.	Wind, at the time of observation.	Barometer.* No. 1421.		Thermometers.			
Year 1920	Month V	Observed.	Dead Reckoning.	Observed.	Dead Reckoning.		Each four hours.	Height of Ustens above Sea 42 feet.				Uncorrected Reading.	Air Therm.	Dry Bulb. No.	Wet Bulb. No.		
Day.	Civil Time.	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.					True Course.	Distance by Log.	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.					
											True				26415	26411	
4 <sup>th</sup>		4					209°	44			NNE	2	1014.9	29.8	77.1	73.1	
		8					209°	46			NNW	2	1017.2	29.8	80	76	
G.M.T.	NOON	4. 50N	4. 48N	27. 47W	27. 58W		209°	49			N x E	3	1017.0	29.58	80.4	84.9	77.3
1 <sup>st</sup> 48		Current in last 24 hours N 80 E 11 mls.					209°	46			N x E	2-3	1014.5	30.2	83.2	77.0	
		4					209°	45			NW x N	3	1015.9	30.3	81.5	76.5	
		8					209°	46			NW	3-4	1016.5	29.9	77.6	75.8	
MIDN.							209°	46									
5 <sup>th</sup>		4					209°	45			SW x S	1	1014.0	29.8	77.8	75.8	
		8					209°	48				0	1016.2	30.0	81.0	76.5	
G.M.T.	NOON	0. 57N	0. 47N	29. 50W	30. 3W		209°	47		True		0	1016.8	29.54	80.8	82.0	76.5
1 <sup>st</sup> 55		Current in last 24 hours N 82 E 16 mls.					209°	47		logged		0	1014.4	30.0	82.3	75.0	
		4					209°	44			E x S	1	1015.7	30.0	81.0	74.4	
		8					209°	47		are	SE x E	2	1016.5	30.2	80.0	77.0	
MIDN.							209°	47									
6 <sup>th</sup>		4					209°	44			South	1-2	1013.9	29.9	79.1	77.0	
		8					207°	42			ESE	3-4	1015.5	30.0	80.0	76.0	
G.M.T.	NOON	2. 57S	3. 2S	31. 51W	31. 50W		207°	43		All	SE	3-4	1015.9	29.55	80.0	81.0	75.6
2 <sup>nd</sup> 4		Current in last 24 hours N 11 W 5 mls.					216°	44		directions	ESE	3	1014.2	29.9	78.0	75.0	
		4	Position by land fix N 20 W					205°	43		SE x E	4	1015.2	30.0	80.7	77.0	
		6 30	3° 51'S	3° 57'S	32° 30'W	32° 28'W		207°	42		SE x E	4	1016.6	30.0	80.0	74.0	
		8					207°	42									
MIDN.							207°	42									
7 <sup>th</sup>		4	Position by Stellar obs.					209°	42			SE	4	1011.5	30.0	80.3	74.0
		5 30	5° 35'S	5° 42'S	35° 32'W	33° 19'W		207°	41			ESE	4-5	1015.6	29.9	81.0	75.0
		8					209°	42			ESE	4	1015.0	29.46	80.8	82.6	73.0
G.M.T.	NOON	6. 33S	6. 43S	34. 4W	33. 45W		197°	40			SE x E	4	1014.4	29.9	82.5	78.8	
2 <sup>nd</sup> 13		Current in last 24 hours N 62 W 21 mls.					208°				ESE	3	1015.0	30.0	81.0	77.0	
		4															
		8															
MIDN.			Led in Pernambuco Roads					Var	-		ESE	3	1016.9	30.0	80.0	74.0	
1	2	3	4	5	6	6a	7	8	9	10	11	12.	13	14	15	16	17

\* Please give Readings of the Ship's Barometer, say at Noon, at various times during the voyage noting whether it is mercurial or aneroid.

Captain Q.V. Schlanbusch from London to Pernambuco

Hour.	Clouds, at time of observation.			Weather at time of observation.		Sea Surface.						Remarks.		Rain- fall by Gauge
	The direction from which the clouds are moving should be noted, where determinable.			Wind, Dir- ect- ion, Force, and Vari- ation.	Sea State.	Waves.		Swell.		Temp by No.	Spec by No.	Time of Remark.	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, Force and Duration of Squalls; 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.)	
						Direction from.	Dis- turb- ance 0 to 10	Direction from.	Dis- turb- ance					
	Names.			According to Beaufort's Notation.		Also record when Unfused				44° 23'				
	Upper.	Lower.	Percentage of obs. 0 to 100											
4	sc		2	o				o	Confid Slight	79	24			0
8		cu/st	2	o				o	Confid Slight	80	24			0
NOON	ci	st-cu	4	bc				o	Confid Mod	81	24			0
4		Fr-cu	4	bc				o	Confid Mod	82	24			0
8		Fr-cu	4	bc		NW	1	Confid Mod	82	23	11.30 "Arch" clouds appeared in SSE.			0
MIDY.		nb	10	o				o	Confid Mod	81	24	11.15 Wind fell. Heavy rain shower.		8.6
												1.30 Ceased raining		
4		cu	2	o				o	Confid Mod	81	24			13.2
8	A-cu	nb	4	bcp				o	Confid Mod	82	23			14.9
NOON	ci-cu		3	b				o	Confid Slight	83	23	Noon Occasional light airs from S and SW.		15.8
4	ci/A-cu		5	bc				o	Confid Slight	84	23	5.18 Passed object which appeared to be a		0
8		cu	4	bc				o	Confid Slight	82	23	capsized boat overgrown with Marine Growth		0
MIDY.	A-cu	cu	10	o				o	Confid Slight	78	23	Midl' Wind becoming settled in S.E. Heavy passing clouds but no rain		0
4		cu-nb	10	oq				o	Confid Slight	79	23	3.30 Heavy squalls with rain from SE		2.1
8		cu-nb	9	oq				o	ESE Mod	81	24	Passing showers throughout watch		3.2
NOON	ci-cu		8	cv		SE	1	SE Mod	82	24	10.00 Heavy rain showers		6.8	
4		nb	10	o		ESE	1	SE Mod	81	24	Noon Passing distant showers Wind steady		0	
8		cu	4	bc		SE	1	SE Mod	82	24	6.30 C. Placelière (Fernando Noronha)		0	
MIDY.	A-cu		4	bc		SE	1	SE Mod	81	24	Brig E 2 miles		0	
												Stars brilliant		0
4			0	b		SE	1	SE Mod	80	23			0	
8	ci	cu	5	bc		SE	2	SE Mod	82	23			0	
NOON	ci/ci-st		6	bc		SE	2	SE Mod	82	23	Noon Steady trade wind		0	
4	A-cu	ci	4	bc		ESE	2	SE Mod	81	23			0	
8		cu	2	b		ESE	2	SE Mod	81	23			0	
MIDY.	cu/st		2	o		ESE	2	SE Mod	82	23	11.50 1st of Pernambuco Roads		0	
24	17	18	19	20	21	20a	21a	22	23	24	25	26	27	28

In the event of the Office Barometer being broken, the Ship's can be taken into use, and its error can be ascertained.



*Page 75, after line 23 insert :—*

It is requested that the following particulars should be recorded at the end of each passage :—

- Was the speed measured by Log or Revolutions ? .....
- State of Loading, Light or Deep ? .. .....
- Was the Propeller immersed ? .....
- General Remarks as to reliance which may be placed on observations .....
- .....

The following meteorological office publications and reports are affected by this change of visibility scale and should be corrected accordingly.

1. Western Seaboard W/T Report broad-casted from Poldhu.
2. Provisional International Codes for weather. Reports from Ships at Sea. Form 138A.

3. Meteorological Rough Book. M.O. Form 133.
4. Meteorological Logs. M.O. Form 131.
5. Lighthouse Registers. M.O. Form 135.
6. Cadet's Meteorological Log. M.O. Form 134.
7. Ship's Meteorological Report. M.O. Form 121.
8. Telegraphic Reports from Cross-Channel Steamers, p. 5
9. Observations of Air and Sea Temperature Wind and Weather. M.O. Form 129A.
10. Weather Forecasting in the Eastern North Atlantic and Home Waters for Seamen. M.O. 246.
11. Marine Observer's Handbook. M.O. 218, p. 52.
12. The Seaman's Handbook of Meteorology. M.O. 215, p. 55.
13. The Weather of the British Coasts. M.O. 230, p. 40.

Marine Division,

Meteorological Office.

January, 1922.

**Columns 3, 4, 5, 6, and 6a—Latitude, Longitude and Current.**—Whenever the ship's position is taken, whether at noon or at any other hour it should be entered in these columns together with the D.R. position for the corresponding hour and a note made of that hour. If cross bearings can be obtained of land the position should be given as lat. and long. In column 6a the current as computed should be entered. These current observations are most useful, and attention of observers is particularly drawn to them. Observers are urged to give remarks to indicate the reliability of the current observations, as no one ashore can decide whether a current observation expresses the true state of affairs or not. The terms "favourable" and "adverse" should not be used, but the actual figures worked out from the D.R. and observed positions. Currents of less than 5 knots per 24 hours are grouped together, but it is most necessary when such currents (or no current) are experienced that they should be recorded. If the observed and D.R. positions are merely entered as identical and the current entry left blank it is impossible for the computer ashore to know whether it represents a true observation or not. For current observations *see* p. 70.

**Columns 7 and 8—True Course and Distance.**—These columns are used to calculate the positions of each four-hourly observation.

**Columns 9 and 10—Total Compass Error and Ship's Head.**—The columns are not required if the directions of wind, clouds; waves, and swell, are given true.

**Column 11—Direction of Wind** (*vide* Chapter IV.).—At the top of this column should be stated whether direction is given true or subject to compass error.

This observation should state the direction of the wind at the hour of observing, not an estimate of the direction during the watch. If, however, a squall is blowing at the time of observation, the direction and force should be given which existed before the squall. It is particularly requested that the direction, force, and duration of squalls with any other important remarks respecting them, such as how the wind changed during the squall, etc., be entered in Column 25. Any sudden change in direction or force of the wind should be noted with the exact time of the occurrence in Column 25.

**Column 12—Force of Wind.**—The force of the wind should be estimated according to the Beaufort Scale, pages 40 and 41.

**Columns 13 and 14—Barometer and attached Thermometer.**—The number of the instrument and the height of the cistern (or lower end) above the sea level (at least at the beginning and end of each passage) must be entered at the top of the column; this height is, of course, affected by the ship's draught. Any change in the position of the instrument should be noted in the remarks column. The reading of the ship's barometer should be entered once a day for comparison, and a note made in the log of its position in the ship and height above sea level.

Attention should be paid to Chapter II., p. 15, where are enumerated the precautions necessary in reading the barometer.

It should be remembered that the barometer reading from a meteorological point of view is as important in fine weather as in bad.

When two scales are engraved on the barometer viz., millibars and inches *the millibar scale should invariably be read for the purpose of the meteorological log.*

**Columns 15 and 16—Dry and Wet Bulb Thermometers.**—The numbers of the thermometers should be entered at the top of the columns, and any change made in the instruments used should be noted. The thermometers should be read to a tenth of a degree in order that the differences between dry and wet bulb may be accurately obtained. Reference should be made to Chapter III., p. 28.

**Column 17—Clouds.**—This column is divided into two sub-columns headed "upper" and "lower". The entries in these should conform to Chapter V., pp. 47-48, and should be clearly differentiated.

It should be noted that a convenient way of making it clear that two types of clouds are represented and not one compound type is to place a stroke between them; thus St/Cu means that both Stratus and Cumulus are present, but St-Cu means Strato-Cumulus is seen.

Direction of cloud motion should be recorded according to the instructions on p. 49.



**Column 18—Amount of Cloud.**—The amount of cloud is given on the scale described on p. 46.

**Column 19—Weather** (*vide* p. 50).—The weather reported should be that of the time of observation only, not that of the preceding four hours. Fog, rain, snow, and hail, with the hour of commencing and stopping should be entered in the remarks column, the letters **f, r, s, h, p, w**, etc., being only put in column 19 if actually occurring at the time of observation.

Further facts regarding weather that cannot be expressed by the Beaufort Notation should be also entered in the remarks column.

**Column 19a—Fog Intensity and Visibility.**—The appropriate figure should be entered in this column from the tables on p. 52. No observation should be recorded in this column unless it is based on a definite observation of an object such as a ship or land.

**Columns 20 and 20a—Direction of Sea and Swell.**—The direction should be given from which sea and swell are coming, and statement should be made if direction is true or magnetic.

**Column 21—Sea Disturbance.**—This is given according to the table on p. 43.

**Column 21a—Swell Disturbance.**—This is given according to the criteria on p. 43.

**Columns 22 and 23—Surface Temperature and Specific Gravity.**—The numbers of the instruments used for these observations should be given at the heads of these columns. Attention should be paid to the instructions in Chapter III., pp. 30 and 35.

The sea water temperature should be taken immediately before the specific gravity, when that observation is made. As a rule, the sea surface temperature should be taken every four hours, while the specific gravity is only necessary once a day at noon. Observations, however, should be made more frequently, when in the neighbourhood of current rips, on each side of lines of foam, etc. In these cases specific gravity observations may reveal remarkable changes in salinity.

**Column 24—Time of Remarks.**—The hour of entering or leaving port and the exact time of remarks on weather, changes of wind, etc., are most important. The time of altering of the ship's clock should always be noted daily.

**Column 25—Remarks.**—This column should contain any important facts which cannot be recorded in other columns, even though they may not at first sight appear to be related to Meteorology.

The following are a few of many items that can be recorded.

Any state of weather that is unusual.

The appearance of any of the optical phenomena mentioned in Chapter VI. If possible, a short account of these should also be given at the end of the log with more detail than is possible in the remarks column.

Waterspouts; but if details can be obtained it is better to devote a page of foolscap to a brief account and attach it to the log.

The temperature of rain just fallen, and that of the air by the dry bulb at the same time.

Red fog, dust, submarine earthquakes.

Tide and current rips, discoloured or luminous parts of the sea.

Magnetic disturbances.

Peculiar clouds. Line squalls.

The time, distance, and bearing of a few headlands is also of use in the remarks column.

Many other items will occur to the seaman which will be worthy of record. The only thing that should be guarded against is the habit of repeating what has already been said in previous columns, which only confuses the important items of the remarks with a mass of material which is already expressed in a more convenient form.

**Column 25a—Raingauge.**—The raingauge should be measured every four hours. The water is poured out into the measuring glass, and the height of the water is read and recorded. The contents of the measuring glass are then poured back into the gauge except at 12 noon. The effect of this method is to give the rainfall that has occurred at each observation since the previous noon. The rainfall recorded at noon being for a complete 24 hours.

**Additional Remarks.**—At the end of the log will be found a page devoted to Additional Remarks and Observations of Visibility.

These additional remarks should be accounts of any phenomenon that can be observed in detail such as tropical revolving storms, optical phenomena, descriptions of local winds such as Pamperos, etc.

In low latitudes air-whirls are sometimes met with which are revealed by violent commotion in the lower clouds. Detailed descriptions of these are much needed together with notice of any marked movements of the meteorological instruments during the occurrence.

Hydrographic notes given on the lines detailed in Chapter VII. will be forwarded to the proper quarters.

Notes on Magnetism, Biology, or any other scientific subject will be welcome, and every effort will be made to forward them to the correct authority.

**Illustrations.**—The photographing or otherwise illustrating phenomena would be a most excellent record to be preserved, especially when explained fully with remarks.

It is hoped that many more pictures will be obtained in the future.

**Barograms.**—In ships that have barographs it is best that the barograms should be pasted in by one edge into the log at suitable places. These barograms can then be read at the same time as the log.

## APPENDIX

TABLE I.

THE ADJUSTMENT OF FIDUCIAL TEMPERATURE

Latitude N. or S.	Height in Feet of Barometer								
	0	5	10	15	20	25	30	35	40
°	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>
0	-15.2	-14.2	-13.1	-12.1	-11.0	-10.0	-8.9	-7.8	-6.8
2	15.1	14.1	13.0	12.0	10.9	9.9	8.8	7.7	6.7
4	15.0	14.0	12.9	11.8	10.8	9.8	8.7	7.6	6.5
6	14.8	13.8	12.7	11.7	10.6	9.6	8.5	7.4	6.4
8	14.6	13.6	12.5	11.5	10.4	9.4	8.3	7.2	6.2
10	14.2	13.2	12.1	11.1	10.0	9.0	7.9	6.8	5.8
12	13.8	12.8	11.7	10.7	9.6	8.6	7.5	6.4	5.4
14	13.4	12.4	11.3	10.3	9.2	8.2	7.1	6.0	5.0
16	12.8	11.8	10.7	9.7	8.6	7.6	6.5	5.4	4.4
18	12.3	11.3	10.2	9.2	8.1	7.1	6.0	4.9	3.9
20	11.6	10.6	9.5	8.5	7.4	6.4	5.3	4.2	3.2
22	10.9	9.9	8.8	7.8	6.7	5.7	4.6	3.5	2.5
24	10.1	9.1	8.0	7.0	5.9	4.9	3.8	2.7	1.7
26	9.3	8.3	7.2	6.2	5.1	4.1	3.0	1.9	0.9
28	8.5	7.5	6.4	5.4	4.3	3.3	2.2	1.1	-0.1
30	7.6	6.6	5.5	4.5	3.4	2.4	1.3	-0.2	+0.8
32	6.6	5.6	4.5	3.5	2.4	1.4	-0.3	+0.8	1.8
34	5.7	4.7	3.6	2.6	1.5	-0.5	+0.6	1.7	2.7
36	4.7	3.7	2.6	1.6	-0.5	+0.5	1.6	2.7	3.7
38	3.7	2.7	1.6	-0.6	+0.5	1.5	2.6	3.7	4.7
40	2.6	1.6	-0.5	+0.5	1.6	2.6	3.7	4.8	5.8
42	1.6	-0.6	+0.5	1.5	2.6	3.6	4.7	5.8	6.8
44	-0.5	+0.5	1.6	2.6	3.7	4.7	5.8	6.9	7.9
46	+0.5	1.5	2.6	3.6	4.7	5.7	6.8	7.9	8.9
48	1.6	2.6	3.7	4.7	5.8	6.8	7.9	9.0	10.0
50	2.6	3.6	4.7	5.7	6.8	7.8	8.9	10.0	11.0
52	3.7	4.7	5.8	6.8	7.9	8.9	10.0	11.1	12.1
54	4.7	5.7	6.8	7.8	8.9	9.9	11.0	12.1	13.1
56	5.7	6.7	7.8	8.8	9.9	10.9	12.0	13.1	14.1
58	6.6	7.6	8.7	9.7	10.8	11.8	12.9	14.0	15.0
60	+7.6	+8.6	+9.7	+10.7	+11.8	+12.8	+13.9	+15.0	+16.0

Based on a Temperature of 290 a

**TABLES.**

**TABLE I.**

FOR LATITUDE AND HEIGHT ABOVE SEA LEVEL.

Cistern above Sea Level.								Latitude N. or S.
45	50	55	60	65	70	75	80	
<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>	°
-5.7	-4.7	-3.6	-2.6	-1.5	-0.5	+0.6	+1.6	0
5.6	4.6	3.5	2.5	1.4	0.4	0.7	1.7	2
5.5	4.5	3.4	2.4	1.3	0.3	0.8	1.8	4
5.3	4.3	3.2	2.2	1.1	-0.1	1.0	2.0	6
5.1	4.1	3.0	2.0	0.9	+0.1	1.2	2.2	8
4.7	3.7	2.6	1.6	0.5	0.5	1.6	2.6	10
4.3	3.3	2.2	1.2	-0.1	0.9	2.0	3.0	12
3.9	2.9	1.8	0.8	+0.3	1.3	2.4	3.4	14
3.3	2.3	1.2	-0.2	0.9	1.9	3.0	4.0	16
2.8	1.8	-0.7	+0.3	1.4	2.4	3.5	4.5	18
2.1	1.1	0.0	1.0	2.1	3.1	4.2	5.2	20
1.4	-0.4	+0.7	1.7	2.8	3.6	4.9	5.9	22
-0.6	+0.4	1.5	2.5	3.6	4.6	5.7	6.7	24
+0.2	1.2	2.3	3.3	4.4	5.4	6.5	7.5	26
1.0	2.0	3.1	4.1	5.2	6.2	7.3	8.3	28
1.9	2.9	4.0	5.0	6.1	7.1	8.2	9.2	30
2.9	3.9	5.0	6.0	7.1	8.1	9.2	10.2	32
3.8	4.8	5.9	6.9	8.0	9.0	10.1	11.1	34
4.8	5.8	6.9	7.9	9.0	10.0	11.1	12.1	36
5.8	6.8	7.9	8.9	10.0	11.0	12.1	13.1	38
6.9	7.9	9.0	10.0	11.1	12.1	13.2	14.2	40
7.9	8.9	10.0	11.0	12.1	13.1	14.2	15.2	42
9.0	10.0	11.1	12.1	13.2	14.2	15.3	16.3	44
10.0	11.0	12.1	13.1	14.2	15.2	16.3	17.3	46
11.1	12.1	13.2	14.2	15.3	16.3	17.4	18.4	48
12.1	13.1	14.2	15.2	16.3	17.3	18.4	19.4	50
13.2	14.2	15.3	16.3	17.4	18.4	19.5	20.5	52
14.2	15.2	16.3	17.3	18.4	19.4	20.5	21.5	54
5.2	16.2	17.3	18.3	19.4	20.4	21.5	22.5	56
16.1	17.1	18.2	19.2	20.3	21.3	22.4	23.4	58
+17.1	+18.1	+19.2	+20.2	+21.3	+22.3	+23.4	+24.4	60

and Barometer height of 1000 mb.



CORRECTION OF BAROMETER FOR DIFFERENCE BETWEEN " ATTACHED THERMOMETER " AND ADJUSTED FIDUCIAL TEMPERATURE.

**Note.**—This table is based on a Standard Pressure of 1,000 mb. For other pressures an additional correction is necessary, the rule being “Add one per cent. of the correction for each 10 millibars above 1,000, and subtract one per cent. for each 10 mb below.”







TABLE III.

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

Temp.	INCHES.											Temp.
	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	
0	+.068	+.069	+.070	+.072	+.073	+.074	+.076	+.077	+.078	+.080	+.081	0
1	.065	.067	.068	.069	.070	.072	.073	.074	.076	.077	.078	1
2	.063	.064	.065	.067	.068	.069	.070	.072	.073	.074	.075	2
3	.061	.062	.063	.064	.065	.066	.068	.069	.070	.071	.072	3
4	.058	.060	.061	.062	.063	.064	.065	.066	.067	.069	.070	4
5	.056	.057	.058	.059	.060	.061	.062	.064	.065	.066	.067	5
6	.054	.055	.056	.057	.058	.059	.060	.061	.062	.063	.064	6
7	.051	.052	.053	.054	.055	.056	.057	.058	.059	.060	.061	7
8	.049	.050	.051	.052	.053	.053	.054	.055	.056	.057	.058	8
9	.046	.047	.048	.049	.050	.051	.052	.053	.054	.054	.055	9
10	.044	.045	.046	.046	.047	.048	.049	.050	.051	.052	.053	10
11	.042	.043	.043	.044	.045	.046	.047	.047	.048	.049	.050	11
12	.039	.040	.041	.042	.042	.043	.044	.044	.045	.046	.047	12
13	.037	.038	.038	.039	.040	.040	.041	.042	.043	.043	.044	13
14	.035	.035	.036	.036	.037	.037	.039	.039	.040	.041	.041	14
15	.032	.033	.033	.034	.035	.035	.036	.036	.037	.038	.038	15
16	.030	.030	.031	.031	.032	.033	.033	.034	.034	.035	.036	16
17	.027	.028	.029	.029	.030	.030	.031	.031	.032	.032	.033	17
18	.025	.026	.026	.027	.027	.028	.028	.029	.029	.030	.030	18
19	.023	.023	.024	.024	.025	.025	.025	.026	.026	.027	.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	.018	.018	.018	.018	.019	22
23	.013	.014	.014	.014	.014	.015	.015	.015	.015	.016	.016	23
24	.011	.011	.011	.012	.012	.012	.012	.012	.013	.013	.013	24
25	.009	.009	.009	.009	.009	.009	.010	.010	.010	.010	.010	25
26	.006	.006	.006	.007	.007	.007	.007	.007	.007	.007	.007	26
27	.004	.004	.004	.004	.004	.004	.004	.004	.004	.005	.005	27
28	.001	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	28
29	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	29
30	.003	.003	.003	.003	.003	.004	.004	.004	.004	.004	.004	30
31	.006	.006	.006	.006	.006	.006	.006	.006	.006	.007	.007	31
32	.008	.008	.008	.008	.009	.009	.009	.009	.009	.009	.009	32
33	.010	.011	.011	.011	.011	.011	.012	.012	.012	.012	.012	33
34	.013	.013	.013	.013	.014	.014	.014	.014	.015	.015	.015	34
35	.015	.015	.016	.016	.016	.017	.017	.017	.017	.018	.018	35
36	.017	.018	.018	.018	.019	.019	.019	.020	.020	.020	.021	36
37	.020	.020	.021	.021	.021	.022	.022	.022	.023	.023	.024	37
38	.022	.023	.023	.023	.024	.024	.025	.025	.026	.026	.026	38
39	.024	.025	.025	.026	.026	.027	.027	.028	.028	.029	.029	39
40	.027	.027	.028	.028	.029	.030	.030	.031	.031	.032	.032	40
41	.029	.030	.031	.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	.048	.048	.049	46
47	.043	.044	.045	.046	.047	.048	.048	.049	.050	.051	.052	47
48	.046	.047	.047	.048	.049	.050	.051	.052	.053	.054	.054	48
49	.048	.049	.050	.051	.052	.053	.054	.055	.055	.056	.057	49
50	.050	.052	.052	.053	.054	.055	.056	.057	.058	.059	.060	50

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

TABLE III.—*cont.*

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

TABLE IV

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

Height in feet.	Temperature of Air. (Dry Bulb in Screen.)										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 V

CORRECTIONS for reducing BAROMETRIC READINGS to STANDARD GRAVITY  
in LATITUDE 45°

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

TABLE VI.

CONVERSION OF CENTIGRADE DEGREES INTO DEGREES OF FAHRENHEIT.

Centi- grade Degrees.	Tenths of Degrees.									
	0	1	2	3	4	5	6	7	8	9
°										
-39	-38.2	-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 VI.—*cont.*

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	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 VII.

CONVERSION OF DEGREES OF FAHRENHEIT INTO CENTIGRADE DEGREES.

To convert to the ABSOLUTE SCALE add 273° to the Centigrade reading.

Deg. 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	Deg. 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 VII.—*cont.*

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 VIII.

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 IX.

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 X.

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

TABLE XI.

MILLIMETRES OF MERCURY (680.0 TO 779.9) WITH TENTHS AT 0° C. IN  
LATITUDE 45° TO MILLIBARS AND TENTHS.

Tenths.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
mm.	Millibars.									
680	9	06.6	06.7	06.8	07.0	07.1	07.2	07.4	07.5	07.6
681	9	07.9	08.0	08.2	08.3	08.4	08.6	08.7	08.8	09.0
682	9	09.2	09.4	09.5	09.6	09.8	09.9	10.0	10.2	10.3
683	9	10.6	10.7	10.8	11.0	11.1	11.2	11.4	11.5	11.6
684	9	11.9	12.0	11.2	12.3	12.4	12.6	12.7	12.8	13.0
685	9	13.2	13.4	13.5	13.6	13.8	13.9	14.0	14.2	14.3
686	9	14.6	14.7	14.8	15.0	15.1	15.2	15.4	15.5	15.6
687	9	15.9	16.0	16.2	16.3	16.4	16.6	16.7	16.8	17.0
688	9	17.2	17.4	17.5	17.6	17.8	17.9	18.0	18.2	18.3
689	9	18.6	18.7	18.8	19.0	19.1	19.2	19.4	19.5	19.6
690	9	19.9	20.0	20.2	20.3	20.4	20.6	20.7	20.8	21.0
691	9	21.2	21.4	21.5	21.6	21.8	21.9	22.0	22.2	22.3
692	9	22.6	22.7	22.8	23.0	23.1	23.2	23.4	23.5	23.6
693	9	23.9	24.0	24.2	24.3	24.4	24.6	24.7	24.8	25.0
694	9	25.2	25.4	25.5	25.6	25.8	25.9	26.0	26.2	26.3
695	9	26.6	26.7	26.8	27.0	27.1	27.2	27.4	27.5	27.6
696	9	27.9	28.0	28.2	28.3	28.4	28.6	28.7	28.8	29.0
697	9	29.2	29.4	29.5	29.6	29.8	29.9	30.0	30.2	30.3
698	9	30.6	30.7	30.8	31.0	31.1	31.2	31.4	31.5	31.6
699	9	31.9	32.0	32.2	32.3	32.4	32.6	32.7	32.8	33.0
700	9	33.2	33.4	33.5	33.6	33.8	33.9	34.0	34.2	34.3
701	9	34.6	34.7	34.8	35.0	35.1	35.2	35.4	35.5	35.6
702	9	35.9	36.0	36.2	36.3	36.4	36.6	36.7	36.8	37.0
703	9	37.2	37.4	37.5	37.6	37.8	37.9	38.0	38.2	38.3
704	9	38.6	38.7	38.8	39.0	39.1	39.2	39.4	39.5	39.6
705	9	39.9	40.0	40.2	40.3	40.4	40.6	40.7	40.8	41.0
706	9	41.2	41.4	41.5	41.6	41.8	41.9	42.0	42.2	42.3
707	9	42.6	42.7	42.8	43.0	43.1	43.2	43.4	43.5	43.6
708	9	43.9	44.0	44.2	44.3	44.4	44.6	44.7	44.8	45.0
709	9	45.2	45.4	45.5	45.6	45.8	45.9	46.0	46.2	46.3
710	9	46.6	46.7	46.8	47.0	47.1	47.2	47.4	47.5	47.6
711	9	47.9	48.0	48.2	48.3	48.4	48.6	48.7	48.8	49.0
712	9	49.2	49.4	49.5	49.6	49.8	49.9	50.0	50.2	50.3
713	9	50.6	50.7	50.8	51.0	51.1	51.2	51.4	51.5	51.6
714	9	51.9	52.0	52.2	52.3	52.4	52.6	52.7	52.8	53.0
715	9	53.2	53.4	53.5	53.6	53.8	53.9	54.0	54.2	54.3
716	9	54.6	54.7	54.8	55.0	55.1	55.2	55.4	55.5	55.6
717	9	55.9	56.0	56.2	56.3	56.4	56.6	56.7	56.8	57.0
718	9	57.2	57.4	57.5	57.6	57.8	57.9	58.0	58.2	58.3
719	9	58.6	58.7	58.8	59.0	59.1	59.2	59.4	59.5	59.6
720	9	59.9	60.0	60.2	60.3	60.4	60.6	60.7	60.8	61.0
721	9	61.2	61.4	61.5	61.6	61.8	61.9	62.0	62.2	62.3
722	9	62.6	62.7	62.8	63.0	63.1	63.2	63.4	63.5	63.6
723	9	63.9	64.0	64.2	64.3	64.4	64.6	64.7	64.8	65.0
724	9	65.2	65.4	65.5	65.6	65.8	65.9	66.0	66.2	66.3
725	9	66.6	66.7	66.8	67.0	67.1	67.2	67.4	67.5	67.6
726	9	67.9	68.0	68.2	68.3	68.4	68.6	68.7	68.8	69.0
727	9	69.2	69.4	69.5	69.6	69.8	69.9	70.0	70.2	70.3
728	9	70.6	70.7	70.8	71.0	71.1	71.2	71.4	71.5	71.6
729	9	71.9	72.0	72.2	72.3	72.4	72.6	72.7	72.8	73.0

TABLE XI.—*cont.*

MILLIMETRES OF MERCURY (680·0 TO 779·9) WITH TENTHS AT 0° C. IN  
LATITUDE 45° TO MILLIBARS AND TENTHS.

Tenths.		·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
mm.		Millibars.									
<b>730</b>	9	73·2	73·4	73·5	73·6	73·8	73·9	74·0	74·2	74·3	74·4
<b>731</b>	9	74·6	74·7	74·8	75·0	75·1	75·2	75·4	75·5	75·6	75·8
<b>732</b>	9	75·9	76·0	76·2	76·3	76·4	76·6	76·7	76·8	77·0	77·1
<b>733</b>	9	77·2	77·4	77·5	77·6	77·8	77·9	78·0	78·2	78·3	78·4
<b>734</b>	9	78·6	78·7	78·8	79·0	79·1	79·2	79·4	79·5	79·6	79·8
<b>735</b>	9	79·9	80·0	80·2	80·3	80·4	80·6	80·7	80·8	81·0	81·1
<b>736</b>	9	81·2	81·4	81·5	81·6	81·8	81·9	82·0	82·2	82·3	82·4
<b>737</b>	9	82·6	82·7	82·8	83·0	83·1	83·2	83·4	83·5	83·6	83·8
<b>738</b>	9	83·9	84·0	84·2	84·3	84·4	84·6	84·7	84·8	85·0	85·1
<b>739</b>	9	85·2	85·4	85·5	85·6	85·8	85·9	86·0	86·2	86·3	86·4
<b>740</b>	9	86·6	86·7	86·8	87·0	87·1	87·2	87·4	87·5	87·6	87·8
<b>741</b>	9	87·9	88·0	88·2	88·3	88·4	88·6	88·7	88·8	89·0	89·1
<b>742</b>	9	89·2	89·4	89·5	89·6	89·8	89·9	90·0	90·2	90·3	90·4
<b>743</b>	9	90·6	90·7	90·8	91·0	91·1	91·2	91·4	91·5	91·6	91·8
<b>744</b>	9	91·9	92·0	92·2	92·3	92·4	92·6	92·7	92·8	93·0	93·1
<b>745</b>	9	93·2	93·4	93·5	93·6	93·8	93·9	94·0	94·2	94·3	94·4
<b>746</b>	9	94·6	94·7	94·8	95·0	95·1	95·2	95·4	95·5	95·6	95·8
<b>747</b>	9	95·9	96·0	96·2	96·3	96·4	96·6	96·7	96·8	97·0	97·1
<b>748</b>	9	97·2	97·4	97·5	97·6	97·8	97·9	98·0	98·2	98·3	98·4
<b>749</b>	9	98·6	98·7	98·8	99·0	99·1	99·2	99·4	99·5	99·6	99·8
<b>750</b>	9	99·9	00·0	00·2	00·3	00·4	00·6	00·7	00·8	01·0	01·1
<b>751</b>	10	01·2	01·4	01·5	01·6	01·8	01·9	02·0	02·2	02·3	02·4
<b>752</b>	10	02·6	02·7	02·8	03·0	03·1	03·2	03·4	03·5	03·6	03·8
<b>753</b>	10	03·9	04·0	04·2	04·3	04·4	04·6	04·7	04·8	05·0	05·1
<b>754</b>	10	05·2	05·4	05·5	05·6	05·8	05·9	06·0	06·2	06·3	06·4
<b>755</b>	10	06·6	06·7	06·8	07·0	07·1	07·2	07·4	07·5	07·6	07·8
<b>756</b>	10	07·9	08·0	08·2	08·3	08·4	08·6	08·7	08·8	09·0	09·1
<b>757</b>	10	09·2	09·4	09·5	09·6	09·8	09·9	10·0	10·2	10·3	10·4
<b>758</b>	10	10·6	10·7	10·8	11·0	11·1	11·2	11·4	11·5	11·6	11·8
<b>759</b>	10	11·9	12·0	12·2	12·3	12·4	12·6	12·7	12·8	13·0	13·1
<b>760</b>	10	13·2	13·4	13·5	13·6	13·8	13·9	14·0	14·2	14·3	14·4
<b>761</b>	10	14·6	14·7	14·8	15·0	15·1	15·2	15·4	15·5	15·6	15·8
<b>762</b>	10	15·9	16·0	16·2	16·3	16·4	16·6	16·7	16·8	17·0	17·1
<b>763</b>	10	17·2	17·4	17·5	17·6	17·8	17·9	18·0	18·2	18·3	18·4
<b>764</b>	10	18·6	18·7	18·8	19·0	19·1	19·2	19·4	19·5	19·6	19·8
<b>765</b>	10	19·9	20·0	20·2	20·3	20·4	20·6	20·7	20·8	21·0	21·1
<b>766</b>	10	21·2	21·4	21·5	21·6	21·8	21·9	22·0	22·2	22·3	22·4
<b>767</b>	10	22·6	22·7	22·8	23·0	23·1	23·2	23·4	23·5	23·6	23·8
<b>768</b>	10	23·9	24·0	24·2	24·3	24·4	24·6	24·7	24·8	25·0	25·1
<b>769</b>	10	25·2	25·4	25·5	25·6	25·8	25·9	26·0	26·2	26·3	26·4
<b>770</b>	10	26·6	26·7	26·8	27·0	27·1	27·2	27·4	27·5	27·6	27·8
<b>771</b>	10	27·9	28·0	28·2	28·3	28·4	28·6	28·7	28·8	29·0	29·1
<b>772</b>	10	29·2	29·4	29·5	29·6	29·8	29·9	30·0	30·2	30·3	30·4
<b>773</b>	10	30·6	30·7	30·8	31·0	31·1	31·2	31·4	31·5	31·6	31·8
<b>774</b>	10	31·9	32·0	32·2	32·3	32·4	32·6	32·7	32·8	33·0	33·1
<b>775</b>	10	33·2	33·4	33·5	33·6	33·8	33·9	34·0	34·2	34·3	34·4
<b>776</b>	10	34·6	34·7	34·8	35·0	35·1	35·2	35·4	35·5	35·6	35·8
<b>777</b>	10	35·9	36·0	36·2	36·3	36·4	36·6	36·7	36·8	37·0	37·1
<b>778</b>	10	37·2	37·4	37·5	37·6	37·8	37·9	38·0	38·2	38·3	38·4
<b>779</b>	10	38·6	38·7	38·8	39·0	39·1	39·2	39·4	39·5	39·6	39·8

TABLE XII.—RAINFALL.

MILLIMETRES (0 TO 50) AND TENTHS TO INCHES, CORRECT TO HUNDREDTHS,  
ON THE BASIS OF 100 mm.=3·93701 in.

Tenths.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
mm.	Inches.									
0	·00	·00	·01	·01	·02	·02	·02	·03	·03	·04
1	·04	·04	·05	·05	·06	·06	·06	·07	·07	·07
2	·08	·08	·09	·09	·09	·10	·10	·11	·11	·11
3	·12	·12	·13	·13	·13	·14	·14	·15	·15	·15
4	·16	·16	·17	·17	·17	·18	·18	·19	·19	·19
5	·20	·20	·20	·21	·21	·22	·22	·22	·23	·23
6	·24	·24	·24	·25	·25	·26	·26	·26	·27	·27
7	·28	·28	·28	·29	·29	·30	·30	·30	·31	·31
8	·31	·32	·32	·33	·33	·33	·34	·34	·35	·35
9	·35	·36	·36	·37	·37	·37	·38	·38	·39	·39
10	·39	·40	·40	·41	·41	·41	·42	·42	·43	·43
11	·43	·44	·44	·44	·45	·45	·46	·46	·46	·47
12	·47	·48	·48	·48	·49	·49	·50	·50	·50	·51
13	·51	·52	·52	·52	·53	·53	·54	·54	·54	·55
14	·55	·56	·56	·56	·57	·57	·57	·58	·58	·59
15	·59	·59	·60	·60	·61	·61	·61	·62	·62	·63
16	·63	·63	·64	·64	·65	·65	·65	·66	·66	·67
17	·67	·67	·68	·68	·69	·69	·69	·70	·70	·70
18	·71	·71	·72	·72	·72	·73	·73	·74	·74	·74
19	·75	·75	·76	·76	·76	·77	·77	·78	·78	·78
20	·79	·79	·80	·80	·80	·81	·81	·81	·82	·82
21	·83	·83	·83	·84	·84	·85	·85	·85	·86	·86
22	·87	·87	·87	·88	·88	·89	·89	·89	·90	·90
23	·91	·91	·91	·92	·92	·93	·93	·93	·94	·94
24	·95	·95	·95	·96	·96	·96	·97	·97	·98	·98
25	·98	·99	·99	1·00	1·00	1·00	1·01	1·01	1·02	1·02
26	1·02	1·03	1·03	1·04	1·04	1·04	1·05	1·05	1·06	1·06
27	1·06	1·07	1·07	1·07	1·08	1·08	1·09	1·09	1·09	1·10
28	1·10	1·10	1·11	1·11	1·12	1·12	1·13	1·13	1·13	1·14
29	1·14	1·15	1·15	1·15	1·16	1·16	1·17	1·17	1·17	1·18
30	1·18	1·19	1·19	1·19	1·20	1·20	1·20	1·21	1·21	1·22
31	1·22	1·22	1·23	1·23	1·24	1·24	1·24	1·25	1·25	1·26
32	1·26	1·26	1·27	1·27	1·28	1·28	1·28	1·29	1·29	1·30
33	1·30	1·30	1·31	1·31	1·31	1·32	1·32	1·33	1·33	1·33
34	1·34	1·34	1·35	1·35	1·35	1·36	1·36	1·37	1·37	1·37
35	1·38	1·38	1·39	1·39	1·39	1·40	1·40	1·41	1·41	1·41
36	1·42	1·42	1·43	1·43	1·43	1·44	1·44	1·44	1·45	1·45
37	1·46	1·46	1·46	1·47	1·47	1·48	1·48	1·48	1·49	1·49
38	1·50	1·50	1·50	1·51	1·51	1·52	1·52	1·52	1·53	1·53
39	1·54	1·54	1·54	1·55	1·55	1·56	1·56	1·56	1·57	1·57
40	1·57	1·58	1·58	1·59	1·59	1·59	1·60	1·60	1·61	1·61
41	1·61	1·62	1·62	1·63	1·63	1·63	1·64	1·64	1·65	1·65
42	1·65	1·66	1·66	1·67	1·67	1·67	1·68	1·68	1·69	1·69
43	1·69	1·70	1·70	1·70	1·71	1·71	1·72	1·72	1·72	1·73
44	1·73	1·74	1·74	1·74	1·75	1·75	1·76	1·76	1·76	1·77
45	1·77	1·78	1·78	1·78	1·79	1·79	1·80	1·80	1·80	1·81
46	1·81	1·81	1·82	1·82	1·83	1·83	1·83	1·84	1·84	1·85
47	1·85	1·85	1·86	1·86	1·87	1·87	1·87	1·88	1·88	1·89
48	1·89	1·89	1·90	1·90	1·91	1·91	1·91	1·92	1·92	1·93
49	1·93	1·93	1·94	1·94	1·94	1·95	1·95	1·96	1·96	1·96

The table also serves for converting whole millimetres, from 0 to 500, to inches and tenths.

TABLE XII.—(cont.)—RAINFALL.

MILLIMETRES (50 TO 100) AND TENTHS TO INCHES, CORRECT TO HUNDREDTHS,  
ON THE BASIS OF 100 mm. = 3·93701 in.

Tenths.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
mm.	Inches.									
50	1·97	1·97	1·98	1·98	1·98	1·99	1·99	2·00	2·00	2·00
51	2·01	2·01	2·02	2·02	2·02	2·03	2·03	2·04	2·04	2·04
52	2·05	2·05	2·06	2·06	2·06	2·07	2·07	2·07	2·08	2·08
53	2·09	2·09	2·09	2·10	2·10	2·11	2·11	2·11	2·12	2·12
54	2·13	2·13	2·13	2·14	2·14	2·15	2·15	2·15	2·16	2·16
55	2·17	2·17	2·17	2·18	2·18	2·19	2·19	2·19	2·20	2·20
56	2·20	2·21	2·21	2·22	2·22	2·22	2·23	2·23	2·24	2·24
57	2·24	2·25	2·25	2·26	2·26	2·26	2·27	2·27	2·28	2·28
58	2·28	2·29	2·29	2·30	2·30	2·30	2·31	2·31	2·31	2·32
59	2·32	2·33	2·33	2·33	2·34	2·34	2·35	2·35	2·35	2·36
60	2·36	2·37	2·37	2·37	2·38	2·38	2·39	2·39	2·39	2·40
61	2·40	2·41	2·41	2·41	2·42	2·42	2·43	2·43	2·43	2·44
62	2·44	2·44	2·45	2·45	2·46	2·46	2·46	2·47	2·47	2·48
63	2·48	2·48	2·49	2·49	2·50	2·50	2·50	2·51	2·51	2·52
64	2·52	2·52	2·53	2·53	2·54	2·54	2·54	2·55	2·55	2·56
65	2·56	2·56	2·57	2·57	2·57	2·58	2·58	2·59	2·59	2·59
66	2·60	2·60	2·61	2·61	2·61	2·62	2·62	2·63	2·63	2·63
67	2·64	2·64	2·65	2·65	2·65	2·66	2·66	2·67	2·67	2·67
68	2·68	2·68	2·69	2·69	2·69	2·70	2·70	2·70	2·71	2·71
69	2·72	2·72	2·72	2·73	2·73	2·74	2·74	2·74	2·75	2·75
70	2·76	2·76	2·76	2·77	2·77	2·78	2·78	2·78	2·79	2·79
71	2·80	2·80	2·80	2·81	2·81	2·81	2·82	2·82	2·83	2·83
72	2·83	2·84	2·84	2·85	2·85	2·85	2·86	2·86	2·87	2·87
73	2·87	2·88	2·88	2·89	2·89	2·89	2·90	2·90	2·91	2·91
74	2·91	2·92	2·92	2·93	2·93	2·93	2·94	2·94	2·94	2·95
75	2·95	2·96	2·96	2·96	2·97	2·97	2·98	2·98	2·98	2·99
76	2·99	3·00	3·00	3·00	3·01	3·01	3·02	3·02	3·02	3·03
77	3·03	3·04	3·04	3·04	3·05	3·05	3·06	3·06	3·06	3·07
78	3·07	3·07	3·08	3·08	3·09	3·09	3·09	3·10	3·10	3·11
79	3·11	3·11	3·12	3·12	3·13	3·13	3·13	3·14	3·14	3·15
80	3·15	3·15	3·16	3·16	3·17	3·17	3·17	3·18	3·18	3·19
81	3·19	3·19	3·20	3·20	3·20	3·21	3·21	3·22	3·22	3·22
82	3·23	3·23	3·24	3·24	3·24	3·25	3·25	3·26	3·26	3·26
83	3·27	3·27	3·28	3·28	3·28	3·29	3·29	3·30	3·30	3·30
84	3·31	3·31	3·31	3·32	3·32	3·33	3·33	3·33	3·34	3·34
85	3·35	3·35	3·35	3·36	3·36	3·37	3·37	3·37	3·38	3·38
86	3·39	3·39	3·39	3·40	3·40	3·41	3·41	3·41	3·42	3·42
87	3·43	3·43	3·43	3·44	3·44	3·44	3·45	3·45	3·46	3·46
88	3·46	3·47	3·47	3·48	3·48	3·48	3·49	3·49	3·50	3·50
89	3·50	3·51	3·51	3·52	3·52	3·52	3·53	3·53	3·54	3·54
90	3·54	3·55	3·55	3·56	3·56	3·56	3·57	3·57	3·57	3·58
91	3·58	3·59	3·59	3·59	3·60	3·60	3·61	3·61	3·61	3·62
92	3·62	3·63	3·63	3·63	3·64	3·64	3·65	3·65	3·65	3·66
93	3·66	3·67	3·67	3·67	3·68	3·68	3·69	3·69	3·69	3·70
94	3·70	3·70	3·71	3·71	3·72	3·72	3·72	3·73	3·73	3·74
95	3·74	3·74	3·75	3·75	3·76	3·76	3·76	3·77	3·77	3·78
96	3·78	3·78	3·79	3·79	3·80	3·80	3·80	3·81	3·81	3·81
97	3·82	3·82	3·83	3·83	3·83	3·84	3·84	3·85	3·85	3·85
98	3·86	3·86	3·87	3·87	3·87	3·88	3·88	3·89	3·89	3·89
99	3·90	3·90	3·91	3·91	3·91	3·92	3·92	3·93	3·93	3·93

The table also serves for converting whole millimetres, from 500 to 1,000, to inches and tenths.

## CONVERSION TABLES—LINEAR.

TABLE XIII.

Nautical Miles.	Statute Miles.	Kilo-metres.
1	1.2	1.8
2	2.3	3.7
3	3.5	5.6
4	4.6	7.4
5	5.8	9.3
6	6.9	11.1
7	8.1	13.0
8	9.2	14.8
9	10.4	16.7
10	11.5	18.5
20	23.0	37
30	34.5	56
40	46.1	74
50	57.6	92
60	69.1	111
70	80.6	148
80	92.1	130
90	103.6	167
100	115.2	185

Based on Nautical  
mile of 6080 feet.

TABLE XIV.

FOR HEIGHTS.

Feet.	Metres
1	0.3
2	0.6
3	0.9
4	1.2
5	1.5
6	1.8
7	2.1
8	2.4
9	2.7
10	3.1
20	6.1
30	9.1
40	12.2
50	15.2
100	30.5
500	152.4
1,000	304.8
10,000	3048.0

TABLE XV.

FOR VISIBILITY.

Yds.	Metres	Yds.	Metres.
5	5	1,000	914
10	9	2,000	1,829
20	18	3,000	2,743
30	27	4,000	3,658
40	37	5,000	4,572
50	46	10,000	9,144
60	55		
70	64		
80	73		
90	82		
100	91		
200	183		
300	274		
400	366		
500	457		
600	549		
700	640		
800	732		
900	823		

Based on figures of the Bureau International des  
Poids et Mesures.



TABLE XVI.

CORRECTION IN UNITS OF SPECIFIC GRAVITY TO BE APPLIED TO  
M.O. HYDROMETER READINGS FOR VARIOUS TEMPERATURES.

Temperature of Sea Water.		Specific Gravities.				
C°	F°	16	20	24	28	32
-2	28·4	-1·2	-1·4	-1·6	-1·8	-2·0
0	32·0	-1·2	-1·4	-1·6	-1·7	-1·9
+2	35·6	-1·1	-1·3	-1·5	-1·6	-1·8
4	39·2	-1·1	-1·3	-1·4	-1·5	-1·6
6	42·8	-1·0	-1·2	-1·3	-1·4	-1·4
8	46·4	-0·9	-1·0	-1·1	-1·2	-1·2
10	50·0	-0·7	-0·8	-0·8	-0·9	-0·9
12	53·8	-0·4	-0·5	-0·5	-0·5	-0·6
14	57·2	-0·2	-0·2	-0·2	-0·2	-0·2
16	60·8	+0·2	+0·2	+0·2	+0·2	+0·2
18	64·4	+0·5	+0·5	+0·6	+0·6	+0·6
20	68·0	+1·0	+1·0	+1·1	+1·1	+1·1
22	71·6	+1·4	+1·4	+1·5	+1·6	+1·6
24	75·2	+1·9	+2·0	+2·1	+2·1	+2·2
26	78·8	+2·4	+2·5	+2·6	+2·6	+2·7
28	82·4	+2·9	+3·0	+3·1	+3·2	+3·3
30	86·0	+3·5	+3·6	+3·7	+3·8	+3·9
32	89·6	+4·1	+4·2	+4·3	+4·4	+4·5

This table is based on the values given by Martin Knudsen quoted in von Krummel's *Handbuch der Ozeanographie*.

It is applicable to all M.O. hydrometers in the series beginning No. 191, in which instruments the density of water at 4°C is taken as unity; these instruments are graduated to read correctly at 15°C (59°F).