when considered in conjunction with the difference in the rotational velocities of these regions, implies that the mass of air over an equatorial zone some 50° or 60° wide, must, upon the whole, have a motion from the east as compared with the earth beneath it; and that the mass of air over all the rest of the earth must, upon the whole, have a relative motion from the west. This theoretical conclusion is corroborated by the distribution of barometric pressure. The barometer stands highest at the two parallels which, according to this theory, form the boundaries between easterly and westerly winds, while at the equator and poles it stands low. This difference may be accounted for by the excess of centrifugal force possessed by west winds, and the defect of centrifugal force in east winds. If the air simply turned with the earth, centrifugal force combined with gravity would not tend to produce accumulation of air over any particular zone, the ellipticity of the earth being precisely adapted to an equable distribution. But if a body of air or other fluid is moving with sensibly different rotational velocity from the earth, the difference in centrifugal force will give a tendency to move towards the equator, or from it, according as the differential motion is from the west or from the east. The easterly winds over the equatorial zone should therefore tend to remove air from the equator and heap it up at the limiting parallels; and the westerly winds over the remainder of the earth should tend to draw air away from the poles and heap it up at the same limiting parallels. This theoretical consequence exactly agrees with the following table of mean barometric heights in different zones given by Maury:[1]—

North Latitude.	Barometer.	South Latitude.	Barometer.
0° to 5°	29·915	0° to 5°	29·940
5° to 10°	29·922	5° to 10°	29·981
10° to 15°	29·964	10° to 15°	30·028
15° to 20°	30·018	15° to 20°	30·060
20° to 25°	30·081	20° to 25°	30·102
25° to 30°	30·149	25° to 30°	30·095
30° to 35°	30·210	30° to 36°	30·052
35° to 40°	30·124	42° 53′	29·90
40° to 45°	30·077	45° 0′	29·66
45° to 50°	30·060	49° 8′	29·47
51° 29′	29·99	51° 33′	29·50
59° 51′	29·88	54° 26′	29·35
78° 37′	29·759	55° 52′	29·36
		60° 0′	29·11
		66° 0′	29·08
		74° 0′	28·93

[1] *Physical Geography and Meteorology of the Sea*, p. 180, art. 362, edition 1860.

This table shows that the barometric height falls off regularly on both sides from the two limiting zones 30° to 35° N. and 20° to 25° S., the fall continuing towards both poles as far as the observations extend, and continuing inwards to a central minimum between 0° and 5° N.

If the bottom of a cylindrical vessel of water be covered with saw-dust, and the water made to rotate by stirring, the saw-dust will be drawn away from the edges, and heaped up in the middle, thus showing an indraught of water along the bottom towards the region of low barometer in the centre. It is probable that, from a similar cause (a central depression due to centrifugal force), there is an indraught of air along the earth's surface towards the poles, underneath the primary circulation which our theory supposes; the diminution of velocity by friction against the earth, rendering the lowest portion of the air obedient to this indraught, which the upper strata are enabled to resist by the centrifugal force of their more rapid motion. This, according to Professor James Thomson,[1] is the explanation of the prevalence of south-west winds in the north temperate zone; their southerly component being due to the barometric indraught and their westerly component to differential velocity of rotation. The indraught which also exists from the limiting parallels to the region of low barometer at the equator, coincides with the current due to difference of temperature; and this coincidence may be a main reason of the constancy of the trade-winds.

277. Origin of Cyclones.—In the northern hemisphere a wind which would blow towards the north if the earth were at rest, does actually blow towards the north-east; and a wind which would blow towards the south blows towards the south-west. In both cases, the earth's rotation introduces a component towards the right with reference to a person travelling with the wind. In the southern hemisphere it introduces a component towards the left.

Again, a west wind has an excess of centrifugal force which tends to carry it towards the equator, and an east wind has a tendency to move towards the pole; so that here again, in the northern hemi-

[1] The fullest and clearest account, historical and expository, of the theory of general atmospheric circulation is the Bakerian Lecture by Professor James Thomson, *Phil. Trans.*, 1892. Some calculations bearing on the subject will be found in a paper by the editor of the present work in *Phil. Mag.*, Sept. 1871.

sphere the deviation is in both cases to the right, and in the southern hemisphere to the left.

We have thus an explanation of cyclonic movements. In the northern hemisphere, if a sudden diminution of pressure occurs over any large area, the air all around for a considerable distance receives an impetus directed towards this area. But, before the converging streams can meet, they undergo deviation, each to its own right, so that, instead of arriving at their common centre, they blow tangentially to a closed curve surrounding it, and thus produce an eddy from right to left with respect to a person standing in the centre. This is the universal direction of cyclonic rotation in the northern hemisphere; and the opposite rule holds for the southern hemisphere. The former is opposite to, the latter the same as the direction of motion of the hands of a watch lying with its face up. In each case the motion is opposite to the apparent diurnal motion of the sun for the hemisphere in which it occurs.

278. **Anemometers.**—Instruments for measuring either the force or the velocity of the wind are called *anemometers*. Its force is usually measured by Osler's anemometer, in which the pressure of the wind is received upon a square plate attached to one end of a spiral spring (with its axis horizontal), which yields more or less according to the force of the wind, and transmits its motion to a pencil which leaves a trace upon paper moved by clock-work. It seems that the force received by the plate is not rigorously proportional to its size, and that a plate a yard square receives rather more than 9 times the pressure of a plate a foot square. The anemometer which has yielded the most satisfactory results is that invented by the Rev. Dr. Robinson of Armagh, which is represented in Fig. 140, and which indicates the velocity of the wind. It consists of four hemispherical cups attached to the ends of equal horizontal arms, forming a horizontal cross, which turns freely about a vertical axis. By means of an endless screw carried by the axis, a train of wheel-work is set in motion; and the indication is given by a hand which moves round a dial; or, in some instruments, by several hands moving round different dials like those of a gas-meter. The anemometer can also be made to leave a continuous record on paper, for which purpose various contrivances have been successfully employed. It was calculated by the inventor, and confirmed by his own experiments both in air and water, as well as by experiments conducted by Prof. C. Piazzi Smyth at Edinburgh, and more

recently by Sir George Airy at Greenwich, that the centre of each cup moves with a velocity which is almost exactly one-third of that of the wind. This is the only velocity-anemometer whose indications are exactly proportional to the velocity itself. Dr. Whewell's anemometer, which resembles a small windmill, is very far from fulfilling this condition, its variations of velocity being much less than those of the wind.

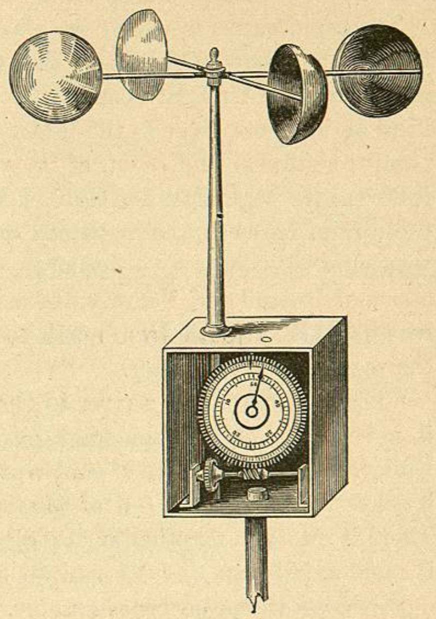

Fig. 140.—Robinson's Anemometer.

The direction of the wind, as indicated by a vane, can also be made to leave a continuous record by various contrivances; one of the most common being a pinion carried by the shaft of the vane, and driving a rack which carries a pencil. But perhaps the neatest arrangement for this purpose is a large screw with only one thread composed of a metal which will write on paper. A sheet of paper is moved by clock-work in a direction perpendicular to the axis of the screw, and is pressed against the thread, touching it of course only in one point, which travels parallel to the axis as the screw turns, and comes back to its original place after one revolution. When one end of the thread leaves the paper, the other end at the same instant comes on. The screw turns with the vane, so that a complete revolution of the screw corresponds to a complete revolution of the wind. This is one of the many ingenious contrivances devised and executed by Mr. Beckley, mechanical assistant in Kew Observatory.

279. **Oceanic Currents.**—The general principle of § 274 applies to liquids as well as to gases; though the effects are usually smaller, owing to their smaller expansibility.

The warm water in the equatorial regions overflows towards the poles, and an under-current of cold water which has descended in the polar regions flows towards the equator. Recent observations have shown that a temperature not much above 0° C. prevails at the bottom of the ocean even between the tropics. A very gradual circulation is thus produced on a very large scale.

The rapid currents which are observed on some parts of the surface of the ocean are probably due to wind. Among these may be mentioned the Gulf Stream. This current of warm water forms a kind of immense river in the midst of the sea, differing in the temperature, saltness, and colour of its waters from the medium in which it flows. Its origin is in the Gulf of Mexico, whence it issues through the straits between the Bahamas and Florida, turns to the northwest, and splits into two branches, one of which goes to warm the coasts of Ireland and Norway, the other gradually turns southwards, traverses the Atlantic from north to south, and finally loses itself in the regions of the equator.

"The Gulf Stream is a river in the ocean; in the severest droughts it never fails, and in the mightiest floods it never overflows; its banks and its bottom are of cold water, while its current is of warm; it takes its rise in the Gulf of Mexico, and empties into Arctic seas. There is on earth no other such majestic flow of waters. Its current is more rapid than the Mississippi or the Amazon, and its volume more than a thousand times greater. Its waters, as far out from the Gulf as the Carolina coasts, are of indigo blue. They are so distinctly marked that their line of junction with the common sea-water may be traced by the eye. Often one-half of the vessel may be perceived floating in Gulf Stream water, while the other half is in common water of the sea, so sharp is the line."—(Maury, *Physical Geography of the Sea.*)

It would appear that an accumulation of water is produced in the Gulf of Mexico by the trade-wind which blows steadily towards it over the South Atlantic, and that the elevation of level thus occasioned is the principal cause of the Gulf Stream.

EXAMPLES.

[*The Centigrade Scale is employed, except where otherwise stated.*]

Scales of Temperature.

1. The difference between the temperatures of two bodies is 30° F. Express this difference in degrees Cent. and in degrees Réau.
2. The difference between the temperatures of two bodies is 12° C. Express this difference in degrees Réau. and in degrees Fahr.
3. The difference between the temperatures of two bodies is 25° R. Express this difference in the Cent. and Fahr. scales.
4. Express the temperature 70° F. in the Cent. and Réau. scales.
5. Express the temperature 60° C. in the Réau. and Fahr. scales.
6. Express the temperature 30° R. in the Cent. and Fahr. scales.
7. Air expands by ·00366 of its volume at the freezing-point of water for each degree Cent. By how much does it expand for each degree Fahr.?
8. The temperature of the earth increases by about one degree Fahr. for every 50 feet of descent. How many feet of descent will give an increase of 1° Cent., and how many centimetres of descent will give an increase of 1° Cent., the foot being 30·48 cm.?
9. The mean annual range of temperature at a certain place is 100° F. What is this in degrees Cent.?
10. Lead melts at 326° C., and in melting absorbs as much heat as would raise 5·37 times its mass of water 1° C. What numbers will take the place of 326 and 5·37 when the Fahrenheit scale is employed?
11. Show that the temperature −40° C. and the temperature −40° F. are identical.
12. What temperature is expressed by the same number in the Fahr. and Réau. scales?

Expansion.

The following coefficients of expansion can be used:—

Linear.		Cubical.	
Steel,	·0000116	Glass,	·000024
Copper,	·0000172	Mercury,	·000179
Brass,	·0000188	Alcohol,	·001050
Glass,	·0000080	Ether,	·001520

13. The correct length of a steel chain for land measuring is 66 ft. Express, as a decimal of an inch, the difference between the actual lengths of such a chain at 0° and 20°.