greatest convexity, farthest away from the vestibule. This decussation of *e* and *f*, like the twining inosculation of *f* and *d*, is well known. It may not be so generally understood that there is (in the eagle; I do not know whether or not in birds generally) a *third* extra-vestibular communication of the bony canals. My sections show this perfectly. The great loop of *d*, sweeping past the decussation of *e* and *f*, is thrown into a cavity common to all three. Bristles threaded through each of the three canals can all be seen in contact, crossing one another through this curious extra-vestibular chamber. I call it the *trivia*, or 'three-way place.' It is just where, in fig. 6, the three membranous canals decussate, — midway between the letters *e*, *f*, and *c*. It does not, of course, follow, that the contained membranous canals intercommunicate here, and it appears from Ibsen's figures that they do not. The ampullar dilatations of the ends of the canals are well marked. The anatomy of associate soft parts is explained to some extent under fig. 7.

The endolymph may contain otoliths similar to those great concretions called 'ear-stones' in fishes. The equilibrating function of the labyrinth and its fluid appears to have been determined mainly from experiments upon birds. The apparatus may be likened to the glass tubes filled with water and a bubble of air, by a combination of which a surveyor, for example, is enabled to adjust his theodolite true; for a bird somehow knows how the liquid stands in these self-registering levelling tubes, and adjusts itself accordingly. Observations made upon pigeons show, that, "when the membranous canals are divided, very remarkable disturbances of equilibrium ensue, which vary in character according to the seat of the lesion. When the horizontal canals are divided, rapid movements of the head from side to side in a horizontal plane take place, along with oscillation of the eyeballs, and the animal tends to spin round on a vertical axis. When the posterior or inferior vertical canals are divided, the head is moved rapidly backwards and forwards, and the animal tends to execute a backward somersault, head over heels. When the superior vertical canals are divided, the head is moved rapidly forwards and backwards, and the animal tends to execute a forward somersault, heels over head. Combined section of the various canals causes the most bizarre contortions of the head and body." — (Ferrier, *Funct. of the brain*, 1876, p. 57.) Injury of the canals does not cause loss of hearing, nor does loss of equilibrium follow destruction of the cochlea. Two diverse though intimately connected functions are thus presided over by the acoustic nerve, — audition and equilibration.

The wonderful and endlessly varied songs of birds may acquire for us a new significance, now that we understand the mechanism by which these engaging creatures derive pleasure from their own music. Though no two things can well be conceived more different than an anatomical disquisition and a bird-song, either may be made to subserve the purpose of a truer appreciation of the other; and there may be physiological aspects of even a 'Christmas carol.' ELLIOTT COUES.

Washington, Christmas, 1882.

WHIRLWINDS, CYCLONES, AND TORNADOES.[1] — I.

THE general circulation of the winds is at times interrupted by local and temporary disturbances of very varied size and strength, to which the general name of 'storms' is given. Their most constant features are, a more or less pronounced inward spiral whirling of the air near the ground, feeding an up-draught at the centre, and an outflow above; and a progressive motion from place to place, along a tolerably well-defined track. Clouds, and generally rain as well, accompany the larger storms.

It is our object to explain how these disturbances arise, to examine the causes and methods of their peculiar action, and to study their distribution in time and place. With this end in view, the small dust-whirlwinds that commonly arise in the hot dry air of deserts will be first considered. Next will come the great hurricanes and typhoons of the tropical seas, and the less violent rotary storms of our own latitudes, all of which may be grouped together as cyclones. The tornadoes and water-spouts, showing a peculiar concentration of power over a very limited area, will be discussed last.

The dry whirlwinds in flat desert regions suddenly interrupt the calmness of the air, and begin turning, catching up dust and sand, and carrying them upwards through the spiral vortex to a height of many hundred feet. They are therefore not at all like those whirls formed about our street-corners at the meeting of opposing currents of blustering wind, or the eddies of greater strength seen in windy mountain regions; for they arise in a time of quiet, and begin their motion without apparent cause. Hence we must, at the outset, inquire into the

[1] Based on a series of lectures delivered at the Lowell institute, Boston, in January, 1883.

condition of the atmosphere when it lies at rest, examining it especially with regard to the kind of equilibrium that then exists, and the changes necessary to produce a tendency to motion.

When the air is at rest, it is normally densest and warmest next to the earth's surface, and becomes thinner and cooler at successive altitudes above it. It is denser below because the earth's attraction pulls it down, and compresses the lower layers by the weight of the upper ones. It is warmer below, mainly because the air gets nearly all of its heat by contact with, or radiation from, the warm earth, and not directly from the sun's rays, which pass through it with but little obstruction. The average rate of upward cooling, determined by many observations on mountains and in balloons, is about one degree F. for every three hundred feet of ascent. In this restful condition let us take a block of the dry air (the effect of the presence of water-vapor will be considered with the storms at sea) from the earth's surface, where the temperature is, say, 60° (fig. 1), and lift it up three hundred feet, to where the temperature is one degree less, or 59°. The block of lower air expands as it rises, because it is pressed on by less atmospheric weight,—less, at least, by the weight of three hundred feet of air; and, in thus expanding, it is cooled mechanically. It has been shown that this mechanical cooling of an ascending mass of dry air amounts to one degree F. in a hundred and eighty-three feet of ascent, whatever its initial temperature; so that in this special case the block is cooled by 1.6°, and its temperature is reduced to 58.4°. Now, let us compare it, when thus expanded and cooled, with an equal-sized block of air beside it, whose temperature is 59°. Evidently, of these two blocks of the same volume, and at the same pressure, the cooler will be the heavier. The block brought up from the surface, and now at a temperature of 58.4°, will weigh more than the air at 59° beside it, and hence it will tend to sink; and it must sink all the way down to its original level before it finds any air as heavy as itself. In this imaginary experiment we have disturbed the arrangement of the normal, quiet atmosphere; and the disturbed mass returns to its original position as soon as freed from the constraining force. Such an atmosphere is therefore in a condition of stable equilibrium, like a rod hung by its upper end, which is opposed to any change in its position, and, when displaced, tends to return to its original attitude.

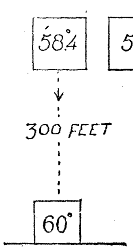

FIG. 1.

Evidently, when a whirlwind springs up in the calm air of a desert, as is so often the case, the atmosphere cannot possess this normal stability: for then there would be no temptation to any such disturbance; the air would prefer to stand as it is. Before the whirlwind can arise, there must have been a change to a condition of unstable equilibrium, in which the air, like a rod balanced on its lower end, is ready to move on small provocation; and we have now to look for the cause of this change. To be guided properly in the search, the conditions necessary and antecedent to the formation of the whirls must be examined. They are, that the whirls occur generally in level, barren, warm regions, in quiet air, and only in the daytime after the sun has risen high enough to warm the sandy ground, and the air next to it, to a rather high temperature. As the first and second of these conditions may be present at night as well as by day, it must, without doubt, be the heat from the sun that disturbs the quiet equilibrium into which the air tends to settle, and, by warming the lower layers, causes a departure from the ordinary stable condition of rest.

Let a case be supposed: the sun has warmed the lower air of the first example to a temperature of 90° (fig. 2), while the air three hundred feet above the desert sands has, in virtue of its diathermance, risen only to 70°; so that there is now a difference of twenty degrees between these two layers. If we here repeat the experiment of carrying a block of surface-air to a height of three hundred feet, it is again mechanically cooled 1.6°, so that its temperature is reduced to 88.4°; and now, comparing it with an equal volume of adjoining air at 70°, the latter is evidently the heavier, and therefore the block of air brought up from the surface, instead of tending to sink, as in the first case, tends strongly to rise farther, and continue the motion given to it. In other words, the air is now in a condition of unstable equilibrium: it is ready to upset and re-arrange itself. The lower layer may be compared to a film of oil balanced beneath a quiet sheet of water: a little disturbance would cause the two liquids to change places, and the oil would rise through the water, draining itself upwards.

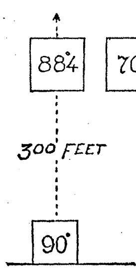

FIG. 2.

In such a condition as this, the desert-whirls may begin. It is clearly not necessary, in order to produce this result, that the vertical decrease of temperature should be as much as twenty degrees in three hundred feet, as in the case just assumed. In order to pass from the stable equilibrium, through the indifferent to the unstable equilibrium, it is sufficient, in dry air, that the vertical decrease should be greater than 1.6° in three hundred feet, or greater than one degree in one hundred and eighty-three feet. Moreover, it is important to notice, that, according to this theoretical explanation, the condition of indifferent equilibrium is passed before the surface-air is, as Franklin (1753) and Belt (1859) have said, specifically lighter than that above it. This would require a temperature difference of at least 5.6° F. in three hundred feet. It is sufficient that the surface-air shall be potentially lighter, though absolutely (before any motion takes place) heavier, than the higher layers, as Reye first showed (1864); or, in other words, stable equilibrium is lost, and indifferent equilibrium reached, when the surface-air is just enough warmer than any layer above it to make up for the change of temperatures produced in equalizing their densities. Any further excess of surface-warmth brings about theoretic unstable equilibrium. On the other hand, whirlwinds of decided activity will not be formed until the difference of temperature is much in excess of the narrow limits just given, the strength of the up-current increasing with its excess of warmth. Motion of the atmosphere caused by small differences of temperature would be very gentle, and would be perceived only in the 'boiling' of the air, often seen in summer-time over the brow of a hill.

It must be, then, the sun's heat, as was supposed, that destroys the normal stable equilibrium of our atmosphere; and to a disturbance of this kind we can refer more or less directly all storms, and, indeed, all winds that blow about the earth. Without the heat that is constantly showered down on us, we should soon gravitate into a lifeless condition of stable equilibrium, chemical, organic, and physical, and there remain in endless death. But the sun allows no such inactivity on its attendant planets: it keeps them alive and at work.

(To be continued.)

THE FRENCH ECLIPSE EXPEDITION.

P. J. JANSSEN, the leader of the French expedition which visited Caroline Island to observe the solar eclipse of May 6, has made a report to the French academy of sciences, which is published in full in the *Bulletin hebdomadaire de l'Association scientifique*, no. 181. It contains, first, an interesting account of the voyage to Caroline Island, and a brief description of the island, with the difficulties encountered in landing the instruments; then follows a statement of the instrumental outfit and the plan of observations. The search for intra-mercurial planets was assigned to Messrs. Palisa and Trouvelot. The former used an equatorial of 0.16 m. aperture, having a short focus and large field: the latter was provided with an equatorial of the same size, which had a finder of 0.08 m. aperture, thus giving the observer two telescopes. The finder had a field of 4°.5, and was used in examining the region in the vicinity of the sun, while the larger instrument was intended to give the position of any strange object that might be noted by means of its position-circles. In order to avoid the necessity of reading the circles, an attachment was made to both right ascension and declination circles, by which fine marks could be made upon the circles and verniers by the observer's assistants, and the corresponding readings determined at leisure. The finder was also furnished with a reticule containing cross-threads, and a position-circle for use in noting the appearance of the corona, to the drawing of which Mr. Trouvelot gave a portion of the time of the total phase.

The search for intra-mercurial planets was also conducted by the aid of photographic apparatus, which Mr. Janssen thus describes: —

"At my order, Mr. Gautier had prepared an equatorial mounting with an hour-axis two metres long, carrying a strong and large platform, upon which were fastened the following photographic apparatus: a large camera having a lens of eight inches (0.21 m.), made by Darlot, giving a field of 20° to 25° (plate of 0.40 m. by 0.50 m.), and designed for photographing the corona and the region about the sun with reference to the stars there found; a second camera, with a Darlot lens of six inches (0.16 m.), giving a field of 26° to 35° (plate of 0.30 m. by 0.40 m.), for the same purpose; and a very fine apparatus by Steinheil, for studying the corona. A second mounting carried several cameras with lenses of four inches (0.10 m.), giving a great amount of light, and designed to determine by very sensitive plates what are the limits of the corona, — an apparatus of great light-power, the exposure lasting during the whole of totality."

For spectrum analysis the following apparatus was employed: "a [reflecting] telescope of 0.50 m. aperture, having a very short focus (1.60 m.), and supplied with a direct-vision spectroscope of ten prisms; the slit of the spectroscope could be placed at different position-angles, and rapidly opened or closed, at the pleasure of the observer. An excellent finder, supplied with a reticule, was placed near the spectroscope, and distant from it by such an amount, that, when one eye had fixed upon some point of the corona in the finder, the other could obtain the spectroscopic analysis of this point." There was also attached to this telescope a biquartz polariscope by Prazmowski, and a spectroscope for showing Respighi's rings. A