from the summit, and the snow had disappeared from the island. After the first disturbances were over, it was found that the northern slope of the summit had fallen to the level of the cliffs which form the shore, and the mountain appeared as if split in two. Two previously quiet volcanoes on the peninsula of Aliaska began simultaneously to emit smoke and dust; and in the ten-fathom passage between Augutin Island and the mainland a new island, seventy-five feet high and a mile and a half in extent, has made its appearance. It is stated that subterranean noises had previously been heard by a party of hunters, some of whom are reported missing.

The volcano has not been approached nearer than ten miles since the eruption, at which distance the new island was distinctly seen northwest from Augustin Island. Its dimensions, therefore, are merely approximate. The morning of the eruption was perfectly clear, with a light south-west wind, and the tide extremely low. Three days before, all the fish are said to have disappeared from Port Graham. At last accounts smoke was arising from a point on Augustin Island, south from the cleft above mentioned, which crosses the island from east to west.

It would seem as if these events were local manifestations of an awakening of volcanic energy nearly world-wide. WM. H. DALL.

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

TORNADOES differ from the storms thus far mentioned in their excessive violence over a very restricted area, and their visibly rapid advance. After a great deal of theorizing, it is now possible to explain them very satisfactorily and simply as whirls in the air, a little above the ground, into the vortex of which the surface-winds are drawn up with great velocity. Electricity has no essential share in their action.

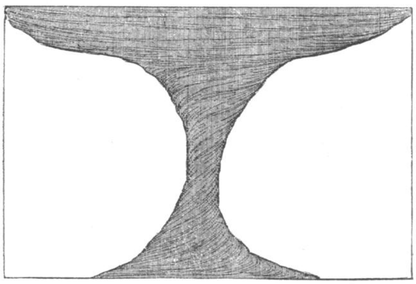
Recent studies, especially the reports by Mr. Finley of the signal-service, have done much to show us the regions of, and general conditions preceding, tornadoes. They are most numerous in Kansas, Missouri, and Illinois, although they have been recorded throughout the states east of the Mississippi, except in the far north-east and on the central Alleghanies. So they have occurred in all the months, and at nearly all hours of the day; but their time of greatest frequency is in the afternoons of June and the months adjoining. Where most fully studied, they seem to occur along the contact-line of warm southerly winds and cooler north-westerly or westerly winds. Local quiet and rather excessive warmth commonly precede them, and chilly winds come after their passage. Rain and hail fall in their neighborhood, but usually at a moderate distance away from the destructive wind-centre. Their advance is nearly always to the north-east, at about thirty miles an hour.

When first perceived, the tornado is generally described as a dark, funnel-shaped mass, hanging from heavy, dark, agitated clouds (fig. 23). Its roaring sound is heard as it comes nearer; and the whirling funnel is often seen to swing from side to side, and to rise and fall. Within its dark column, various objects snatched from the ground may be seen rising and turning round and round in the eddying winds: pine-trees appear like bushes, and barn-doors are mistaken for shingles. At a certain height these fragments are thrown laterally out of the power of the ascending current, and then fall to the ground, often with violence, from their lofty flight. If such a cloud appear in the west or south-west, one should make all possible haste to the north or south of its probable track; but there is seldom time to escape. The rapidity of the storm's approach, the noise of its roaring, the fear that its darkness and destruction naturally inspire, too often serve to take away one's presence of mind; and, before there is time for reflection, the whirl has come and passed, and the danger is over for those who survive. The force of the wind is terrific. Heavy carts have been carried, free from the ground, at such a velocity, that, when they strike, the tires are bent and twisted, and the spokes are broken from the hubs. Iron chains are blown through the air. Large beams are thrown with such strength that they penetrate the firm earth a foot or more. Children, and even men, have often been carried many feet above the ground, and sometimes dropped unhurt. A velocity of wind exceeding one hundred miles an hour is required to produce such effects. Strange examples of the wind's strength are found in the treatment of small objects: nails are found driven head first firmly into planks; a cornstalk is shot partly through a door, recalling the firing of a candle through a board. More than this, the wind shows signs of very unequal motions in a small space: bedding and clothing are torn to rags; harness is stripped from horses. Nothing can withstand the awful violence of the tornado's centre; and yet, at a little distance one side or the other, there is not only no harm

[1] Concluded from No. 50.

done, but there is no noticeable disturbance in the gentle winds. The track of marked disturbance averages only half a mile, and the path of great destruction is often only a few hundred feet wide.

The whirling at the centre is evident enough, in many cases, from the rotary motion of the funnel-cloud: it is, in all reported cases, from right to left, like the cyclones of this hemisphere. At a little distance from the centre, the wind is probably nearly radial, as is shown fully enough by the direction in which fences or trees are blown over, or houses and other loose objects carried. On the right side of the track the winds are more violent, and their destructive effect consequently reaches farther from the whirl than on the left. This is evidently because, on the right, the motion of the wind and the advance of the storm are combined, as has been explained under cyclones. Here are several examples from the Kansas tornadoes of May, 1879, as described in Finley's report, showing the opposed currents of air.



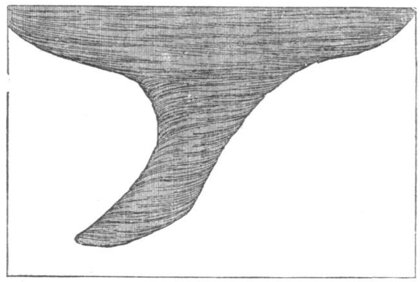


Fig. 23.[1]

Fig. 24 shows the fence on the right blown to the east; the fences on the left, to the west and south; and the hay from a stack, scattered in a curved line. When fences are not blown over, rubbish often collects on their windward side.

Fig. 25 illustrates, by arrows, the direction of the wind, by which several buildings were more or less injured; but most peculiar is the track of a man, who, on coming out of the east side of a barn, was caught up by the winds and carried half way around the building, and there set down very dizzy, but unhurt. At the same time, two horses near by were killed, their harness stripped off and torn to pieces. A scantling four inches square and ten feet long was found driven three feet and a half into the ground, only forty-five feet from its starting-point. A large board sixteen feet long was found two miles to the north-east, where it was identified by the color of its paint.

Fig. 26 shows a more disastrous case. The house was swept away, and its fragments filled the creek to the south-east. The trees west of the house were not hurt; but those in the grove on the track were blown over to the north-east, their bark and leaves stripped off, and their south-western side blackened as if burnt. In such position, branches have been found twisted from right to left about the trunks. As the storm came on, the family occupying the house ran out, turning to the north and west. One by one they were blown away, — first a little girl, who was found dead; then a girl and boy, not seriously hurt; next the mother was thrown against a tree and killed; and last, the father, carrying the baby, and becoming confused in the rushing wind, turned back from his safe flight to the west, was caught up and thrown over one hundred yards to the north-east, and killed. The accounts of tornadoes only too often give a record like this. In six hundred and odd tornadoes, forty are recorded as fatal to the people on their track. In these forty, four hundred and sixty-six lives were lost, and six hundred and eighty-seven persons were injured.

In addition to the violence of the whirling winds, an explosive effect is often noted in buildings where the windows and doors are closed. Doubtless this is one reason why roofs are so generally carried away. Doors

[1] Figs. 23, 24, 25, and 26 are from Finley's Report on tornadoes of May 29 and 30, 1879.

and windows have been blown outward. The four walls of a house have fallen outward from the centre. Still more definite is the account of a railroad-agent who had barred the window-shutters and locked the door of his station after a train had gone by. A tornado passed over it, and burst the window open outwards. Evidently the air of ordinary density within the building suddenly expands as the outside pressure of the atmosphere is taken off when the storm-centre passes. Possibly this action may aid in the plucking of poultry in tornadoes: the unfortunate chickens that are caught near the centre are nearly always stripped of their feathers. So with the remarkable penetration of mud into clothing, which cannot be cleansed by repeated washings: perhaps the air is drawn out as the storm passes, and then the mud is forced closely into the fabric by the returning atmospheric pressure. The ground

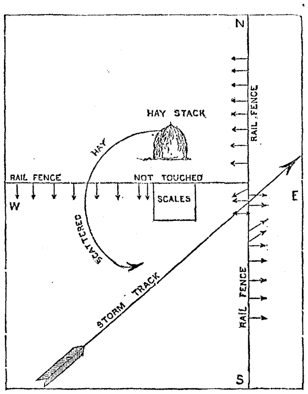


FIG. 24.

is sometimes said to look as if heavily washed on the central path: it may be that the expansion of air in a loose soil aids such a result.

Nothing can be better proven than the existence of a continuous and violent updraught at the centre of the whirl. An observer far enough from the track of the tornado to watch it composedly, and yet near enough to see it with some distinctness, seldom fails to note the rapid rising of *débris* and rubbish in the vortex, whirling as it rises; and a current of air strong enough to lift boards and beams must ascend with great energy. Most of the fragments thus captured by the wind are thrown to one side, and allowed to fall after a short flight; but smaller, lighter objects, such as hats, clothes, papers, shingles, are often carried several miles through the clouds, and dropped far away from home. But observers often report, also, that the extremity of the funnel-clouds is seen to descend, and from hanging aloft it suddenly darts downward to the ground. How can these two contradictory motions be reconciled? Simply enough: for the last is purely an apparent motion. It is simply the downward extension of the cloud-forming space faster than the cloud-particles

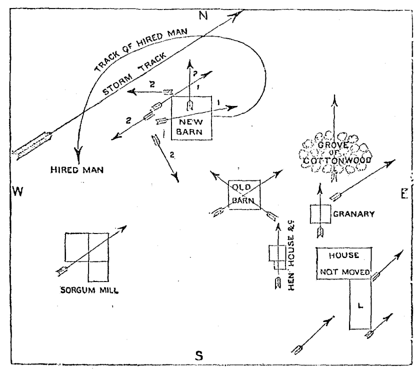


FIG. 25.

are carried upward. The same style of apparent motion against the wind may be seen in some thunder-showers where a cloud forms faster than the wind blows, and so eats its way to windward. There has been much needless mystification here, for the point was neatly explained by Franklin a century and a quarter ago. He wrote, that "the spout appears to drop or descend from the cloud, though the materials of which it is composed are all the while ascending;" for the moisture is con-

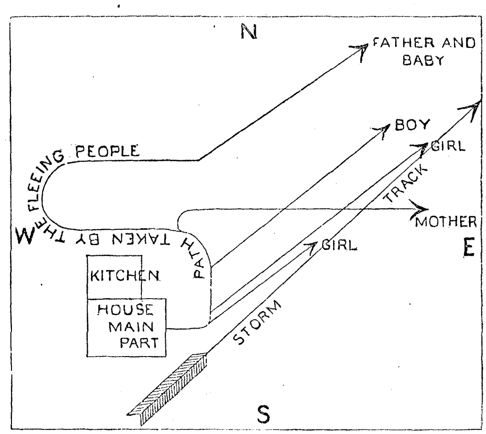


FIG. 26.

densed "faster in a right line downwards than the vapors themselves can climb in a spiral line upwards" (Franklin's Works, Sparks's ed., vi. 153, 154; letter dated Feb. 4, 1753).

Now let us look for the explanation of these varied effects, and discover, if possible, the reason of the extremely local development of such intense motions.

The explanation given for sand-whirls in the desert fails to provide for the excessive force of the tornado. A thin, warm surface-stratum of air would be prevented by friction with the ground from attaining any very excessive velocity; and, moreover, it is often excessively hot without tornadoes following, and tornadoes often happen when the air is not perfectly still. Yet, as they occur most frequently on warm or hot afternoons, surface-warmth very probably re-enforces other causes up to the point of violent storm development.

The existence of conflicting winds, as already noted, gives us more aid. So long as the cold wind passes under the warm, there will be no great disturbance, for the equilibrium will remain stable; but, if the warm wind advances under the cold, an unstable equilibrium may result. We have already seen that warm saturated air requires the smallest vertical difference of temperature to destroy its stability; and also that the saturated condition may often be met in the cloud stratum, although absent below it. For these two reasons we may infer that a tendency to upset will be more frequently reached a few hundred or thousand feet above the earth than closer to the ground. Suppose that such a condition is reached when a mass of warm southerly wind has pushed itself below the colder north-westerly stratum: the surface-air will often rest quiet and become warm below such a meeting, for the same reason that calms occur along the equator at the meeting of the trades; and a change must soon relieve this unnatural arrangement. The warm wind, feeling about for a point of escape through its cold cover, soon makes or finds a vent where it can drain away upwards; and then the entire warm mass, even a mile or more in diameter, and often more than one thousand feet in thickness, begins the rotary motion already described in whirls and cyclones, rises at the centre, and passes away. Before describing the peculiar tornado features, let us contrast the storm as now developed with the two other kinds of storms already explained. The desert-whirl arises from a thin layer of hot dry air, warmed at the place where the whirl begins, ascending in a small column through a considerable thickness of colder air. Friction with the ground prevents the attainment of an excessive velocity; and the ascending current can lift only sand and light objects. As soon as the bottom-air is drained away, the whirl stops. The cyclone is fairly compared, on account of its great horizontal extension, to a broad, relatively thin disk, with a horizontal measure several hundred times greater than its thickness, having a spiral motion of much rapidity, inward below and outward above, but a central ascending component of its motion so gentle that raindrops can ordinarily fall down through it. Its continuance depends largely on heat derived from vapor condensation: it is therefore self-acting after it has once begun, and goes on drawing in new air long after the original supply is exhausted. The tornado is like a cylinder, with a height equal to or greater than its diameter. Its warmth is chiefly imported to the point where its action begins, partly as sensible, partly as 'latent' heat; but, unlike the cyclone, its action ceases as soon as the original mass of warm air escapes upward through its warm cover. On apprehending these peculiarities, we may better appreciate its farther development.

The tornado has two motions to be considered, in addition to its general progression, — the spiral rotation, and the central updraught. The latter cannot, except under special conditions yet to be mentioned, become very rapid, for it depends primarily, simply on differences of temperature insufficient to produce very active motion; but the former attains a great velocity near the centre in virtue of the mechanical principle already quoted, — the 'preservation of areas.' When a whirling body is drawn toward the centre about which it swings, its velocity of rotation will increase as much as its radius of rotation decreases; the centrifugal force will also increase, and with the square of the velocity, or inversely as the square of the radius. This law claims obedience from air, as well as from solid bodies: hence, if the air of a tornado mass have a gentle rotary velocity of twenty or thirty feet a second at a thousand yards from the centre, this velocity will increase as the central air is drained away and the outer particles move inward; so that, when their radius is only one hundred yards, they will fly around at the rate of two or three hundred feet a second, or over one hundred and fifty miles an hour. It must be understood, however, that this requires that there should have been no loss of motion by friction, and hence can be true only for the air at a distance above the ground; and, further, that, in spite of the great horizontal rotary motion, there is still only a moderate vertical current. And consequently we have not yet arrived at the cause of the violent central and upward winds that distinguish the tornado from other storms, but this cause is close at hand.

Admit for a moment that there is no friction between the air and the ground. We should then have a tall vertical cylinder of air, spinning around near the centre at a terrific speed, at the base as well as aloft, and consequently developing a great centrifugal force. As a result, the density of the central core of air must be greatly diminished. Most of the central air must be drawn out by friction into the whirling cylinder, and prevented from returning by the centrifugal force. The core will be left with a feeling of emptiness, like an imperfect vacuum. If there were any air near by not controlled by the centrifugal force, it would rush violently into the central core to fill it again. Now consider the effect of friction with the ground. The lowermost air is prevented from attaining the great rotary velocity of the upper parts, and consequently is much less under the control of the centrifugal force, which is measured by the square of the velocity. The surface-air is therefore just what is wanted to fill the incipient vacuum: so it rushes into the core and up through it with a velocity comparable to that of the whirling itself; and *this inward-rushing air is the destructive surface-blast of the tornado.*

This explanation, first proposed by Mr. Ferrel a few years ago, is most ingenious and satisfactory. Moreover, he has followed its several parts by close mathematical analysis, and shown that the moderate antecedent conditions are amply sufficient to account for all the violence of the observed results.

There are still several points to be considered. The whirling motion has been described as corresponding in nearly all cases with that of northern cyclones; and yet it cannot be supposed that the indraught winds of a tornado are drawn from sufficient distances to show the effect of the earth's deflective force: it is more probable that the tornado is to be regarded as a small whirl within a larger one, for the warm and cold winds are probably part of a large cyclonic system in which differential and rotary motions are established; and, when such winds form a small local whirl of their own, it will rotate in the same direction as they do, from right to left. For a like reason the planets rotate on their axes in the direction in which they revolve around the sun. The constant direction of rotation in tornadoes may therefore, by itself, be taken as evidence that their cause is not in a stagnant atmosphere, like that of the desert-whirls, but is connected with the conflicting currents of a large, gentle cyclone.

The progressive motion of the tornado-centre is so constant in its direction to the north-east or east, that it cannot depend on local conditions within itself, but must rather result from its bodily transportation by the prevailing winds, with which the tornado-tracks agree very well in direction and rate. It will last till the lower warm air, which constituted the original unstable mass, is exhausted. This generally happens in about an hour, when it has traversed a distance of nearly thirty miles.

The tornado thus constituted may be likened to a very active air-pump, carried along a few hundred feet above the ground, sucking up the air over which it passes. It is for this reason that the surface-winds are so nearly radial. For this reason an enclosed mass of air, as in a house, suddenly explodes as the vacuum is formed over it; and as the air rushes to the centre, and there expands and cools, its vapor becomes visible in the great funnel, or spout, pendent from the clouds above. No rain can fall at the centre. Bodies much heavier than rain are lifted there, instead of dropped: so the rain must rise through the central core, and fall to one side of the storm, or before or behind it. If the expansion be very great, and the altitude reached by the drops rather excessive, then they will be frozen to hailstones before falling. Hail-storms and tornadoes commonly go together: they mutually explain each other. Electricity has no important part to play in the disturbance.

It was stated under cyclones that their central barometric depression had two causes, — the overflow caused by the central warmth, and the dishing-out of the air by centrifugal force. The first of these is ordinarily regarded as the effective cause of the wind's inward blowing. It has already been pointed out that the second and greater part of the depression is also effective in drawing in the winds when friction decreases their rotary velocity. We may now call attention to a third cause of centripetal motion in the cyclone already alluded to, in which it is like the tornado. The upper winds move with great rapidity, and cause a strong barometric depression at the centre of their whirling; but at the base of the storm, where friction with the sea, or still more with the land, reduces the lower wind's motion, and so diminishes their centrifugal force, we may have an indraught of the tornado style, in which the centrifugal diminution of central pressure in the upper winds is an effective cause of centripetal motion in the lower winds. While this is not the principal cause of surface-winds in a cyclone, it may be an important aid to central warmth.

Water-spouts are closely allied to tornadoes: but when seen in small form they approach the character of simple desert-whirls; that is, they then depend merely on air warmed at the place where they occur, and not on the running together of warm and cold winds from other regions. A probable cause for the excess of their strength above that of the sand-whirls lies in the smoothness of the water-surface on which they spring up, which will allow a long time of preparation; and in the moisture in the air, which will cause the warming of a greater thickness than if the air were very dry. The greater the thickness, the more their action will resemble that of a typical tornado. The appearance of the downward extension of the funnel-shaped cloud to meet the rising column of water is almost certainly only an appearance, and has the explanation already quoted from Franklin's ingenious writings.

We have relied largely, in the preceding explanations, on deductions from general principles, checked by the results of observation. The writings of many investigators have been examined, and in a few cases their names have been given; but the literature of the subject is now so extensive that full reference has been deemed unadvisable. Little attention has been paid to the older theories, in which conflicting winds and electricity were looked on as the chief causes of storms. The latter is regarded as an effect rather than a cause; and, while the former has much importance when rightly considered in connection with the earth's rotation, it is of small value as originally stated, and is then limited to the production of short-lived storms in mountainous districts. The more important factors of the modern theory of storms are the consideration of the conditions of stable and unstable equilibrium of the atmosphere, the true measure of the action of condensing water-vapor, the full estimation of the effect of the earth's rotation, and the recognition of the necessary increase in the wind's velocity as it is drawn in toward the storm-centre. W. M. DAVIS.

THE CRITICAL STATE OF GASES.

THE *Philosophical magazine* for August, 1883, contains a letter from Dr. William Ramsay which refers to observations upon the critical state of gases, published in the Proceedings of the London royal society, 1879–80. The chief observations that had previously been made upon this interesting subject are those of Cagniard de la Tour (*Annales de chimie*, 2ème série, xxi. et xxii.), Faraday (*Phil. trans.*, 1823 and 1845), Thilorier (*Annales de chimie*, 2ème série, lx.), Natterer (*Pogg. ann.*, xciv.), Andrews (*Phil. trans.*, 1869). Andrews found that when a gas was compressed in a closed space, and was maintained at a temperature below a certain limit, the pressure of the gas increased up to a fixed point, beyond which condensation occurred. The pressure at which condensation takes place increases rapidly with the temperature of the gas. At and beyond a certain temperature — the critical temperature — no amount of pressure can produce any of the usual phenomena of condensation. The isothermal lines below the critical temperature are apparently discontinuous, one portion representing no change of pressure corresponding to a change of volume. Above the critical temperature the isothermals are continuous.

The experiments of Dr. Ramsay were made upon benzine and ether, and a mixture of equal weights of benzine and ether. In one experiment a closed glass tube, somewhat in the shape of an hourglass, was used. One end of the tube was partly filled with ether, and was heated in an inclined position. The liquid expanded until, at the moment the meniscus disappeared, it nearly filled the lower half of the tube. On cooling, the liquid all condensed in the lower half.

The experiment was varied by inverting the tube after the meniscus had disappeared. On cooling, the liquid condensed in the upper half of the tube. The tube was next maintained for some time at a temperature above that at which the meniscus disappeared. On cooling, an equal quantity condensed in each division of the tube. It was observed, that, after the meniscus had disappeared, the part of the tube containing liquid had a different index of refraction from the other part.

The conclusion to be drawn from these results is, that, at and above the critical point, the density of the liquid is the same as that of its saturated vapor: consequently, after a sufficient time, the liquid and its vapor will become mixed. Above the critical point, the surface tension of a liquid disappears.

This conclusion is confirmed by the experiments of M. Cailletet (*Comptes rendus*, Feb. 2, 1880). He found that when the lower part of his experimental tube was filled with liquid carbonic anhydride at a temperature of 5°.5, and the upper part was filled with air and gaseous carbonic anhydride, a pressure of a hundred and fifty to two hundred atmospheres was necessary to cause the liquid to mix with the gas. At the suggestion of Mr. Jamin (*Comptes rendus*, May 21, 1883), hydrogen was substituted for the air in the upper part of the tube, and it was then found that a greater pressure was necessary to produce the mixture. This result would necessarily follow if we suppose that the mixture takes place when the densities of the liquid and the gas become equal. We cannot say that the liquid is converted into gas by pressure.

Though the densities of a liquid and its saturated vapor are equal, above the critical point, the two states of matter are still distinguished by other physical properties. Their indices of refraction are differ-