SCIENCE

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THE TORNADO: THEORIES; OBJECTIONS.

IT is somewhat difficult to give an adequate idea of the development of theories or pure speculations in this subject. Owing to the complex nature of the phenomenon, and the well-nigh utter lack of observations in the region of tornado-formation, the earlier views were more or less crude, and in some particulars have been slightly modified as broader and more comprehensive generalizations have been made. We shall be surprised, however, to find, on a careful study, how few changes the last fifty years have wrought. The original and essential ideas of tornado-generation and of sources of its power remain to-day as first propounded by Espy in 1840. Since his day, Professor Ferrel has been the most prominent exponent and amplifier of his views; and, with very few exceptions, theorists have followed Ferrel down to the present time. In many respects it would be a great advantage if one could give an impartial and trustworthy summing-up of the views of these men, and could bring out distinctly their gradual development. It will be far safer, however, since there are scores of students to-day who call in question many of these deductions, to give, as far as possible, an unbiassed *résumé* of these theories in the exact words of their defenders, and thus enable any one for himself to examine their adequacy for explaining the phenomena as they are manifested before our eyes.

Espy's Views.

It is not a little remarkable that the first investigator of any note in this field based all his theories on direct experiment in the laboratory. All theorists since Espy's day have not considered that there was any need of propounding any of these questions to Nature herself, but have contented themselves with the assumptions and necessarily imperfect and crude results obtained by the first experimenter. This is the more remarkable when we consider the extreme gravity of the subject, and the methods employed in all other sciences, except meteorology, to establish upon a firm and impregnable basis such profound and far-reaching theories. Espy's few and simple experiments at almost the very dawn of this science have never been repeated by theorists as far as the writer is aware. This one fact would seem of the extremest importance; and when we see, further, that even Espy himself was entirely unable to account for some of the anomalies in these very experiments, we can but feel the extreme necessity of further light. This feeling has borne fruit in other countries, as is shown by the diligence recently manifested in researches with rapidly revolving fans, which cause a supposed simulation of the phenomena in nature. While we can never hope to completely unravel the mysteries hidden in our storms until we question Nature herself in her own great laboratory, yet we can insist upon an examination of the original researches used as a basis for these theories, and demand a determination of their adequacy upon which to base the completer speculations of modern times.

Nephelescope.

The apparatus Espy used he called a "cloud-examiner." It consisted of a glass cylindrical vessel, having attached to it by an opening at the top (1) a condensing syringe, by which the air in the vessel could be compressed; (2) a glass U-tube half full of mercury, by which the amount of compression could be measured; (3) a stop-cock between the syringe and the vessel. "After the instrument is charged, the stop-cock is turned, and the pump removed. When the air within acquires the temperature of the air without, a measure is carefully applied to the barometer gauge to ascertain how much higher the mercury stands in the outer leg than in the inner; the stop-cock is then turned, and the air permitted to escape; and at the moment of equilibrium the stop-cock is closed again. Now, as the cock is closed at the moment the greatest cold is produced by expansion, the mercury in the outer leg will begin to ascend, and that in the inner leg to descend, because the air within receives heat from without; and the difference of level, being measured as before, will indicate the number of degrees cooled by a given expansion. When dry air is used in the experiment, the temperature is reduced about twice as much as when moist air is used, on account of latent caloric evolved in the latter case by the formation of cloud which is plainly visible." Saturation of the air was attempted by placing a little water in the bottom of the vessel. The amount of compression varied from two to twenty-five inches; that is, the gauge indicated an increased pressure inside the vessel, amounting in some instances to nearly that of an atmosphere. These experiments were certainly unique; and, while we shall see that they by no means prove Espy's theory, yet they must be regarded as a step in the right direction, and a faithful effort to elucidate a most complex problem. As all clouds in these experiments were formed by expansion of compressed air, it is not a little remarkable to read the following as Espy's method of forming clouds, given by Professor Ferrel: "As Espy with a few strokes of the handle of an air-pump produced a cloud in the receiver from the expansion and cooling of the moist air within, so nature, by means of a whirl in the open atmosphere, produces a cloud in the vortex of a tornado, from the expansion and cooling of the air there, on account of the partial vacuum caused by the centrifugal force of the gyrations." It is entirely probable that the rapidity of this expansion and consequent cool-

ing was very much greater than can ever occur in nature. It is also probable that his air was far from saturation, and that the cloud he saw was due to dust which was pumped in. Experiment has shown that such a cloud can be formed in quite dry air, provided the expansion is quick enough.

One very important element does not seem to have been considered, and that is the velocity of escape of the compressed air needed to form a cloud. It is probable that this was more than five hundred feet per second, or at least fifty times as great as can ever take place in the formation of cloud in our storms. It is a little singular that Espy himself did not discover more than he did. He found, that, while the results he obtained with dry air were very regular and constant, yet with moist air they were just the contrary; and the irregularities seemed to depend in part upon the interval after the compression, before the escape of the air. The following table is of much interest, and shows, in the first column, the number of minutes after compression, before opening the stop-cock, and, in the second column, the ratio between the amount of compression and the final reading of the gauge. In dry air this ratio was found to be from four to five; so that if Espy's statement just given is correct, that the temperature with dry air is reduced twice as much as with moist, the ratios should be eight to ten in this second column, according to his reasoning.

Minutes.	Ratio.	Minutes.	Ratio.
13,160	4.2	360	6.9
10,080	7.5	180	7.3
7,200	4.5	180	6.9
5,760	4.5	180	7.4
5,760	4.2	180	7.0
5,040	4.3	90	6.9
4,320	4.4	60	7.4
4,320	4.5	60	7.4
1,800	4.4	15	5.5
1,680	4.5	10	7.8
1,200	4.7	10	5.1
1,080	5.5		

Espy considers this result, "so contrary to all our notions since the experiments of Dalton on the subject of the dew-point," very remarkable.

We have not all the data needed to give a complete explanation of Espy's results, but this much we do know: if Espy had allowed a slower escape of the moist air, there would have been no cloud, and he would have had no difference between dry and moist air. When the explosion was very sudden, a cloud was formed, and the conditions inside the apparatus were very different from those with dry air, but not because of the liberation of latent caloric. At the end of ten minutes he found the ratio much smaller, apparently, than at the end of an hour or two; and after that the ratio diminished until it became exactly what it was in dry air. It is plain that this final result could not be attributed to the gradual non-saturation of the air, as Espy thought. There are no other experiments made by Espy under exactly similar conditions of temperature in moist and dry air. The evidence is conclusive, from these and other more recent experiments by the writer, that practically no different result will be produced, whether moist or dry air be introduced into the nephelescope.

I have dwelt upon these experiments at some length for the reason that they form the sum and substance of all efforts in this line up to very recent times.

Upon these experiments depend all of Espy's theories as to tornado-formation, and he has been quite closely followed in all views as to the essence of the forces underlying our most violent tornadoes. Mr. Espy gives the following *résumé* of his theories as ascertained and promulgated by the French Academy of Sciences:—

"If a very extended stratum of warm and humid air at rest covers the surface of a region of land or sea, and by any cause whatever (for example, a less local density) an ascending current is formed in this mass of humid air, the ascending force, instead of diminishing in consequence of the elevation of the rising column, will increase with the height of the column exactly as though a current of hydrogen was rising through the common air, which current would be pushed towards the top of the atmosphere with a force and velocity in proportion to its height. This column of heated air may also be compared to that in chimneys and stove-pipes, of which the draught is in proportion to the height of the pipe containing the warm air. What, then, is the cause which renders the warm and humid ascending current lighter in each of its parts than the air which is found at the same height with these different portions of the ascending column?

"This cause, according to the sufficiently exact calculations of Mr. Espy, is the constantly higher temperature which the ascending column retains, and which proceeds from the heat furnished by the partial condensation of the vapor mixed with the air, making this ascending column a true column of heated air, that is to say, of a lighter gas; for the weight of the water which passes into the liquid state is far from compensating the excess of levity which proceeds from the more elevated temperature which the air preserves.

"Thus the higher the column is, the greater is the ascending force; and the rushing-in of the surrounding air on all sides will be produced with more energy. To understand this effect better, let us consider a mass of warm and dry air rising in the midst of a colder atmosphere. In proportion as this air rises it will expand, because of the less pressure which it will experience, and consequently become colder; it will arrive then quickly at an equilibrium both of temperature and pressure with a layer more or less elevated, which it will soon reach, and in which it will remain; but if this only cause of cold, expansion, is overbalanced by a cause of heat (for example, the heat furnished by the vapor which is condensing), this air will remain constantly warmer than would have been necessary to attain the same temperature and pressure as the surrounding air. It will then be constantly lighter; and the higher the column, the greater the ascending force."

This statement contains, perhaps, as clear a view of Espy's theories as can be obtained. There are, however, one or two additional opinions, regarding tornadoes specifically, that should be mentioned. Mr. Espy says, "Suppose a receiver (Fig. 4) only a few hundred yards in diameter, but so lofty that its top would reach to where the barometer would stand at 10 inches, and that it contained air about 25.25°, for example, hotter than the air on the outside, this latter being at a mean, 32°. The column of air then in the inside of the receiver would be expanded $\frac{25.25}{505.25}$ of the whole, or one-twentieth of the whole bulk. Now, as the air on the outside

of the receiver, from the surface of the earth to the top of the receiver, weighs 20 inches of mercury, the air on the inside will weigh only 19 inches; and of course it will be pressed upwards against the upper end of the receiver at *a* with a force of about half a pound on the square inch, the bottom of the receiver being open at *c*.

"Also, if a barometer should be placed in the inside at the top *a*, it would stand an inch higher than one on the outside at the same height: therefore, if a small hole should be made in the top of the receiver, the air would spout out with a velocity due to a head of pressure equal to one inch of mercury. This is equal in weight to about 900 feet of air of mean density at the earth's surface. The velocity with which it would spout, on supposition of its having this density, will be found to be $8\sqrt{900} = 240$ feet per second (164 miles per hour). But the air at the top *a* is only one-third the assumed density, provided no allowance is made for temperature; and as the velocity of spouting fluids under equal

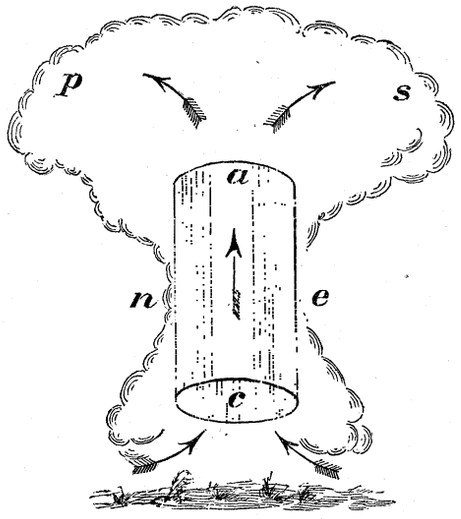

FIG. 4.

pressure is inversely as the square root of their densities, the real velocity with which the air will spout out at *a* will be $240\sqrt{3} = 415$ feet per second (283 miles per hour).

"If, now, we suppose the whole top of the receiver to be taken off, the velocity will be the same, if there is no friction up the sides of the receiver, and the air gets freely in at the bottom; an allowance, of course, being made for the reaction of the air in the upper part of the receiver on the air below, in consequence of the velocity increasing all the way up. If we remove the entire sides of the receiver, it is manifest that the heated column of air, which we suppose to be the same as before, would spread out laterally in ascending, in the form of an inverted cone, or mushroom, as exhibited by the dotted lines *p*, *s*, *n*, *e*.

"When the air near the earth's surface becomes very much heated, or very highly charged with aqueous vapor, such an ascending column as is here imagined may actually take place, and be kept up for a long time. The difference of temperature of the ascending column and that of the atmosphere through which it passes may be much greater than that here supposed, partly caused by its greater temperature below, but chiefly from the great quantity of latent caloric evolved by the condensation of vapor into cloud."

These quotations might be multiplied by the score; but enough has been given to show that Espy relied upon his experiments with the nephelescope for the facts upon which to base his theory, and that, according to his view, the setting-free of latent caloric by the condensation of moisture in an uprushing current was the principal factor to be considered in tornado-generation.

Ferrel's Views.

Professor Ferrel began writing upon mathematical theories in meteorology more than thirty years ago, and it will be of some interest to quote from both the earlier and later works. According to these earlier views, we may consider that there are two forces acting in the production of a tornado or hurricane: 1. A primitive impulse, such as an abnormal heating of the air, thus giving rise to an upward tendency; 2. A constantly acting force. "This force (2) may be furnished by the condensation of vapor ascending in the upward current in the middle of the hurricane, in accordance with Professor Espy's theory of storms and rains. According to this theory, all storms are produced by an ascending current of warmer atmosphere saturated with moisture, and this current is kept in motion by the continual rarefaction of the atmosphere above by means of the caloric given out of the vapor which is condensed as it ascends to colder regions above. The violence of the hurricane, and also its duration, depend upon the quantity of vapor supplied by the currents flowing in below" (see *Nashville Journal of Medicine and Surgery*, 1856).

Again: "The preceding condition, found in the unequal distribution of temperature, must be regarded simply as a primary cause of disturbance, giving rise merely to the initial cyclonic disturbances; for without other conditions, depending upon the hygrometric state of the atmosphere, and upon the rate of decrease of temperature with increase of altitude in the atmosphere generally in which the cyclone exists, we would have no cyclone of long continuance or of much violence. If air is saturated with vapor, after ascending to only a moderate elevation, its tension and temperature are so much diminished that the vapor is condensed into cloud and rain; and the heat given out in the condensation of the vapor as the air ascends prevents the rapid cooling which takes place in dry air, and the rate of cooling with increase of altitude is reduced, in ordinary temperatures and elevations, to less than half of what it is in dry air. Tornadoes are simply very small cyclones, extending over so small an area that the effect of the earth's rotation has no sensible influence; and the gyrations arise from a disturbed state of the atmosphere in which the tornado occurs, which renders it impossible for the air to flow from all sides towards a centre without running into gyrations around that centre." An illustration of this principle is given in the flow of water from a basin by an opening at the bottom. "In a tornado the diminution of pressure and tension in the centre arises almost entirely from the centrifugal force. On account of the rapidity of the gyrations near the centre, this diminution of pressure may be very great there, while at a very short distance from the centre it is imperceptible. When these gyrations begin above, as they usually do, since the air there is most frequently in the state of unstable equilibrium (i.e., having a tendency to rush upward), they

gradually extend downward; for the gyrations cause a great diminution of tension and of density, and the air consequently in the centre rushes up with great velocity, and that below of the still unagitated strata is drawn in to supply its place, which likewise runs into gyrations around the centre, so that the gyrations in a very short time extend down to the earth's surface. The whole column of gyrating air is like a tall flue containing very rarefied air, the centrifugal force of the gyrations acting as a barrier to prevent the inflow of air from all sides into the interior; and if the gyrations at the earth's surface were as rapid as those above, it would be similar to such a flue with all the draught cut off.

"But very near the earth these gyrations, and consequently the centrifugal force, are very much diminished on account of the friction at the surface, and this allows the air to rush in quite near the surface to supply the draught of the interior ascending current" (see *American Journal of Science*, July, 1881).

These views are repeated or amplified in "Recent Advances in Meteorology" (1886), with the following suggestions added: "When the air expands as it is heated, it requires a greater quantity of heat to raise its temperature through 1°, since in this case work is done, and it is done at the expense of heat supplied. An additional amount of heat, therefore, the equivalent of the work done, has to be supplied." "The complete temperature conditions of a cyclone, therefore, rarely extend down to the earth's surface, but the interchanging and gyratory motions, commencing first up in the cloud regions, are soon propagated downwards to the earth's surface by the action through friction of the upper strata upon the lower ones." Speaking of unstable equilibrium, we find, "Currents of air at the earth's surface which come from a warmer latitude are caused to flow under the colder upper strata, where the normal motion is nearly eastward. In the south-east octant within the cyclone, the surface currents are from the south, bringing warm and moist air northward under the cold-air currents above from the north. This increases the temperature below, and decreases it above, and gives rise to the large vertical gradient of temperature, decreasing with increase of altitude, which is necessary to the unstable state."

A few final quotations are made from "Popular Treatise on the Winds" (1889):—

"The pressure near the centre of tornadoes becomes very much diminished, and in their passage over a place there is sometimes a very sudden change in pressure. Corks fly from empty bottles, cellar-doors are burst open against the force of a strong wind blowing against them on the outside, the walls of houses are thrown outward on all sides." "The direction of the general drift of the air is very nearly that of the progressive motion of the tornado, and so mostly from south-west to north-east. The velocity of this is always considerable in comparison with, though generally much less than, the gyratory velocity of the violent part of the tornado." Professor Ferrel quotes a statement regarding the fall of trees in the Gentry County tornado: "Those on the south (right-hand) side of the centre were pointing to the east and north-east, and even north-west when very near the centre. On the north side they were pointing north-west, west, south-west, and south-east."

Hail-Storms.

"A hail-storm is simply a tornado in which the ascending currents are so strong, and reach so high up into the upper strata of the atmosphere, that the raindrops are carried up into the cold regions above, where they are frozen into hail." The theoretical velocity needed to keep up a hail-stone 2.58 inches in diameter is one hundred miles per hour. The fall of rain and hail is said to always precede the tornado by ten to thirty minutes.

Thunder-Storms.

"The fundamental conditions of thunder-storms, as of cyclones and tornadoes, are the state of unstable equilibrium, at least for saturated if not for dry air, and a high relative humidity. In what are usually called thunder-storms, the conditions are nearly or quite absent which give rise to a gyratory circulation over a large area, such as takes place in the case of cyclones, and usually the conditions are wanting which give rise to small local and violent tornadic gyrations, though most tornadoes are thunder-storms. According to Finley, "of 473 cases in which the atmospheric conditions preceding tornadoes were observed, 410 were reported as violent thunder-storms." If the air is in the unstable state, and over a given circular area is a little warmer and lighter than that of the surrounding parts, there is set up a vertical circulation, with an ascending current in the interior, and an incoming current from all sides in the lower part of the air, to supply the ascending current. In the interior ascending current the height of incipient condensation and of the base of the cloud depends upon the depression of the dew-point of the air; and the aqueous vapor above that height is condensed, falls as rain, and cools the air through which it falls, until its temperature is lower than that of the surrounding air. This central cooled air, being now heavier than the surrounding air, both on account of its greater density and the amount of falling rain pressing on it, now gradually settles down, and causes an outward current in all directions from the centre. If there were at any one time rain and hail falling with uniform velocity equivalent to a rainfall of 13.6 millimetres in depth, it would increase the barometric pressure 1 millimetre; and from this alone would arise a squall with a velocity of about 34 miles per hour, making no allowance for friction."

More than two thousand pages have been perused in making these quotations. While no one person, perhaps, could give a perfect *résumé* of such a mass of matter, yet it is hoped that no important theory has been omitted.

Faye's Views.

It is necessary to mention one other theory that has been maintained by M. Faye of Paris. He has made a study of the appearances on the sun around his spots, and has been led to conclude that action in terrestrial storms is analogous in many respects. He thinks that this action originates in the upper atmosphere, and is propagated downward to the earth. A storm is practically a whirl in the swift-moving easterly current, similar to whirls in streams where an obstruction exists. This theory calls for a single remark. There does not seem to be a cause existent in the atmosphere in any degree adequate to set up such a whirl, unless we appeal to some force outside of the motion of the upper current. The transfer of the origin of the storm to the upper

current is satisfactory, and we have seen that Professor Ferrel has done the same thing in his later studies. The fatal objection to Faye's view is, that a downrush of air must necessarily cause its heating; and it has been proved that in such a case there can be no condensation of vapor and precipitation, but just the reverse.

Objections.

I am well aware that the position of an objector is an unenviable one, and to be avoided if possible. It seems to me, however, that all modern theories of tornadoes have intrenched themselves behind such a flimsy breastwork of fact that they can be regarded as little more than the "baseless fabric of a dream," and it is very important that the utter valuelessness of these supposed experiments be demonstrated. An attempt has been made to give, as nearly as could be done in so short a space, all the theories that have had their origin in Espy's experiments, and it is my purpose to examine these a little in detail.

Nephelescope.

The earlier form of this apparatus just described was superseded some years later by a double instrument, with which very extensive researches were made. These later experiments were much more complicated than the earlier, but, when properly interpreted, do not seem to lead to any different conclusions. It has already been shown that Espy was entirely misled by his results, and that, if they show any thing at all, they show that moist air did not behave differently in his apparatus from dry. Somewhat the same line of research, carried on by the writer with the best of modern appliances, has shown conclusively that no different result is had on the condensation of cloud from moist air than from the expansion of air in which no cloud is formed (see *American Meteorological Journal*, September, 1889).

Summation of Theories.

In tornado-generation there must be (1) a primitive impulse or an unstable equilibrium, brought about (*a*) by a local diminution of density, or (*b*) by an abnormal heating of the air near the earth, or (*c*) by a warm current from the south underrunning a cooler from the north; (2) a constantly acting force furnished by the condensation of vapor in an uprushing column of warm, moist air, which produces rarefaction by means of the caloric given out of the vapor; (3) work performed by the uprushing air in pushing aside the atmosphere into which it expands; (4) gyrations of great velocity from right to left set up in the uprushing air, which, from the centrifugal effect, produce a great diminution of pressure (corks fly from empty bottles, cellar-doors are thrown off, whole houses burst open, etc.); (5) a violent inrush of air into the partial vacuum in the centre, the whole effect being likened to that of heated air rushing into a flue or chimney; (6) an origin of these motions in the cloud region from which they are gradually propagated to the earth by the action through friction of the upper strata upon the lower; (7) a progressive motion of the tornado in the direction of the general drift of the atmosphere from south-west to north-east; (8) frequently a passing from a severe thunder-storm into a tornado.

Let us consider each of these theories in turn.

1. A PRIMITIVE IMPULSE.—It is a mistake to suppose that the sun heats any particular locality, whereby circumscribed ascending currents are set up. The hottest part of the day, that is, the time during which the heating effect is greatest, is about one hour, so that the heat of the sun acts uniformly upon a circle about a thousand miles in diameter. This heat acts only upon the earth's surface, and that in turn upon a layer of air only a few feet in thickness, as has been proved by experiment. To avoid these difficulties, it has been suggested that warm south wind underruns that which is cooler from the north. This, however, is an impossible condition, for the denser must always be beneath the lighter; moreover, as we have seen before, the clouds are always in the same direction as the lower wind. Finally, by (7) we see, that, if the tornado drifts in the upper current from south-west to north-east, that current certainly cannot be from the north.

2, 3. CONDENSATION OF VAPOR, AND WORK PERFORMED.—There is nothing in the science of meteorology, or possibly in any physical science, that has been developed from such a worthless origin as this theory of the liberation of energy on the condensation of moisture. We have already seen that Espy's own researches contradicted themselves. Ought we not to be allowed to theorize a little on this question? The most important effect of the liberation of latent heat is conceded to be the heating of the air, which produces a marked diminution of density. In cooling any air, we must consider the heating effect upon the surrounding air; that is, if a mass of air is cooled, the heat must be used up either in performing work or in heating other air. Take a cubic foot of saturated air at 80°, and cool it down to 79° by expansion: moisture is condensed, and latent heat becomes sensible. For the sake of the argument, let us suppose that a fraction of this heat is used in performing the work of expansion. The remainder of the heat will warm up, let us say, a cubic foot of air near by to above 81°, thereby rendering it no longer saturated. We shall have, then, one cubic foot of air at 79° and saturated, and another at above 81° and unsaturated. If we mix these, we shall have two cubic feet of air at just above 80° and unsaturated, and this must be cooled below 80° to saturate it; so that the air in no wise is heated by the liberation of latent heat.

We may look at this from another standpoint. The liberation of an infinitesimal amount of latent heat from the condensation of moisture would be just sufficient to re-evaporate the condensed moisture, so that no heat could be spared for heating the air. Even if a portion of the heat is used up in performing *work*, it is very plain that that could not be used in heating the air. Surely, no one thinks for a moment that this heat from condensation can be used for two purposes, each of which must take all of it at the same time. This reasoning is so obvious, that it is difficult to see how the force of it can be avoided. We have arrived at precisely the same result both by most careful experiment and by an unanswerable train of reasoning. The proof is overwhelming that this great source of energy amounts to nothing.

The following language, recently used by Professor Davis, seems very remarkable. When the air is warm and saturated, he says (*American Meteorological Journal*, December, 1889), "a given amount of cooling causes a larger amount of condensation than the same cooling of cold saturated air. This is thoroughly in accord with well-tried

physical principles; it has been abundantly tested by experiment, both on a small scale in the laboratory, and, as we may say, on a large scale in nature; it is universally accepted by men eminent in physical study, whose original ability and careful, studious work have led them to be regarded as authorities in their science, but who, being authorities, have not thereby become arbitrary and irrational. It is therefore difficult to understand why the question should be so confused by Hazen in the *American Meteorological Journal*, September, 1889."

We have already seen that these so-called authorities have tried no personal experiments,—at least, Ferrel does not allude to any such experiments,—and have been entirely misled by a few crude and contradictory researches. Is it not high time that this appeal to authorities be done away with? One of the main arguments advanced in support of storm theories is that such men as Ferrel, Hann, Mohn, and a host of others, are agreed,—agreed, however, as we have seen, upon exceedingly unsatisfactory evidence. Professor Davis suggests that these theories rest upon experiments, "as we may say, on a large scale in nature." This certainly is far from the truth. All the reasoning regarding the diminution of temperature in dry and moist air as we ascend in the atmosphere is founded upon purely theoretical considerations. Every experiment, whether in the laboratory or in nature, has proved that these theories, in their sum and substance, are false. But there is no use in arguing this question. I am so confident of my position in this controversy, and have become so deeply interested in studies regarding it, that I propose risking a little money upon it.

I will give a hundred dollars to the first physicist who will show that Espy's observations and experiments with the nephelescope, as published in his "Philosophy of Storms," giving the effects of expansion in moist and dry air, when properly interpreted, prove his theory.

It will be necessary to show,—

1. That the rise of mercury in the gauge after expansion was entirely due to heat from outside.

2. That the speed of expansion Espy used, or the amount of cooling from expansion, was comparable to the probable speed of expansion in the free air.

3. That by placing water in the bottom of the nephelescope the air would be saturated.

4. That air, under the conditions observed by Espy, will lose its dew-point or become unsaturated to the extent of four or five degrees in twenty hours.

5. That the cloud Espy observed was not largely formed by dust pumped into partly dry air.

6. How, if the heat liberated on condensation of the moisture is used in performing the work of expansion, there can be any heat from that source for expanding the air.

7. Why, if there is any latent heat set free on condensation in saturated air, it would not at once re-evaporate the condensed moisture, or heat the surrounding air to an unsaturated state.

8. That if latent heat is set free on the formation of a cloud in the nephelescope, its effect does not disappear at the moment the cloud disappears, provided none of the moisture settles to the bottom or sides of the nephelescope.

9. By means of delicate thermometers, that there is not practically the same effect upon the air, as regards heat, in expansions like these, whether we use dry or moist air, or, what is the same thing, disprove the experiments and statements made in the *American Meteorological Journal*, September, 1889.

[Continued on p. 358.]

MENTAL SCIENCE.

Motor Hallucinations.[1]

THE hallucinations most frequently recognized are those of sight and hearing. Something is seen that has no objective existence, or something is heard when no sound is made. There is, however, another form of hallucination to which attention has been directed. In the hallucinations connected with language, all these varieties are evident. Imaginary words are seen or heard, and they may also be felt as movements. One patient, subject to all kinds of hallucinations, perceived internal voices compelling her to do and say things against her will; but there was no sound emitted, and the patient perceived the sense of the words by the movements impressed upon her tongue. Several other cases have been reported in which messages are received, not by sight or hearing, but by the feeling of movements in the articulatory apparatus. In one case this was unaccompanied by any other mental defect, so that it was a pure case of verbal hallucination of this motor type. This hallucination has its seat probably in the third frontal convolution, the same part that is affected when motor aphasia sets in, — a condition in which the patient is able to understand written and spoken words, but is unable to give expression to his thoughts for lack of the association between the words and the motor feelings in the organs where those words are to be formed. The hallucination thus arising may be of various degrees of cogency: it may be entirely sensory, or there may be slight movements of the articulatory apparatus, or there may be an irresistible tendency to speak the words that are imparted to the tongue. Moreover, there sometimes occurs the hallucination that the patient is speaking, and yet he utters no word. Here there is in part an auditory hallucination, but also in part a motor one; for the patient has the feeling of having made the movements necessary for speaking the words.

While the special development of speech makes the motor hallucinations of speech unusually prominent, they are by no means limited to this type, but may occur in any field of motor action. While sleeping, we often have the feeling of going through fatiguing and complicated motions, when in reality no movement takes place. This is likewise to be referred to a stimulation of these cortical centres. Similarly we dream of falling down a precipice or of flying, — hallucinations equally frequent in insanity. It is not unlikely that this was the basis of the flights through the air of the witches and those possessed. A special class of these sensations arising from the stimulation of a central organ is to be found in cases of amputation. It is well known, that, when an arm or a leg has been lost, the person still retains all the feelings of the lost member. The hallucination is at times so definite that the clinching of the separate fingers may be felt, though the arm and hand have been gone for years. Out of ninety cases, there were only four who did not describe these hallucinatory sensations. While these hallucinations are in part sensory, there are also motor. Some feel the movements in the absent hand, describing its position as in the act of grasping, of writing, and so on. The seat of these sensations is doubtless in the brain and in those portions from which the innervation impulses arose when the limb was intact.

With regard to the genesis of the hallucinations, we seem warranted in assuming three stages in their formation. The first is central, and consists in forming a sensory image of the movement; the second is centrifugal, and consists of an impulse from the centre to the muscles and nerves; the third is centripetal, indicating that the peripheral organs of locomotion have undergone the changes due to the movement. That the last stage is not necessary to the production of the motor hallucination is shown in the case of the amputated limbs and elsewhere. We

[1] M. Tamburiai, in Revue Scientifique, May 10, 1890.

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THE TORNADO: THEORIES; OBJECTIONS.

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Professor Davis says, further, "It is a mistake to say that the latent heat, when liberated, will warm the air enough to allow the condensed vapor to evaporate again; for the latent heat is completely expended in the work of pushing away the air that surrounds the ascending expanding mass, and therefore cannot be applied to any other task. Espy made this error for a time, but afterwards corrected himself. It is regrettable to see the error now revived by Hazen." I am sure no one could ask for a stronger confirmation of his views than this from an opponent. If the above argument amounts to any thing, it declares that the latent heat of condensation would certainly immediately re-evaporate the moisture, unless it were used up in performing *work*. If it is used for this purpose, it certainly and most emphatically cannot be used for causing a rarefaction in the cloud, and for increasing the energy of the tornado. Professor Davis is entirely wrong in his allusion to Espy. I am inclined to think that even Espy, with all his disadvantages, was too well informed to adopt such a doubtful and visionary idea as this of effective *work* performed in the free upper air. There is not one scintilla of evidence that he ever considered this question, except, possibly, to deny that any thing of the kind was to be thought of.

I challenge Professor Davis, or any one else, to show by Espy's writings that he disposed of any of his heat on this hypothesis, or that he ever thought that the latent heat would re-evaporate the moisture. He very quickly saw that the liberation of so much latent heat as his theory called for would heat up the air enormously, and was forced to dispose of it by radiation into space. It is probable that the amount of energy made effective by this so-called "work" in the free upper air is infinitesimal as regards the development of force. The explosions that Espy made in his nephelescope caused the air to rush with a velocity of perhaps a thousand feet per second. This enormous velocity caused a sufficient cooling to produce a cloud, which, however, was quickly evaporated. All reliable experiments have shown that the expansion of saturated air at velocities probably at least ten times as great as can ever occur in nature does *not* produce any cloud; and we see the reason for this in the fact that the latent heat made sensible does not permit the formation of cloud, for the condensing moisture is re-evaporated before it becomes visible.

It is a very significant fact, and one that has been borne in upon me with no little force by conversation with others, that Ferrel has introduced a long general discussion of this question of work performed by expanding air in his two lastest treatises, but has nowhere made this theory available, or even discussed it, in connection with the generation of storms or tornadoes. It would seem as though the amount of effective energy ought to be computed very closely, and its proper place given it. It is probable that an ascending cylinder of air a hundred miles in diameter would not produce any effective energy or any expenditure of heat in its centre from this cause. I am inclined to think that the total energy that can ever be developed from an ascending mass of saturated air is no whit greater than what may be called the balloon effect. If a hot-air balloon rises in the air at the rate of ten feet per second, it has carried a certain weight, say three thousand pounds, to twenty thousand feet, and there we have potential energy; but, if the balloon descends at the same rate, there will be no display of extraordinary force. If, instead of the confined mass of enormously heated air, we had a mass of air heated a few degrees above the surrounding air, it would rise; but here the air would spread over a great space, and we would not have the concentrated potential energy that we had in the balloon. To say that this air had any power of producing effective energy, or even to say that it could have arisen at all without the corresponding descent of nearly an equal amount of cooler air, is highly problematical.

4, 5. GYRATIONS IN THE UPRUSHING AIR AND A VIOLENT INRUSH.—We have already seen that the evidence for these gyrations is exceedingly contradictory, and the weight of evidence is overwhelmingly against them. It would almost seem as though this theory were introduced to avoid a serious difficulty; at all events, we hear nothing of it for nearly forty years after the first studies. It is plain that a partial vacuum, if there were one, would be filled at once by the air rushing from all sides. Has this theory been invented to provide a whirling mass having sufficient consistency to keep

out the inflowing air? This theory really proves too much; for, if there is this enormous centrifugal effect producing a partial vacuum, how is it possible for moist air to flow in against the centrifugal effect? The theoretical explanation that there is friction at the earth's surface, which breaks up the centrifugal effect at that point, is exceedingly unsatisfactory.

It is given as a proof of this vacuum, that "corks fly from empty bottles." I have searched the tornado literature through and through, and have not found a single well-authenticated case of this phenomenon. The questions naturally arise, "Why were corks *put* in *empty* bottles?" also "Why did not the corks fly from the full bottles?" It is probable that empty bottles and corks were found in a cellar, and the theory could have very easily arisen that they had met with a separation. It would be very interesting to have a confirmation of this fact. It is said that whole houses sometimes burst from the passage of this partial vacuum. We have already advanced an explanation of this.

It should be noted that nearly all pictures of tornado-funnels make them exceedingly circumscribed, perhaps not more than ten feet across at the tip (see Fig. 1). The earliest representation of a tornado-cloud is very different from this, and it is probable that the imagination has had altogether too much to do with all these later pictures. It is to be hoped that wherever possible, in future drawings, there will be given some idea of the size of the funnel. If houses are affected, the funnel should be at least from a hundred to two hundred feet across at the earth. A remarkable evidence of the desire for showing a gyration in a tornado-cloud is to be found in the quotation regarding the Gentry County tornado, from Professor Ferrel's last book, at p. 354. This statement was of an observation in which it was claimed that trees on the north side of the track were thrown to the west and south-west. As shown in Fig. 2, this is exactly the way trees ought to be thrown, if this theory of a gyration is a correct one. This is the only instance, if we grant its authenticity, in which, out of a hundred or a hundred and fifty reports of this phenomenon, trees were ever thrown this way. The evidence of this kind is overwhelmingly in favor of the supposition that there is *no* gyration.

6. ORIGIN IN THE CLOUD REGION.—There can be no doubt that the tornado originates in the cloud region; but to say that this must be from an unstable equilibrium at that point, is a violent assumption. The sun, contrary to theory, undoubtedly heats up a cloud so that there is a steady increase of temperature with height, as shown by balloon observations; but there is no unstable equilibrium, though theory indicates that this should be enormous under these conditions. The tornado frequently arises after sunset, when there is no abnormal heating of the cloud. This transfer of the primitive impulse from the earth to the cloud is very significant, and seems to have been done to avoid a difficulty; which, however, has been increased rather than avoided. The hypothesis that such a disturbance, after starting in the cloud region, is transmitted through friction to the earth's surface, seems a little strained, when we reflect, that, according to computation, it would require more than twenty years for such transmission through a depth of three hundred feet.

7. A PROGRESSIVE MOTION IN THE DRIFT OF THE UPPER CURRENT.—If the general storm motion is in this drift, it certainly seems impossible to ascribe that of the tornado to the same. The tornado moves with a velocity fully double that of the general storm, and it is probable that the centre of its motion is not more than half the height of the former; and, as it is known that the velocity of the current increases rapidly with the height, it is safe to say that the drift at the "power" of the tornado is not more than half that in the case of the general storm. It is also impossible to account for the motion of the tornado for more than a hundred miles, unless it has its own generating force, through the drift of the upper current. If the cloud is about three thousand feet high (not an underestimate), the motion of the upper part will approximate double that of the lower, and, in spite of the utmost centrifugal action, it would in a few minutes be torn apart. The hypothesis that the upper part breaks off, and re-forms itself in front, and afterward communicates its gyrations to the earth through a frictionless medium, must be regarded as one of the most strained that was ever advanced. This would break up the absolutely necessary continuity of the vertical ascending current, and would be fatal to the whole tornado theory.

8. A SIMILARITY BETWEEN THUNDER-STORMS AND TORNADOES.—This view was advanced prominently in 1884, and in the past few years has become a most important factor in all discussions. It demands a notice by itself, which will be given later.

It will be asked, Is not the foregoing a too severe setting-forth of the general weakness of tornado theories? Is not there some good to be gotten out of such theories, even if there are some points not fully settled? I leave the questions where they stand. I have not tried to overdraw the picture. The essential weakness of such theories is a starting from insufficient data and reasoning regarding most complex motions in a region in which we have hardly a dozen reliable records. It may be put down as an undoubted fact that no great advance can be hoped for in such studies, except the abandonment of these theories, until we investigate carefully the region where all these disturbances are developed.

H. A. HAZEN.

ON THE GROUP OF METEORITES RECENTLY DISCOVERED IN BRENHAM TOWNSHIP, KIOWA COUNTY, KAN.[1]

ABOUT four years ago the farmers of Brenham Township ploughed up a number of heavy objects, which they used to weight down haystacks and for other such purposes, as they would have used bowlders. It was discovered in March last that these were not common rocks, but an interesting group of meteorites, numbering over twenty in all, weighing together about 2,000 pounds, and individually from 466 pounds down to one ounce each. They were found embedded at a slight depth in the soil, which here, for about one hundred feet in depth, is formed of a pleistocene marl, originally the bottom of an ancient lake, scattered over a surface over one mile in length; principally, however, in a square of about sixty acres.

What is now Kiowa County, Kan., five years ago formed parts of Edwards and Comanche Counties, and was occupied by large ranges and cattle-ranches. Brenham Township, or Township 27 as it was then called, is in the north-western part of Kiowa County, is covered by a high prairie with some areas of sand-hills,

[1] First announced at the New York Academy of Sciences, April 7, 1890.