PHYSICAL PHENOMENA OF THE HIGH REGIONS OF THE ATMOSPHERE.[1]

THE first and decisive cause of nearly all physical phenomena occurring in the terrestrial atmosphere is the solar heat. The atmosphere may therefore be considered an immense heat machine, of which the sun is the focus; the boiler is represented by the soil or the clouds heated by its rays, and the condenser by the radiation towards the interplanetary space.

The means by which physicists and meteorologists study the various regions of the atmosphere are very limited; they are obliged to content themselves, more often than not, with very indirect observations, and to proceed by induction. In fact, the most interesting phenomena occur in the high regions—that is to say, at almost inaccessible heights. The object of this lecture is to show by some experiments that meteorological physicists are beginning to approach very closely the real explanation of natural phenomena. You will see, in fact, that in certain cases, not only an exact image of these phenomena is obtained, but often a veritable synthesis of them may be produced by the employment of processes entirely analogous to those which really operate in nature.

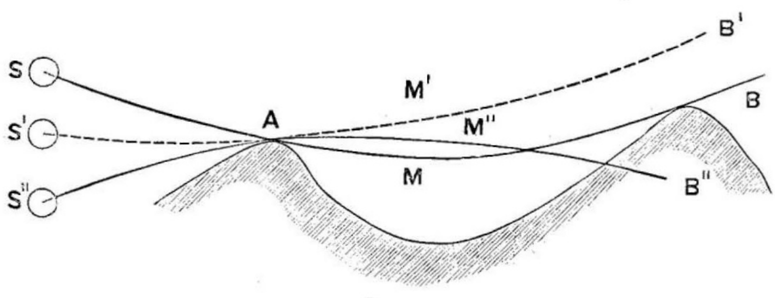

FIG. 1.

I will begin by enumerating the means in use amongst meteorologists for studying the different regions of the atmosphere.

The most direct method is the use of the aerostat; the aerostat or balloon makes it possible to take instruments of measurement to the very heart of the atmospheric regions one wishes to study. Unfortunately the method is difficult, expensive, and also dangerous; it is therefore only used in exceptional cases. The balloon ascents which have resulted best are those of Gay-Lussac (1804), of Glaisher (1862), and recently of Dr. Berson, of Strassfurt (1894), who ascended more than 9000 metres.

The most important facts observed in the balloon were very unexpected; here is the *résumé* of them:

(1) There exist very frequently clouds formed of *crystals of ice;* they constitute the cirrus, which float at very great heights.

(2) The *direction* of the *wind changes* at different heights.

(3) The temperature does not always diminish regularly with the altitude; very often *cold layers* and *hot layers* are met with *alternately*.

The second direct method for studying the atmosphere is the constructing of mountain observatories, as much as possible on isolated peaks. In these observatories the reality is daily verified of these unforeseen *inversions* of *wind* and *temperature* at different altitudes.

As for the clouds of ice, they are too high to be attained directly by the mountain observatories.

It will, perhaps, be interesting for you to know the principal mountain observatories constructed in France.

[Projection of the photographs of the following observatories:

Pic du Midi	(altitude	2800	metres)	in the Pyrenees.
Mont Ventoux	,,	1900	,,	in Provence.
Puy-de-Dôme	,,	1900	,,	in Auvergne.
The Eiffel Tower	,,	330	,,	in Paris.

This last observatory, owing to the lightness of its construction, entirely in open work, may almost be considered a captive balloon, permanent and fixed, 300 metres above the ground.]

Halos.—We have said that mountain observatories do not attain the region of the clouds of ice (6000 to 10,000 metres in altitude); it would, therefore, be only possible to observe them in a balloon. Fortunately these crystals of ice reveal themselves by an optical phenomenon, *the halo*, which is even seen from the low levels. It is a brilliant circle, with radius of about 22°, which encircles the sun or moon; it has a reddish tint inside, and slightly bluish tint towards the exterior. It is explained, as well as many appearances of the same kind, by the refraction of the light of the body through ice crystals; in fact, the crystals of ice are hexagonal prisms, of which the faces are in pairs inclined at 60°. These crystals, disseminated in the air, and pointing in all directions, refract the light, but the refracted rays cannot exceed the slant of 22° which the *minimum deviation* discovered by Sir Isaac Newton imposes on them; the limit of the refracted rays is, therefore, a cone of 22° round the line which joins the eye with the sun or moon.

[*Experiment imitating the Halo.*—Crystals are produced in a transparent medium, consisting of a mixture of appropriate liquids; in this way the mixture of hot and damp layers of the atmosphere is reproduced precisely, with the cold layers, which form the crystals of ice.

For this purpose a saturated aqueous solution of potash alum is placed in a glass cell, and through this cell a stream of light is made to pass, projecting the image of a circular opening representing the sun on a dark sky. Then a quarter of the total volume of rectified alcohol is added; the alum, insoluble in alcoholised water, is precipitated in very small crystals which float about in the liquid. The image of the sun is at first indistinct, as in a mist, but soon a brilliant circle, with delicate rainbow tints, appears, and represents exactly the appearance of the halo. The experiment is brilliant and instructive.]

This phenomenon is well known by country people; it is a sure sign of rain when it appears on a hot day, even if no other indications predict a metereological disturbance.

Alternation and Inversion of Temperatures.—In neighbouring observatories situated at very different altitudes, such as that of Puy-de-Dôme and Clermont, the existence of hot currents are often noted in the high regions. It is to successive inversions of the same nature that Mr. Amsler, of Schaffhousen, attributes that beautiful phenomenon known in Switzerland as "Alpenglühen," and which consists of a second illumination of the snowy caps of the Alps some minutes after they had become dark by the setting of the sun.

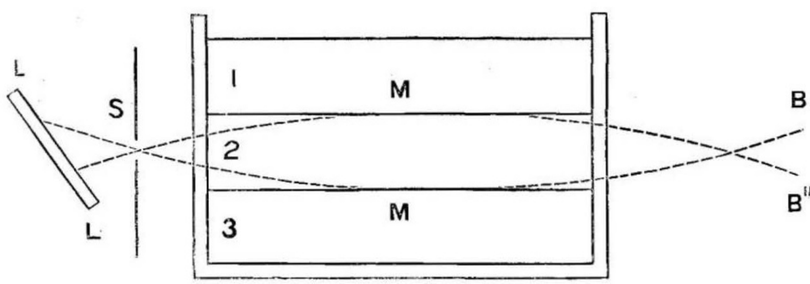

FIG. 2.—(1) Glycerine $\frac{1}{3}$, water $\frac{2}{3}$; (2) glycerine $\frac{2}{3}$, water $\frac{1}{3}$; (3) anhydrous chloride of zinc, $\frac{1}{3}$, water $\frac{2}{3}$.

[Projection of a photograph of the summits of the Bernese Oberland, the Jungfrau, the Mönch, the Eiger; the view having been taken from St. Beatenberg, close to the lake of Thun. Picturesque imitation of the phenomenon by a coloured glass and proper diaphragms.]

Mr. Amsler's explanation is founded on the change of the direction of the curvature of the trajectory of the luminous rays depending on whether the air at the bottom of the valleys is warmer or colder than that of the higher regions.

Before the setting of the sun the ground warmed by the solar heat imprints on the trajectory a curve analogous to that of the

[1] Discourse delivered by Prof. Cornu, at the Royal Institution. (Translated by Winifred Lockyer.)

mirage S A M B, that is to say, convex towards the earth (Fig. 1); the sun in going down, at S′, throws the shadow of the summit A on summit B, which should therefore afterwards remain in shadow, as the sun continues to set, and as the last ray is S′ A M′ B′. But if in the interval the air of the valley gets sufficiently cold, the trajectory takes an inverse curve, S″ A M″ B″, and summit B is again illuminated.

[*Experimental Realisation of the Inversion of the Curves of the Luminous Trajectories.*—With a little care it is possible to superpose in a transparent cell of about 20 centimetres thickness three layers of liquid, of which the composition is given under Fig. 2. A movable mirror, L L, throws a stream of light through the opening, S, of a diaphragm. This beam of light, sent under different inclinations, is reflected either by the inferior layer of chloride of zinc (dense, but less refracting), or by the layer of diluted glycerine (lighter and also less refracting than the intermediate layer).

A little fluorescene illuminates the trajectory of the streams of light, and renders their curves visible; the Alpenglühen can thus be represented with a few accessory arrangements.]

Scintillation of Stars.—This phenomenon is also a proof of the alternation of the temperature and of the movement of the layers of air in the high regions. Spectrum analysis shows that the scintillation is produced by a disappearance following a regular order (in accordance with the variation of the zenith distance of the star) of the successive colours of the spectrum.

[*Imitation of the Phenomenon.*—It is obtained by a very brilliant experiment, which consists in throwing the image of a luminous opening, O, with the help of a lens, L, on a little silvered ball, B, of 3 or 4 centimetres in diameter, resting on black velvet. Thus the aspect of a fixed star is obtained, with remarkable brightness (Fig. 3).

But the luminous opening, O, is made in a card, on which is thrown the spectral image of a slit, F, which is dispersed by a direct vision prism, P.

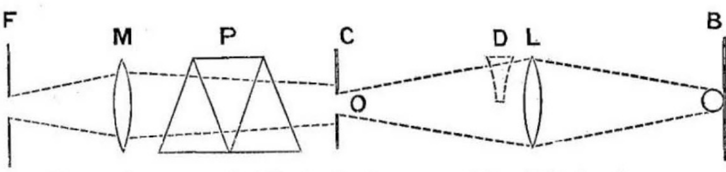

FIG 3.—Arrangement for imitating the phenomenon of the scintillation of stars.

In truth, [illegible] which focus is formed further off, in the plane of the lens L. The result is that the rainbow image of the slit on the card has a white part in its centre; it is there that the opening, O, is placed. Also the light thrown on the ball, B, is entirely colourless. But the beam of light, on coming out of the opening, expands into spectrum on the lens of projection L, which recomposes it in B, as in a celebrated Newtonian experiment.

Then by placing a screen with large meshes before the lens L, certain radiations are taken away, and the star, B, appears coloured.

A *divergent half-lens*, D, with same focus as L, cancels its effect, and the spectrum of the star, with the artificial bands created by the screen, appears on a white screen by the side of the ball. This is the imitation of the spectrum analysis of the scintillation of stars.]

It is seen by these few examples that the study of the *optical phenomena* of the atmosphere, aided by physical analysis and *synthesis*, can, and must, teach much about the calorific phenomena of the regions beyond our reach.

Dynamic Phenomena of the Atmosphere.—The phenomena studied up till now are due to conditions of almost perfect equilibrium in the atmospheric layers; they might be called *static*. But the calorific action of the sun, combined with the cooling action of radiation in space, can produce phenomena of movement representing every degree of intensity, from the feeblest to the most violent: we call these phenomena *dynamic*. They make themselves apparent in very different ways.

(1) Under the form of *mechanical energy*: winds, whirlwinds, cyclones, water-spouts, &c. (2) Under the form of *calorific energy*, which makes itself felt by the formation of clouds, rain, hail corresponding to different changes of state of water, the element of the atmosphere which is continually varying. (3) Under the form of *electric energy*: lightning, thunder, &c.

In fact, it is the transformation of the solar energy into mechanical energy which is the fundamental phenomenon; it brings all others with it. It is the only transformation which, for shortness, I shall deal with here.

The simplest mechanical phenomenon which is produced in the atmosphere is the wind. The origin of the wind is the difference of pressure between two points more or less distant; since the time of Pascal, it is known that the pressure of air is measured by the barometer. It might be thought, according to this property, that the direction of the wind is always determined by the indications of this instrument; that is to say, that the wind must go from the point where the barometric pressure is strongest to the point where the barometric pressure is feeblest.

Well, this is hardly ever the case; the real direction of the wind is always oblique to this theoretical direction. This fact has only been known a very few years; it is the general meteorological maps, suggested by Le Verrier about thirty years ago, and so universally known at the present day, which have put this fact beyond doubt.

The direction of the wind seems to *turn round* the point of the map where the *minimum* pressure is to be found, in the *opposite direction* to the hands of a watch; or, rather, in a *direct sense* round the point of maximum pressure. Such is the direction of the phenomenon in the *northern hemisphere*; it is contrary in the southern. In fact, the most ordinary movement of the atmosphere is a *gyratory* movement, which is called a cyclone.

The whirling movement of the air has been observed for a long time; we often see it produced around us. The dust, the dead leaves are lifted by the wind in a whirlwind resembling eddies in rivers. Sailors know of *cyclones* and *water-spouts*, and fear their dangerous effects. On the American continent there are terrible hurricanes called *tornados*. These gyratory movements seem only to belong to great stormy perturbations; but the more the study of the atmosphere is followed in detail, the more it is seen that this kind of disturbance is met with in all [illegible] air. It is therefore concluded that the gyratory movement is to some extent the *normal* condition of agitated air; it would hardly be possible to employ force on a gaseous mass without developing more or less rapid rotations, which tend to acquire for themselves a permanent condition.

Experimental Proofs.—Every time a rapid jet of gas is produced, one or more cyclonic movements are formed at the side of the jet. If the projected column is of a cylinder shape, the cyclonic movement will take the form of a ring; for example, the rings of smoke which are observed after the explosion of cannons, guns, &c.

[Repetition of the well-known experiment of smoke-rings, produced by striking the canvased end of a box filled with vapour of hydrochlorate of ammonia, with a circular opening on the opposite side. The smoke-rings are rendered visible by throwing them in the line of a beam of electric light.]

Multiple Origin of the Gyratory Movements of the Atmosphere.—Nearly all the general causes which act on the movement of the atmosphere are gyratory influences; when once the movement is set going, it continues of itself, and sometimes increases in amount; in the first place, the movement of the rotation of the earth must be cited, which always brings with it a small component of rotation for a displacement of a gaseous mass in *latitude* or *altitude*; in the second place, and as decisive cause, the solar heat, which warms the air near the surface, or the clouds. As the ascending tendency of the heated gas cannot be equal over the whole surface exposed to the rays of the sun (as much because of the nature of the ground as because of its inequalities), the equilibrium is upset in certain parts, and gaseous columns ascend. This is, therefore, the same case as the jets, quoted above, and consequently under favourable circumstances for gyrations round horizontal axes. When once the gyration is established, the causes which have produced it keep it up and augment it.

The existence of whirlwinds with horizontal axes in hailstorms, particularly in that of May 20, 1893, at Pittsburg, has been observed by an American meteorologist, Mr. Frank W. Very, and has furnished him with a very ingenious explanation of the formation of hail. Indeed, such a whirlwind (if it has sufficient dimensions) takes the hot and damp air of the surface of the ground to high and cold regions; the vapour condenses, freezes, and crystals of ice are brought into the gyratory movement; they ascend and descend alternately, following the spirals of the whirlwind, and increase at every passage in the inferior regions, which are charged with humidity. This explanation accounts for all the peculiarities which are observed in a fall of hail: zoned structure, very low temperature; special sound before the fall; electric manifestations which accompany them; for a whirlwind of hail is a veritable influence electric machine, a sort of *replenisher*.

Artificial Reproduction of Natural Gyratory Phenomena.—The phenomena produced by the rapid rotation of the air are altogether unexpected in consequence of the singularity of forces put in play. The ordinary laws of mechanics, to which daily experience has accustomed us, seem entirely different to those which the cyclonic movements seem to obey; and this must not astonish us. We have reduced mechanics to its simplest elements; the material point, the constant force, the rectilinear movement: thanks to these simplifications, we have been able to understand the movement of spherical projectiles, that of a pendulum, the rotation of a fly-wheel, &c. But as soon as the solid body becomes complex as to its form, when the movement which it may take has at the same time a translation and a rotation, our imagination represents it badly; if to this complication of form we add the resistance of the surrounding medium, then we have no idea of the probable resulting effect; for example, the *boomerang*. As to the movements of fluids, they are so difficult for us to foresee, that we receive fresh surprises every time we move a vessel of water; as soon as the mass of water is at all considerable, the tumultuous movements, which we unwillingly cause, always produce some awkwardness.

We understand then how impossible it is for us to anticipate the atmospheric movements, of which the mass is so immense, for each cubic metre weighs 1,300 grs.; if the energy expended in setting in movement such masses is considerable, inversely the stability of the system is enormous, since we have to wait for the dissipation of this energy by the passive resistances, almost always reduced to friction on the earth's surface.

We will, therefore, not endeavour to analyse the forces put in play in the gyratory movements of the air. I will limit myself to repeating before you some of the beautiful experiments of M. Ch. Weyher, who has been good enough to come himself to help me arrange the apparatus now before you.

Here is a sphere composed of ten circular paddles, put in rapid motion round axis A B (Fig. 4); the air caught in the rotation produces a general whirlwind movement, symmetric in relation to the plane of the equator. On all sides the air is sucked in by the revolving sphere, which may be seen by the effect on smoke or pieces of paper brought near it. This air is expelled from the equatorial circumference, and only in the almost mathematical plane of this circumference; in fact, look at these pieces of paper which keep themselves concentrically to the equator, following an arrangement which reminds us of Saturn's ring. The tension of the paper and its vibrations show that it is the repulsion of the equatorial outflow which maintains them.

It might be concluded from this, that the revolving sphere could only produce equatorial repulsions; but the complexity of the turbulent streams baffles the most evident anticipations. If a light balloon be approached a little distance from the sphere, it is immediately attracted, and begins to revolve rapidly round the sphere in the equatorial plane; if a second or third be let loose in the same way, they will follow it at varied velocity, and represent satellites; the planetary configuration is complete.

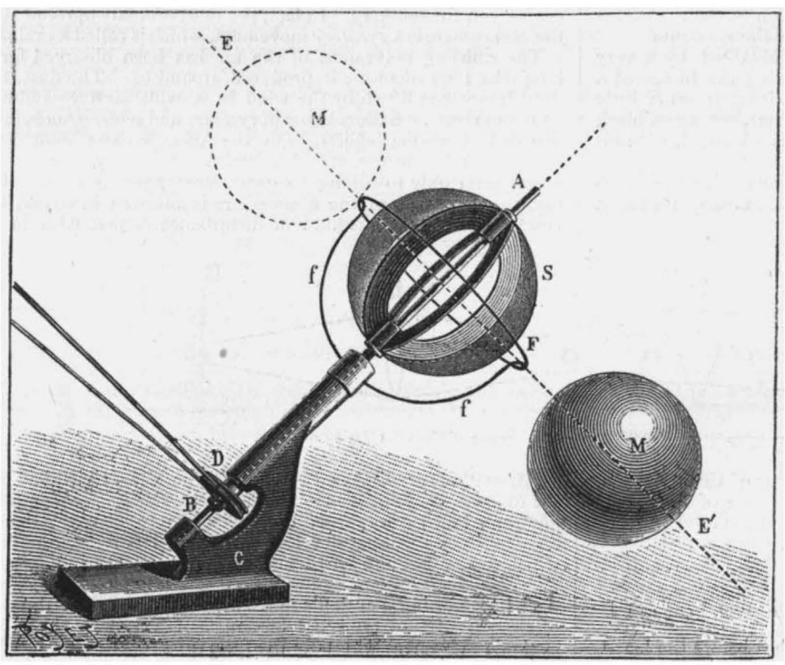

FIG. 4.—Artificial reproduction of the gyratory natural phenomena.

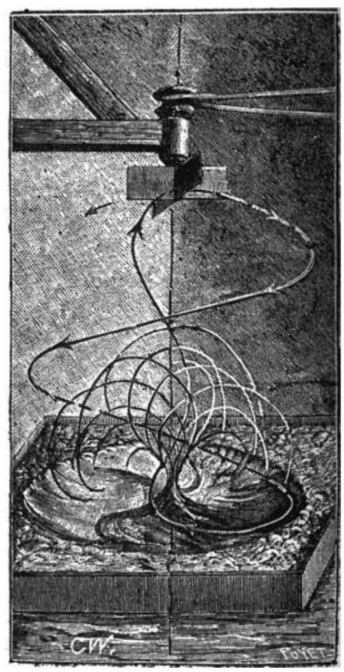

FIG. 5.

This paradox of a repulsion transformed into attraction by a change of form of the presented body, is easily solved by considering the resultant of aspiring and repelling actions on the surface of the moving body. On the greatest angular space round the revolving sphere it is the whirlwind attraction which dominates. This is easily proved by placing underneath this sphere a basin full of hot water; if the atmosphere of the room is quiet, little by little the vapour will be seen to collect in a whirl from the surface of the water to the revolving sphere (Fig. 5). This is the imitation of a water-spout. The importance of this phenomenon has led M. Weyher to reproduce it in a more striking way, and by bringing into play a much more considerable quantity of mechanical energies, thus recalling better those which constitute this natural phenomenon.

The excitement of the gyratory movement (which, in nature, has its source in higher regions of the atmosphere) is produced by a small mill, placed three metres above a reservoir of water four metres in diameter (Fig. 6). When the small mill is made to revolve (400 to 500 revolutions a minute), the aerial whirlwind sucks up little by little the surface of the water, which is seen to be agitated and to be forming *centripetal* spirals, and producing a liquid cone several centimetres in height. Above this cone a great number of little drops accumulate, which fall back in spirals. This attraction, *at a distance*, is even more striking if the water is slightly heated; the vapour then forms a *hollow* tube, of which the hollow part is distinguished by its dark colour and its geometrical regularity; it shoots forth from the water towards the small mill, causing light objects, such as bits of straw, which are floating on the liquid, to be thrown up.

Such is the experiment which in 1887 was made in the open air at the great works of the Weyher and Richmond Company. With the reduced apparatus, now placed before you (Fig. 6), we can repeat it in conditions quite as convincing. The small mill is placed at the top of the case two metres high, closed on one side by a glass; the water, slightly warmed and containing a little soap, is placed at the bottom of the case in a basin. I set the small mill going; you see the agitation at once, the soap-bubbles precipitate themselves at the foot of the column of vapour. Soon the column takes the form already described, and represents exactly the appearance of a real water-spout; at the foot is the *buisson*—that is to say, the collection of bubbles and little drops; at the top, the expanded hollow tube of vapour.

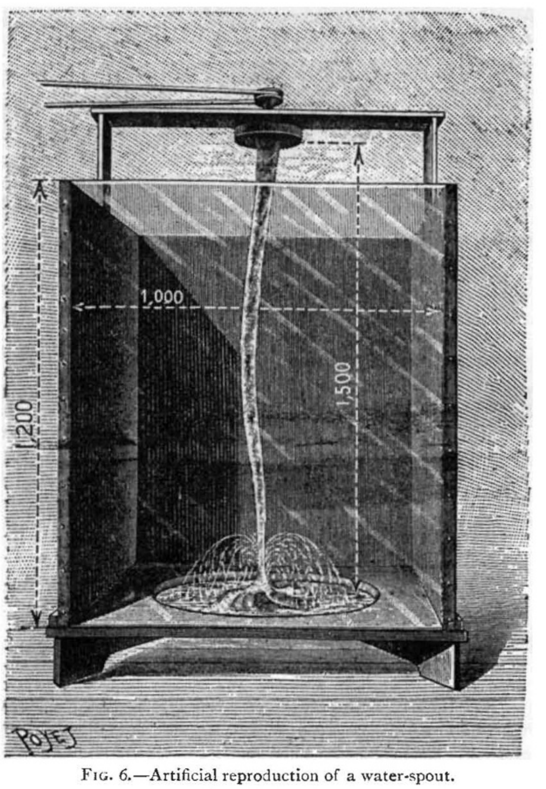

FIG. 6.—Artificial reproduction of a water-spout.

A light balloon placed at the surface of the water is first carried to the centre, and rendered captive at its foot; by quickening the rotation (which increases the power of the whirlwind) the balloon is raised by the water-spout, and sometimes follows the spiral the whole of its height.

The helicoidal movement of this light balloon, as well as the aspect of the nebulous spiral, shows well the constitution of the water-spout; one sees the superposed rolls of helicoidal currents, some ascending, others descending (Fig. 7); it is a perpetual going and coming between the mill and the surface of the water. As all the currents turn in the same direction if the ascending ones *screw* to the *right*, the descending ones *screw* to the *left*. It is the absence of having recognised this double movement of ascent and descent which is at the bottom of the misunderstanding between the partisans of ascending water-spouts and those who maintain that they are only descending phenomena.

The ascending movement of the light balloons caught up by the water-spout, shows well the ascending velocities; it is more difficult to put in evidence the descending region, declared in some theories to be the only existing one, because it occupies in the reduced experiment a very small space; it is confined to the interior of the nebulous sheath, of which the hollow centre is distinguished by its dark colour. I will, however, show it to you with the help of a very simple artifice. Take a body emitting smoke to the top of the water-spout; we see this aspirated smoke at once reach the interior of the sheath, roll itself into a slender cone, and descend to the surface of the water. This is exactly what is seen in nature when, in a water-spout, the clouds descend in the form of a stream which grafts itself in the middle of the *buisson* formed by the water at the surface of the boiling sea. This spiral is, so to speak, the harmless part of the water-spout; the terrible part is invisible; it is formed by the mass of air which rages round the spiral. In the experiment before us it is contrary. The raging mass is visible owing to the smoke which is supplied; the interior of the spiral remains dark; it is by the introduction of the smoke that the existence and form are recognised.

There still remains to show you that with a similar arrangement a cyclone can be produced with all its characteristics—variation of pressure at its passage, barometric minimum, central

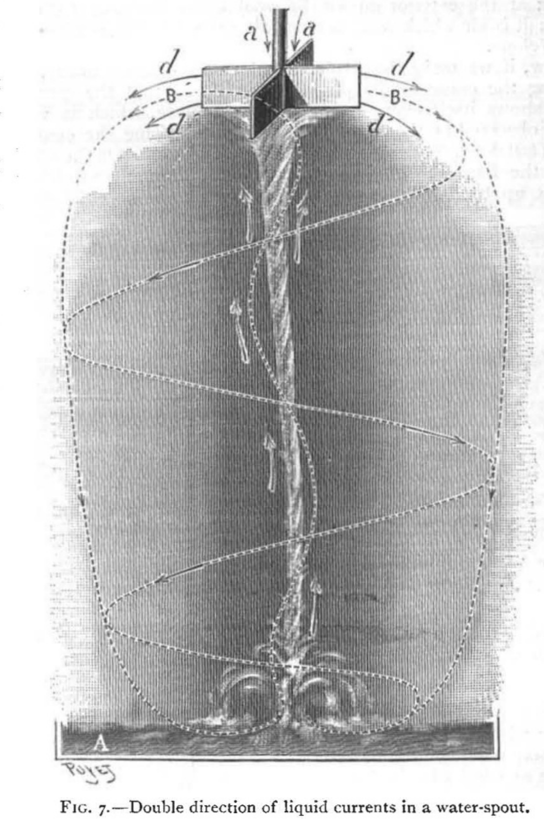

FIG. 7.—Double direction of liquid currents in a water-spout.

calm, brisk rising of wind, centre of the storm, &c.—which has also been attained by M. Weyher.

The following remarks have been subsequently added to the lecture at the Royal Institution:—

We will conclude by describing with some detail that experiment which reproduces so accurately all cyclonic phenomena. In reality a cyclone is nothing else than an immense aërial whirlwind; it only differs from a water-spout by its proportions, and principally with respect to the height and the diameter; in a water-spout the diameter is very small in relation to the height, whereas in the cyclone it is the contrary. But in both cases the general movement is the same; the aërial currents descend all around, to remount immediately on the interior spirals, with a diameter more or less great, but leaving, as in a water-spout, a central region free, in which the descending movement is equally to be found.

Here is a flat rotating disc, about 1 metre in diameter, mounted on the extremity of a crane 2 metres in radius; by means of this arrangement it is possible to make the rotating disc travel horizontally above a large table in which are fixed a great number of pins, to the head of each of which is attached a bit of wool some centimetres in length, and thus forming many flags, which will show us the directions of the wind in each point traversed by the cyclone. In the centre of the table a hole is pierced communicating underneath with a very sensitive barometer, which will show us the variations of atmospheric pressure at the passage of the meteor (Fig. 8).

We set the rotating disc in rotation after having placed it above one of the extremities of the table; you see at once all the flags situated underneath indicate the directions of the wind. Those which form the centre of the whirlwind remain flat and rest inert on the table, their extremities directed one towards the other. They represent wonderfully well the central calm.

The flags surrounding the central calm form a circumference; they imply a wind forcing them all in a direction slightly centripetal, and ascending. In the following ranges the pieces of wool place themselves again along a circumference, but scarcely showing the centripetal direction, and not at all the ascending one; then the more distant the flags are from the centre, the more they inflect towards the table, and indicate the descending wind; at the exterior circuit the wool takes centrifugal directions; it is air which escapes from all sides on the borders of the cyclone.

Now, if we make the artificial cyclone travel horizontally, by moving the crane on its pivot, you will see that the central calm shows itself every instant at a new place, which is very easily observed by the aspect of the flags occupying the centre, which fall down suddenly and rest inert on the table. On the other hand the flags immediately adjacent raise themselves quickly, caught up by the tempest, and those which but recently were

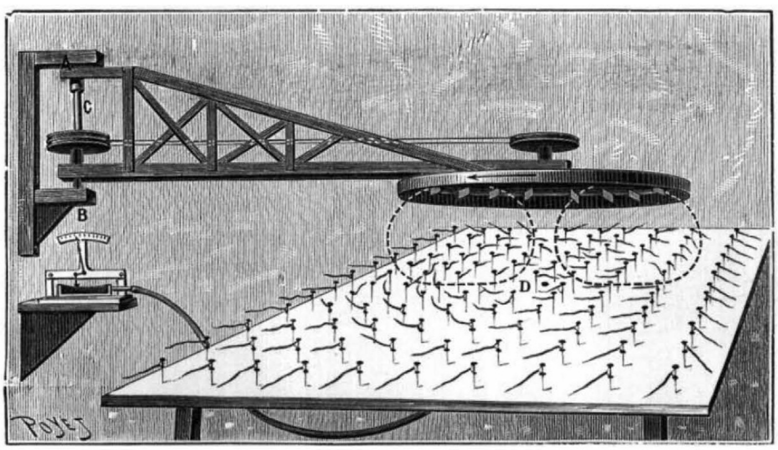

FIG. 8.—Artificial reproduction of cyclonic phenomena.

pointing in one direction, turn all at once in the opposite one, and make it possible to observe with all its sharpness the abrupt change of wind which takes place on leaving the central calm.

By making the cyclone travel with sufficient quickness, the flags permit us to take note of the dangerous and manageable sides of a cyclone, according as one looks at the semicircle in which the wind turns in the same direction as the movement of translation, or in the opposite one.

The variations of pressure are indicated by the passage of the cyclone above the hole made in the table, and communicating with the barometer; you see the needle falling little by little, indicating the minimum precisely at the moment when the centre of the cyclone passes above the hole, then rising slowly.

A thermometer sufficiently sensitive, placed in the centre of the cyclone, allows us to observe a rise of temperature.

In great cyclones, a ship on reaching the centre not only finds a general calm, but the sun or stars may be seen to shine through a great opening in the clouds; it is the eye of the storm.

In order to explain this fact, it suffices to remark that a cyclone is only in fact a water-spout of enormous diameter, in the immense sheath of which rages the storm of a descending movement, dragging down the hurricane and the clouds from the high regions to the level of the sea; but, as in the water-spout, the central nucleus remains free, and allows a clear sky to be seen.

The realisation of this eye of the storm succeeds equally well with steam or smoke by taking necessary precautions with the experiment.

Finally, as the centre of the cyclone is free of water vapour (at least in the visible form), whilst in the enveloping sheath storm and darkness reign, is it not evident that a hygrometer placed in this cloudy sheath will show a degree of moisture above that of the central nucleus?

To sum up—it may be seen that, however small the scale of the experiments in comparison to that which passes in nature, nevertheless these experiments reproduce with fidelity and with all the particularities of the great natural meteorological phenomenon.

The experiments which you have just seen will, I hope, suffice to show you how complete the experimental syntheses are, and how they represent the natural phenomena in the smallest details.

I will conclude by making the simple remark that meteorology gains in extent and certainly when we treat it as an experimental science.

A. CORNU.

IMMUNISATION AGAINST SERPENTS' VENOM, AND THE TREATMENT OF SNAKE-BITE WITH ANTIVENENE.[1]

II.

THE experiments now to be described were made with antivenene derived from a horse which had last received a dose of cobra venom estimated to be twenty times the minimum-lethal. On some previous occasions I have stated the results of observations on the antidotal value of the blood-serum of rabbits which had last received thirty and fifty times the minimum-lethal. The antivenene obtained from cats and white rats has also been examined. The special interest, however, is attached to antivenene derived from the horse, that it is more likely than any others to be used in the treatment of snake-bite in man.

The experiments were so planned as to obtain in different conditions of administration as exact a definition as possible of the antidotal power of the antivenene. In the meantime, four series of experiments have been undertaken on rabbits. In one series the venom was mixed outside of the body with the antivenene, and immediately thereafter the mixture was injected under the skin of the animal; in the second series the venom and antivenene were almost simultaneously injected into opposite sides of the body; in the third series the antivenene was injected some considerable time before the venom; and in the fourth series the venom was first injected, and thirty minutes afterwards the antivenene.

In the experiments of the *first series*, the doses of cobra venom administered were the minimum-lethal, one-and-a-half the minimum-lethal, twice, thrice, four times, five times, eight times, and ten times the minimum-lethal. In the case of each dose of venom, experiments were made with different quantities of antivenene, until the smallest quantity required to prevent death was discovered. In order to render it certain, in this and in the other series, that a lethal dose had been administered in the experiments with the so-called minimum-lethal, the minimum-lethal indicated by previous experiments was not used, but instead of it a slightly larger dose (·00025 instead of ·00024 gramme per kilogramme).

When this certainly lethal dose, capable of producing death in five or six hours, was mixed with the antivenene, and the mixture injected two minutes afterwards, under the skin, it was found that so small quantities were sufficient to prevent death as ·001 cc., ·0008 cc., ·0005 cc., and ·0004 cc. (1/1000, 1/1500, 1/2000, and 1/2500 of a cc.) for each kilogramme of the weight of animal; with ·0003 cc. (1/3333) per kilogramme, however, the animal died. The antivenene was therefore found to be so

[1] Continued from page 572.