Resins and waxes may serve only as protection to the surfaces of plants; coloring matters, as screens to shut off or admit certain of the sun's rays; but we are still far from penetrating the mystery of life.

A simple plant does what animals more highly endowed cannot do. From simplest substances they manufacture the most complex. We owe our existence to plants, as they do theirs to the air and soil.

The elements carbon, oxygen, hydrogen, and nitrogen pass through a cycle of changes from simple inorganic substances to the complex compounds of the living cell. Upon the decomposition of these bodies the elements return to their original state. During this transition those properties of protoplasm which were mentioned at the beginning, in turn, follow their path. From germination to death this course appears like a crescent, the other half of the circle closed from view. Where chemistry begins and ends it is difficult to say.

ON ANEMOMETERS.

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[Translated by G. E. Curtis, from the "*Annuaire météorologique*" of the Danish Meteorological Institute, Copenhagen, 1877.]

INTRODUCTION.—As the Hagemann anemometer has attracted some attention, and is easily obtained by purchase of the maker, Nyrop, of Copenhagen, and as the original memoir describing it is rather rare, I have, in compliance with several requests, suggested to the Franklin Institute, the propriety of publishing the following translation.

It is evident that Dr. Hagemann's preliminary investigation needs further development before the value of the instrument can be considered to be finally established. For measuring severe gusts and high wind velocities, an anemometer which has a minimum inertia of its own moving parts is very desirable, and this seems to be obtainable through the application of the principle of suction.

CLEVELAND ABBE.

A series of experiments upon the drafts of chimneys, for which I used a gauge constructed for the purpose, drew my attention to the fact that the draft up the chimney depends upon the force of the wind, so that each gust of air, no matter how feeble, that grazed the summit of the chimney, could be perceived in the apparatus for measuring the draft. Thus occurred the idea of utilizing the instrument as an anemometer, and I think I have established by the following experiments, its applicability to the simple and relatively very exact indication of the force of the wind, and thereby to the determination of the velocity.

The apparatus, as shown in *Fig. 3*, is substantially as follows:

In a reservoir, *a*, filled with water up to the level marked *l*, there is suspended by a wire or silk-thread a thin metallic bell, *b*; the upper end of the wire is fastened to a finely-tempered spring. A slit cut in the tube, containing the wire and spring, shows at *e* a small needle attached to the wire, whose motion is read off on a divided scale, *k*.

If now the metal-bell be given a diameter of 0.1128 m., or a section of 100 square centimetres, a suction in the tube *c*, whose top is above the water, equivalent in amount to one millimetre of water pressure, will produce a tension of ten grammes on the spring, which latter will be stretched thereby.

By choosing a spring of suitable force, the needle can easily be made to move ten millimetres for a pressure of ten grammes, and

thus the suction, as indicated on the scale, will be amplified ten times. The use of wheel-work admits of converting the original rectilinear motion into circular motion, and of amplifying still more the indications. If instead of suction, we wish to measure pressure, it is only necessary to load the bell, *b*, so as to make it sink, and the intensity of the wind-pressure can then be measured by the height to which the bell is raised, when the air in the tube *c* is compressed.

As a receiver of the wind, I have used a Pitot tube, *i. e.*, a tube with its aperture facing the wind, of 6 mm. interior diameter and with nicely sharpened edge, and also the tube designed by Captain Magius, of Copenhagen. The latter is simply a vertical tube, acting like a chimney, across whose top, also with sharpened edge, the wind blows at right angles to the axis of the tube.

In order to produce the currents of air requisite in these experiments, an apparatus was used represented in *Fig. 4*. The reservoir *A*, furnished with a grating *a. a* is constantly fed with compressed air by a fan worked by hand. The pressure is such as the experiment requires. A manometer, *e*, is so placed that the person working the fan can constantly follow with his eye the variations of pressure in the reservoir *A*. This latter contains an orifice *d*, of 9.5 cm. interior diameter that can be fitted with tubes of different diameters. On the Table *D* are placed the various receivers, connected by rubber tubes with the apparatus, *g*, for measuring pressure or suction.

After having compared the gauges, and having found them to agree within a limit of error not exceeding 0.1 mm., I fixed a Pitot tube, 6 mm. aperture, facing a jet of air which emerged from *A*.

through a round orifice 1.7 cm. in diameter. It then became manifest that the Pitot tube, as indicated by the manometers, *always* gave a pressure identical with the statical pressure in the reservoir *A*, when the distance of the tube to the orifice of escape did not exceed 5 cm. Experiments were made with pressures varying from 0 to 100 mm. of water and gave results agreeing perfectly.

From Weisbach's *Mechanik*, the velocity, *v*, of a current of air passing through an orifice in a thin plate is,

$$v = 396 \sqrt{(1 + \delta t) \frac{h'}{b + h'}} \text{ metres,}$$

where *h'* is the pressure in the reservoir expressed in millimetres of mercury.

Since the Pitot tube indicates a pressure precisely equal to that which forces the air to flow with the velocity *v*, the above formula ought also to indicate the velocity of a current of air producing an effect *h'* in the gauge attached to the Pitot tube.

As, moreover, the temperature, *t*, is the same in the whole mass of air in motion, and as *h'* is always a very small quantity compared with *b* = 760 mm., we can simplify the formula and substitute the approximation:

$$v = 396 \sqrt{\frac{h}{760 \times 13.598}} = 3.9 \sqrt{h} \text{ metres,}$$

where *h* is the pressure in millimetres of water, indicated by the manometer.

The diminution of pressure indicated by the Pitot tube, when its axis is oblique to the direction of the wind has been made the subject of observation and my results are contained in the following table.

TABLE I.

Distance from *d*, 30 cm. Diameter of *d*, 6 cm. Pressure in *A*, 10 mm.

Angle.	Pressure in Pitot Tube. mm.
0	6.1
10	6.1
20	6.0
30	5.75

The variations are so small that, up to an angle of 30° between

the direction of the wind and the axis of the tube, they do not exceed a few per cent.

The use of the Pitot tube, then, makes possible the construction of an anemometer that will operate with simplicity and precision; farther on, after having mentioned some difficulties that anemometers of this kind present, I will indicate more in detail the best method of construction.

Before beginning a review of my experiments made with the Magius tube, it will not be out of the way to examine more closely the current of air which emerges from an orifice in a thin plate, and to review the following experiments.

TABLE II.

Pressure in A, 8 mm.

<i>Distance from d. Pressure in Pitot Tube.</i>		<i>Distance from d. Pressure in Pitot Tube.</i>	
cm.	mm.	cm.	mm.
0.25	8.	9.	5.5
1.	8.	10.	4.45
2.	8.	15.	2.1
4.	8.	21.5	1.4
5.	8.	26.	1.1
6.	7.5	30.	0.75
7.	6.9	41.6	0.6
8.	6.35		

Whence it results in detail that for a distance from the orifice less than 5.5 cm., the latter having a diameter of 1.7 cm., a Pitot of 7 mm. diameter indicates the same pressure at the centre of the current of air as in the interior of the reservoir *A*. But if this distance be exceeded, the pressure begins to diminish rapidly, because the jet of air drags along the surrounding air in its course, and so loses velocity. It is only at a distance of 40 cm. that the mass of air seems to flow with a pretty uniform motion. Further experiments will throw more light on the distribution of pressure in the air-current.

The vertical tubes proposed by Captain Magius have not yet, so far as I know, been subjected to precise investigation, and consequently it was necessary, as a preliminary step, to know just how far the size and shape of the orifice exerts an influence, and also at what limits the indications remain proportional to the wind

velocity. Such was the object of the experiments presented below:

TABLE III.

Distance from d , 6 cm. Diameter of d , 2 cm.

Suction in Tubes of different Sizes and Shapes.

Pressure in A , mm.	7 mm.	6 mm.	4 mm.	2 mm.	1 mm.	4 mm.
	mm.	mm.	mm.	mm.	mm.	mm.
1	0.4	0.4				0.4
2	0.7	0.7	0.7	0.6	0.5	0.7
3	1.1	1.1				
4	1.5	1.5	1.55	1.2	1.0	1.5
5	1.9	1.9				
6	2.3	2.4	2.4	1.8	1.5	2.4
7	2.9	2.9				
8	3.4	3.4	3.4	2.9	2.0	3.25

These experiments show that all the Magius tubes having an aperture of 7 to 4 mm., give results which agree very closely, and impress a certain stamp of continuity on the curve that is obtained by making the pressure in A an abscissa and the suction an ordinate. For very small capillary tubes, on the contrary, such is no longer the case. The energy of suction diminishes with the diameter, and there is no continuity in the indications. A cause, however, which contributes to this irregularity, is found in the fact that the experiments were not continued a sufficiently long time, as is apparent from the following series of experiments in which the first and third tubes had their edges sharpened, but the middle tube not.

TABLE IV.

Distance from d , 6.5 cm. Diameter of d , 8 cm. Pressure in A , 10 mm.

<i>Duration of Experiment.</i> minute.	<i>Suction in Magius Tubes.</i>		
	5 mm. diam.	1.25 mm. diam.	1.25 mm. diam.
0.5	5.25	2.0	2.0
1.0	6.1	3.5	3.4
1.5	6.3	4.25	4.25
2.0	6.4	4.7	5.0
3.0	6.4	4.9	5.5
4.0		5.0	5.7
5.0		5.1	5.75
6.0		5.1	5.75

A Magius tube, even of 5 mm. diameter, takes an appreciable

time to rarefy all the enclosed air, and consequently it is not surprising that the capillary tubes require still more time. The reason that these latter tubes do not come to indicate a suction as great as tubes of larger calibre ought assuredly to be found in the influence of the capillary walls on the air. The following result then obtains: Capillary tubes are poorer receivers of the wind, and ought to be employed only so far as they can be shown to be more suitable than larger tubes in keeping free from obstruction in all kinds of weather.

Magius tubes of large diameter give, suctions proportional to the velocity of the wind, at least up to 8 mm. of pressure in *A*.

Beyond that limit I have been obliged to content myself with using simple curved glass tubes as gauges, instead of the form of manometer previously described.

TABLE V.

Distance from *d*, 6 cm. Diameter of *d*, 2 cm.

Pressure in <i>A</i> .	Suction in Magius Tubes.			mean.
	7 mm. diam.	7 mm. diam.	5 mm. diam.	
7'		3'0		3'0
8'	3'4			3'4
11'5		5'0		5'0
16'		7'0		7'0
20'	7'5	9'0		8'25
30'	11'0		12'0	11'5
40'	14'0		17'0	15'5

In spite of the comparatively large uncertainty in these measurements, nevertheless, I venture to assume, that further experiments will show that the ratio is maintained at least up to 100 mm. of pressure in *A*, and perhaps even beyond that limit. The action of the Magius tube is to be explained as being the result of cohesion between the molecules of the air current, which touches the open end of the tube and those of the air contained in the tube.

That is the reason we ought to find in these tubes the total effect which corresponds to different velocities, so long as cohesion does not vanish, which never occurs until a perfect vacuum is reached. It is presumable, however, that the higher velocities demand an appreciable time for the suction to attain its full value, but I have not yet measured this time.

If then, relying on the experiments presented in Tables III and V, one should conclude that the velocity of the wind preserves a

definite ratio to the suction measured in the Magius tube, and consequently that it could be expressed by

$$v = 3.9 \sqrt{a h} \text{ metres,}$$

he would be in error, because what we have really measured in these experiments is not the velocity of the current of air or the suction that the current is able to produce, but, on the contrary, *the difference between the suction and the pressure shown by the air-jet*. In order that a current of air shall open a way for itself in a mass of quiet air, it must do mechanical work, and consequently at every point must undergo a compression or exercise a pressure which is proportional to the work to be performed. It is this pressure which affects the indications of a Magius tube; if we contract the orifice of escapement, there is added to these causes a contraction of the air-jet. By changing the diameter of the orifice, and consequently the pressure of the jet, we obtain—

TABLE VI.

Distance from d , 6.5 cm. Diameter of d , 9.5 cm.

<i>Pressure in A. Suction in Magius Tubes.</i>		<i>Pressure in A. Suction in Magius Tubes.</i>	
1	1.0	6	4.75
2	1.8	8	6.25
4	3.3	10	7.75

So long as the velocity of the air current is small, and consequently the pressure of the jet light, the Magius tubes indicate a suction almost equal to the pressure in the reservoir A , but in proportion as the velocity and, with it, the pressure of the jet increases, this very pressure reacts on the suction, but to a less degree than that observed in experiments III and V, because now the orifice is very much larger. We can now draw the conclusion that the Magius tube cannot afford a very exact measure of wind gusts, because such gusts behave in the same way with respect to surrounding air, as the air-jet in these experiments. These gusts must contain compressed air, which naturally renders them incapable of producing in the Magius tube a suction as great as it ought to be by reason of their velocity. The following experiment will set forth, in a most striking manner, the distribution of pressure in the jet:

TABLE VII.

Diameter of d , 1.7 cm. Pressures in A , 8 mm.

Distance from d .	Pitot Tube, 6 mm.	Magius Tube, 6 mm.	Pressure in Jet.
0.25	8.0	1.8	6.2
4.0	8.0	2.9	5.1
6.0	7.5	3.4	4.1
10.	4.5	2.9	1.6
17.	2.0	1.6	0.4
21.5	1.5	1.2	0.3
26.	1.1	1.0	0.1
30.	0.75	0.75	0.0
41.6	0.6	0.6	0.0

I have shown above that experiments III, V and VI cannot lead to the expression of the velocity of the wind measured in the Magius tube. The conditions of experiment are such as do not admit of obtaining empirically the true expression, because we cannot produce an artificial current of air in which there is no additional pressure. However, we can arrive at it approximately. As the tables show, the pressure of the jet must be less at the opening of large orifices than at that of small ones, because the Magius tubes indicate with the latter a larger suction. If, then, we look for some law, according to which the size of the orifice exerts an influence on the suction, or on the diminution of pressure in the jet, we shall reach the desired result. The following experiment throws light on this point :

TABLE VIII.

Distance from d , 30 cm. Pressure in A , 10 mm.

Diameter of d .	Pitot Tube, 6 mm.	Magius Tube, 6 mm.
2.		1.0
4.2		3.25
6.		4.6
8.	6.6	5.75
9.5	6.75	6.35

If the squares of the diameters, d , be laid off on the axis of abscissas and the suctions be used as ordinates, we obtain a continuous curve. (*Fig. 5.*)

Just as this curve manifestly tends, with the increase of abscissas, to become parallel to the axis of abscissas, so we see it, in addition, approaching a portion of the curve generated in the same manner with the Pitot tube, and we cannot doubt that, by sufficiently increasing the abscissas, even up to the point where the air,

rushing through the orifice, constitutes a mass animated with a uniform motion, we shall obtain, both from the Pitot tube and the Magius tube, indications of pressure in the first and of suction in the second, corresponding exactly to the pressure under which the air-current is expelled from the reservoir A.

As experiments with natural and uniform air-currents have confirmed the correctness of this conclusion, the velocity of the wind, as measured with a Magius tube, will be expressed by the same formula as in the case of the Pitot tube, namely:

$$V = 3.9 \sqrt{h},$$

where h is the suction expressed in millimetres of water, indicated by the gauge.

When the air-current does not move normally to the orifice of the Magius tube, we shall no longer have, as one could suppose

in advance, the indication given by the whole velocity of the wind. In the following table are given the measurements obtained for different angular displacements.

TABLE X.

Distance from d , 6.5 cm. Diameter of d , 2 cm. Pressure in A , 8 mm.
Deviation of Tube from the Vertical. Magius Tube.

<div style="display: flex; align-items: center; justify-content: center;"> < → > </div>		<div style="display: flex; align-items: center; justify-content: center;"> </div>	
		mm.	mm.
6°	6°	3.4	3.4
6°			3.1
10°			2.8
	10°		3.3
			3.35

Distance from d , 30.0 cm. Diameter of d , 9.5 cm. Pressure in A , 10 mm.

Deviation of the Tube from the Vertical.

Magius Tube.

	mm.	
6°	6.5	
	6.5	
12°	6.5	
	6.25	
15°	6.25	
	5.70	
15°	5.40	

Any small deviations from the vertical made by the tube are, from the above, insignificant. If, however, the angle amounts to 15°, the resulting effect assumes sensible proportions. We see also that it is preferable to give the tube a very sharp bevelled edge, and to admit only a very small thickness at the lips of the orifice.

If now we take a glance at all the preceding measurements, and the conclusions deduced therefrom, we arrive at the following results:

(1.) The Pitot tube can form the basis of a good, precise anemometer, which is only a very little affected by small deviations from parallelism with the direction of the wind.

(2.) The Magius tube, except with capillary diameters, constitutes a good receiver of the wind for constant velocities, but is not able to register accurately gusts of wind, because the latter are composed of compressed air. The Magius tube will not admit any great deviation from the vertical.

I have found these results fully justified by experiment with natural winds. So long as the wind blows uniformly, the Pitot and Magius tubes are on exactly the same footing, but as soon as there comes a gust, their agreement disappears, the two gauges then begin at once to indicate the change, but whilst the manometer connected with the Pitot tube rapidly attains its maximum, a noticeable time elapses before the apparatus, which measures the suction in the Magius tube, can keep pace with it, and it is only when the gust reaches the condition of a uniform wind of higher velocity that the Magius tube comes finally to give the same change as the Pitot tube. Many gusts are of so short duration that one can scarcely observe them by means of their feeble instantaneous

suction in the Magius tube, which, besides, is not at all a true measure of their velocity.

While for the reasons presented, the Magius tube gives as a general result too weak indications, yet there are two other factors which ought to be mentioned as tending partly to counter-balance this error; namely, the force of expansion of the air in the tube itself, when the latter is in any place having a temperature higher than that of the surrounding air, or when it is heated by the sun; second, the oscillations of the tube. The first source of error is common to both Pitot and Magius tubes, and it is easy enough to make a correction for it; but as to the latter, which is complicated in its action, it is hard to give any general rules. So far as I have been able to observe, it is not the oscillation that takes place in the direction of the wind which increases the suction, because its effect should cancel itself (that is why the oscillation has no perceptible effect in the case of the Pitot tube), but it is any oscillation that makes an angle with the direction of the wind. Suppose the wind sweeps over the upper open end of the tube, and suppose that the tube oscillates in the air, the effect should be the same, because it is the relative velocity which is the cause of the suction.

In order to estimate the amount of the error, I have used a Magius tube, 10 cm. long, set in a rubber collar, so as to be oscillated by a strong current of air and I found—

TABLE XI.

<i>Distance from d.</i>	<i>Pitot Tube.</i>		<i>Magius Tube.</i>	
	<i>Oscillating.</i>	<i>Fixed.</i>	<i>Oscillating.</i>	<i>Fixed.</i>
0'15	50	50	54	47
0'40	50	51	57	51
0'70	35	35	45	37
1'00	24	24	24	24
0'40	90		93	
0'40	85		95	
0'40	80		90	

Although the oscillation of the tube was scarcely visible, and although the tube was not a long one, yet the error is so considerable in the Magius tube, that the suction could evidently not be used for giving an accurate determination of the wind velocity.

However, I do not regard it as impossible, whenever the opportunity presents itself, to determine at least approximately the amount of error, by calculating the duration of the oscillations

from the length of the tube exposed to the weather; the experiment would not be long in making known the amount of the effect produced by different velocities.

The Magius tube presents, on the whole, by reason of its very simple form, so many advantages that, at least in places where up to the present time the observer has been obliged to be satisfied

with estimating the force of the wind, he will be able to derive benefit by using this tube as an anemometer. If a precise anemometer is desired then we must use the Pitot tube, and I will venture to recommend the following construction, *Fig. 1.*

The iron tube *a* carries at the top the Pitot tube *b* as well as the wind-vane *c* and its counterpoise *d*. At *e*₁ and *e*₂ the tube is

fastened by collars fixed to the beams f_1, f_2 . The bottom of the tube ends in a steel point which moves in the socket g ; a bell h is fixed on the tube and is partly submerged in oil which surrounds the lower end of the tube, and is contained in a reservoir i . Within the bell, but above the oil, the tube is perforated with a series of holes through which the pressure of the wind received in the Pitot tube is transmitted to the bell where the tube K conducts it to the manometer.

In order to draw off the water which comes through the tube a in storms, the tube and cock, L , is used.

The cost of such an apparatus is small. The instrument can be set up so that there shall be no danger of its being overturned by high winds, and for precision, it leaves nothing to be desired.

For a manometer I should recommend using an arrangement a little different from that used in these experiments, to wit, the kind

of letter-balance shown in *Fig. 2.* The bell rests in use as before but in place of a spring, the steel-guard $a-b$ is used, of which the short arm a carries an arc of a pulley on which rests the silk thread c , whilst the long arm moves over the divisions of a scale graduated on another arc d . By giving this arc three or more different graduations which, according to circumstances, correspond to different positions of the weight e , the same apparatus can be used to measure pressure or suction expressed as height of water from 0 to 120 mm., and that, too, with a precision proportional to the smallness of the quantities.