Studies in the Permeability of the Pulvinus of *Mimosa pudica*.

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With five Figures in the Text.

AS a result of the work of numerous investigators (see the summaries by Pfeffer (1) and Jost (2)), it may be considered as established that the movement of the pulvinus of *Mimosa pudica* under the stimulus of shock (the so-called seismonastic movement) is due to a change in the turgor of the cells. The change in the shape of the pulvinus is mainly brought about by a loss of turgor in the cells of the lower half of the pulvinus; the loss of turgor allowing of the elastic recoil of the stretched cell wall, assisted under normal conditions by the weight of the leaf and the tension of the upper half of the pulvinus. The loss of turgor appears to be associated, as is to be expected, with a loss of water from the cell.

But although the seismonastic movement of *Mimosa* is associated with a turgor change yet the mechanism of that change remains uncertain. Pfeffer has pointed out that the reduction of turgor is most likely to be due either to a reduction in the quantity of osmotically active substances in the cell, thus allowing water to escape from the cell, or to an increase in the permeability of the cell, thus allowing of the escape of some of these osmotic substances together with some of the water of the cell-sap. The second hypothesis, that of the increase of protoplasmic permeability to such a degree as to bring about a serious reduction in the cell turgor, is difficult of acceptance as a working hypothesis since there is no obvious mechanism by which the osmotic substances which thus escape in solution can be drawn back so as to allow the cell to regain its turgor.

Lepeschkin (3) has shown that the pulvinus of *Mimosa* and of *Phaseolus* is sensitive to light, the permeability of the cells being increased when illuminated; he associates the nyctinastic movements of the leaves

with these changes in permeability. Owing perhaps to the observations and conclusions of Lepeschkin with reference to nyctinastic movements the view seems to have gained ground, in spite of the inherent objection already cited, that a similar change of permeability will explain the response of *Mimosa* to shock.

It seemed of importance that this view should, if possible, be subjected to the test of experiment. A method to be suitable must be one by which the exosmosis of very small quantities of the cell-contents can be recognized, for it would be difficult to work with more than a single pulvinus. As the increase of permeability, if it occurs, would almost certainly lead to the increase of rate of exosmosis of *electrolytes* as well as of *non-electrolytes*, it seemed likely that the electrical conductivity method for the estimation of dilute solution of electrolytes could be used to solve this question.

Experiments using this method were begun some years ago; since that time the method has been used in many investigations on cell permeability. The erratic behaviour of the pulvini, i. e. the refusal of many of them to respond, after removal from the plant, to shock stimuli, has delayed the work.

EXPERIMENTAL.

The method employed was essentially the same throughout; a pulvinus of *Mimosa pudica* was removed from the plant and immersed in a small volume of 'conductivity water' distilled over glass. The rate of exosmosis of electrolytes was determined periodically by the electrical conductivity method.

After removal of the leaf from the plant by a clean cut at the base of the pulvinus the upper part of the petiole was cut away so that a length of about an inch and a half remained attached to the pulvinus. In order to increase the rate of diffusion the internal tissue was further exposed by slicing away an equal portion of tissue from each *side* of the pulvinus, but leaving the upper and lower surfaces in the main intact. This operation was made with a sharp scalpel and as speedily as possible. The pulvinus was immediately placed in water so as to wash away the contents of the cut cells before beginning the experiment. The petiole was then gripped by a split rubber cork held in a cork-borer, which was lowered by a rack and pinion until the pulvinus was completely immersed in the liquid of the conductivity 'cell'. Treatment of the pulvinus in this way did not destroy its power to contract when stimulated. In a great many cases response to stimulation was obtained within fifteen minutes from the time of removal of the pulvinus from the plant; in others a period of some thirty or thirty-five minutes elapsed before the pulvini becomes stimuable. The unstimulable condition seemed to be associated with extreme turgor of the cells of the under side of the pulvinus, since it was frequently observed that the

contour of this side during the dormant period was convex, but when it returned to the normal, slightly concave condition the response to stimuli was again established. As already stated, for some reason unexplained some pulvini never recovered from this dormant condition. In one case, however, a pulvinus, which during two hours had given no response to stimulation, was left immersed in the cell at 4 p.m., and was found two hours later to have recovered. The factors which determine this behaviour were not discovered, and a certain element of doubt always existed as to

FIG. 1.

whether a given pulvinus would behave normally. Such cases of failure to obtain response to stimulation were in the later part of the work reduced to one in ten.

The conductivity cell employed was designed for the purpose, and is specially serviceable for conductivity determinations where the volume of liquid available is very small. The actual cell A (Fig. 1) was a small glass cup six or seven millimetres in diameter with electrodes, two millimetres apart, fused in at the sides; the electrodes had an area of about two square

millimetres each and were made from platinum wire hammered flat. In order to increase their surface the electrodes were platinized and roasted before insertion. The capacity of the cell was about 1 c.c. and the volume of liquid usually employed was between 0.5 c.c. and 0.7 c.c. The 'cell constant', which naturally varied with the height to which the cell was filled, was of the order of 3 to 4. Above the cell the apparatus widened out to a cup-shaped mouth which could be closed with a cork when not in use. During an experiment this mouth was left open to air, but the liquid in the cell was protected from dust falling vertically by a wide tin lid B, perforated in the centre and soldered to the cork-borer which carried the pulvinus.

The liquid was agitated by a regular intermittent stream of air-bubbles, a system which proved very efficient and at the same time prevented the accumulation in the liquid of carbon dioxide produced by the respiration of the pulvinus. The air was forced from a gas-holder and entered at the base of the cell through a capillary of such narrow dimensions that a considerable pressure was required. The magnitude of this pressure was observed in the open side tube C shown on the left in the figure. The pressure alternately rose to about 13 cm. of water and fell to about 12 cm. At the maximum pressure air entered the cell in a rapid stream of some five or six bubbles. A short interval of time then elapsed before the maximum pressure was again attained; this interval could be regulated by means of the screw-clip D compressing the rubber tubing upon a wire passing through it. In most of the experiments this interval was approximately ten seconds. The whole apparatus was placed in water in a thermostat with glass sides. The air before entering the cell was saturated with water vapour at the temperature of the thermostat by passage over moist glass beads in the tube E immersed in the bath. In this way evaporation of the liquid in the cell was reduced to a minimum. In order to prevent electrolytes being carried into the cell the splash-trap F was interposed between this vessel E and the capillary entrance to the cell. Most of the experiments were carried out at temperatures between 25° and 40° C.

For estimations of conductivity, instead of the usual method of Kohlrausch, an ordinary moving coil galvanometer and a rotating commutator of the Fitzpatrick (4) type was employed. Owing to the weakness of the solutions and the high constant of the cell, a high balancing resistance had to be used; one variable between 10,000 and 100,000 ohms, made by Gambrell Bros., was usually employed.¹ In all cases the rate of increase of conductivity was taken as the measure of the rate of exosmosis.

¹ In order to make certain that the accuracy of the readings was not vitiated by the capacity of the resistance, which was of the ordinary type with non-inductive winding, comparative experiments were made with a resistance of the same range made of 'anti-capacity gauze' by W. Paul. The results were found to be identical.

Various methods were used for stimulating the pulvinus, such as mechanical shock by touching or cutting the top of the petiole, electrical stimulation with the help of an induction coil, and stimulation by sudden alteration of temperature. The last method was found to be most convenient, for the stimulus could be applied by simply raising the pulvinus out of the warm fluid. The sudden transition to the cooler air above the fluid acts as a stimulus and brings about contraction.

An experiment was conducted in the following way :

The condition of the cell was tested by filling it with conductivity water which was kept continually stirred by means of a slow stream of bubbles. The conductivity was then noted periodically, and the cell was considered to be satisfactory when the rise of conductivity was not above a certain rate ; owing to the cell being made of ordinary glass and to very slight evaporation from the fluid there was always a steady, slight rise of conductivity. This 'washing factor' could be allowed for, if necessary, in the later readings. The cut pulvinus, previously washed, was then inserted. The rate of exosmosis from the cells indicated by the rate of increase of conductivity was then determined periodically, the fluid being changed, if necessary, after the first few minutes. Stimulation was brought about by raising, by means of a rack-and-pinion adjustment, the cork through which the petiole was threaded, care being taken that the pulvinus did not come in contact with the sides of the cell. If the petiole was raised only sufficiently to bring the pulvinus just above the fluid no stimulation resulted, but if the pulvinus was raised 25 to 30 mm. above, so that the fall in temperature was considerable, stimulation was quickly effected in favourable cases, and the end of the pulvinus showed the characteristic curvature after the lapse of a few seconds. After a period of time (often 30 sec.) which was constant for each experiment, the pulvinus was returned to the fluid. Readings were taken at regular intervals of $\frac{1}{2}$, 1, 2, 3, or 5 min. The bubbling was continued throughout the experiment, being stopped only for a definite period to allow of a reading being taken.

As the permeability of the pulvinus was found to be affected by light changes (see later) the experiments were usually conducted with the pulvinus brightly illuminated by means of a Nernst burner (micro-Nernst lamp of Zeiss).

TABLE I.

Effect of Contraction on the Rate of Exosmosis from the Pulvinus of Mimosa pudica.

August 3, 1915. Pulvinus with sides sliced. Temperature 39.9° C. Illuminated by Nernst lamp. Stimulated at intervals of fifteen minutes by raising the pulvinus into cold air for thirty seconds while taking the reading of the conductivity. At other times the readings were taken with the

pulvinus raised just above the liquid where the air was only slightly below the temperature of the bath; this, as seen below, caused no contraction of the pulvinus. *A* and *A'* give the angles which the pulvinus made with the petiole before and after raising.

<i>Time in Minutes.</i>	<i>Treatment of Pulvinus.</i>	<i>A.</i>	<i>A'.</i>	<i>Conductivity in Gemhos.</i>	<i>Rate of Exosmosis.</i>
0	Leaf cut	—	—	—	—
5	Experiment started	125°	—	—	—
10	Raised	143°	147°	56.2	—
15	„ and stimulated	157°	112°	62.4	6.2
20	„	141°	141°	68.2	5.8
25	„	153°	153°	72.6	4.4
30	„ and stimulated	154°	127°	76.3	3.7
35	„	151°	154°	80.6	4.3
40	„	154°	154°	84.1	3.5
45	„ and stimulated	154°	118°	86.8	2.7
50	„	145°	145°	90.9	4.1
55	„	149°	149°	93.3	2.4
60	„ and stimulated	149°	114°	95.6	2.3
65	„	143°	143°	98.8	3.2
70	„	143°	143°	100.9	2.1
75	„ and stimulated	143°	110°	102.7	1.8
80	„	136°	136°	105.8	3.1
85	„	136°	136°	107.7	1.9
90	„ and stimulated	136°	109°	109.3	1.6
95	„	120°	122°	112.4	3.1
100	„	135°	135°	114.0	1.6
105	„ and stimulated	134°	106°	115.5	1.5
110	„	117°	117°	118.7	3.2
115	„	125°	125°	120.0	1.3
120	„ and stimulated	125°	95°	121.0	1.0
125	„	110°	110°	123.6	2.6
130	„	119°	119°	124.9	1.3
135	Experiment ended	119°	—	125.7	0.8

The result shown in Table I is typical of many. It shows that the cut pulvinus kept immersed in warm water will exhibit a large number of contractions when suitably stimulated. The mere fact that the pulvinus will continue to respond to stimulation under these conditions is sufficient in itself to negative the hypothesis that the loss of turgor on contraction is dependent on an escape of osmotic substances from the tissues. For, with the internal tissues of the pulvinus freely exposed to warm water not only at the base but at the sides, such substances, if they left the cell, would pass rapidly into the surrounding fluid. There these substances would be lost to the tissues; for it is hardly conceivable that they could be reabsorbed, at least within any short period. Again, it is hardly possible that, if at each contraction there is a loss of osmotic substances sufficient to markedly reduce the turgor of the cells, such substances could be produced again at such a rate as to allow the pulvinus to continue to contract every fifteen minutes during two hours.

In nearly all the experiments a slow exosmosis of electrolytes from the cut surfaces of the pulvinus is to be observed. The rate of this exosmosis, apart from contractions of the pulvinus, falls off steadily for a long period.

The fall in the early period is possibly due to the washing away of substances derived from the cut cells, but it may be that there is an actual decrease of permeability as a result of the washing out of salts from the living cells as indicated by some of Loeb's experiments on eggs. The fall in the rate of exosmosis cannot be due to a fall in the diffusion gradient between the living cells and the surrounding medium. For a dead pulvinus may raise the conductivity of the fluid to 400 gemhos (which corresponds to about N/10 NaCl), and as the volume of the pulvinus is only 0.1, or less, of that of the surrounding fluid the concentration of electrolytes in the cells would seem to be of an order corresponding to several thousand gemhos.

Turning now to the actual rate of exosmosis in relation to contraction we find that the response to stimulation is associated with an increased loss by exosmosis; the increased loss being of the order of 2-3 times, as seen in the readings of the second hour. In the earlier period of the experiment the greater rapidity of the fall in what one may call the normal rate of exosmosis tends to reduce the apparent effect of contraction in increasing the rate of loss.

As, however, the rate of normal loss of electrolytes under the conditions of the experiment is so small that the pulvinus may be subjected to it for many hours without loss of power of response, it is clear that an increase of that loss during five minutes to two or three times the normal can in no way account for the loss of turgor of the cells. It is clear then that contraction of the pulvinus is not associated with an increase in the permeability of the cells to electrolytes in any way sufficient to produce such a loss of turgor of the cells as would explain the contraction.

These experimental results give no direct information as to the behaviour of non-electrolytes such as sugars, and it might be suggested that a rapid loss of these substances from the cell would explain the fall in turgor of the cells of the lower half of the pulvinus. It is, however, improbable that there should be a very marked increase of permeability in relation to non-electrolytes unaccompanied by any corresponding increase in the rate of exosmosis of electrolytes. Apart from this, however, the repeated contractions and recoveries of the cut pulvinus when immersed in warm water seem to exclude, as already pointed out, any explanation of the contraction which is based on the passage of osmotic substances out of the cells, whether those substances be electrolytes or non-electrolytes.

The increased loss of electrolytes associated with the contraction of the pulvinus may be due to a change of permeability associated with stimulation or it may be a mere secondary mechanical effect, the contraction of the pulvinus squeezing a certain amount of material out of the intercellular spaces or cell walls. An experiment with the immotile pulvinus of *Sapindus emarginatus* suggested that here also cooling affected the rate of exosmosis in spite of the absence of contraction. An experiment with a pulvinus of *Mimosa* which was not responsive to stimuli also gave the same result.

These experiments suggest that the sudden cooling in itself affects the permeability of the tissues, but the experiments were not carried far enough to enable this point to be decided. The difficulty of obtaining material of sliced pulvini which would give quantitatively comparable results was a bar to more accurate work.

TABLE II.

Effect of Contraction on the Rate of Exosmosis from the Pulvinus of Mimosa pudica.

October 14, 1915. Pulvinus with sides sliced away almost to the vascular bundle. Temperature 39.4°C. Illuminated by Nernst lamp. Stimulated by touching with platinum wire. *A* and *A'* give the angles which the pulvinus makes with the petiole before and after stimulation.

<i>Time.</i> <i>Mins.</i>	<i>A.</i>	<i>A'</i>	<i>Gemhos.</i>	<i>Rate of</i> <i>Exosmosis.</i>	<i>Time.</i> <i>Mins.</i>	<i>A.</i>	<i>A'</i>	<i>Gemhos.</i>	<i>Rate of</i> <i>Exosmosis.</i>
0	Leaf cut					169°	150°	Stimulated	
11	170°	—	27.8	—	31	155°	—	38.0	0.7
12	170°	—	28.7	0.9	32	160°	—	38.4	0.4
13	170°	—	29.5	0.8	33	164°	—	38.8	0.4
14	170°	—	30.2	0.7	34	166°	—	39.1	0.3
15	170°	—	30.7	0.5	35	167°	—	39.4	0.3
	170°	161°	Stimulated			167°	147°	Stimulated	
16	164°	—	31.3	0.6	36	155°	—	40.2	0.8
17	168°	—	31.9	0.6	37	160°	—	40.6	0.4
18	170°	—	32.4	0.5	38	163°	—	41.0	0.4
19	170°	—	32.8	0.4	39	165°	—	41.3	0.3
20	170°	—	33.3	0.5	40	166°	—	41.6	0.3
	170°	152°	Stimulated			166°	149°	Stimulated	
21	157°	—	33.7	0.4	41	154°	—	42.4	0.8
22	—	—	34.2	0.5	42	157°	—	42.7	0.3
23	168°	—	34.5	0.3	43	162°	—	43.1	0.4
24	170°	—	34.9	0.4	44	163°	—	43.4	0.3
25	170°	—	35.2	0.3	45	164°	—	43.6	0.2
	170°	150°	Stimulated			164°	146°	Stimulated	
26	157°	—	35.8	0.6	46	150°	—	44.3	0.7
27	163°	—	36.1	0.3	47	155°	—	44.7	0.4
28	—	—	36.7	0.6	48	159°	—	45.1	0.4
29	168°	—	37.0	0.3	49	162°	—	45.4	0.3
30	169°	—	37.3	0.3	50	163°	—	45.7	0.3

That cooling itself is not responsible for the slight increase of exosmosis of electrolytes associated with contraction is shown by the results given in Table II, where stimulation was brought about by touching the pulvinus with a loop of platinum wire which hung beside the pulvinus in the water of the conductivity cell. The pulvinus was thus kept at constant temperature; but the increase of exosmosis is well marked, especially in the second half of the table. The readings were taken every minute in this experiment, thus their accuracy is not very high. It is possible, though not probable, that part of the increase may be due to mechanical injury produced by contact of the wire with the tissues. The fact that most of the increase appears in the first minute after stimulation suggests that cell injury is not responsible

or the result. The association of increased permeability with contraction, apart from cooling or mechanical stimulation, is well shown in Table III, where the contractions are autonomous.

It is to be noted that in Tables I and II the pulvinus recovers less and less fully after each contraction, so that the angle in column *A* gets less as the experiment proceeds. On the other hand, the extent of the contractions seems to get greater and greater, so that the angles reached after contraction, and shown in column *A'*, also tend to get less. This is well shown in Fig. 2.

FIG. 2.

The observations here described show that the loss of turgor in the cells of the lower half of the pulvinus cannot be explained by a rapid exosmosis of osmotic substances. The loss of turgor must almost certainly be due to the disappearance or inactivation of these substances. As to the mechanism of this process we have at present no knowledge; it is suggested that changes in the adsorptive power of the colloids of the cell play a large part.

AUTONOMOUS CONTRACTIONS OF THE PULVINUS.

While carrying out these experiments a very interesting and, in the case of *Mimosa*, an entirely new phenomenon was met with, that of a series of rapid contractions of the pulvinus similar to those due to shock, but

autonomous or autogenic in nature, i. e. occurring when the external conditions of temperature, light, &c., were quite constant.

The first occasion on which they were observed was on April 4, 1913, when a pulvinus was placed in water in the cell at a temperature of 29.9°C . and brightly illuminated. Twenty-nine minutes after cutting it reacted to the stimulus of cooling, and after several stimulations in this way when replaced in the fluid it exhibited a series of nine contractions. The interval between two successive contractions was at first about 4 min., but it gradually decreased till the interval between the last and penultimate contractions was reduced to 1 min. 53 sec.

FIG. 3.

This striking phenomenon was observed on some ten occasions at temperatures between 30° and 40°C .; in all cases the pulvinus was brightly illuminated. The contractions as they proceeded were always found to occur at shorter and shorter intervals, with the result that the extent of the contractions gradually decreased, since the pulvinus had less and less time to straighten between successive contractions; the pulvinus thus finally came to rest in the partly contracted state. A graphic representation of one of these series showing sixteen autonomous movements is given in Fig. 3.

Bose (5) has observed a similar series of movements following on a single stimulation in *Biophytum* and *Averrhoa*, and he applies to them the term 'multiple response', pointing out, however, that no sharp line can be drawn between multiple responses and autonomous movements.

Bose describes in *Mimosa* a multiple *electrical* response as the result of one strong stimulation ; our results, however, show that under appropriate conditions *Mimosa* may, like *Biophytum*, exhibit temporarily a series of movements which can be closely compared with those of *Desmodium gyrans*.

The high degree of sensitiveness brought about by a bright light and high temperature is no doubt related to this striking phenomenon.

Details of an experiment in which autonomous contractions appeared are given in Table III. It is to be noted that the increase in the rate of exosmosis is visible after each response in spite of the absence of either cooling or of mechanical stimulation.

TABLE III.

Effect of Autogenic Contraction on Exosmosis from the Pulvinus of Mimosa.

October 6, 1913. Pulvinus with sides sliced. Temp. 35.0° C. Illuminated by 'Lilliput' arc lamp focused on pulvinus by lens. Stimulation by cooling was followed by three autogenic responses during the first seventy minutes. The liquid was then changed and a sequence of eight more autogenic responses followed the initial stimulation by cooling.

<i>Time.</i> <i>Min.</i>		<i>Gemhos.</i>	<i>Diff.</i> <i>1 min.</i>	<i>Diff.</i> <i>3 min.</i>
0	Leaf cut	—	—	—
73	Pulvinus raised ; the liquid changed	—	—	—
75		18.5	—	—
78		24.4	—	5.9
79.5	Autogenic response	—	—	—
81		30.1	—	5.7
84		34.2	—	4.1
85	Autogenic response	—	—	—
87		39.7	—	5.5
90		42.4	—	2.7
91	Autogenic response	—	—	—
93		46.8	—	4.4
95	Autogenic response	—	—	—
96		50.8	—	4.0
97		51.7	0.9	—
98		52.3	0.6	—
98.75	Autogenic response	—	—	—
99		53.4	1.1	—
100		54.9	3.5	—
101		55.8	0.9	—
102		56.6	0.8	—
102.75	Autogenic response	—	—	—
103		58.2	1.6	—
104		59.1	0.9	—
105		60.0	0.9	—
106		60.8	0.8	—
106.75	Autogenic response	—	—	—
107		62.3	1.5	—
108		63.3	1.0	—
109		64.0	0.7	—
110		64.6	0.6	—
110.75	Autogenic response	—	—	—
111		65.8	1.2	—
112		66.8	1.0	—
113		67.5	0.7	—

EFFECT OF LIGHT ON PROTOPLASMIC PERMEABILITY OF THE
PULVINUS.

That light increases the permeability of the protoplasm has been demonstrated by Lepeschkin (3) and Tröndle (6). The former demonstrated the effect of light on the permeability of the cells of the pulvinus of *Phaseolus* and of *Mimosa*, mainly by the use of the indirect plasmolytic method; but he also showed that the total exudate from a number of pulvini of *Mimosa* in water was greater in the light than in the dark. Tröndle relied entirely on the indirect plasmolytic method in his study of the mesophyll cells of the leaf of *Buxus* and *Tilia*.

It is clear that the conductivity method provides an almost ideal one by which the effect of light on the permeability to electrolytes can be studied, for the method can be made sensitive to extremely small quantities and readings can be for any period of time and the same organ can be used continuously throughout the investigation.

The relation of light to permeability was not studied exhaustively, but a few experiments were made to test the value of the method. The pulvinus was prepared in the ordinary way with the sides sliced to increase the surface for diffusion, and it was illuminated through the glass side of the bath by a Nernst lamp of 50 candle-power placed 10 cm. from the pulvinus. As it was considered possible that the temperature of the water in the conductivity cell might be of a higher temperature than that of the bath, owing to the greater absorption of light by the green-coloured pulvinus, some of the experiments were made with a thermo-couple in the water of the 'cell' and in the bath. A difference of not more than 0.3°C . was observed, which would mean that the readings in the light and dark would only differ by 0.6 per cent. from this cause. Owing to the magnitude of the effect of light such a difference is, of course, quite negligible.

Occasionally a pulvinus was met with which refused to react to light for unknown reasons, but the majority showed a very marked reaction, the rate of exosmosis of electrolytes, as measured by the increase of conductivity, being greatly increased. The graph shown in Fig. 4 shows the results obtained during an experiment of which Table IV gives the details. The increase in conductivity, measured in gemhos, for successive periods of 15 min. is plotted against time; the periods of darkness are indicated by the dark lines on the axis of the abscissae. It will be seen that the pulvinus was kept in darkness during the first hour; on exposure to light exosmosis increased during the first half-hour, then, although still illuminated, the permeability began to decrease; when placed in darkness for a second period an initial rise in the rate of exosmosis was observed. These effects were repeated on further changes from darkness to light and from light to darkness.

TABLE IV.

Effect of Light and Darkness on the Rate of Exosmosis from the Pulvinus of Mimosa.

March 24, 1913. Pulvinus slit down axis in the anterior-posterior plane, washed well with water and placed in darkness. Experiment started 12.7 p.m. Temp. 26.1°C .

Time. p.m.	Gemhos corr. to 26.4°C .	Diff. 15 min.	Time. p.m.	Gemhos corr. to 26.4°C .	Diff. 15 min.
Darkness			Daylight and Nernst lamp		
h. m.			h. m.		
12 10	24.8	—	3 40	156.8	2.8
12 25	44.2	19.4	3 55	161.3	4.5
12 40	54.9	10.7	4 10	165.2	3.9
12 55	63.5	8.6	4 25	167.9	2.7
1 10	70.3	6.8	4 40	170.0	2.1
Daylight and Nernst lamp			Darkness		
1 25	81.6	11.3	4 55	173.6	3.6
1 40	96.0	14.4	5 10	176.2	2.6
1 55	108.3	12.3	5 25	178.3	2.1
2 10	119.3	11.0	5 40	179.7	1.4
Darkness			5 55	181.2	1.5
2 25	131.2	11.9			
2 40	140.0	8.8			
2 55	147.2	7.2			
3 10	152.2	5.0			
3 25	154.0	1.8

FIG. 4.

This and other experiments brought out very clearly: (1) That light has a marked effect in increasing permeability to electrolytes; (2) that the effect takes some time to reach a maximum, and then, after a varying period of time, begins to fall off; (3) that the sudden change from light to darkness also increases the permeability.

This last phenomenon is well seen in the 'humps' in the curve after the withdrawal of light. This 'after-effect' of light was shown in a number of cases.

These results fully confirm the main result obtained by Lepeschkin and Tröndle, that light increases the permeability of the protoplasm for salts. The results show also that the method here used, besides being direct, is much superior to that employed by those workers, in that it is far more delicate and is also capable of giving practically continuous records. An exhaustive study by this method of changes of permeability due to light, changes which are probably photochemical in origin, would be of great value.

EFFECT OF TEMPERATURE ON RATE OF EXOSMOSIS.

A few experiments were carried out by the conductivity method to investigate the effect on permeability of slow rise of temperature.

All the experiments showed that with a rise at the rate of about 5° C. in 20 min. the effect of rise of temperature on the rate of exosmosis of electrolytes was very slight up to 52°. Only when the temperature was likely to produce quickly a harmful, and no doubt irreversible, effect was there a marked increase of permeability.

TABLE V.

Effect of Temperature on the Permeability of the Pulvinus of Mimosa.

December 17, 1913. Pulvinus with sides sliced, washed in cold water for one hour and a quarter. Illuminated by daylight only. Temperature raised gradually from 39° C. to 64° C.

<i>Time in Minutes.</i>	<i>Temperature. Degrees C.</i>	<i>Conductivity. Gemhos.</i>	<i>Rate of In- crease of Conductivity.</i>
0	38.0	26.8	—
6	39.15	30.1	3.3
12	41.15	33.1	3.0
18	43.0	36.0	2.9
24	44.55	39.2	3.2
30	46.25	41.9	2.7
36	48.05	44.8	2.9
42	49.5	48.0	3.2
48	50.9	51.6	3.6
54	52.3	55.4	3.8
60	53.65	61.1	5.7
66	54.95	69.6	8.5
72	56.15	81.2	11.6
78	57.3	110.6	29.4
84	58.25	188.2	77.6
90	59.45	279.1	90.9
96	60.35	345.4	66.3
102	61.25	378.4	23.0
108	62.1	394.0	15.6
114	62.9	401.2	7.2
120	63.5	404.0	2.8

The results of one experiment are given in Table V, and a graphic representation is shown in Fig. 5, where the experiment was begun at 38° C., and the temperature was allowed to rise at first at a rate of 2° C. in six minutes, later somewhat more slowly. From 38° to 50° C. there is practically no change in permeability when the conductivity readings are calculated to a constant temperature (64° C.) on a basis of a change of 2 per cent. per degree. Only after 48° or 50° is there a distinct rise in the rate of exosmosis, which rapidly reaches a maximum as the impermeability of the protoplasm breaks down. With the loss of salts from the cell the gradient of concentration lessens, and so the rate of exosmosis slows down and finally falls rapidly in spite of the increased permeability.

FIG. 5.

Of course in such experiments as these, where the temperature is above what may be termed normal, the time factor plays a large part. Experiments with different rates of rise of temperature would thus give curves of

a different shape. The experiments, however, seem clearly to indicate that in the case of the pulvinus of *Mimosa*, the temperature coefficient between 35° and 50° C. for the rate of exosmosis of electrolytes into water is not markedly greater than unity.

SUMMARY.

An excised pulvinus of *Mimosa pudica* when placed in warm water with its internal tissues freely exposed exhibits, on stimulation, repeated contractions during many hours. This indicates very clearly that the loss of turgor in the cells of the lower half of the pulvinus, which is associated with contraction, cannot be explained, as has been suggested, by a sudden increase of permeability of the tissues allowing of a rapid exosmosis of osmotic substances.

By placing a pulvinus in a very small quantity of water in a specially constructed conductivity 'cell' the exosmosis of electrolytes can be studied by the change of the electrical conductivity of the fluid. By this means it has been shown that contraction is associated with an increase in the rate of exosmosis of electrolytes from the pulvinus. The exact nature of this increase is obscure, but the increase is far too small to account for the sudden loss of turgor of the cells. The loss of turgor is probably due to the disappearance or inactivation of a considerable part of the osmotic substances of the cells.

The 'conductivity method' being direct is much superior to the indirect plasmolytic method used by previous workers for the study of the effect of light on permeability. Using the 'conductivity method' it can be shown that in the case of the pulvinus of *Mimosa* the permeability of the cells for electrolytes is markedly increased by exposure to light, but the effect rapidly falls off in time. A sudden change from light to darkness also increases permeability.

A curious autonomous (autogenic) contraction of the pulvinus was observed. In some cases, after the pulvinus had been stimulated by cooling on being brought back into warm fluid, it exhibited a series of contractions (in one case sixteen in number) although the external conditions remained perfectly constant. The contractions occurred at gradually decreasing intervals, so that the time for recovery becoming less and less the contractions also decreased in extent, and the pulvinus at the end of the series remained in the contracted state. The pulvinus of *Mimosa* thus for a time showed movements as autonomous as those of *Desmodium gyrans*.

Below 50° C. a slow rise of temperature appears to have little effect on the rate of exosmosis into water of electrolytes from the cells of the pulvinus of *Mimosa*. The increase of permeability with higher temperatures is apparently due to lethal, no doubt irreversible, changes.

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