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Comparative Anatomy

of the

Filz-like Hair-covering of Leaf-organs.

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INAUGURAL DISSERTATION

FOR

OBTAINING THE DEGREE OF DOCTOR OF PHILOSOPHY

presented

before the Philosophical Faculty

of the

UNIVERSITY OF ZÜRICH

BY

EMILY L. GREGORY.

Bryn Mawr College. Pa. U. S. A.

Approved by the Professors

Dr. A. Dodel-Port

Dr. A. Heim.

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Printed by Zürcher and Furrer
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Comparative Anatomy

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Filz-like Hair-covering of Leaf-organs.

This question was suggested to me by Prof. Schwendener, who had observed that the under cells of the hairs on certain leaves were thin-walled, also the epidermal cells, while the wall of the upper hair cell or cells was thickened, often to such an extent as nearly to fill the lumen. Together with this peculiarity was noticed a certain form of stoma which hitherto had been observed only on leaves growing in a very moist atmosphere but destitute of any hair covering. These two facts suggested the probability of a connection between the hair-covering and the ability of the leaf to take up moisture in a liquid form from the atmosphere.

Authorities agree in ascribing to this coating the office of protection. This may be against too rapid transpiration in case the plant is exposed to sun and wind and destined to endure a long dry season. The fact that this coating is often on the under side of the leaf only, where the greater number of stomata usually occur, supports this view of the function of the hair in these cases. Protection may thus be given against injury to the chlorophyll through insolation; this can apply only to a small number of plants, namely, those whose leaves are coated on both sides, or on the physiological upper side, or

those which stand on the stem at such an angle as to expose the under side to the rays of the sun. Under any or all of these conditions, the coating may serve as protection against rapid changes of temperature, or mechanical injury from insects or from plant parasites.

This function of protection in some one or all of these various ways, is too well substantiated to require any farther proof. The possibility of another, perhaps equally important one, by which the hair may contribute actively to the supply of water for the use of the plant, as well as merely to prevent the escape of that taken up by the root-hairs, suggested the anatomical study of the various kinds of Filz in reference to this point.

The great variety in form of Trichomes and their probable physiological meaning has long been the subject of thorough and patient investigation. The literature on this subject is too well known and too far-reaching to render a formal statement of it of any particular value in this connection, except it may be a brief reference to several more recent articles which have a special bearing on this point.

Among these is „Die Anpassung der Pflanzen an Regen und Thau“ von Axel L. Lundstrom, Docenten der Botanik an der Universität Upsala, 1883. The object of this article as the name implies, is to show that the higher land plants have peculiar arrangements to enable them to make use of the moisture contained in the atmosphere and that received direct from the rain-falls. A large number of plants were studied with special reference to such peculiarities of structure as are usually considered accidental and which have hitherto been passed by, or overlooked, as destitute of any physiological interest.

Such peculiarities are the various forms of leaves, their manner of insertion, ridges and furrows formed by the nerves, hairs on the leaf edges, hair clusters where the nerves intersect, the character of the epidermis and the anatomical structure of the leaf and petiole. All these are considered in reference to their fitness to catch the rain drops, lead them to other parts of the plant, hold them in such localities where they can be most easily used and there absorbed.

In an article by H. W. F. Schimper published in the Botanical Central-Blatt No. 6 1884 entitled „Bau und Lebensweise der Epiphyten West-Indiens“ the author gives an account of the various forms of these plants and describes the manner in which the basal cell of the hair scale probably aids in drawing in water out of the atmosphere from which source the plant receives its nourishment. Various experiments were tried in proof of this supposition, the resistance of the membrane to the passage of the water tested &c. The result of these observations shows that the living cells at the base of the hair scales have the same physiological meaning as the hairs of the rootlets of ordinary land plants.

In a short sketch entitled „Zur Flora der ägyptisch-arabischen Wüste“ in the Sitzungsberichte der königlich preussischen Akademie der Wissenschaften zu Berlin VI 1886 28th Jan. presented by Dr. Georg Volken, the author refers to the question of plants absorbing water from the air, but only to mention several examples from the Aegyptian Flora which appear to favor this probability. The only one of interest in this connection is that of *Diploaxis Harra* which he describes as possessing long, single-celled, thick-walled hairs, whose bases

terminate in a cup-shaped enlargement sunk into the mesophyll and connected with it by pores. The membrane of the hair in the immediate vicinity of this enlargement, is said not only to lack the wax coating which covers the upper part of the hair but also to have a zone where the cuticle entirely fails. The author gives his opinion that this hair is just as truly an organ for absorption as the minute thread-like rootlets which break out suddenly just below the stem of the plant immediately after a rain-fall or heavy dew and then just as suddenly disappear.

These articles are selected from the numerous recent ones touching the question of water absorption from the air, and it may be said in general that in most of the literature on the subject of Trichomes the function of absorption is usually referred to as a probable one, though always of secondary importance.

The material used for the following work was obtained, in part, from the Botanical garden in Berlin, in part, from that of Zürich. The leaves were examined fresh from the garden or green-house, the time extending from the first of May till the middle of October. About 80 specimens were examined which are described as *filzig* *). By *filzig* is meant, where the coating is so thick and the hairs are so interwoven or matted together as to form a system of capillary tubes between the inter-

*) The German words *Filz* and *filzig* have been used throughout this work, as they seem to express the meaning more clearly than the English, felt and felt like. The latter are used more with reference to the cloth or tissue as a whole than the German words where the idea of the interweaving of threads, by which process the tissue is made, is retained in the word *filz*.

lacing cells or hair branches. In general, this may arise in two ways, either from the coiling or matting together of long hairs, consisting either of one long cell, or of a single cell row, or the filz may be formed by the interlacing of the horns or branches of the so-called star-shaped or branched hairs.

The greater number of leaves examined, however, may be placed in three categories according to the supposed physiological characteristics, as well as the anatomical structure of the hair covering. The first class includes those leaves with hairs consisting of cell rows, whose first basal cell or cells are living and thinwalled, the remaining part of the hair consists of one long, thickwalled or dead cell.

Second class: hairs whose bases or stems consist of cell bodies of greater or less diameter (in a few cases of a single cell), the cells composing this basis are living and thin-walled, while the remaining portion consists of long thick-walled cells. Third class: hairs varying in anatomical structure but showing throughout no appearance of life.

In addition to these are a small number which cannot be so classified, some of which are so heavily coated as to be strictly filzig, others on the limit between filzig and ordinary hairy leaves.

The three classes are as follows.

LIST.

1 st Class.	2. <i>Petasites niveus</i> . Alps of Europe.	4. <i>Helichrysum</i> <i>graveolens</i> .
1. <i>Petasites albus</i> . Shady places and woods in Europe, Al- giers. Subalpine.	3. <i>Centaurea ar- gentea</i> . Crete, on rocks or dry places.	Tauris and Cau- casus, South Russia only.

<p>5. <i>Helichrysum petiolatum</i>.
Cape of Good Hope.</p> <hr/> <p>6. <i>Salvia argentea</i>.
South Europe, Spain, Sicily, Crete, region of the Med. Sea.</p> <hr/> <p>7. <i>Tussilago farfara</i>.
South Europe, found on both moist and dry clay soils.</p> <hr/> <p>8. <i>Teucrium fruticosum</i>.
Same as <i>Salvia argentea</i>, on stony places in Spain at a height of from 1000 to 2000 ft.</p> <hr/> <p>9. <i>Stachys germanica</i>.
Wide spread. Europe, Africa. Especially in England, Greece, Persia, throughout Germany. Dry warm sunny places.</p> <hr/> <p>10. <i>Stachys lanata</i>.
Caucasus, Persia, Tauris, Bithynia, Ceylon. In sunny dry fields.</p> <hr/> <p>11. <i>Alfredia nivea</i>.
Siberia. Stony places on rocks and dry places.</p> | <p>12. <i>Alfredia cernua</i>.
Siberia.</p> <hr/> <p>13. <i>Centaurea Fischeri</i>.
Macedonia, Pontus, Caucasus, Tauris.</p> <hr/> <p>14. <i>Inula Helenium</i>.
England, Belgium, France, Germany. In wet fields all over France. Canton Zürich in damp meadows.</p> <hr/> <p>15. <i>Rhaponticum Helenifolium</i>. Gren.
Dry Alps.</p> <hr/> <p>16. <i>Artemisia ludoviciana</i>.
Banks of Mississippi. Near St. Louis. U. S. A.</p> <hr/> <p>17. <i>A. l. variety gnaph.</i>
In dry places. North America. Near Lake, Mich., near Missouri and Arkansas rivers.</p> <hr/> <p>18. <i>Antennaria plantaginea</i>.
Canada to North Carolina. Woody places and dry hills.</p> | <p>19. <i>Echinops xanthacanthus</i>.
Species (?).
Genus. South Europe, Tropical Africa, also in Asia.</p> <hr/> <p>20. <i>Echinops exaltatus</i>.
Hungary on river banks and in dry places.</p> <hr/> <p>21. <i>Potentilla Anserina</i>.
South Europe.
Found in moist as well as dry places.</p> <hr/> <p>22. <i>Cerastium tomentosum</i>.
Dalmatia, Greece, Servia, Italy &c.
Warm sunny climate.</p> <hr/> <p>23. <i>Mentha aquatica</i>.
Europe, Asia, Siberia.</p> <hr/> <p>24. <i>Salvia sclarea</i>.
France, Italy, all south Europe to India.</p> <hr/> <p>25. <i>Momordica elaterium</i>.
South Europe, Spain to Syria and Caucasus, Borders of the Med. Sea.</p> |
|--|---|--|

26. *Onopordon tauricum*.
South Russia, Tauris.

27. *Gnaphalium margaritaceum*.
North America.
From Canada to Georgia.

28. *Artemisia vulgaris*.
Europe, Africa, Siberia. Also Cape of Good Hope but probably introduced here.

29. *Artemisia stelleria*.
Kamtschatka.

30. *Gazinia splendens*.

31. *Cineraria Webbi*.

32. *Cineraria lan-tana*.

33. *Cineraria villosa*.

34. *Lappa tomentosa*. Lam.
In dry places. Europe.

II^d Class.

1. *Phlomis fruticosa*.

South Europe, Greece, Dalmatia, Sicily. Warm climate, dry sunny places where there are no woods.

2. *Phlomis Russelliana*.

Syria by Aleppo. (Only there).

3. *Lavatera oblongifolia*.

South Spain, Granada. Arid stony places. Kalk soil, where cistus grows, up the mountains as far as from 2000 to 3500 ft.

4. *Viburnum lantana*.

All Europe to Caucasus. In sunny also shady places.

5. *Pomaderris aphylla*.

Van Diemen's Land, New South Wales, also in Australia itself. On low hills.

6. *Correa alba*.

New Holland, south west coast.

7. *Correa Backhouseana*.
Van Diemen's Land.

8. *Marrubium pseudo-dictamnus*.

Crete. (Nowhere else.)

9. *Abutilon atropurpureum*.

10. *Verbascum nigrum*.
Europe. Russia.

11. *Verbascum Phlomoides*.
South Europe, Spain, France and Italy.

12. *Arabis alba*.
South Russia, Tauris.

13. *Vesicaria sinuata*.
Spain, Italy. Dry places.

14. *Alyssum saxatile*.
South Russia, Hungary.

15. *Lithospermum oleae-folium*.
In rocky clefts of the East Pyrenees.

16. *Hieracium piloselliforme*.

In dry places. Europe.

III^d Class.

1. *Populus alba*.

South and west Europe, also in Corsica and Algiers.

2. *Spiraea ulmaria*.

All Europe. Never in dry places, always in moist.

3. *Rubus Idaeus*.

All Europe. Thrives best in dry sunny places.

4. *Vitis*.

Caucasus (supposed).

5. *Vitis Thunbergii*.

Japan.

6. *Shawia paniculata*.

New Zealand.

7. *Lavendula vera*.

Spain, South France, North Africa, borders of Med. Sea. In dry sunny places to 2000 ft. high. Kalk soil.

8. *Tilia alba*.

North America, Hungary, Asia Minor, Turkey.

9. *Quercus Ilex*.

South Europe, Orient, Med. Sea, to Syria.

10. *Tilia pubescens*.

North America, from Virginia northward.

11. *Metrosideros tomentosa*.

New Zealand.

12. *Althaea officinalis*.

South Europe. Moist places.

13. *Cynoglossum officinale*.

All Europe, from Scotland to the Islands in the Med. Also in Canada N. A. Stony places.

14. *Dryas octopetala*.

Alps in Europe.

15. *Quercus suber*.

South Europe, Italy, Spain, Algiers, Istria &c.

16. *Quercus Fordii*.

17. *Cinnamomum ce-
risium*.

Japan.

18. *Tilia argentea*.

Hungary.

19. *Alyssum montanum*.

Hohen Twiel. Canton Berne, Switzerland. Dry places.

20. *Quercus cocci-
fera*.

Coast of Med. Sea.

21. *Dryas Drum-
mondi*.

North America.

22. *Quercus cerris*.

South Europe and the Orient, Asia Minor, Hungary, also in France.

23. *Ledum latifolium*.

North America, Labrador, Greenland, Canada.

24. *Ledum palustre*.

North Germany. Moist places.

The results of the comparison of these three classes show that, in general, the leaves of the first class are best fitted to absorb the water, either rain or dew, which may adhere to the rough surface of the filz. Several of the second class appear to absorb water as readily as any of the first, but the number is proportionately smaller than in the first class. In the third, it is questionable whether this can in any single case, be considered the chief function of the hair, though the possibility of its contributing in a greater or less degree to this result, is by no means excluded.

Beginning with the first class, some few cases occur in which the hair has nearly the same diameter throughout, consists of only two cells, the first, that is the one cut off next the epidermis, is nearly isodiametric, the second, extremely long and either thick-walled and round, or having lost its contents, flattened by the pressure of the air from outside. In the former case the separate hairs are coiled spirally so that a very firm elastic coating is formed by their interlacing. In the latter, the separate hairs are occasionally twisted but never coiled and the filz is formed by their matting together instead of twisting and coiling around each other as in the former case.

The outer wall of the remaining epidermis cells, those without hairs, corresponds generally in thickness with that of the first hair cell. Examples are *Teucrium fruticosum* L., *Alfredia nivea* Karel, *Cerastium tomentosum* L., *Petasites niveus* Cass., one species of *Cineraria* and two of *Artemisia*.

It is easily seen that this filz might serve to fasten or hold the water, either rain or dew, until by capillary force it could be drawn between the meshes and so find

its way to the first hair and epidermal cells. Here in case the water supply from the roots were not sufficient, the endosmotic force of these living cells might be able to draw the water through their walls which are themselves thin, and protected in all cases only by a very thin cuticle. The thin-walled cells of the hair would serve to increase the surface which has the ability to absorb water.

Supposing this to be one function of the hair, it is plain that the greater the number and size of the thin-walled cells, the greater the ability of the hair to take up water, other things being equal.

In all the remaining examples of the first class this surface is increased by a greater number of thin-walled cells at the base of the hairs, which always have a greater diameter than that of the upper long cell forming the filz. In some instances this end cell remains small from the beginning, in others it grows to the size of the other cells but losing its contents, collapses so that it is several times smaller than the fresh living cells below.

In order to verify this hypothesis concerning the hair function, it must first be proved that the surface of the hair is free from any substance which is not easily miscible with water, such as oil, wax, and so forth. At least, it must be shown that if such substances are present they do not act in such a manner as to prevent the action of capillary force. In some instances the first assumption was shown to be true by simply immersing the leaf in water and quickly withdrawing it: while in the water no silvery coating was seen, and when taken out the hairy surface was seen to be completely wet. Quite a large number of leaves, however, when dipped

in water showed a silvery coating over the filz, which shows the existence of a layer of air between the water and the surface of the hairs. In many instances this was rapidly absorbed by the water and after a few minutes the hairy surface appeared evenly wet. Other examples were less easily affected and retained the air layer for several hours, the leaf appearing perfectly dry, when at the end of this time it was removed from the water. None were examined where this hindrance to the entrance of water was not removed by allowing the leaf to lie some time in water. In all cases where the leaf was really filzig, wax was not present in sufficient quantities to be detected with the microscope.

The second assumption, namely, that the endosmotic force of the living cells is sufficient to draw the water into the leaf tissue, can be proven only by experiment and a few examples will best show what degree of certainty was reached.

Before entering upon a description of these examples, a few words are necessary in explanation of what has already been asserted. It is usually claimed that the hairs of this filz are without contents, or that they contain only air*); also that in some cases they are not covered by a cuticle**). The former is strictly true only of those leaves which we have placed in the third class. This contains a large portion of the leaves under consideration, but by no means so large a part as the first and second classes combined. In these two classes a portion of the hair is living and contains active protoplasm as has been demonstrated by the action of the primordial „schlauch“.

*) De Bary. Vergl. Anatomie. Page 73.

**) Tschirch Linnaea B. 43. H. 3 and 4. Page 152.

In regard to the second point, there may cases occur where no cuticle exists on the hair, but among those here described the first 50 were treated with concentrated sulphuric acid and in no single instance can I say with certainty that the cuticle was entirely absent from the hair. This was the more thoroughly tested, as the absence of the cuticle would have added to the probability of the hypothesis assumed. In many cases there was a difference in the color produced by the action of the acid, the first cell often coloring darker than the long end cell. This difference was more marked in the hairs of the second class of leaves, where the stem often assumed a much darker color than the rest of the hair. Here also the action of the acid often left very little, if any, traces of cuticle from the horns or branches, but that part in immediate connection with the epidermis seemed to be affected exactly as the epidermal wall itself was, that is, there were always traces of a thin cuticle left on the glass. That this was sufficient to retard the passage of water through the membrane but very slightly, was proved satisfactorily by experiment.

One of the best examples of the first class is *Helichrysum petiolatum* D.C. The leaf is small, filzig on both sides, but much stronger below, and on plunging it in water it is at once wetted, shows no silvery sheen. A cross section through the leaf shows a filz on the under side about three times as thick as the leaf itself; above on the older leaves it is much less in thickness and some times wanting. The hairs stand erect (perpendicular) from the surface as far as the living cells extend; these are from two to four in number, about 25 mik. in diameter and 75 mik. in length. The end cell, which joins the last

living cell, sometimes narrows abruptly down to 6 mik. in diameter, is extremely thick-walled, showing only a small lumen throughout its entire length; sometimes it is thin-walled, flattened, and pressed together. These cells lie mostly horizontally across the leaf surface and are coiled and matted together into a thick filz.

Between the living cells standing at right angles to the surface are the raised stomata, thus surrounded by an atmosphere which may vary considerably from that surrounding the leaf itself, both as to temperature and amount of moisture contained. The consideration of this peculiarity of the stomata, however, we will leave for the present, to be taken up by itself.

In order to ascertain the ability of the leaf to absorb water, it was allowed to wilt till no trace of turgescence could be seen, the leaf when held by the petiole could no longer sustain its own weight but hung limp from its support. In this condition it was lightly brushed with a hair brush containing water, none being allowed to come in contact with it except on the hairy surface. The water was sometimes applied in this way, sometimes the leaf was immersed in water and instantly removed, sometimes allowed to remain with the hairy surface in contact, the petiole or broken surface being carefully protected by a wax covering.

The *Helichrysum* leaf, after having water applied with a brush and lying one half hour, became fresh, stiff, and turgescient. No attempt was made to ascertain the exact amount of water taken up, owing to the extreme difficulty of obtaining accurate results. The chemical balance offers, perhaps, the most practical method but there is no means of determining exactly how much

water remains in the hair meshes and how much has actually entered the leaf tissue at the time of weighing. The method used proves beyond a question that *some* of the water applied must have entered the tissues, as by no other means could the leaf have resumed its turgescence.

The question remains to be answered, what part was played by the hairs in this process. To answer this another example may be given, namely, *Salvia argentea* L. The lower or root leaves of this plant are large and thickly coated on both sides with long, soft, white hairs which remain during the entire season. Above on the stem the leaves are gradually smaller and less filzig, the surface of the extreme upper ones being barely covered. The anatomy of the filz differs but little in principle from that of *Helichrysum petiolatum*. The living cells, however, are much larger, averaging 35 mik. in diameter, in length the shorter ones are 100 mik., the longer from 400 to 500 mik. There are usually more of these in number than in the *Helichrysum* hair. The end cell is always thin-walled, remaining small from the first, as may be seen in some instances where the contents are not lost, about 15 mik. in diameter, and so long as to make it impossible to extricate any from the filz to measure them, flat, pressed together, sometimes divided in two by a partition wall, makes rather a loose filz; stomata, raised somewhat not so much as in many other instances.

It is not difficult to calculate approximately the amount of surface thus gained over the ordinary epidermal surface. In addition to this, the leaf blade, which is about 10 by 12 centimeters in size, is so constructed

as to present at least twice this amount of surface. This is effected by the very small, proportionately high protuberances between the veins. In a recent article*) by Prof. Kny, it is claimed that these little elevations found on the blades of various leaves are especially adapted to protect the leaf from the injury to which it is exposed from the force of the falling rain or hail. In this connection, however, we have to do only with the increased amount of surface thus provided with living active cells; one other fact may also be mentioned here, that is, that these living cells are in this way protected from the pressure of the surface filz, the cells of the latter lying, for the most part, horizontally across from one to the other of these protuberances. The stomata which here occur on both sides of the leaf are surrounded by an atmosphere doubly protected, that is, by lying in these little cavities, as well as by the filz-covering.

One of these lower leaves, a little under the medium size was allowed to wilt rapidly, exposed to sun and wind, after having been separated from the plant, till it was completely limp, then held by the petiole and lightly brushed, first on the upper, then on the under surface, with water. In about five minutes, water having been several times lightly applied, the leaf began to stiffen so it was perceptible to the feeling, it being yet in the hand. Ten or fifteen minutes later it was as fresh and stiff, as when picked from the plant. This was the most rapid and remarkable action obtained. The experiment was repeated with leaves of various sizes taken from the same plant, the result was always the same,

*) Bericht der deutschen Bot. Gesellschaft. Jahrgang 1885 Band III, Heft VI.

but the time required varied, the larger and less filzig the leaf the more time was required for it to resume its turgescence, 30 minutes being the average time.

The following method was used to determine how much the living hair cells contributed to this result, or more strictly, to prove definitely that the walls of these cells offered no more resistance to the entrance of water than those of the epidermal cells, in which case it will readily be seen that a far greater amount could enter the hair cells and so find its way into the leaf tissue, than could be taken in by the comparatively small surface of the epidermis proper.

A few drops of a ten per cent salt solution were laid upon the filzig surface of a fresh, entire leaf, allowed to remain four minutes, then a longitudinal section through this part of the leaf was made and laid quickly in oil, as little time as possible being consumed in the operation in order to preclude the possibility of any change in the water contents of any of the cells till the oil could be applied, which would prevent any farther change, at least, for a sufficient time to examine the condition of the cells. Sections of the same leaf, cut not far from the surface where the salt solution was applied, were examined and the hair and epidermal cells found to be in a normal condition, fresh, full and turgescient. On examining the section treated with the salt solution, nearly all the living hair cells were found to be plasmolytic. In a few instances the cells of the epidermis immediately in connection with these hair cells, were also plasmolytic, still fewer were in this condition that were not connected with the hairs at all.

This test shows that the water was drawn, by the

force of the solution, through the cell walls of the hairs more readily than through those of the epidermis, as there were comparatively few instances where it had acted on the epidermal cells.

The only objection, which can be urged against the accuracy of the method is that it is possible for the solution to act on the cut surface of the leaf, during the time elapsing between making the section and applying the oil, thus drawing the water out through the uncircularized walls of the leaf tissue instead of those of the hair cells. That this objection has but little weight is shown by two considerations. First: were this the fact, the water would have to be drawn through several walls, as 4, 3, 2, 1 (in the figure) before the cell *d* could lose

enough to become plasmolytic. In many instances the cell *d* (or cells similarly situated) was plasmolytic, while those below *c b a* were normal and turgescient. Secondly: If the plasmolyse of the hair cells was accomplished by the water escaping into the cells below and then from these cells, all the epidermal cells not connected

with the hair cells, being subjected to the same influence, would have suffered loss of water in the same way; but in all the numerous sections thus tested nearly all of these cells were full and turgescient.

The experiment was repeated several times and always with a similar result; in various other ways the same conclusion was reached, fresh sections were laid

in water, this drawn out while under the microscope, the salt solution applied and the effect on the hair cell wall watched, solution removed and water reapplied, and the rapidity with which the cell regained its turgescence noted. In these ways it was proved conclusively that the cell wall of the hair offers little resistance to the entrance of water.

One more example from the first class may be allowed, owing to its peculiarly beautiful adaptation, anatomically, to the support of this assumed function of the hair. The leaf of *Alfredia cernua* Cass. is about 15 by 30 centimeters in size, filzig on the under side, immersed in water the surface between the veins shows a bright silver color, which does not extend, however, over the veins themselves, on removing it quickly from the water, these are seen to be thoroughly wetted. The hairs are of two kinds, those on the leaf surface between the veins are like those first described, first a single thin-walled cell, then the usual long dead cell. These latter cells together form a thick filz over the surface. The hairs on the veins have from five to seven large living cells, averaging 100 mik. in diameter by 200 mik. in length. The end cells which are very long, lie along and across the veins having the appearance of spiderwebs and may easily be removed by the pincette without injuring the filz below formed by the smaller hairs of the leaf surface. As is well known, the veins project a little from the under surface of the leaf making that part of the leaf slightly convex. Were this a contrivance to make use of the dew which collects on the under surface of the leaf, no improvement could be suggested, for the weight of the water would incline it toward the

veins where the extremely large hair cells are ready to absorb it. Here it could pass at once into the circulation without the necessity of first passing through the parenchym cells.

On experimenting with this leaf, it was found that by brushing the veins alone on the under side with water, the leaf absorbed the water about as rapidly as the *Salvia* leaf described. The surface between the veins also absorbed water but less rapidly.

The greater number of the leaves of this class were tested with greater or less thoroughness in reference to their readiness to absorb water when applied to the surface. Some few cases occurred where the action was very slow. For example, *Centaurea argentea* L. Of the whole class only one was found which refused to act in this way. A leaf from *Onopordon tauricum* Willd. from the botanical garden in Zürich, when allowed to wilt, then brushed with water, remained limp and wilted, placed directly in water and allowed to remain for several hours it still showed no signs of turgescence. The anatomy of this leaf, however, is very similar to that of those already described, several large living hair cells below, covered with rather a light filz. Stomata somewhat raised. A very good explanation for this apparently contradictory result may be found in the fact that the leaf was examined in September after the plant had finished its summer's growth. The hypothesis rests entirely on the supposition that the cell sap of the epidermis and hair-cells has osmotic force sufficient to draw the water through their walls. It is not impossible that in this instance, the chemical nature of the cell sap had undergone some change by which this force was so diminished

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as to render the cells inactive there being no longer any necessity for their action.

In the second class the anatomy of the hair is far more complex, the construction of the leaf more varied, so that the simple tests described, could not be so successfully applied. The leaves of several species are stiff and leathery, these could not be tested by allowing them to wilt. One very beautiful filz as far as the theory is concerned, occurs on both sides of a thick fleshy leaf, *Arabis albida*, here of course this test is out of the question. Several were studied in September when the same reason could be given for the leaf failing to absorb water rapidly as that suggested for *Onopordon*.

Still, quite a number may be cited, which were thoroughly tested in the same manner as those of the first class with equally satisfactory results. Such are *Phlomis fruticosa* L., *Lavatera oblongifolia*, *Phlomis Russelliana* Lag. and others. In all the examples given in this class the important characteristics are present, namely: thin-walled epidermis cells, raised stomata and above all, a large surface of thin-walled hair cells. These compose the stems of the hairs, which consist in a few cases of a single cell. Such are the hairs of *Verbascum*, *Arabis*, *Vesicaria* &c. Generally the stem consists of a cell body of considerable size three or four cells in diameter and eight or ten in length.

Lavatera oblongifolia has a thick filz on both surfaces of the leaf, especially is this true of the under surface. This filz is composed of two sets of hairs; the larger ones have a stem surmounted with long rays or horns projecting in all directions. Another set, lying completely hidden under these, consists simply of these

horns formed by the division of a single epidermal cell: Sometimes one of the outer cells of a stem divides, in the same manner as the epidermal cells and grows into a stemless hair, but these hairs are of rare occurrence. The cells composing the stem are, for the most part, living and active, on applying salt-solution or glycerine, the primordial schlauch rapidly contracts; the rays or horns are thick-walled and show no plasmolyse although they seldom contain air bubbles; where they join the stem the wall between is seen to contain frequent pores. A leaf, completely wilted, was placed with both surfaces in water, the stem being carefully protected, in less than half an hour it was fresh and stiff.

Phlomis fruticosa L. is another example similar to this in anatomical character. Less difference occurs in the size of the various hairs, the stem varies in size and length but there are fewer stemless hairs. This leaf regained its turgescence also when placed with both surfaces in water in less than an hour, when simply brushed with water, in an hour and a half. As the stem was smaller in diameter than the foregoing, it was easier to experiment with in regard to the exact place where the water drawn out by the salt solution passed through the wall. The solution was applied to the uninjured leaf surface, allowed to lie 20 minutes, sections rapidly made and oil applied. Not only once or twice, but repeatedly, the upper cells of the stem were found to be plasmolytic while those lying between these and the epidermis had lost no water. This proves conclusively that the water passed through the outer wall of the hair cell, or what is the same thing, that water could easily be absorbed

by these cells, provided the cell sap possessed sufficient osmotic force.

It is not meant to be assumed here that this force corresponds to that of a ten per cent salt solution. It is probably much less, the solution was made of this strength for convenience in working. The time actually required by the leaf to perform this work is of minor importance, as the water held by the hair meshes would be effectually hindered from evaporation, therefore could more slowly enter the leaf tissue.

Phlomis Russeliana Lag. has a similar filz and acts in the same manner in reference to absorbing water. The hair may be described as several storied, the stem branching several times. The walls of the branches are not much thicker than those of the stem, but they often contain air. Experiments with the salt solution showed that the cells between the epidermis and the first set of branches were living, also many of the upper ones of the stem. Some of these latter, however, did not react and some contained air. The pores here are very noticeable, occurring between the cells of the stem, as well as where the branches join it.

The hair forming the filz of *Arabis albida* is somewhat remarkable for its size and simplicity of structure. The stem is one long cell averaging about 360 mik. in length, 45 in diameter. For about one fourth of its length this stem is entirely solid, the lumen extending only through the lower part, terminating above in a sharp pointed cone; the wall below is rather thick, the diameter of the hair being so great the lumen is still of considerable size. The lower end of this stem cell is surrounded by eight or nine raised epidermal cells, with

which it is connected by numerous pores, these cells are also connected together in the same way and are thinner walled than the lower end of the stem cell. From the other end of the stem spread the long branches in every direction, these seem entirely solid, probably not cut off from the stem cell by a wall, the outer surface is scaly and the hairs stand so close together that a dense filz is formed by the interlacing branches. A salt solution was applied, this time of unknown strength, and the stem cell responded at once to the action of the salt by becoming plasmolytic.

So throughout the whole list, no example is given in which the hair did not have one or more living cells in immediate connection with the epidermis.

We have thus shown that the leaves of the plants placed in the first and second classes are furnished with a special apparatus, one of whose functions *may be*, to aid in supplying the plant with water from the atmosphere.

In the third class this arrangement is wanting. Here the hair cells are either entirely unseptirt, consisting of a single epidermal cell which has prolonged itself into a long hair, or an epidermal cell divides at first into several, which then grow into shorter horn-like projections, spreading in all directions over the surface of the leaf. In both cases the walls are either thickened so as to contain only a small lumen, or they remain thin, the cells losing their contents at an early stage, so that those of the mature leaf contain air, or are quite empty, the walls pressed together.

From this difference in anatomical structure, it would follow that if the reasoning in reference to the two former

classes were valid, the same experiments tried with leaves of the third class would show an opposite result. This is true in part, but the woody texture which is a marked characteristic of nearly all the leaves of this class, prevents the use of these simple methods, at least so far as to render the results less satisfactory.

The hair forming the filz of *Populus alba* L., *Spiraea ulmaria* L., *Rubus Idaeus* L. and one variety of *Vitis vinifera* L. consists of a single epidermal cell prolonged to a sufficient extent to form a thin filz, in all except *Populus*, where it is very thick. Here the epidermis cell which forms the hair is smaller than the others, the hairs very long, empty, walls thin and pressed together, matted and twisted together into a filz several times thicker than the leaf, stomata slightly raised. The leaf dipped in water shows a silver color on the hair which soon disappears, the surface soon becoming thoroughly wet. When separated from the stem it grows brittle by losing water instead of becoming limp as in case of the herbaceous leaves. A leaf which was dry and brittle placed with the under surface on the water for two hours, became fresh and soft, but the upper surface was discolored being nearly black. Others were picked from the stem and while yet fresh were placed with their under surface in contact with water. The next day they were still fresh, the upper surface green and glossy. In similar ways efforts were repeatedly made to compare the behavior of this leaf in contact with water, with that of the leaves already described, but with no more satisfactory results than the last mentioned. Unquestionably some moisture was taken up by the surface resting on the water, for the loss from evaporation from the upper surface and

cut stem was in this way made good, the leaves so treated remaining fresh and bright for 24 hours. It is not improbable but that an equal amount would be absorbed by an ordinary leaf without filz under the same circumstances, as the evaporation from the under surface was suspended by the leaf resting on the water. Other considerations beside the anatomical structure indicate that this is not the *chief* function of the filz. Owing to the height to which the tree usually grows the leaves are not likely to acquire much water by the formation of dew: the upper leaf surface is peculiarly adapted to shed rain; the only opportunity for the leaf to acquire water is by means of the wind turning the surface so the raindrops would strike the under side.

The hair of *Vitis* is very similar to that of *Populus*, but the filz is not nearly so thick. The stomata are raised. The silvery luster on placing the leaf in water does not disappear so readily. The leaf was very thoroughly tested and its ability to take up water is even less than that of *Populus*. Leaves placed with their under surface on water did not absorb enough to keep them fresh, although they were by no means so wilted as those left for the same time without water. Some were tried by placing the upper only, on water, the under one exposed to the air. These also absorbed a very little, so that the condition of the leaf was about the same as when the under surface was wet. Some were first allowed to wilt, and then were brushed, dipped and immersed but all to no purpose. These were examined in the middle of July, at a time when we would expect the life forces all to be in action.

The leaf of *Rubus Idaeus* L. is covered by a thin

whitish filz, hair is thick walled so only a slight lumen is seen, inclined to coil spirally, stomata raised, under surface wets very slowly, its action in regard to absorbing water very similar to that of *Vitis*. A slight quantity is taken up but not enough to render it probable that the filz plays an important part.

In *Spiraea ulmaria* we find the same construction with one exception. The walls of the hairs are thin but not pressed together; they are very small in diameter and some appear to contain water or cell sap throughout their entire length. The greater number, however, contain air bubbles, or watery vapor. This air is seldom or never of the same density as that of the outside atmosphere, which is easily seen by adding water to the preparation while under the microscope and watching the result. The bubbles contract as the water enters the cell till the air reaches the same density as that outside. Sometimes they disappear entirely, showing that instead of thin air they consist of watery vapor. In these instances it is not impossible that the hairs absorb water by the means of atmospheric pressure as they do in the preparation. It is extremely difficult to prove this by experiment, but theoretically there can be no decided objections against this supposition. However, it is not probable that the amount of water thus obtained by the plant is very considerable.

Whatever the cause may be, the leaf actually does take up water a little more readily than any of the three others described. In none of these, however, is this action decided enough to lead to the conclusion that this is an important function of the filz. It may contribute slightly to this result, simply by retaining and drawing the water

between its meshes to the epidermal surface which is thin-walled and therefore better adapted to take up water than the ordinary leaf surface.

The other type of hair described as belonging to this class is represented by *Tilia alba* Ait., *pubescens* Ait. and *argentea* D. C. The epidermal cell here divides into several which grow into horns or branches spreading themselves horizontally over the leaf surface. In these three cases the horns contain thin air or watery vapor. Experiments in regard to absorption were made but the results are of little value owing to the peculiar texture of the leaf, its stiffeners not being materially affected by the loss of water. Here as with *Populus*, owing to the height to which the tree grows, the amount of water which is obtained from dew is probably much less than in case of those plants whose leaves are spread out near the ground.

In *Tilia argentea* D. C. a peculiarity occurs which may be mentioned here, though perhaps it has no particular bearing on the function of the hair. This tree has been introduced in Zürich in large numbers as a shade and ornamental tree for the streets. The leaves growing on and toward the end of the upper outside branches are turned from the ordinary leaf position by the twisting of the petiole where it joins the stem, so that the under gray-filzig surface is exposed to the sun and rain, while the upper side is shielded. It was found on examining a large tree of this species, standing on a side hill in the botanical garden, that on all the inside branches, and those growing next the bank so as to be shaded by it, the leaves grew straight and normal; on the outside branches which were more exposed to the sun and rain,

the leaves were turned, not completely over, but so far as to screen the upper surface effectually. Frequently leaves of the same branch, not more than three feet in length, were found to vary in this respect, those near the end being turned from their normal position, while the others nearer the body of the tree grew straight on the stem. This peculiarity is the more striking as this species is considered less sensitive to climatic influences than either of the other two where the leaves all have the normal position. These facts seem to indicate the protection of the chlorophyll from the influence of the sun, which is effectually rendered by the chlorophyll-filled pallisade cells being thus turned away. The hair covering may add to this effect, as it is not impossible that in this way the rain drops are secured and drawn into the horns by the agency of the thin air.

Several species of *Quercus* have filz corresponding to that of *Tilia* in structure, except the cell walls are usually thicker, and in one species, *Quercus Fordii*, there is a decided stem. Two other plants are placed in this class whose anatomy varies from the two types described by the presence of a stem, *Shawia paniculata* Forst. and *Lavendula vera* Benth. In the stem of the latter the wall is so thickened as to leave but a small lumen, while in *Shawia* there is often no lumen. The wall consists here of two layers of different chemical nature as is shown by the action of reagents, as well as by the difference in color and light breaking without the application of reagents. All plants placed in this class agree in having no living cells in the hair.

In addition to those placed in these three categories, quite a number were examined, which although strictly

filzig according to the assumed definition, varied somewhat from the regular types. Examples are *Brachyglottis repanda* Forst. and *Leucophaea canariensis* where the anatomy of the hair differs from that of the classes given. *Pyrethrum balsamita* Willd., *Eurybia argyrophylla* Cass., *Artemisia absinthium* L. and *maritima* L. form a little class by themselves in respect to anatomical structure; the stem consists of a cell row of from two to five cells, the filz is formed by a long cell attached to the upper stem cell nearly at its center and lying horizontally across the leaf surface. These upper cells appear to be lifeless and easily separate from the stem when the leaf is placed in water. In *Eurybia* the stems vary in length, so as to make several layers of long cells, forming a thick filz. These upper cells often contain air, others are empty, all are thinwalled. The filz of these leaves being less permanent than in most cases, they are not included among those considered as typical.

By glancing through the list it is seen at once, that the greater number of these plants originate from countries where vegetation is obliged to protect itself from drouth. Only seven out of the whole number are said to flourish in moist soil, four of these prefer a moist soil to a dry. Before passing to the consideration of special cases, a few words in regard to the peculiarity of stomata already several times referred to, and which is a constant characteristic of the leaves under consideration.

The important office of the stomata in general, has given rise to an extended and exhaustive study of their mechanism and its adaptability to the various climatic

influences to which the plant is exposed. So exact is this fitness, that it is claimed that the climate of the country in which a plant originates, may be determined from a knowledge of the mechanism of its stomata. We must exclude from the number, however, all those plants which have been subjected to the influences of continued cultivation as here too many unknown conditions may have been introduced to render possible an accurate judgment. The form of stoma which we have referred to as „*raised*“ is that where the schliess-cells are lifted a little from the epidermal surface. This may be effected by a number of the cells joining these, or by a single epidermal cell in which the stoma lies projecting from the surface. The latter is a peculiarity of *Aneimia fraxinifolia*.

Disregarding the more minute details of the structure of these organs, this raised form is universally admitted to be the form best adapted for transpiration. It is found accordingly, on a number of species of ferns growing in the East Indies (Indian Monsoon Region) where the moisture of the air currents coming from the sea and condensing against the mountain sides, keeps the air perpetually moist, and the soil also contains an abundant supply of water. These leaves are destitute of any hair covering, their stomata are thus in immediate connection with the moist warm atmosphere. Their form together with their surrounding conditions furnishes an exact contrast to the sunken stomata found on plants inhabiting countries where the air contains but little moisture. The natural inference therefore is, that the raised stomata are in this case, especially fitted to aid transpiration which would otherwise be too much impeded by the nearly saturated condition of the atmosphere.

This same form of stoma is characteristic of all the leaves described as filzig except, it may be, two, *Tussilago* and *Petasites*; in the latter even of these one sees a tendency toward this form. This is also the case with leaves whose epidermal surface is protected by the so-called scaly hairs or scales, where no real filz occurs. For example the leaf of *Elaeagnus salicifolius* Schlecht. Here the scales of the hairs often fit into each other, forming a close roof-like covering, very seldom is any portion of the leaf-surface left uncovered, and the stomata stand quite high. The star-shaped hairs of *Deutzia scabra* Thunb. on the contrary, are far apart, so that the surface is only dotted and not covered, here the stomata stand on a level with the other epidermal cells. This same contrast is seen between those leaves described as filzig and those whose surfaces are thickly covered with hair, but always in such a manner as to leave a free communication between the stomata and the outside air. Quite a number of leaves of this latter class were examined and in all cases the stomata were either on a level with the epidermal cells, or sunken a trifle below. Such are *Glaucium luteum* Scop., *Androsace lanuginosa*, *Cephalaria cretacea*, *Convolvulus cneorum* L.

These examples are perhaps sufficient to establish the fact here insisted upon, namely: *Whenever the hairs or scales form a covering so that a protected layer of air exists between this covering and the epidermis, the stomata are raised, and where the outside air has free communication with the stomata they are not raised.*

It is hardly necessary to add here, that there exists in nature no such clear sharp lines of distinction between filzig and not filzig leaves, raised or level stomata as the

language here used may seem to imply. The usual transition stages occur here as every where else and are exemplified by numerous other plants which were examined but not described.

Farther, this raised stoma occurs on many leaves where the stomata are sunken in cavities or along furrows. Such are several species of *Banksia*, *Nerium Oleander*, *Erica*, &c.

In *Nerium Oleander* which is usually cited as an illustration of an admirable arrangement to prevent too rapid transpiration, the cavities containing the stomata have a much smaller opening than their greatest diameter and this opening is covered more or less closely by single-celled thick-walled hairs. The cells lining this cavity are extremely thin-walled, stomata raised, numerous thin-walled single celled hairs project into the cavity, which are proved to be living, by applying the salt solution, they react at once. Here is an arrangement entirely similar to that of the filz covered leaf of *Salvia* or *Helichrysum*, except that the filzig surface is not exposed to the same extent to dew or rain; the only way for moisture from outside to enter, being through the comparatively small openings which stud the leaf surface.

Several species of *Banksia* have a similar structure, such are *Banksia serrata* L., *australis* R.B., and *integri-folia* R.B., also *Dryandra speciosa* Meisn. In *Erica carnea* L. the stomata lying in the ridge or furrow, which runs along the under side of the leaf, are also raised, the epidermal walls are thin, but the hairs are thick-walled and show no reaction on applying salt solution or glycerine.

One example from the third class of filz-covered

leaves may be described in this connection, namely, *Ledum latifolium* Ait. The under surface of the leaf has small half-spherical projections or elevations on which the raised stomata occur. Here are three distinct features aiding transpiration: First, the extremely large air spaces existing in these elevations; Second, the projections themselves which serve to increase the surface covered with stomata and also aid in throwing these higher; Third, the raised stomata. On the other hand, transpiration is retarded by the filz formed by the long hair cells which grow close together through the central portion of the leaf but more scattered toward the edges, here the lack of hair is supplied by the edges rolling under. Thus again is formed a protected cavity where the moisture passing from the stomata may be retained.

These are, in brief, the conditions under which this form of stoma was found in the plants studied. Its constancy of occurrence under similar conditions suggests some definite advantage thus secured to the plant, but these conditions are too complicated to admit of the simple solution suggested in case of the tropical ferns. With these every thing points to the one conclusion; the supply of water in the soil is abundant throughout the entire year either through frequent rains or its equivalent of moisture in the air; the ferns are known to grow rapidly, acquire great size and to be extremely sensitive to a lessening of the amount of moisture in the air surrounding them. The conclusion is a very natural one, that the principal object of the raised stomata, is to counteract the hindrance which the heavy moist air offers to a free and rapid passage of water through the plant. If we compare these circumstances with those

surrounding the plants given as typical illustrations, such as *Helichrysum*, *Salvia* &c., notwithstanding they are in most respects the exact opposite of those surrounding the ferns, we may yet find a certain parallel which suggests a similar reason for the presence of the raised stomata.

Our first example, *Helichrysum petiolatum* originates from the Cape of Good Hope: According to the accounts of Botanists, who have travelled in this region for the purpose of studying the Flora, both soil and climate work together to retard the growth of vegetation. The soil along the coast is so sandy and shallow that it has very little power to hold the water falling as rain, while in the interior the sand is mixed with clay and baked so hard by the sun as to render it almost of the consistency of bricks. The amount of rain falling through the year is small, and what is still more disadvantageous for vegetation, of very irregular occurrence. Notwithstanding these disadvantages of outward circumstances, a great variety of vegetable forms exists and flourishes here. As might be expected, one finds every possible device which nature makes use of to defend itself against these untoward outward conditions. The predominating shrubs belong to the *Ericaceae* or *Proteaceae* *), the trees are largely those whose leaf organs are reduced in surface as much as possible, often furnished with thorns of extraordinary size. Succulent plants abound, also *Halophyten* and resin bearing plants. Among other means for resisting drouth may be reckoned the hairy coating of the leaves of such herbs as *Gnaphalium* and *Helichrysum*. The

*) *Grisebach*, *Veg. der Erde*. Bd. II, P. 187.

necessity for some peculiar means for this purpose is seen from the difference in structure between these and the woody evergreen shrubs and trees. The latter are always supplied with apparatus (fresh living leaves) necessary to make immediate use of the material offered, whenever a chance shower moistens the sandy soil of the coast or makes its impress on the clay of the interior. It is otherwise with an herb like *Helichrysum*. This does not possess the strength of resistance residing in the longer-lived thicker-leaved evergreens, its period of vegetation is limited, therefore the necessity for some special means to make use of every particle of moisture which is so grudgingly given, and which is so essential to its welfare. This may be furnished by the arrangement of the hairs of the leaf surface already described. We are met at once here by an apparent contradiction in function: That is, the very arrangement which we suppose for the purpose of taking up water from the atmosphere, namely: the thin-walled surface of the living hair-cells, offers, on the other hand, just so much more surface from which the water in the plant may be given off by transpiration. Farther, the raised stomata contribute also to the same end. If the object of the filz were simply to prevent the escape of the water already taken up by the roots, we would certainly not expect to find two such counter-acting influences. The matter would be much simplified by a lighter hair-covering without the living cells, and with ordinary level stomata. But if, on the other hand the plant is thus enabled to make use of the moisture of the atmosphere, this apparent contradiction of function is not so difficult of explanation. The covering formed by the interwoven end cells of the hair, protects the leaf

against the danger of too rapid transpiration from the increased leaf surface, at the same time forming passages through which the water on the surface may be drawn within. The raised stomata enable the plant to throw off sufficient water to render the flow from the roots upward unbroken, this moisture is allowed to escape very slowly and if the outward conditions are such as to condense even a small amount of moisture on the leaf surface, it may still be sufficient to prolong the life of the plant through a period of drouth, if not to enable it to create new building material necessary for growth.

Salvia argentea L. originates from Southern Europe, along the coast of the Med. sea, Spain, Sicily, Crete &c. It is much more difficult to learn accurately concerning the influences surrounding this plant, as the territory over which it is spread is so much greater, and the liability to variation of climate thus increased. One thing, however, is certain, that is, notwithstanding both soil and climate are here much more favorable to vegetable activity than in the former case described, still in nearly every section where this plant is said to appear, the period of growth is interrupted by a dry season, causing a stillstand in this process of greater or less duration. For example, in Spain vegetation is said to make rapid progress in spring-time, its course is then suddenly checked by the summer's drouth, to begin again when the fall rains occur. In other sections the time varies, the greater amount of rain falling in summer and the longest period of growth occurring then, but in few localities, if indeed in any, of this whole region, is the rainy season of sufficient length to enable a plant like *Salvia* to begin and finish its growth uninterrupted by a

dry season. Again is seen the same necessity as before for a plant provided with no special means for hoarding a water supply, like that of woody or succulent plants, to adapt itself by some other means to the surrounding circumstances. One thing noticed in this connection, may be mentioned here though it may have but little weight. During the time spent in studying these leaves, I noticed carefully from time to time, the difference in the amount of dew found on leaves near the surface of the earth and those a few feet distant. This was often very considerable, leaves a few inches from the ground would sometimes be completely wet with dew, while those one and a half or two feet distant were quite dry. This was especially the case when the dew was light, in case of a so-called heavy dew the difference was less perceptible. The lower leaves of *Salvia argentea* are crowded on the stem, covered on both sides with a most complete and beautiful filz, while those higher up on the stem are more scantily furnished with hairs, many of the extreme upper ones being not really filzig.

Phlomis fruticosa and *Lavatera oblongifolia* originate from the same localities as *Salvia argentea*, therefore must have been subjected to similar influences. *Alfredia cernua* has its home in Siberia, grows on stony places.

This reasoning in regard to the raised stomata and their connection with an inclosed air space about the epidermal surface can also be applied to the plants forming the third class, though the hairs here appear to play a less important part, and the objection before suggested, that a thinner coating of filz and level stomata would serve just as well for protection, may be made here with more force than in case of the two other

classes. In answer to this, it must be remembered that in no case is it claimed that the only function of the filz is to draw in water from the atmosphere, or to lessen the transpiration. In all the examples of this class there may exist a need for protection of some other nature than that against drouth. In order to meet this, a filz may be necessary of such thickness that transpiration would be too much impeded without the intervention of the raised stomata. As before intimated, several facts of different kinds, aside from the anatomy of the hair, point to some other function than that of regulating the water supply. Many of these plants originate from countries not remarkable for lack of water, nearly all of them are of woody texture, the leaves growing on stems removed from the earth's surface; lastly all the experiments tried failed to prove that any considerable amount of water was taken up by the hairs.

On the other hand it is claimed that even here, in these more questionable examples, there is a strong probability that *one* function of the filz is to conduct moisture to the epidermal surface by means of its capillary passages, where it may be taken into the leaf texture, though of course in much smaller quantities and much less rapidly than where the surface is increased by large living hair cells.

Such examples as *Spiraea*, where the hair cells were found always to contain diluted air, and where the membrane offered so little resistance to the entrance of water from outside, indicate the reciprocal play of certain forces, more thorough investigation and more fortunate methods of experimenting may make clear how these forces act,

and prove unquestionably the truth or falsity of the assumption.

Lastly we come to those cases where the raised stomata lie in ridges or cavities, as *Banksia*, *Dryandra*, *Erica*, *Nerium*, &c. These plants furnish the most popular and well known examples of the power of nature to adapt itself to unfavorable outward surroundings and are every where quoted as examples of plants specially fitted to endure long continued, as well as irregular seasons of drouth. They are all found among the various forms native to the Cape of Good Hope and those belonging to the family *Proteaceae* are filzig. These are not included in any of the three classes, because at the time of making this study only a few fresh, living species could be obtained and these unfortunately were not such that experiments could be satisfactorily made. Quite a number of dried specimens were examined and these were covered with a thick filz protecting the openings of the cavities where the stomata occur.

In the cavities in the leaves of *Nerium Oleander*, the arrangement of the stomata and hairs is such as to suggest the power on the part of the plant to regulate to a certain degree the amount of moisture in the atmosphere immediately surrounding the stomata. When the soil contains moisture enough to allow free transpiration and yet continue the supply, the superfluous moisture may escape from the leaves slowly between the meshes of hairs which loosely cover the openings. When the supply from the roots is lessened, it is not impossible that the contents of the epidermal and thin-walled hair cells, acting together with the diminished tension of the membrane, may be able to draw in the

water which has condensed on the surface of these cells. The openings to these cavities cover from one third to one half of the surface of the leaf and are partially closed by short hairs lying horizontally across. By this arrangement it is possible that some part of the water collecting as dew on the leaf surface may be retained and drawn into the cavities in the same manner we have supposed this to take place in the case of filzig leaves.

The hairs accompanying the stomata in the furrows of *Erica* are thicker walled and show no life-reaction on the application of salt-solution.

In conclusion, it may be said, that if the importance of the form of the stomata and their position in respect to the other epidermis cells has not hitherto been overrated, as regards their power in regulating the amount of water thrown off by transpiration, the facts observed furnish a strong probability that in the majority of so-called „filzige Blätter“ a special arrangement exists for making use of the moisture in the atmosphere. Lack of time has prevented the attainment of more definite results.

DESCRIPTION OF PLATES.

- I. A large hair of *Phlomis Russeliana* from the under epidermis. Partly schematisch, *aa* are Pores. Enlarged about 160 times.
- II. Hair and stomata from *Helichrysum petiolatum*. The end cell *c* shows a lumen only for a short distance; these cells are so long and interwoven that it is not possible to separate them to get the exact length. The stoma *a* is raised a little more than the average. Enlarged about 330 times.
- III. From *Salvia argentea*. *a* shows a cell next the epidermis and a part of the second cell; *b* shows the end cell and the manner of joining the next cell; *c* the stoma. Enlarged about 330 times.
- IV. Lower part of hair from *Rubus Idaeus*, also a stoma. Enlarged about 330 times.
- V. *Alfredia cernua*. The two kinds of hairs shown, *a'* is from the lower part of a hair of the mid vein; *a''* shows the end cell pressed together. Enlarged 160 times. *b* is the lower part of a hair from the epidermis of the leaf surface, first cell living and thin walled. Enlarged about 330 times.
- VI. *Lavatera oblongifolia*, *aa* are stemless hairs, *b* has a short stem. *A* shows a part of the upper epidermis with the bases 1 and 2 respectively of the long and short stemmed hairs.
- VII. Shows a cross-section through the leaf of *Helichrysum* to show the filz and the comparative thickness of that of the upper and under side of the leaf.
- VIII. *Nerium Oleander*. *a* is a cross-section through one of the cavities containing the stomata, *b* is the cavity as seen from above.

VI

VI

IV

VII

VI

A

IV

VIII

a

b

VIII

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