bean seedlings being grown entirely under the rays. Good outlines of the leaves and tracings of the principal veins were obtained, while the stems, roots and cotyledons of the pea and beans made strong pictures. The contrast between the general groundwork of the leaves and the surrounding space is quite strong, which shows that there was considerable absorption of the Röntgen rays even by the delicate seedlings experimented upon, and that the absence of any marked injury or other influence could not be due to non-absorption of the rays.

The other plant parts which were photographed by the Röntgen rays are the following: Leaves of two species of Begonia, in which quite strong pictures of the leaves and of the venation were obtained. The venation of B, rex, with rather prominent red veins coming out more strongly than B, nitida-alba, both were being taken on the same plate. The interior of various nuts, as almond, peanut, hickorynut, makes quite strong pictures. Good pictures were obtained of the endosperm (prothallium), of the fruit of cycas, also of the seeds of green peas and beans still within the pod. Flower buds of Fuschia show the pistill and stamens in position before opening and the delicate flowers of Begonia also absorb the rays sufficiently to be photographed, although the picture made was weak. Fruits of apricot and green fruit of the plum and pea absorb the rays so strongly that it is difficult to get a good contrast between the flesh and stone, while the ripe fruit of a black cherry (probably a variety of *Prunus avium*) gives better contrast. The placenta and young ovules of *Podophyllum peltatum* show rather indistinctly through the walls of the ovary. A knot in the pine board makes a distinct Röntgen photograph. The spadix and flowers of *Arisæma triphyllum* show distinctly through the spathe, and the vascular ducts of the stem are also photographed. In specimens of Peltandra, in which the spadix was entirely enclosed within the spathe the spadix and outlines of the staminate and pistillate flowers are quite distinctly shown in a Röntgen photograph, while the vascular ducts of the stem show quite strongly in the picture (see Plate I., Frontispiece).

It is thus seen that plant tissues absorb the Röntgen rays quite freely, and it is singular that there is not a more marked influence on growing parts, especially that there are no visible external injuries, even when the parts are exposed at close range a large part of the time during several days, since the general impression is that the rays, even with comparatively short exposures, are injurious to the human tissues.

The longer my experiments continued the more mysterious the whole subject seemed. On a dark night, when the electric-light rays were intercepted by a black screen, exploring the field with a fluoroscope there was an abundance of light, flashing and quivering with the variations in the electric transmission through the tube, penetrating, and yet capable of absorption to a considerable degree. That it should present no easily discernible influence for the time during which the work continued was cause for profound surprise.

G. F. ATKINSON.
CORNELL UNIVERSITY.

SOME CONSIDERATIONS UPON THE FUNCTIONS OF STOMATA.*

THE sporophytes of many Bryophyta and of all Pteridophyta and Spermatophyta have their epidermis pierced with minute openings known as stomata. These occur upon particular portions of the aërial structures, not being found upon roots, nor upon subaqueous stems and leaves. They always stand over masses of chlorophyll-bearing

* Read before Section K. of the British Association for the Advancement of Science, August 19, 1897.

cells, and communicate directly with their intercellular spaces.

Every stoma is more than a mere slit between the epidermal cells. It is, in fact, a simple organ consisting of two active cells, the 'guard cells,' between which is the elongated opening. By changes in shape the guard cells narrow or broaden the opening, or completely close it.

It has been found that gases and water-vapor pass through the open stomata. In the case of gases the passage is in either direction, while it appears that the water-vapor passes in one direction only, namely, from the intercellular spaces outward. From the fact that the stomata serve for the passage of both gases and water-vapor have arisen two views as to their proper function, some botanists holding that they are organs of respiration, that is, breathing pores, while others regard them as transpiration organs, that is, organs for permitting the escape of surplus water from the tissues of the plant. According to the first view the stomata are connected directly with the process of photosyntax and the metabolic changes which follow it, in other words, with the supply of carbon to the plants, while according to the second view they are connected with the supply of inorganic salts to the ash constituents of the plant. Since the passage of water-vapor through the stomata is a much more noticeable phenomenon than the ingress or egress of gases, it is quite natural that at first the former should be considered as the primary function. With this view have come corresponding explanations of the purpose of transpiration, involving much of the discussion of nutrition in the treatises on plant physiology. If stomata are organs of transpiration, then transpiration is a physiological phenomenon of much importance, and it behooves us to find out why plants have developed organs for its promotion.

In considering the questions involved, it is well to remember that terrestrial plants which possess stomata have developed from aquatics none of which have stomata. These aquatics, living in the ocean or the fresh-water rivers and lakes, must supply themselves with all their food constituents from the water and the substances it holds in solution. In the simpler plants every cell absorbs these directly from the surrounding water, and this is true of the larger plants also, with slight modification. We must not, however, overlook the fact that water itself is an indispensable constituent of every cell, not as food, but as a part of its mechanical structure. More than nine-tenths of every active cell is water, upon whose presence the activity of the cell is dependent. In aquatics this necessary water is supplied directly from the surrounding medium, and since there is no loss of water each cell easily maintains all that it requires.

Terrestrial plants must supply their cells with the necessary food constituents, and must, also, maintain in them the proper amount of water. Every cell in a terrestrial plant must be turgid with water in order to be active, and if this be impaired the plant suffers. The maintenance of the water supply is thus of the greatest importance in terrestrial plants. Accordingly, the roots are always in communication with water in the soil from which they obtain their supply. The cells of the stems and leaves must obtain their water by absorbing it from the turgid root-cells. Now, these cells in the stems and leaves not only have no direct access to water, having to obtain their supply indirectly, at second hand as it were, but they are surrounded by a medium which is drier than they, so that they are constantly losing water by evaporation. This loss of water is usually greater than the scanty supply from the water of the soil, and accordingly the aërial parts of plants are protected by a layer of

cuticularized cells, the epidermis. The drier the air in which a plant grows the thicker the epidermal layer, an extreme case occurring in the Burro Thorn (*Holocantha emoryi*) of the arid regions of southern Arizona, where there are from three to five layers of cells in the epidermis. That plants are able to protect themselves against very dry air is shown by the fact that even in excessively dry climates there are many species which are able to live and form flowers and seeds.

But with the change from the aquatic to to the terrestrial habit there came a division of labor in the organs of absorption. The roots now absorb water and solutions, while the stems and leaves absorb carbon dioxide. And here arises a difficulty: The epidermis which prevents the escape of water-vapor also prevents the absorption of carbon dioxide. This difficulty was surmounted by the formation of stomata. A leaf without stomata, or what is the same thing, with its stomata permanently closed as with wax, will not lose water, but it will starve for want of carbon dioxide. These stomata are open as long as there is no danger of such a water loss as would result in loss of turgidity, but when the cells show an approach to flaccidity the stomata close. While open there may be a free interchange of gases, carbon dioxide entering and being absorbed by the chlorophyll-bearing cells, but while this is going on there is certain to be a considerable loss of water, especially if the air be dry. On every dry day land plants lose much water, since they must have their stomata open in order to obtain their supply of carbon dioxide.

Aërial plants, as many Tillandsias and Orchids, do not differ in any essential respect from terrestrial plants. They must have enough water to keep their cells turgid, and, at the same time, their chlorophyll-bearing cells must be supplied with carbon dioxide. They invariably grow in moist climates, where the constant moisture of the air is supplemented by frequent drenching rains. Under such conditions many terrestrial plants would be able to live and grow for some time. At the same time it is to be observed that many aërial plants have a greatly thickened epidermis, or have their surfaces covered by a coat of dry hairs. They evidently have taken some precautions to guard against harmful water loss.

It is not too much to say that the facts cited above indicate that respiration is the normal function of stomata, and that the loss of water through stomata is incidental and secondary. Some experimental results may be cited here.

a. Stahl has shown that when the stomata are closed no starch is made,* showing that the carbon dioxide must enter by the stomata.

b. Blackman concludes that "practically the sole pathway for carbon dioxide into or out of the leaf is by the stomata."†

c. Stahl has shown that transpiration takes place through the stomata, and this only when they are open.‡

d. Observations often repeated by many physiologists show that the stomata of many cultivated plants close quickly when the supply of water to the roots is deficient, and that plants in dry climates have remarkable devices for preventing the loss of water.

e. Stahl has shown§ that in many evergreen plants the stomata close during the period when there is no carbon assimilation.

f. It is a well known fact that stomata are usually open in sunlight, when carbon-assimilation (photosyntax) is possible.

g. Plants from which carbon assimila-

* *Bot. Zeit.*, 52: 127–133 (1894).

† Phil. Trans. Roy. Soc. London, 186, B: 485 (1895); from abstract in *Bot. Gaz.*, 20: 336.

‡ *Bot. Zeit.*, 52: 117–127 (1894).

§ l. c.

tion is absent have greatly reduced numbers of stomata, as in the dodders (Cuscuta) and the little mistletoes (Razoumofskya), while they are present in abundance in green parasites (Viscum and Phoradendron).

From the foregoing rapid and quite summary survey of the different phases of this question we are warranted in concluding:

1. That one of the functions of stomata is the admission of carbon dioxide to the chlorophyll-bearing tissues of the plant, for use in the formation of the carbohydrates.

2. That the loss of water by terrestrial plants was originally hurtful, and is so now in many cases.

3. That if plants have utilized this constant phenomenon it is for the supply of food matters of secondary importance, as the salts in solution in the water of the soil.

Charles E. Bessey.
The University of Nebraska.

*RECENT PROGRESS IN AGRICULTURAL CHEMISTRY.**

I.

Since the last *résumé* of progress in agricultural chemistry was reported to this body a considerable advance has been made in our knowledge of the methods and means of nitrogen assimilation. The most marked progress has been made along the line of the inoculation of seed and the soil with nitrifying ferments. Much has been done in this direction, and the results of the experiments are sufficiently encouraging to warrant the belief that much good may yet come to agriculture by following out this line of investigation. In 1895, in the Yearbook of the Department of Agriculture, the following statements occur:

"It may not be long until the farmer may apply to the laboratory for particular nitrifying ferments to be applied to such special purposes as are mentioned above. Because of the extreme minuteness of these organisms the too practical agronomist may laugh at the idea of producing fertility thereby, and this idea, indeed, would be of no value were it not for the wonderful facility of propagation which an organism of this kind has when exposed in a favorable environment. It is true that the pure cultures which the laboratory affords would be of little avail if limited to their own activity, and it is alone in the possibility of their almost illimitable development that their fertilizing effects may be secured."

It cannot be said that the prophecies foreshadowed in the above quotation have been fully verified, but at least something has been accomplished.

From the time that it was demonstrated by Hellriegel and Wilfarth that the power which leguminous plants possess of increasing their stores of nitrogen was due to the bacteria inhabiting nodules on their rootlets, the study of this phenomenon has been pushed with great vigor in all parts of the world. Intimately related, as it is, to the nitrifying organisms of the soil, it has, nevertheless, been demonstrated that the two species of bacteria, the general nitrifying species and the special so-called symbiotic species, inhabiting the roots of plants, are entirely different in their nature, and that their activity is not mutually convertible.

The most extensive experiments in the direct inoculation of the soil with nitrifying ferments have been conducted by Dr. Salfeld, of Lingen, in Hanover. The greater part of the experiments has been made on peaty soils, as it is in such soils that the greatest deficiency of nitrifying organisms is observed. An excellent review of Dr. Salfeld's work has been pub-

* Prepared at the request of the officers of Section C, of the A. A. A. S., and read before Section C and the American Chemical Society at the Detroit meeting, August, 1897.