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XXVI.—*On Germination at different Degrees of Constant Temperature.* By M. Alph. de Candolle*.

[Plate IV.]

Two motives gave rise to my undertaking a series of experiments upon germination at different degrees of temperature. First, I desired to continue and complete my earlier experiments upon the duration of the germination and of the germinative power of seeds of different species or families†. I also wished to study in a direct manner, and in regard to a particular function, the effect of time in compensating a low temperature, and that of an elevated temperature in diminishing the amount of time required for one function. It is well known how this problem has engaged the attention of agriculturalists and naturalists for some years; but, in almost all the known facts, there is always an inextricable mixture of several functions considered collectively, either of the influence of light mixed with that of heat, or of temperatures which are continually varying. My aim has been to eliminate all these complications; and if I have been anticipated by a judicious observer, M. F. Burckhardt ‡, in some experiments which the perusal of my 'Botanical Geography' appears to have suggested to him, it will be seen that my experiments bear out his, that they apply to a larger number of species submitted to more normal conditions, and that they consequently lead to more extended and more certain conclusions.

* Memoir read at the General Meeting of the Swiss Society of Natural Sciences at Geneva, on August 21, 1865. Translated from the 'Biblioth. Univ. de Genève,' 1865, p. 243.

† "Tables of the duration of the Germination of 863 Species observed in the Botanic Garden of Geneva," by Alph. de Candolle (in the 'Physiologie Végét.' of Aug.-Pyr. de Candolle, vol. ii. pp. 640 & 646).

‡ On the Determination of the Zero of Vegetation (Verhandl. d. Naturforsch. Gesellsch. Basel, 1858, vol. ii. 1. pp. 47–62.

I will first describe my experiments, and afterwards give the results.

§ 1. *Details of the Experiments.*

I first procured the seeds of ten species, in good condition, and belonging to several different families of plants. They were of or below the average size, some suitable for germinating at low temperatures, others requiring heat—at least according to the ordinary modes of culture. I selected three Cruciferæ (*Lepidium sativum, Sinapis alba,* and *Iberis amara*), one of the Polemoniaceæ (*Collomia coccinea*), one of the Linaceæ (*Linum usitatissimum*), one of the Cucurbitaceæ (*Cantaloup Melon*), one of the Ranunculaceæ (*Nigella sativa*), one of the Sesameæ (*Sesamum orientale*), one of the Leguminosæ (*Trifolium repens*), and one of the Graminaceæ (*Zea maïs,* var. *præcox*). Notwithstanding the importance of the last two families, I preferred a single species only of each. The Leguminosæ are well known for their irregular germination. It is not an uncommon circumstance, in the same sowing of the lupine or *Vicia,* to see the seeds sprout up week after week, month after month, and even until the following year, without our being able to account for it*. The Graminaceæ germinate somewhat slowly, and are furnished with an envelope (pericarp) adherent to the grains, which perhaps complicates the physiological phenomena.

After having convinced myself that all my seeds were susceptible of germination, they were deposited in a dry place, where the temperature varied but little, and from which they were removed for each experiment. In each case they were sown upon sand in an earthen vessel, a wooden box, or a glass bottle, according to circumstances. The seeds were laid upon the dry sand, and each sowing, thus prepared, was left for twenty-four hours at least in the medium the mean temperature of which they were to acquire; they were then watered with water of the temperature wished for in the experiment. The first watering was always copious, so that the seeds might be rapidly penetrated by the moisture—a necessary condition for their germination being induced by the temperature and the oxygen. The seeds were covered with a thin layer of sand, but the watering nearly always uncovered them. In fact, I have not remarked any difference in regard to the period of germination between the seeds upon the surface and those which remained covered by a thin layer of

* I formerly pointed out to M. Vilmorin, senior, that *Vicia narbonensis* was a plant which would form excellent forage if its proper cultivation could be carried out. This skilful horticulturist took great trouble, and after having proved the real merits of the species, was compelled to renounce it, because he could not succeed in making the seeds gathered and sown together spring up at the same time.

sand—a proof that uniformity of temperature was preserved in these two positions, in consequence of the favourable arrangement of the experiments.

The determination of the moment at which germination takes place is a delicate point, and to a certain extent arbitrary. The embryo alters within the seed before it appears outside, the radicle elongates more or less quickly, and, according to the species, the young plant shows itself in various ways. I have regarded as the moment of germination, that at which, the spermoderm being ruptured, the radicle begins to escape*.

Several thermometers were at my command, most of them being graduated upon the tube itself. Although they were carefully made, I verified in each case the correction requisite to be made at zero; and for the higher degrees, I compared them at every ten degrees with a very accurate standard thermometer, belonging to the Geneva Society for the construction of philosophical instruments. This thermometer had been verified by M. Louis Soret, by passing a drop of mercury from place to place in the inner column. The principal cause of error arises from the difficulty of determining the fractions of degrees in thermometers constructed of thickish glass, when placed in various positions, and when the eye is not always perpendicular to the tube. I hope, however, that the numbers are accurate to within one-tenth of a degree†.

The object of my experiments being to observe the germination at different but constant temperatures, I had an apparatus constructed under the direction of Professor Thury, which was satisfactory as regards the temperatures near 0°, but which was not found sufficient for the other circumstances. This apparatus consists of a cubical zinc reservoir, 44 centimetres in each dimension, surrounded by sawdust and contained within a large wooden box. The reservoir could be filled with ice or water of a given temperature, and the vessels or bottles containing the seeds could be arranged either in the reservoir or in the sawdust, or even in the compartments of a zinc projection springing from one of the faces of the box. This lateral addition did not answer, because its cavities did not afford fixed conditions of temperature and it occasioned a loss of part of the advantages, in

* M. Burckhardt, in the experiments alluded to above, and with which I was not then acquainted, regarded the moment at which the cotyledons became exposed as the period of germination. This is rather a period of vegetation. It may be of value in the comparison of the same species under different conditions, but it varies greatly in the case of different species, certain embryos remaining for a long time recurved under the surface of the soil or with their cotyledons imprisoned in the remains of the spermoderm.

† The degrees are always those of the Centigrade thermometer.

regard to heat, of the isolation of the reservoir. The box was placed in an arched deep cellar, having no other outlet than a door opening into a vault. The temperature was therefore naturally very steady, at least entirely removed from the influence of daily and even weekly variations.

The temperatures near 0° were maintained with steadiness in the reservoir as long as I wished, by renewing the ice every three days; but in the case of other temperatures, especially from 18° upwards, the apparatus was unsatisfactory. Water at 50° or 55° very rapidly loses its heat; and the apparatus being difficult to move, I gave up its use, preferring to take advantage of the succession of the seasons for placing the sowings sometimes in the cellar, at others in the open air, then in rooms or cupboards where the temperature scarcely varies from day to day, which has allowed me to continue the observations to about somewhat less than 24°; and for the higher degrees, I had recourse to the artificial heat of a lamp.

Temperature of 0°.

Three small vessels to contain the sowings of the seeds were placed in a large glass bottle closed with a cork. This floated in the reservoir of melting ice, without ever entirely emerging or becoming submerged. The temperature of 0° was maintained in the interior of the apparatus with remarkable steadiness. Even when a somewhat larger proportion of ice than usual was allowed to melt, the thermometer immersed in the vessels containing the seeds indicated exactly 0°. Another cylindrical box, made of tin, which floated in the same reservoir and contained some sowings, also retained the temperature of 0° with great steadiness.

The experiment lasted from 4 o'clock on the 7th of March until the same hour on the 11th of April, *i. e.* thirty-five days. The results in the case of ten species are subjoined*.

The following did not germinate at all:—*Collomia, Lepidium, Linum,* maize, the melon, *Nigella, Sesamum, Trifolium,* and *Celosia.*

Two sowings were made of *Trifolium,* one in the vessels contained in the large bottle, the other in the tin box.

The only species which germinated was the *Sinapis,* of which also two sowings were made, one in the bottle, the other in the box. Of the former, some seeds (five out of thirty) germinated from the 23rd to the 25th of March, the mean being the seventeenth day. In the box, in which the sowing only took place on the

* The *Iberis* was not sown in some of my experiments, one of the Amaranthaceæ (*Celosia cristata*) being substituted for it.

evening of the 16th of March, some of the seeds germinated on the 27th in the evening, *i. e.* the eleventh day, and others continued to sprout successively. It is difficult to determine to what this difference of from eleven to seventeen days was owing; for the surrounding temperature was 0° in both cases. I suspected that the seeds in the second sowing were not brought sufficiently near 0° at the moment at which they were placed in the soil, which was of this temperature. They were also but few in number, and too crowded. It may be that the outer temperature had not surrounded them with sufficient rapidity at first, and that, a certain chemical change having ensued, the approximation of the seeds had produced a local heat sufficient to alter the supposed conditions. For these reasons, the result of the first experiment (seventeen days) appears to me to be most probably correct.

At the end of thirty-five days, being obliged to absent myself, I ceased to renew the ice in the apparatus; but the experiment had lasted sufficiently long. And what proves it, was, that at my return nearly a month later, on the 9th of May, I found the vessels in the apparatus at 7°·7, and no other species except the *Sinapis* had germinated. Several might have sprouted at similar temperatures, as we shall see presently; but in such a prolonged experiment they had probably rotted. *Lepidium* and linseed germinate at ordinary temperatures, almost as soon as *Sinapis*, and would certainly have germinated between the seventeenth and the thirty-fifth day of the experiment if the temperature of 0° had not formed an obstacle.

There are probably alpine species which sprout below a temperature of 0°, especially nival species, as *Soldanella* for example. We are advised to sow the seeds of rhododendrons in melting snow, and foresters sometimes sow in the same way the seeds of trees on mountain-slopes. Undoubtedly, in the natural course of things, the rays of the sun between whiles may cause a rise of temperature above 0° at the expense of the water of the snow; but we may believe that, as in the instance of *Sinapis*, certain species germinate whenever water comes into contact with them, even at 0°. On the other hand, according to my experiments, several do not germinate at so low a temperature. It still remains to be determined whether they really cannot germinate, or whether they require so long a time that their tissue usually passes into a state of putrefaction which reaches the embryo.

Temperature of 1°·4 *to* 2°·2.

Four small porous earthen vessels were immersed up to the rim in the sawdust surrounding the reservoir of ice. On the 7th of March, at 4 p.m., the seeds of all the above species, except the melon and *Trifolium repens*, were placed in them. The first would certainly not have sprouted; the second did not then appear to me disposed to germinate with sufficient uniformity to be worth trying. I have since found that it would have been better not to reject it.

The first vessel contained the seeds of *Collomia* and *Celosia.* Its temperature varied but very slightly, from 1°·6 to 2° (mean 1°·8). The seeds did not germinate. The experiment lasted thirty-five days. Afterwards the temperature gradually rose to 8°. This temperature of 1°·8 to 8°, having lasted twenty-eight days, did not induce germination.

The second vessel varied in temperature from 1°·4 to 1°·9 (mean 1°·65). It contained sowings of *Lepidium* and linseed. The former sprouted on the thirtieth day, in tolerable abundance, the latter on the thirty-fourth day*.

The third vessel varied from 1°·5 to 2° (mean 1°·75). It contained seeds of maize and *Nigella.* None germinated. After the experiment had lasted thirty-five days, the temperature being slowly raised during twenty-eight days as high as 8°, they still had not germinated.

Lastly, the fourth vessel, containing the seeds of *Sesamum* and *Sinapis,* varied from 1°·6 to 2°·2 (mean 1°·9). The *Sesamum* did not germinate; neither did it germinate during the twenty-eight days of 1°·8 to 8°, subsequent to the experiment. The *Sinapis,* however, germinated on the sixteenth day. The mean of these sixteen days was 1°·9, as that of the entire experiment.

These facts, which are nearly all negative, help to confirm and explain the experiment at 0°. The germination of *Sinapis* on the sixteenth day, at 1°·9, shows that its true germination at 0° was rather the seventeenth day than the eleventh.

At temperatures of 2°·6 *to* 3°·2.

The three cylindrical and lateral cavities nearest the reservoir of ice contained the same species, sown, in three vessels, from the 6th of March.

The cavity α contained seeds of *Collomia* and *Lepidium.* The temperature varied from 2°·8 to 3°·2 (mean 3°) during the thirty-six days which the experiment lasted. The *Collomia* did not germinate. Some of the seeds of *Lepidium* germinated on the eleventh day†; they then perished; others, somewhat fewer in number, germinated on the sixteenth day; lastly, three germinated on the thirty-first day. Hence about half the seeds germinated, in succession.

* In saying that a species germinated on the thirty-fourth day, I mean that thirty-four complete days were required for the radicle to show itself.

† I mean the end of the eleventh day. The same applies to all that follows.

The cavity β, sown with linseed and maize, varied from 2°·8 to 3°·2 (mean 3°). During the seventeen first days the temperature was steady at 3°·1, and the linseed germinated on the seventeenth and eighteenth days, in tolerable quantity. The maize did not germinate.

The cavity γ contained *Nigella, Sesamum,* and *Sinapis.* The temperature usually varied between 2°·6 and 3°·2; but on the sixth day of the experiment an accidental cause of increased heat occurred, raising the temperature to 5°. The *Nigella* and *Sesamum* did not germinate. Three seeds of *Sinapis* germinated on the ninth day, or rather on the eighth and a half day; on the seventeenth one more germinated; the rest were unchanged. Finding the experiment useless, I again sowed *Sinapis,* at 2 o'clock on the 18th of March, in an additional vessel placed in the cavity γ. One seed germinated on the sixth day, another on the thirteenth, subsequently two more, which proves but little, for 60 or 80 grains were sown. After the experiment the temperature gradually rose to 8° during twenty-eight days, and the seeds which had not previously germinated did not then do so.

At temperatures of 4°·2 to 6°·1.

The same species were placed in the lateral cavities furthest from the reservoir of ice, also in three vessels.

α varied from 4°·6 to 6°·1 (mean 5°·35). It contained *Collomia,* which germinated on the seventeenth day in tolerably large proportion (nearly half), and *Lepidium,* which germinated on the eighth day in tolerable abundance.

β varied only from 4°·7 to 4°·9. It contained maize, which did not germinate, and linseed, which germinated on the seventeenth day in the proportion of nearly a fifth of the seeds sown.

γ varied from 4°·2 to 4°·9 (mean 4°·55). It contained *Nigella, Sesamum,* and *Sinapis.* None of these germinated, not even the *Sinapis.* Evidently the seeds of the latter species, which sprout so readily, had suffered; for a month afterwards, when the temperature had risen to 8°, only a single individual showed itself out of thirty or forty sown on the 6th of March.

The moisture had probably been too great in these three cavities, as in those in which the mean was from 2°·6 to 3°·2, just alluded to. On the 9th of May, twenty-eight days after the experiment, of all the sowings there only remained a single plant belonging to *Sinapis.*

At a temperature of about 5°·7.

From the 6th of March to the 11th of April, the temperature of the cellar in which the experiment was made varied only from

5°·4 to 6°. The mean temperature every two days was 5°·68, say 5°·7.

All the species were sown on the 9th of March, upon a basis of sand, in a large box. They were wetted with water of the surrounding temperature.

At higher temperatures evaporation would lower the mean of the soil in which the seeds were sown, which circumstance was taken into account, in the following experiments, by measuring the temperature of the soil instead of the air. At 5° or 6° this cause could be of but little importance, but it would give rise to the presumption that the mean was a little below 5°·7.

The following were the results to the 11th of April:—

Collomia. Some seeds germinated on the fourteenth day; the others failed.

Lepidium. Germinated abundantly on the fifth day.

Linum. Germinated abundantly on the sixth day.

Maize. Did not germinate.

Nigella. Germinated on the twenty-seventh day.

Sesamum. Did not germinate.

Sinapis. Germinated abundantly on the fourth day.

Iberis. Germinated on the fourteenth day.

Trifolium. Germinated on the tenth day.

Melon. Did not germinate.

From the 11th of April to the 9th of May the temperature of the cellar gradually rose to 8°. Still the seeds of maize, *Sesamum*, and melon did not germinate. Those of the *Sesamum* had perhaps suffered from the damp; but those of the maize and melon were hardly swollen, and some of them were mouldy.

At a temperature of about 9°.

In the middle of May the temperature of the cellar had risen to nearly 9°. I took advantage of this to sow, at 1 o'clock, on the 17th, all the species, in a broad box, exposed to the free air. On the 18th, at half-past 2, I watered them, and allowed the experiment to continue. From the 18th of May to the 2nd of June the thermometer in the open air only varied 0°·6. In the sand containing the sowings the variation was 0°·8. The humidity caused by the watering always lowered the temperature of the soil relatively to that of the air, which induced me to determine, as exactly as possible, the temperature of the upper layer of soil. On making every correction with the standard thermometer, I found 9°·2 to be the most probable temperature to which the seeds had been subjected. The following are the results:—

Collomia. Germinated six days and three-quarters after the sowing.

Lepidium. Germinated on the third day.

Linum. One seed commenced on the second day, several others on the fourth.

Maize. One seed on the tenth day, two others on the twelfth, and others subsequently.

Melon. Did not germinate.

Nigella. Germinated on the fifteenth day.

Sesamum. Did not germinate.

Sinapis. Germinated at the end of three days and a half.

Iberis. On the sixth day.

Trifolium. Some seeds on the fifth day, others on the sixth, the eighth, &c.

At a temperature of 12° *to* 13°.

The same kinds of seeds were sown and watered on the 15th of July, in the same manner as the preceding, but at a temperature which in the cellar, from the 15th to the 30th of July, was 13°·66 in the air, and 12°·6 in the soil,—the extreme variation in the air being 1°·0, and in the soil 0°·8. During the first three days, the mean in the soil was 12°·9 : this refers especially to four of the species mentioned below. The results were :—

Collomia. Germinated on the sixth to the seventh day.

Lepidium. Germinated after about a day and three-quarters.

Linum. Germinated in about two days and three-quarters.

Maize. Two seeds out of seventeen germinated at the end of the fifth day; and on the seventh day half had germinated.

Melon. Did not germinate, not only from the 1st to the 31st of July, but also during the month of August.

Nigella. The ninth day (at the end) a fourth part of the seeds germinated.

Sesamum. Germinated abundantly at the end of the ninth day.

Sinapis. Germinated after one day and three-quarters.

Iberis. From three and a quarter to four days.

Trifolium. Germinated at the end of the third day, unequally.

The uncertainty which existed in regard to four of these sowings, induced me to repeat the experiment at once.

Lepidium, at 12°·9, sprouted in one day and three-quarters, as before.

The *linseed* failed; but on again repeating the experiment at 13°·5, it germinated at the end of one day and three-quarters. The mean, with the preceding experiment, is two days and a quarter, at 13°·2.

Sinapis. Germinated in about forty hours. The mean, with the preceding experiment, is forty-one hours, at 12°·9.

Trifolium. In three days, *minus* about three hours, at 13°·0.

At a temperature of about 17°·

Some sowings were placed, on the 15th of May, in a room where the temperature of the air varied 1°·3 to the end of the month, and that of the sand in which the seeds were placed, also, 1°·3. During the first three days, the mean to which the seeds were subjected was 17°·2; the *Lepidium* and *Sinapis* germinated towards the end of one and a half to one and three-quarters day; the *linseed* and *Trifolium* at the end of the second day. Considering the rapidity of the phenomenon, I wished to repeat the experiment with still more exactness, and I found that, the means being 16°·9,

Lepidium germinated in thirty-six hours.

Linseed sprung up partially at the end of the fourth day.

Sinapis at the end of three days and a half.

Trifolium at the end of about three days and a quarter.

Under a mean temperature of 17°·3, in a third experiment, the *Sinapis* germinated at the end of the second day. The mean of these three results, in the case of *Sinapis,* is one day and seven-tenths [? 2·33 days], at 17°·2.

The mean of two experiments gives for the other species, at 17°·05 :—

Lepidium. One day and a half.

Linum. Three days.

Trifolium. Two days and six-tenths.

The other species gave, at 16°·9 :—

Collomia. Five days and a half.

Maize. Three days and three-quarters.

Melon. Commenced at the end of nine days and a quarter, and continued to spring up on the subsequent days.

Nigella. The sixth day.

Sesamum. The third day.

Iberis. The fourth day.

At a temperature of about 20° *to* 21°.

Similar sowings were made in a room in which the temperature was tolerably constant. The seeds, placed in an open box, were copiously watered, covered with moistened brown paper, and the whole shut in a drawer. The shape of the box allowed the thermometer to be placed obliquely in the superficial layer of sand in which the seeds were placed. At 4 p.m. on the 2nd of August, when the experiment was begun, the temperature was

22°·1; the next morning at 10 o'clock it was 21°·2, and on the following day at 10 it was 19°·9. 21°·1 may be considered the approximative mean. The following are the results:—

Lepidium. Germinated in thirty-eight hours.

Linseed. Germinated in about thirty-six hours.

Maize. Two seeds germinated on the forty-second hour, and others followed.

Nigella. In four days and a quarter.

Sesamum. Germinated in from thirty to thirty-six hours, without my being able to determine accurately, in the middle of the second night.

Sinapis. One seed germinated in eighteen hours, and the others followed; say, twenty-two hours for the first of them.

Trifolium. Some seeds germinated in forty-two hours.

On the 5th of August the temperature had fallen, and the mean of the 2nd of August, from 5 in the afternoon till 10 in the morning, may be estimated at 20°·4. *Iberis* germinated under these conditions in two days and three-quarters.

Collomia did not sprout. Its seeds were kept and watered at temperatures of from 18°·8 to 20°·4 (mean from the beginning 19°·6), and on the 18th of August (fifteen days and a half after the sowing) one germinated.

To be sparing of the melon-seeds, of which very few were left, I did not then sow them, but began again on the 16th of August; and at a mean of 19°·4, having varied from 18°·8 to 20°·4, two seeds out of ten germinated in two days and twenty hours.

At a temperature of from 24° *to* 25°.

On the 19th of July, a sowing was made in a room the temperature of which was about 26°, and subsequently, from the 22nd to the end of the month, 23° to 24°. The seeds were placed upon the sand in a drawer which shut tightly, and to guard still more against external variations, they were covered with sheets of brown paper. The sand was watered, and the paper moistened. The temperature in the sand remained for three days between 24°·9 and 25°·2 (mean 25°·05). Under these conditions,

Linseed germinated in thirty-eight hours.

Maize. One seed out of twelve germinated in twenty-three hours; but half the seeds had not germinated until after forty-four hours.

Melon. Two seeds out of ten germinated in forty-four hours, the others followed.

Sesamum germinated in from twenty-one to twenty-two hours and a half. This extreme rapidity having prevented me from determining accurately, I immediately made a fresh sowing at a temperature of 24°·4 to 24°·9; it sprouted in twenty-two hours and a half.

Sinapis appeared to have germinated in thirty-six hours; but it was in the night, and the moment was not ascertained.

Trifolium germinated about the forty-second hour.

Nigella and *Iberis* escaped observation, from an accident.

Lepidium presented a singular fact, probably resulting from an error of observation or the accidental choice of more tardy seeds than the others. This species, which germinates rapidly at low temperatures, only commenced partially to germinate (two grains out of ten) towards the end of the sixth day, and most of the seeds sprouted between the sixth and the seventh day. The temperature of the seven days varied from 22°·1 to 25°·1, the mean being about 23°·6 or 23°·7. The construction of the curve (Plate IV.) shows that this fact is not in harmony with those deduced from higher or lower temperatures, consequently that there was some error or accident. To satisfy myself further, I repeated the experiment in November in another form, with a lamp placed under a large flask of water, in which a bottle containing a sowing of *Lepidium* floated. The mean temperature was 21°·1, with insignificant variations, and the *Lepidium* germinated after thirty-eight or thirty-nine hours, exactly as in the above-mentioned experiment. At a temperature of 26° to 27°, which unfortunately rose much higher (43°) during some hours, the *Lepidium* began to sprout at the sixteenth hour. Hence we may conclude that the experiment at 25° was inaccurate.

Lastly, *Collomia* did not germinate in July. The temperature of the sand remained, from the 24th of July to the 3rd of August, between 22°·5 and 22°·1; on the 8th of August it fell to 18°·5, and then rose on the 14th of August to 28°·6. The seeds had been preserved and watered. I thought they would not germinate; but on the 15th of August two of them did so. The mean temperature varied too much for the experiment to be satisfactory. Assuming it to be accurate, it would be necessary to admit that, at a mean of 21°·5, *Collomia* requires a period of twenty-seven days, which agrees moreover with the observation at 19°·6, as shown in the tracing of the curves in the Plate. It might be questioned, as in the case of *Lepidium*, whether the temperature of the second half of the period, which was momentarily lowered to 18°·5, had not caused the germination which the heat prevented in the preceding period. I doubt this, however, because the germination took place when the mean had returned to 20°·6. Moreover the duration of twenty-seven days agrees tolerably with that of the experiment at 17° to 18°, as is well shown by the curves.

Temperature of about 28°.

Being unable at Geneva, even in a very hot summer, to obtain in the open air constant means above 24°, I had recourse to artificial heat for the higher temperatures.

A basin, nearly filled with warm water, was placed upon a support heated by a lamp, which required to be renewed only three times in twenty-four hours. A porcelain cup filled with sand was immersed two-thirds in the water of the basin to receive the seeds. The temperature remained pretty constant between 29° and 30°. I then sowed the seeds, at an equal distance from the edge of the cup, and, after having allowed them to acquire the temperature of the sand, I watered them well with water at 30° which had not been boiled. The experiment, which was begun at midnight on the 2nd of August, was stopped at noon on the 6th. During this period, the mean temperature of the room fell from 21° to 18°. This cause, as also the evaporation from the more or less moist sand, and the unavoidable alterations in the source of heat, induced a variation of temperature from 27° to 29°, and in the morning of the last day it fell to 26°·3 ; but this could not have had any influence upon most of the seeds, which had already germinated. The results were :—

Lepidium. Two seeds germinated in thirty-nine hours; one or two others sprouted afterwards; but most of them did not germinate.

Linum. One seed germinated at the end of two days and a half; at the end of the third day three only had germinated; the majority, about four-fifths, did not germinate.

Maize. Up to the thirty-sixth hour single seeds sprouted, but after the second day almost all the seeds sprouted vigorously.

Melon. One seed evolved its radicle at the end of the third day, and at the end of the third day and a quarter the majority germinated regularly.

Sesamum. The germination began at the end of twenty-two hours; it was abundant during the three or four following hours.

Sinapis. Two seeds only out of ten germinated at the end of the third day; six hours afterwards a third showed its radicle; most did not germinate.

Trifolium. Some seeds germinated at the end of the third day; most did not germinate.

Collomia and *Nigella* did not germinate. To prolong the experiment, I left these seeds as they were, but under such conditions that the temperature varied from 32° to 37°, until the 10th of August. Two or three of *Trifolium* and one or two of *Linum* sprang up, but neither *Collomia* nor *Nigella.*

On the 4th of August, at 5 p.m., I sowed and watered some seeds of *Sesamum* in a little cup placed so as to maintain a temperature of 27° to 28°. At the end of thirty-one hours, one seed germinated. The experiment was not continued.

Temperature of 40° *to* 41°.

The seeds were sown on the 6th of August, at 8 p.m., in a glass vessel, filled with dry sand, placed in the centre of the porcelain cup containing the moist sand of the preceding experiment. At 11½ p. m. I watered them freely with water at 41° which had not been boiled, The temperature of the sand was maintained, until the 10th of August at 5½ p.m., between 39°·6 and 45°·4, but it only rose to this temperature in the evening of the 7th of August, and the mean, taken every twelve hours, was 40°·6.

Two seeds of *Sesamum* germinated at the end of ten hours and a half, and others followed immediately. The mean during these ten hours and a half must have been 40°·7. None of the other species germinated; and as the seeds of the maize and the melon had assumed a dark tint (especially those of the maize), which indicated a change, I removed the glass vessel and placed it upon a marble mantlepiece, where it rapidly acquired the surrounding temperature of 20° to 21°. To my great surprise, four hours and a half afterwards, three melon-seeds germinated! The other species did not sprout during the following days, up to the 12th of August; it is thus probable that the melon-seeds would have germinated at 40°·6, if I had not interrupted the experiment. They would then have required, under these conditions, four days *minus* two hours, or ninety-four hours.

At higher temperatures.

It appeared to me useless to continue the experiments at higher temperatures, except as regards *Sesamum*, which seemed best to resist an extreme heat. The experiments of Lefébure, as well as of Edwards and Colin, have proved that most seeds undergo a change at temperatures of 50° and upwards when the soil is moist—a change so great that they are incapable of germinating when subsequently placed under favourable circumstances. Seeds heated in the dry state in a stove are capable of bearing a heat approaching the point of combustion*; but in water they lose their power of germinating at 55° or 50°, and perhaps below, according to the species, and especially according to the duration of the immersion†. In moist earth the seed is changed, according to the abundance of water, at various degrees of the thermometer. Thus, with the method of experimenting which I had adopted for a certain purpose, the seeds, always being copiously watered, would lose their power of germinating at 50°, 45°, and

* Edwards & Colin, *l. c.*; Théod. de Saussure in the 'Mém. Soc. de Phys. et d'Hist. Nat. de Genève, iii. part 2.

† Lefébure, p. 120 *et seq.*; Edwards & Colin, *l. c.*; Fr. Burckhardt, *l. c.*

perhaps 44° or 43°, as is proved by the preceding experiment, without its being possible to regulate and to determine this limit exactly.

I therefore confined myself to pursuing the trial of the *Sesamum*-seeds to about 57°, and the following were the results:—

A sowing was made, at 7 p.m., in sand which had been slowly heated, with the seeds in the dry state, to 51°. I watered copiously with water at this temperature. The temperature of the soil rose to 57°; it varied from 50° to 57°, mostly remaining between 51° and 52°. Some of the seeds were accidentally lost. One of five which were left germinated at the end of twenty-five hours and three-quarters. In a final experiment, in which the *Sesamum*, watered in the same way, was exposed to a more fixed mean of 43° to 45° for twenty-six hours, and afterwards left at temperatures of from 18°·5 to 22°, three seeds out of a dozen germinated at the end of six days after sowing; two more followed, and the majority did not germinate, which shows to what extent the heat of from 43° to 45° had been prejudicial.

§ 2. *Deductions and Conclusions.*

1. *Some seeds germinate at* 0°.

MM. Edwards and Colin, in 1834, stated in their memoir:— "No seeds are known which are capable of germinating at the point of melting ice." M. de Seynes, in his very interesting treatise on germination*, repeats, in 1863, "No seeds of the Phanerogamia are known which germinate at 0°." My experiments prove that out of ten species, taken at hazard, one has been found which germinates at 0° (*Sinapis alba*).

The fact is the more singular, as it does not refer to a plant belonging to the polar regions or high mountains. Probably there are other species similarly circumstanced, especially among those which live in the neighbourhood of snow; but we can scarcely become acquainted with this in the ordinary course of events. In fact, the persistence of a temperature of 0° is very rare in nature. A sun's ray or the proximity of a body of a temperature above 0° is sufficient to raise the temperature of a stream springing from melted snow. It is well known how difficult it is to maintain a temperature of 0° in a basin filled with ice, when it is required to verify the zero-point of a thermometer. Only by attentive observation in a prolonged experiment can it be determined whether a species germinates at 0°. There are even some seeds for which an experiment lasting thirty-five days, like mine, is not sufficient.

2. *Necessity of a minimum for each Species.*

Sinapis alba germinated at 0°. Perhaps this species might

* De la Germination, 8vo, Paris, 1863.

have germinated even at a somewhat lower temperature, provided the water were liquid; but this kind of experiment appeared to me too difficult to be attempted*.

Lepidium and *Linum* germinated at a mean of 1°·8, but did not sprout at 0°.

Collomia, which does not germinate at 3°, does so at 5°·3.

Nigella, Iberis, and *Trifolium repens*, which did not germinate at 5°·3, sprouted at 5°·7.

Maize, which did not germinate at 5°·7, did so at 9°.

Sesamum, which did not germinate at 9°, did so at 13°.

Lastly, the seeds of the *melon*, which did not germinate at 13°, did so at 17°.

Some seeds of the *cotton-tree*, at least two years old, which I thought were beyond the condition for germinating, because they had resisted a previous experiment at 18° for several days, sprang up when placed upon a stove the temperature of which was very variable but at times reached 40°.

Lefébure decided upon 5° to 6° C. as the minimum for radish-seeds placed in a moist soil. MM. Edwards and Colin state that they made winter-wheat, barley, and rye germinate at 7° C.; but they do not assert that this is the minimum; and it is highly probable that barley at least would germinate at a lower temperature by prolonging the experiment.

Species therefore require a determinate minimum for germination. Assuredly agricultural practice would give rise to this idea; but we are not sure whether the germination of seeds sown too early in spring is merely retarded, or rendered slower, or whether their subsequent development is absolutely impossible. Experiment shows that in this case germination is impeded; it also shows how necessary it is, in calculations upon temperature in regard to plants, to take as the basis facts deduced from constant and prolonged temperatures †, and then to consider certain temperatures useless for each species, at least as far as relates to germination. Certainly there exist facts in accordance with which the same applies to the foliation, the inflorescence, and the maturation; only, these facts are less exact.

In my experiments, all the species which required the highest *minima* belong to warm countries. They are excluded for this reason from cold countries; for if they germinated in them, it

* Natural philosophers are able to keep water in a liquid state below 0°, as shown by M. L. Dufour's beautiful experiments; but it is almost impossible to preserve this state of things, ensuring at the same time sufficient oxygen for the germination of the seeds.

† M. H. Hoffmann (Witterung & Wachsthum, &c., 1857, p. 525 &c.) doubts the existence of a minimum proper to each species; but he confined himself to experiments under variable temperatures, the means of which he regards as equivalent to a constant temperature.

would be too late in the spring, and the ripening of the seeds would not take place before winter. Among those species which germinate at low temperatures, some belong to temperate countries. They do not advance so far as the polar regions, either from causes not relating to germination, or because, germinating too soon, the herbaceous parts are attacked by the cold.

3. *Existence of a maximum.*

When the temperature remains at a certain rather high degree, some seeds are no longer able to germinate. Thus, in my experiments, the seeds of *Nigella* and *Collomia* did not sprout when the mean exceeded 28°. Most of the seeds of *Trifolium repens* did not germinate at 28°, whence it might be supposed that at about 30° none would have sprouted. Maize must cease at about 35°, for at 40° the seeds became brown and as if burnt. One, however, of the seeds which had been rendered brown by a heat of 50° to 57°, germinated on the eleventh day, when, the experiment having been abandoned, the temperature fell to 18° or 20°. The seeds of the melon and, especially, *Sesamum* bear 40°; but they assume a brown tint, which indicates a certain change, and it is probable that at about 42° in the case of the former, and 45° in that of the latter, germination would usually be impossible. However, some of the *Sesamum* and melon-seeds which had reached 45°, and were subsequently left at 18° to 20°, sprouted.

As stated above, the limit depends greatly upon the moisture. When long immersed in water at 50°, and even 45°*, many of the seeds would suffer. They are still capable of germinating in moist earth; and as the quantity of moisture is very variable, and this could not in my experiments be observed at each degree of elevated temperature during a somewhat considerable length of time, I did not attempt to obtain greater exactness.

Lefébure fixed the maximum for the seeds of the radish sown in moist earth at 38° C. MM. Edwards and Colin found that all the seeds of winter-wheat, spring wheat, barley, rye, and oats, sown at 40° in slightly moist sand, sprouted, that at 45° only a part of them did so, and at 50° none germinated.

4. *Amplitude between the minimum and the maximum.*

If we designate as *amplitude* the number of degrees between the minimum necessary for the germination of a species and the

* None of the seeds of the Leguminosæ and Graminaceæ submitted to experiment by MM. Edwards and Colin were capable of germinating after immersion for a quarter of an hour in water at 50°. According to M. F. Burckhardt's experiments, the seeds of *Lepidium* and linseed were susceptible of germination after immersion for half an hour in water at 50° (49°·6 to 51°·4), but not for the same period in water at 60° (57° to 62°).

maximum beyond which it is impossible, we find differences between one species and another. Thus *Collomia* and *Nigella* have 23° of amplitude, maize 26° or 27°, the melon 24° or 25°, *Sesamum* about 30°, and *Sinapis* nearly 40°. The maximum being variable according to the moisture, no great value can be attached to these numbers. A short amplitude is evidently unfavourable to the geographical extension and cultivation of a species.

5. *Differences between seeds of the same species and origin.*

Sometimes natural philosophers reproach naturalists with neglecting the experimental method and constantly following that of observation. Here we have an instance justifying naturalists. Nothing is easier to submit to experiment than seeds; nothing appears more homogeneous, more comparable, in the same species. And yet seeds derived from the same source, preserved in the same way, and sown together, germinate in succession*. The fact is of common occurrence; I have met with it many times in my experiments. Agriculturists are well acquainted with it. In some families, for instance the Leguminosæ, it occurs, as already stated, to a very inconvenient extent. It is because seeds from the same crop, the same plant, the same capsule, are not identical either physically or chemically. Their organization is very complicated, as is also their evolution, although other physiological facts are still more so. Natural philosophers reason upon homogeneous bodies; naturalists upon heterogeneous bodies. A metal melts at a constant temperature, because it is composed of similar parts. An organized body never presents this complete similitude of all the parts of the same organ. Hence there is less exactness in the experiments, and almost constant necessity of comparing numerous facts, *i. e.* of observing.

In my experiments, one, two, or several seeds have been observed germinating in succession, out of ten or twenty; and I have called germination, somewhat arbitrarily, the second or third appearance of the radicle among the seeds. If the temperature is very favourable, that of several seeds takes place simultaneously. Near the maximum and, especially, the minimum, the seeds germinate more irregularly, and a still larger number do not germinate.

6. *Influence of the albumen.*

The structure of each kind of seed, especially the absence or presence of albumen, and its nature when it exists, must exert a certain influence in accelerating or retarding the action of heat; but the small number of species upon which I experimented has not allowed me to determine this point sufficiently.

* See Cohn, 'Symbola ad Seminis physiologiam,' 8vo, Berlin, 1847.

Six of the species observed have no albumen, viz. the three Cruciferæ, *Cucumis, Trifolium,* and *Sesamum;* the four others, *Nigella, Linum, Collomia,* and *Zea Maïs,* have an albumen. That of maize is considerable; that of linseed, on the other hand, is very small.

The three species which have a more or less considerable amount of albumen, require a minimum of 5°, and sometimes more, for germination. *Sinapis, Lepidium,* and *Linum,* which germinate at very low temperatures, have no albumen, or very little. On the other hand, it is a striking circumstance to find that the seeds of *Sesamum,* which greatly resemble those of the Cruciferæ in the absence of albumen, in texture, and in size, require from 10° to 12° to germinate.

A temperature of 17° to 18° is favourable for all these seeds. At this temperature, germination took place in the following order:—*Lepidium, Sinapis, Trifolium, Sesamum* and *Linum, Iberis, Maize, Collomia, Nigella,* and *Melon;* which shows better that the albumen has a certain retarding influence. The melon, it is true, is the slowest, although free from albumen; but the coriaceous nature of its envelopes must impede development.

7. *Relation of the temperature to the time required for germination.*

All the species presented a tolerably similar progress as regards its duration at different temperatures.

Near the minimum, a slight increase of temperature notably abridges the time of germination. Under more favourable means, the acceleration is slight. Lastly, near the maximum, the intensity of the heat becomes injurious and retards germination. The latter is impossible at a higher degree. MM. Edwards and Colin had already remarked this*; and it is evident at a glance on constructing curves expressing the results of my experiments (see Plate IV.).

The Centigrade degrees being marked on the vertical line, and the days (of twenty-four hours) on the horizontal line, I have set down each observation by means of a point indicating the moment at which the seeds of each species germinated, at each constant temperature. These points are connected by straight lines, which indicate, with the aid of a little imagination, what the normal curves would be if founded upon more numerous and perfectly exact observations.

It is at once evident that my observations at from 3° to 6° and at 17° are not very satisfactory, for they have given the curves an irregular form. It may also be seen that the linseed has presented several anomalies, perhaps arising from the somewhat irregular rupture of the spermoderm at a certain stage of the evolution of the embryo.

* Ann. d. Sc. Nat. sér. 2. vol. i. p. 270.

Omitting these irregularities, the curve of each species ascends at first slowly, and the difference between each species is somewhat considerable. Subsequently all the curves become approximated and nearly parallel to the line of temperatures; and finally they diverge and separate towards the top.

Hence it results that the *relative* order of evolution of the seeds is different, according to whether the low, the mean, or the high temperatures are considered. The lines cross, like the limits of the distribution of the species in geographical botany, and partly from the same causes.

It has been proposed, for the purpose of measuring the temperature required for vegetative functions, considered either individually or in the whole of the life of a plant, to add the thermometric degrees day by day, from the commencement to the end, either of the function or of the life of the individual. According to the calculations of M. Boussingault upon cultivated annual species, and those which I have published upon some indigenous species, nearly the same sum of degrees is found for the performance of one function as for all the functions of the same species. If the temperature has been higher, vegetation will have proceeded more rapidly, and *vice versâ*, so that one of the numbers nearly compensates the other. As temperature and time are absolutely different elements in their essence, as we adopt them in part only of their infinite extension, and we arbitrarily divide this part into degrees and days, there is no *à priori* reason why the days of duration should exactly compensate the degrees. If that happens, it is a fact, at first suspected, then proved; and that is all. The question is to determine to what point this law, which is empirical in its nature, is founded in reality; and, as I stated at the commencement, there is a certain interest in acquiring assurance by direct observations, in regard to a function which is less complicated than the others, and where heat exerts its influence without light. The calculation may be made in two ways—either by adding together all the degrees above zero, or by deducting the degrees which are useless to the species in the function in question, and then adding the other degrees, up to the moment at which the function is accomplished. The latter mode appears, *à priori*, more logical; but the state of ignorance in which we nearly always are, in regard to the minima, prevents our employing it. The following are the numbers in relation to the species observed. I shall quote only three species, the remainder presenting analogous facts.

*Trifolium repens** at 5°·7 requires ten days (of twenty-four

* This species is not indicated in the plate, to prevent complication. It proceeds parallel with linseed in the lower degrees; afterwards, from 21° to 25°, it is almost identical with maize; and still higher, it separates from it.

hours) to germinate. Ten times 5°·7 gives the number fifty-seven, but it has been determined that at 5°·5 the species no longer germinates; hence the truly useful temperature would be only 0°·2 during ten days, which produces a total number of 2° only. Similar calculations being made upon germinations of *Trifolium* observed at 9°, 13°, 17°, &c., have yielded as follows:—

Temperature.		Days.		Calculating above 0°	Deducting the minimum 5°·5.
° 5·7	×	10	=	57	2
9·2		5		46	18
13·2		3		39	23
17·0		2·6		44	30
21·1		1·75		37	27
25·0		1·75		44	34
28·0		3		84	67

In both methods of calculating, the first and the last numbers present a disparity with the others; *i. e.* near the minimum and near the maximum the relation of the temperature to the duration of the germination differs from the ordinary one; in other words, the germination is then more difficult and becomes extremely slow. Under the other conditions of temperature, the numbers do not present greater diversity than is admissible in physiological facts, where so many causes exert their influence and where errors of observation inevitably creep in. In opposition to what I had supposed, the numbers in the present instance differ more from each other if the useless temperatures are deducted than if this is not done.

Lepidium, which requires about 1° to be able to germinate, gives the following numbers*:—

Temperature.		Days.		Calculating above 0°.	Calculating above +1°.
° 1·65	×	30	=	49	19
3·0		11		33	22
5·7		5		28	23
9·2		3		28	25
13·2		1·75		23	21
17·0		1·50		25	24
21·1		1·58		33	32
28·0		1·6		44	43

Let us also take *Sesamum*, which requires a very high minimum, from 10° to 12° (say 11°)—

Temperature.		Days.		Calculating above 0°.	Calculating above 11°.
° 12·6	×	9	=	113	14
16·9		3		51	17
21·1		1·4		29	14
24·6		0·94		23	13
28·0		0·92		25	15
40·7		0·44		18	13

* M. Burckhardt obtained higher numbers; but he regards as germina-

In these two instances, especially in the latter, the numbers become much more equal on deducting the degrees of temperature below the minimum. Probably this correction becomes more requisite as the minimum becomes higher.

When in these three calculations the numbers of the beginning and the end, which are often in non-accordance with the others, are abstracted, germination takes place, in widely different species, under the influence of tolerably similar conditions of time and temperature; for the numbers are comprised between fourteen and thirty-four when the minima are deducted. They are slightly less in the case of the species which requires the most initial heat, but in very unimportant proportion.

Definitively, the method of the sums of temperature applies with moderate accuracy to the facts of germination. What is essentially required to be known in the case of each species, in regard to this function, is the requisite minimum. The rest differs but little in the various plants; and it is easy to foretell the effects of an increase of temperature when once germination is possible, without having recourse to calculations or direct observations in the case of each species. The same probably does not apply to the other functions, nor to the assemblage of functions, from germination to maturation. This would form a point to be decided by experiment. Unfortunately I am unacquainted with any means of causing a phanerogamous plant to undergo regular development at a certain temperature, *without light*. It would be requisite at least to be able to furnish a species with light which is uniform and of the same kind for several weeks. With the progress of knowledge, this will be possible sooner or later; but until then our calculations upon the sums of heat in botanical geography, in agriculture, and in horticulture will be contaminated with hypotheses and manifold causes of inexactitude*.

8. *Variable temperatures.*

I have not yet experimented upon germination at variable temperatures. I even endeavoured to maintain more constant temperatures than M. Burckhardt had done, so as to eliminate as much as possible the errors which might arise from variations.

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tion a more advanced phase of development, that at which the cotyledons become exposed.

* If the other functions agree with germination, the numbers calculated from the extreme limit of the species must be distrusted. We see, in fact, that near the point at which vegetation is arrested, much more time is required to compensate for the loss of heat. The numbers calculated near the limits would only serve for comparison with each other, and the numbers deduced from the centre of a habitat must not be confidently applied to express the necessary conditions at the limits.

We may infer, from the demonstrated existence of a minimum, that a mean temperature does not produce the same effect as the same constant temperature, unless, perhaps, the question is that of a mean calculated above the minimum requisite for the species and below the degree at which the heat becomes injurious to it. On deducting the useless and unfavourable degrees, the means may possibly act as a similar constant temperature. I see, however, a reason for doubting this. It is that temperatures which are too low for the germination of a species, are probably not so as far as relates to some particular detail of the function of germination. Low temperatures appeared to me injurious to the absorption of water by the surface of the seeds; however, slight absorption might occur, which would be beneficial subsequently when the temperature rises for a time. The same holds good in the case of other internal phenomena of the seed. Each of them is a function in the general evolution of the germination, and each has its minimum and maximum. Nothing in nature is simple, even in that which appears comparatively very simple.

9. *Analogy between seeds and eggs.*

Some naturalists have ventured to affirm the existence of a kind of identity between a seed and an egg. There is, however, in a physiological point of view, this great difference, that the embryo is almost entirely stationary and inert in the interior of the seed, while atmospheric influences act upon the animal contained in the egg, and must act to prevent the animal from perishing. The egg constantly disengages carbonic acid and aqueous vapour. It therefore requires air, while the seed can dispense with it.

However, to all the existing points of resemblance, it must be added that zoologists are at present content, like botanists, with rather vague notions of the effects of temperature upon the germs. If I have been well informed, and I have consulted good authorities, exact and slightly varied experiments upon incubation at definite thermometric degrees have not been made. There is, however, a memoir upon rearing silkworms, by MM. Millet and Robinet and Madame Millet, which contains precise details upon one species. These authors say that, "to hatch silkworms, the eggs must be subjected to a temperature of $+9°$ C. The number of degrees necessary for incubation diminishes at the same time as the number of days employed in producing them. In other words, if it is required to distribute the number of degrees of heat between fifty days on the one hand and one hundred on the other, this number is found to be more than sufficient in the first case, and the hatching takes place before the employment of all the heat; or, again, a temperature of 20° during ten days, which makes 200°, has more influence upon the development of the worm than a temperature of 10° during twenty days, which also amounts to 200°. The 200° are insufficient in the latter case and superabundant in the former."

We here see the influence of a minimum, which exists in the instance of the egg as also of the seed: if the silkworm requires 9°, it is evident that a mean of 10° is of little use.

10. *Analogy of germination with combustion.*

The production of carbonic acid by means of the oxygen of the air has always caused germination, like respiration, to be classed with phenomena which may be termed generally combustion. For the sake of analogy, the necessity of a certain initial heat must also be added in the case of germination; only, in seeds the minimum of temperature is low: mustard-seed burns at 0°. As regards the more or less rapid progress of germination, the seed must be compared to a combustible which is acted upon slowly and successively within by heat. There are two envelopes, and frequently cellular tissue gorged with starch, surrounding the embryo, which must evidently retard the influence of heat, as also of oxygen and moisture, upon the internal organs.

11. *Peculiar nature of germination.*

At first sight, every one is inclined to regard germination as something extraordinary and inexplicable, *i. e.* vital, in which heat and oxygen reanimate the young plant, which is well-known, however, not to be dead. I fear that this kind of consideration must be left to poets; for the more germination is studied, the more it seems to be composed of solely physical and chemical phenomena.

It is true that I have not examined the modifications undergone by the tissues of seeds at the different temperatures to which I have subjected them. This kind of research would be of great interest, and would require explanation by means of the microscope, with the same care as that used by M. Arthur Gris in his recent papers on the anatomy of seeds beginning to germinate. We should like to know what alterations the seeds undergo below their minimum of germination, above their maximum, also in the intermediate degrees which favour more or less each partial function, of which the sum total constitutes germination. It is true, that the external appearance indicates part of these phenomena. Below the minimum, seeds kept in a moist medium and being unable to germinate, slowly decay; above 45° to 50° they begin to be carbonized. It is easy to understand that these external alterations reach the internal tissue, the substances deposited in the cells, and even the embryo. Thus the young plant in the seed exists as a prisoner confined in a small space. Physical and chemical causes separate the walls of the prison, rendering them flexible, penetrable, and sometimes transforming the encumbering matters into liquid and nutritive substances. If these physical and chemical operations do not take place too slowly or too suddenly, if they do not tend to a putrid fermentation or to the carbonization of the tissues, if the materials of the albumen or the cotyledons are properly and suitably resolved, the young plant enlarges. Its nutrition had been trammelled, or almost suspended; it is so no longer. This is the whole secret. Hence this phenomenon appears more easily understood in accordance with the ordinary laws of matter than numerous others relating to animal and vegetable life, although undoubtedly it is still very complicated and in part imperfectly understood.

XXVII.—*On the* Menispermaceæ. By John Miers, F.R.S., F.L.S. &c.

[Continued from p. 138.]

26. Antizoma.

Under this name I separated from *Cissampelos*, in 1851 (Ann. Nat. Hist. 2 ser. vii. 41), a small group of South-African plants possessing a very peculiar habit: two of them had been described by De Candolle,—one as *Cissampelos calcarifera* of Burchell, of which the male flower only was known; the other being the *Cissampelos angustifolia* of the same botanist, from a specimen of which I derived a knowledge of the female flower: to these, three other new species were then added. They are all small, erect shrubs, with somewhat the habit of *Lycium*, having almost simple stems or subscandent branches. The leaves, unlike those of other *Menispermaceæ*, are linear, with extremely abbreviated petioles; they are opake, thick, revolute on their margins, both surfaces being shagreened with extremely minute and crowded granulations. At each node, below the point of insertion of the petiole, there is a short, rigid and somewhat reflected spine—a feature peculiar to this genus, and quite singular in this family. The male inflorescence consists of one or two very short peduncles springing out of each axil, which bear on their summit from three to six minute flowers on short closely approximated pedicels; these male flowers differ in no respect from those of *Cissampelos*. The inflorescence and the structure of the female flower are, however, very different: this I found in a unique specimen in