[p. 194] Chapter 6
Of Plant Growth in Oxygen-Free Environments

In focusing, in the two preceding chapters, on the decomposition that plants may undergo after their death, I interrupted the train of my research on plant growth, but this digression was necessary so that effects of a dead plant or its fermentation could be distinguished from those of plant growth.

The development of some plants in oxygen-free environments presents phenomena arising from a combination of these two effects.

6.1 Of Plants that Cannot Maintain their Growth in Nitrogen Gas

Plant growth seems able to maintain itself, with the aid of water, in pure nitrogen gas only **[p. 195]** through the oxygen gas that the green parts of the plants exhale there.

Plants lacking green parts or having them only in small amount cannot grow in this atmosphere. Thus, seeds do not germinate in it, and if apparent exceptions to this rule are found, it is because of the use in these experiments of too much water, which, because it cannot be entirely depleted of the oxygen gas that is dissolved or interposed in it, provides enough gas for development to begin. Not only does germination fail to occur in nitrogen gas, but seeds that have already germinated and are placed in it always die if they have sprouted only their radicles before being put into this gas. I performed these experiments on seeds of pea, garden and water cresses, and *Polygonum amphibium*. They all rotted without developing. But most of the plants that developed from these seeds were able to survive and elongate indefinitely in this gas, if they were placed in it after they had abundant green parts or leaves.

Woody branches **[p. 196]** of poplar (*Populus nigra*) and willow (*Salix alba*), with leaf buds ready to open, could not bring about this development with the aid of water, in nitrogen gas, either in the sun or in the shade. They began to putrefy after a fortnight. These same branches leafed out after 3 or 4 days when they were placed, in conditions otherwise the same, under receptacles filled with ordinary air, and they maintained their growth there for several weeks.

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A wilted plant placed in a weakly lit spot, in a receptacle filled with ordinary air or oxygen gas confined by water, always becomes covered with mold, but it does not acquire mold in nitrogen gas. When I placed these molds, fully formed, in nitrogen gas, they did not develop further. But the gas must be completely pure, for the least amount of oxygen gas suffices to maintain the growth of these very small plants.

Roses, lilies, and carnations that were picked 2 or 3 hours before full bloom and that did in fact bloom at the end of this period under receptacles filled with ordinary air, could not accomplish this, with the aid of water, in nitrogen gas. They rotted there, at the **[p. 197]** same developmental stage as when they had been cut, and more rapidly than in ordinary air. These effects also occurred in a vacuum.

A rose has been said to last longer in a vacuum than in ordinary air, but appearances are deceiving. It is true that the rose drops its petals sooner in ordinary air, but this loss, which is a natural process in plant growth, does not indicate any decomposition in the plant. The fallen petals give off a weak but agreeable odor. The opposite occurs in a vacuum or in nitrogen gas: A rose appears to preserve its form and color there for a long time, but when, after a fortnight, we expect to withdraw it still fresh, it gives off a stench. Its petals are rotten, and it is clear that this apparent life conceals a veritable death.

6.2 Of Plants that can Grow in Nitrogen Gas

As I have said, only plants that are amply provided with green parts can grow in nitrogen gas, **[p. 198]** and even these are not all equally successful. It seemed to me that they had to present a lot of surface area, and that they had to belong to the class of plants that consume the least oxygen gas when growing in atmospheric air in darkness.

Cactus opuntia, nourished by water, was able to maintain its growth in the sun for 3 weeks in nitrogen gas, but it was greatly harmed. In the shade it died in 5 to 6 days. It was about the same with *Sedum telephium*. These plants grow indefinitely under receptacles full of ordinary air.

Pea plants that were able to withstand the first 4 or 5 days in an atmosphere of nitrogen gas (which is not always the case) continued to grow there, in the sun, for months, but only sluggishly.

I will report an experiment made on these plants. The result can be considered an average taken from several observations.

Three partially developed pea plants, which together weighed about 3 grams, gained, under a receptacle full of ordinary air, in the sun, **[p. 199]** with nourishment from pure water, 1.27 grams (24 grains) in 10 days. Similar plants that withstood the effects of nitrogen gas, in the sun, for the same length of time gained no more than 106 milligrams (3 grains). [*There is a conversion error here; 106 milligrams = 2 grains*.] These plants, when placed in nitrogen gas in the shade, always died within the first 4 days. They survived for several weeks in ordinary air.

Smaller periwinkles survived, both in the sun and in the shade, for as long in nitrogen gas as in ordinary air, namely, about 3 weeks. In both cases, they died only because they could not tolerate an excessively humid atmosphere.

Lythrum salicaria, *Inula dysenterica*, *Epilobium hirsutum*, *E. molle*, *E. montanum*, and *Polygonum persicaria*, which are all more or less marsh plants, grew admirably in nitrogen gas and made good development there for an indefinite time, similar to that under receptacles full of ordinary air. They could even sustain their growth **[p. 200]** in nitrogen gas for months, if exposed to a weak light or protected from the direct effect of sunlight. I turn now to the changes these plants make in this atmosphere.

I grew *Lythrum salicaria* in the sun in 65 cubic inches of nitrogen gas, which showed no decrease by nitric oxide [*a test for oxygen; see "nitrous air test," in Glossary*]. This plant displaced about 1/8 cubic inch, and it was immersed, only by its roots, in an ounce of water. This liquid had no contact with the water that closed the receptacle. In the course of the experiment, I had to renew [*replace*] the plant five or six times because, in elongating, it pressed and burned against the walls of the vessel that covered it. After 2 months, its atmosphere had increased by 3.4 cubic inches. The eudiometer then indicated 5/100 oxygen gas there. I prolonged the experiment for another month in this improved atmosphere but the plant did not continue to add oxygen gas to it. *Polygonum* and other plants gave me similar results. I ascertained, by several experiments, that in general the amount of oxygen gas that is developed in nitrogen gas is not proportional to the length of stay of the plant under the **[p. 201]** receptacle, but that the amount of gas usually produced in the first weeks does not increase further in the following weeks, although growth is equally vigorous at all times.

Similar plants that I grew for the same time under receptacles filled with ordinary air never added oxygen gas there.

When I placed these plants in nitrogen gas in complete darkness,[1] renewing them every 12 hours so that their growth would not languish, they produced no oxygen gas. They augmented their atmosphere with carbon dioxide gas that they formed entirely from their own substance.

If the same experiment was performed in ordinary air, carbon dioxide gas was also produced, **[p. 202]** but the volume of the atmosphere was neither increased nor decreased by it. This gas thus had another origin. It was formed by the carbon of the plant and the surrounding oxygen gas.

These observations show us the source of the oxygen gas that plants eliminate in nitrogen gas. The oxygen comes from the decomposition of the carbon dioxide gas that the plant forms entirely from its own substance. When the plant has thereby

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[1] *Lythrum salicaria*, *Polygonum persicaria*, and other marsh plants exposed to a weak or diffuse light do not leave carbon dioxide in their atmosphere of nitrogen gas. They add oxygen gas to it. But for them to produce this effect and maintain their growth for a long time at this exposure, the temperature must not be excessively elevated, for plants, like animals, require and consume less oxygen gas, the lower the temperature.

made itself an atmosphere having sufficient oxygen gas, it releases no more of it, because the carbon dioxide gas that it then produces and decomposes is the result of the union of its carbon with oxygen gas that is already formed. Then it makes almost all the oxygen that it has caused to disappear during the night reappear during the day.

The small amount of oxygen gas that *Lythrum* and *Polygonum* formed in nitrogen gas was necessary for the development of these plants, but it was much more than they needed to maintain their growth without developing.

I suspended, at the upper part of a receptacle containing 60 cubic inches of nitrogen gas, a mixture of 1 part iron filings, 2 parts flowers of sulfur [*sublimed sulfur*], and 1-1/2 parts water.[2] [*This mixture would remove oxygen gas*] **[p. 203]** At the same time, I introduced into this atmosphere confined by water two *Lythrum salicaria* plants, which together displaced 1/8 cubic inch. Their roots alone were immersed under the receptacle, in a small vessel containing 2 centiliters of water. The apparatus was exposed, in a room, to the effects of sunlight moderated by window glass. Ten days later, one of the plants was dead. The other continued to grow or maintain itself without suffering harm, without the wilting of any leaf, for 4 months, from the third of thermidor [*11th month (July–Aug.) of the French republican calendar*] to the second of frimaire [*3rd month (Nov.–Dec.) of that calendar*], at which time I withdrew the plant, as healthy as before its introduction. The air of the receptacle underwent no reduction by nitric oxide. The plant had made no development whatsoever during its confinement. Its growth remained, somehow, suspended. This is the only effect produced by the sulfide in this experiment. The same plant elongated by 5 or 6 inches after 10 days **[p. 204]** in nitrogen gas in which this substance was not present. The removal of the oxygen gas developed by the *Lythrum* presented the only obstacle to its development. The sulfide vapors had no role in this effect, for similar plants elongated considerably with iron sulfide under a receptacle filled with ordinary air that I renewed every 3 days.

For 5 weeks, a *Polygonum persicaria* plant responded very nearly as the *Lythrum* had, under a receptacle filled with nitrogen gas in which I had suspended concentrated potassium sulfide ["*hydrosulfide of potash*"]. The plant did not develop at all and lost two leaves from the vicinity of its roots. It died after the allotted time, only from the effects of too-strong sunlight, from which I had not taken the precaution of protecting it.

Plants that I grew in nitrogen gas in the sun died much more quickly than did plants in ordinary air, from the effects of quicklime or potash suspended in their vicinity.

It is strange to see marsh plants withstand the effect of a sulfide, which removes oxygen gas from them, and not withstand the effect of lime, which removes **[p. 205]** carbon dioxide gas from them. But it should be noted that the sulfide removes oxygen gas only after the oxygen is formed, whereas lime or potash removes this same gas

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[2] Each part here is equivalent to 11.5 grams (3 *gros*.) The correct proportion of water is essential for the mixture to exert a strong effect on oxygen gas.

from them before its release. [*Lime and potash remove carbon dioxide before the plant has a chance to break it down and release the oxygen contained in it.*]

A superabundance of carbon dioxide gas is much more harmful to plants growing in nitrogen gas than to ones growing in ordinary air. I have said elsewhere that carbon dioxide gas mixed in the proportion of one-twelfth with atmospheric air, in which I grew pea plants in the sun, favored their development. It did not harm marsh plants in the same circumstances. But marsh plants were never able to tolerate this mixture, in the proportions indicated, with pure nitrogen gas. They died there in a few days, as did the pea plants. The elaboration of a certain amount of oxygen gas thus appears necessary for the elaboration of a certain amount of carbon dioxide gas. Carbon dioxide always becomes harmful to plants when they cannot decompose it.

Priestley believed that he had found that some plants have the ability to absorb the nitrogen gas in which they are growing. He reported that an *Epilobium hirsutum* plant, **[p. 206]** placed in a receptacle 10 inches high and 1 inch wide, absorbed, after a month, seven-eighths of the atmospheric air that it contained.[3]

Ingen-Housz did not limit this faculty to a small number of plants. He observed[4] that all the plants grown in nitrogen gas caused an appreciable decrease in the amount of this gas in a few hours. I followed, with great care, the growth of *Epilobium hirsutum*, both in ordinary air and in pure nitrogen gas, using the procedures indicated by Priestley for this experiment,[5] and prolonging it greatly, but I did not see any decrease in the nitrogen gas after the removal of the oxygen gas that was formed there. It was the same with all the other plants that I tested **[p. 207]**. Thus plants do not condense nitrogen gas appreciably. The experiments of Senebier and Woodhouse confirm this assertion.

If nitrogen is a simple substance, if it is not an element of water, we are forced to recognize that plants assimilate it only from plant and animal extracts and from ammonia vapors,[6] or from other water-soluble compounds that they can absorb from the soil and atmosphere. We must acknowledge that when they grow in an unrenewed atmosphere, with the aid of a small amount of pure water, the parts that develop obtain nitrogen only at the expense of the nitrogen that the other parts of the plant contained before the experiment.

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[3] *Experiments and Observations on Different Kinds of Airs*, Vol. 3, p. 332.

[4] *Expériences sur les Végétaux*, Vol. 2, p. 146.

[5] The procedure consists of planting the plant in a pot full of plant mold, submerging this pot and the origin of the stem in water underneath the shelf of a basin, and covering the rest of the plant with a receptacle full of air. The plant then undergoes much greater development than it does when it has its roots in pure water. For this reason, I was obliged to replace the plant several times.

[6] The presence of ammonia vapors in the atmosphere cannot be doubted, when we observe that pure aluminum sulfate [*"sulfate of alumina"*] is eventually converted, in the open air, into ammonium aluminum sulfate [*"ammoniacal sulfate of alumina"*]. The superiority of animal manures to plant manures seems, in large part, due only to a greater proportion of nitrogen in the former.

6.3 Of Plant Growth in Carbon Monoxide [*"oxide of carbon"*] Gas[7] (Berthollet's oxycarburetted hydrogen) [p.208]

I prepared this gas by distilling, in a gun barrel, at a red heat, a mixture of equal parts calcite ["*calcareous spar*"] and iron filings. The gaseous fluid that was obtained after having been freed of carbon dioxide contained 1/100 oxygen, which I removed by potassium sulfide [*"hydrosulfide of potash"*].

Plants grew in the carbon monoxide gas as in nitrogen gas. Those lacking green parts died in it. The growth of developed pea plants languished in it in the sun **[p. 209]** and could not maintain itself in the shade. *Epilobium hirsutum*, *Lythrum salicaria*, and *Polygonum persicaria* thrived in it as in ordinary air. After having grown in this gas for 6 weeks, in the sun, they had not decomposed it. They had increased its volume, as they had that of nitrogen gas, by a corresponding amount of oxygen gas. In total darkness, they increased this atmosphere by carbon dioxide gas.

6.4 Of Plant Growth in Hydrogen Gas

All of the seeds that I tested, without exception, failed to germinate in hydrogen gas, when placed in it with a small amount of water. Senebier observed that they bring about a very considerable reduction in the volume of this gas, by putrefying. The gaseous fluid that is a residue of this condensation is carbon monoxide gas. The carbon dioxide gas that the seeds form from their own substance is decomposed by the hydrogen gas, with the aid of the caloric **[p. 210]** disengaged in fermentation. Water forms, and the carbon dioxide, freed of a part of its oxygen, is converted into carbon monoxide gas.

Green plants grow in hydrogen gas very nearly as they do in nitrogen gas. Plants that languish in nitrogen gas also languish in hydrogen gas, and those that thrive in nitrogen thrive in hydrogen. If there is some difference in the vigor of plants growing in these two gases, it seemed to me that it was in favor of growth in nitrogen gas. Plants grown in hydrogen gas have been said to develop a darker green color, but I did not notice this effect.

I consistently observed that marsh plants, such as *Lythrum salicaria* and *Polygonum persicaria*, that I grew in the sun for 5 or 6 weeks in hydrogen gas left little or no oxygen gas there, whereas in the same period in nitrogen gas they always left fifteen or twenty times their volume of oxygen gas. This result is very likely due to the fact that, in hydrogen gas, the plants cannot completely decompose **[p. 211]**

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[7] The idea that hydrogen is an essential component of oxide of carbon gas may be based on evidence that is still too indirect to be recognized as certain.—I will note, however, in favor of oxycarburetted hydrogen, that it is odd that plants do not decompose carbon monoxide gas and that they never reduce carbon dioxide into carbon monoxide gas directly, or without the presence of hydrogen gas. [*Even after it was established that hydrogen was not a component of this gas, Berthollet continued to believe that it was*.]

all the carbon dioxide gas that they form there, because a large part of this carbon dioxide is itself decomposed by the hydrogen gas. As I have already observed, water and carbon monoxide gas are the products of this decomposition. The oxygen gas that the plants would have emitted without the hydrogen gas is concealed in these two compounds. One hundred parts (60 cubic inches) of hydrogen gas that had served as atmosphere for 5 weeks to a *Lythrum salicaria* plant exposed to the sun could not be diminished appreciably by nitric oxide. The gaseous fluid then contained no carbon dioxide, but when I ignited it by an electric spark, with the correct proportion of oxygen gas, it left a residue of water, 3 parts carbon dioxide gas, and 4 parts nitrogen gas. Hydrogen gas in which there had been no plants and that had been placed alongside the preceding, under the same conditions, did not produce a detectable amount of carbon dioxide gas when burned.

The volume of the atmosphere of the *Lythrum* decreased during growth, but to the same degree as hydrogen gas that was confined **[p. 212]** by water[8] and not in contact with *Lythrum*. Considering that this plant formed carbon monoxide gas and that the addition of this gas was not detectable through an increase in the volume of the gaseous fluid contained by the receptacle, there must have been a compensation here, and the hydrogen gas was diminished by the effect of the plant growth. It does not appear that the plants absorbed this gas. They condensed it by forming water through an indirect route.

6.5 Of Plant Growth in a Vacuum

In the vacuum produced by the best air pumps, some seeds may give signs of the beginning of germination. This result is not surprising, as it has been shown that this vacuum cannot **[p. 213]** be complete, and because, moreover, even the most perfect of these machines are never joined exactly enough to prevent the ingress of external air entirely. The pump that I used produced a vacuum in which the barometer at first stayed at 3/4 of a line, when there was no water in the receptacle. In 24 hours, it climbed by 1 line, through the imperceptible introduction of external air. Peas germinated in it after 12 days, even when I renewed the vacuum every day, but the development never went beyond the first appearance of the radicle.

Fully developed, leaf-bearing pea plants, as well as favas and haricots, always died after 3 days in a vacuum, either in the sun or in the shade. They also perished in nitrogen gas in the shade, but they often survived in it in the sun. No thin-leaved plant seemed to me able to maintain its growth in a vacuum in the sun. The thickest joints or leaves of *Cactus opuntia* survived more than a month in a vacuum in the sun. Only their epidermis dried out, in part. After this experiment, these leaves regained

[8] For a year I kept hydrogen gas in a receptacle containing water and resting on mercury. The water absorbed approximately its own volume of gas, but no more. When I withdrew the metallic fluid, there was no limit to the absorption of the hydrogen gas by the water. It is quite probable that, as Guyton conjectured, this gas was released by the water to the atmospheric air.

their vigor **[p. 214]** when I planted them in plant mold. The thinnest cactus leaves were dead after several days in a vacuum in the sun.

A one-foot-tall *Polygonum persicaria* plant, with its roots immersed in 1 ounce of water, was placed in the vacuum that I mentioned and that I renewed each day. The plant elongated several inches. It was only withdrawn after 6 weeks, as healthy as it was before the experiment except for two or three leaves that had yellowed, in the vicinity of the roots. I obtained the same results with *Epilobium molle*, *E. hirsutum*, *Lythrum salicaria*, and *Inula dysenterica*. All of these plants thrived as well in a vacuum as under a receptacle full of ordinary air. Their transpiration was the same in both cases.

The experiments just described were carried out in full daylight but protected from the direct effects of sunlight. The plants wilted as soon as they were exposed to it, even if the rays were weak and produced no effect on similar plants confined in receptacles filled with ordinary air or pure nitrogen gas. **[p. 215]** It is likely that plants survive in a vacuum only with the aid of the oxygen gas trapped in their parenchyma, and that the sun harms the plants in expelling this gas by the expansion it causes in the gas. Solar rays do not exert the same effect on plants in nitrogen gas because the oxygen gas that the plants contain is compressed by the full weight of the atmosphere.

Plants do not seem to survive and develop in a vacuum, except with the aid of the oxygen gas eliminated by their green parts. Seeds that have only their radicles die in it. Woody plants in the springtime were unable to open their leaf buds in it.

The buds of rose, lily, and carnation were as if paralyzed there. It is evident that, in many respects, plants behave in a vacuum as in nitrogen gas, hydrogen gas, etc. The suppression of the weight of the atmosphere, or the expansion that the plant necessarily undergoes by this suppression, does not appear to have a very appreciable effect on its growth. Only the removal of oxygen gas is harmful to it.

6.6 Summary [p. 216]

Only plants provided with their green parts seem to be able to grow in oxygen-free environments, because these plants release this gas there. When this gas is removed as the plants form it, their development is arrested. The amount of oxygen gas that some require to survive, without developing, is inappreciable.

Plants do not absorb nitrogen gas. Neither do they absorb hydrogen gas. They reduce the amount of the latter a little, but this decrease occurs because the hydrogen gas decomposes the carbon dioxide gas formed by the plant. The result of this decomposition is water and carbon monoxide gas.

The green parts emit less oxygen gas in hydrogen gas than in nitrogen gas.

Green plants growing in carbon monoxide gas in the sun do not decompose this gas. They add oxygen gas to it.

Green plants grow in the vacuum produced by an air pump as in nitrogen gas, provided that the experiment takes place away from direct sunlight.