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A UNIVERSAL LAW.[1]

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Now that we appreciate fully that physics, geology, engineering, physiology, medicine, botany, zoology, and biology are subdivisions of the broader science of chemistry, we see that the chemist of the future must know a great deal more than any of us now do, if he is to keep in touch with the whole subject. Many people believe that this is impossible and that the scientific man of the future will be a narrow specialist, knowing only a small part of a single division of one science. I do not believe this. As we look back over the history of any science, we see always two opposing tendencies, one that complicates and one that simplifies. The discovery of new facts makes a subject more complex and more difficult to grasp. The discovery of new relations simplifies matters because it enables us to correlate facts and thus to get a better grasp of the subject.[2]

In the chemistry of to-day we have three, great, simplifying generalizations which are familiar to all of you: the atomic theory, the periodic law, and the phase rule. These have long since proved their value as a means of correlating facts and as working hypotheses enabling us to predict new facts. The value of these is not great, however, when we get beyond what is called chemistry in the narrower sense of the word.

As one universal law we have the great, simplifying generalization known as the Law of the Conservation of Energy. The marvelous effect of this in enabling one to correlate and remember apparently unrelated facts was brought out in a most striking way in Kundt's lectures on physics.

[1] Presidential address delivered at the Minneapolis meeting of the American Chemical Society, December 28, 1910.

[2] Cf. Bancroft, *J. Elisha Mitchell Soc.*, 20, 39 (1904).

I wish to call your attention to-night to what I believe to be another universal law, a qualitative one and not a quantitative one. The chemists call it the Theorem of Le Chatelier. The physicists call it the Theorem of De Maupertuis or the Principle of Least Action. By the biologists it is known as the Law of the Survival of the Fittest, while the business man speaks of the Law of Supply and Demand. The broadest definition of it is that a system tends to change so as to minimize an external disturbance.

In chemistry proper and in physics we study chiefly the effects of temperature, pressure, concentrations, electricity, and light; but in the natural history sciences we must also take account of moisture, food and fertilizers, secretions, climate, etc.

If we heat a liquid we convert a portion of the liquid into vapor, an operation which absorbs heat. If we heat a saturated solution, the solubility increases if the solid dissolves with an absorption of heat. If we increase the pressure on a dissociating compound or if we increase the concentration of the dissociation products, we get a decrease of dissociation which involves a decrease in pressure and a decrease in the amount of the dissociation product. If we pass an electric current through a solution, we tend to get a counter-electromotive force which cuts down the electrical stress. If we have suspended particles in a liquid, a difference of potential causes them to move in the direction which reduces the electrical stress. Since all substances absorb light of some wave length to a greater or lesser extent, all substances are light-sensitive to some rays and tend to change in such a way as to eliminate the strain caused by the light. Whether any measurable change takes place, depends on other conditions. With some silver salts or with Eder's solution of mercuric oxalate, we get visible decomposition. With chromium salts we get no measurable change unless some reducing agent is present. With some substances we get fluorescence or phosphorescence but ordinarily without apparent change. With copper sulfate solution there is apparently no effect due to light. Yet all these solutions are really light-sensitive and they all tend to change in the same way, namely, to eliminate the substance which absorbs the light.

In the business world, continuous over-production of any commodity necessitates a fall in the price of the article. Also, a sufficiently widespread and prolonged decrease in the demand for meat will bring down the price, at least temporarily. This may not help the consumer, because he may have to pay more for fish, eggs, and vegetables; but that is not our problem.

If one should ship enough copper abroad as export copper and should bring it back as ballast, one would create a state of strain which would eventually play havoc with the price of copper. It is said that this experiment was tried when the price of copper was over twenty cents; but the details have never been published. Over-production of silver destroyed the ratio of sixteen to one, while over-production of gold is now said to be one of the factors in the high cost of living.

In physiology and medicine we find many illustrations of our law. "When irritating substances get into the eye, a flow of tears occurs to wash them away; from the nose and respiratory passages, they are ejected by sneezing or by cough; and from the stomach or intestines, they are removed by the vomiting and purging to which they themselves give rise."[1]

If a splinter lodges in one's finger and is not removed, festering occurs and the splinter is sloughed out. The throwing off of a cold is merely the elimination by the system of the disturbing factors and the same may be said about the recovery from any disease. Herter[2] says that "disease is generally the expression of a reaction on the part of the cell to injurious influences."

When studying chemical reactions, we find some cases, such as the inversion of sugar, in which the reaction products have little or no effect on the reaction. In many other cases, the reaction may come to an end if the reaction products are not removed. In these latter cases the reaction products might be said to be toxic to the system. Analogous cases occur in physiology. Some secretions or reaction products are not toxic to the system while others are. Brunton[3] says that "cells excrete poisons formed within their bodies... [and that] an excessive quantity of their own products is usually injurious to cells." We all know that the waste products of digestion must be removed from the intestines periodically or poisoning will ensue, and we also know that the system tends to react in such a way as to remove these products.

In the cases thus far considered, it has been fairly clear what the response of the system would be; but this is not always so. If a man goes out into the street and slaps another man's face, he creates a state of strain, which may be relieved by the other man's running away. It is quite possible, however, that the other man may knock the first man down, or he may hand the first man over to a policeman, if one happens to be near. What happens depends on the relative sizes and temperaments of the two men and on the nearness of the policeman. We cannot make A, B, and C represent the first man, the other man, and the policeman, and then interchange the letters. We have the same thing in mixtures of three liquids. If we add one liquid to another, we always lower the vapor pressure of the second to a certain extent. We cannot

[1] Brunton, *St. Louis Congress of Arts and Sciences*, 6, 176 (1904).

[2] *Chemical Pathology*, 2 (1902).

[3] *St. Louis Congress of Arts and Sciences*, 6, 174 (1904).

make any such definite statement about what will happen if we add a third liquid to the other two. The addition of the third liquid may decrease the partial pressures of both the other liquids or it may decrease the partial pressure of either one and increase that of the other. We must know the specific properties of the liquids before we can predict what will happen.

We know that an irritating substance is often removed from the stomach by vomiting; but if we administer poison continuously for a long time, the system tends to eliminate the irritating effect by becoming immune to the poison. We need not hark back to the mythical case of Mithridates who qualified for the throne by living on all the known poisons while young. The case of the arsenic eaters is better authenticated.[1] The whole of immunochemistry is an illustration of the applicability of our law.[2]

The most interesting field for the study of our law is to be found in the natural history sciences. Here we must consider the survival of the race as well as the survival of the individual or we shall make serious mistakes. Thus plants and trees often flower at an abnormal time after receiving serious injury.[3] This is really one form of tendency to eliminate the disturbing factor. One should also distinguish between the direct injury to the plant or animal and the change in the organism which enables it or its descendants to withstand the disturbing influences.

A great deal has been done in the way of collecting facts illustrating the effect of environment on plants and animals; but the real reason for any particular change is rarely given,[4] and the change is only too often the resultant of two or more factors which are not differentiated carefully. I am going to cite some cases in which the application of the Theorem of Le Chatelier is quite clear, and also others which seem interesting enough to warrant attention being called to them.

Pressure and Concentration.

The wind blows against the trees and the boughs bend so as to spill the wind. A prevailing wind from a given direction causes the trees to assume a permanent set. This is not especially interesting because this change is probably not inherited to any appreciable extent.

Bailey[5] has pointed out that plants tend to become circular instead of bilateral, because they are sessile. "They, therefore, found it to their advantage to reach out in every direction from their support in the search for food. While the centrifugal arrangement has strongly tended to

[1] Brunton, *St. Louis Congress of Arts and Sciences*, 6, 177 (1904).

[2] Cf. Le Dantec, *La Stabilité de la Vie*, 25 (1910).

[3] Cf. Möbius, *Lehre von der Fortpflanzung der Gewächse*, 6, 122 (1897).

[4] Cf. Bailey, *The Survival of the Unlike*, 32 (1896); McDougal, *Memoirs N. Y. Bot. Garden*, 2, 1 (1903); Crozier, *The Modification of Plants by Climate* (1885); Eimer, *Organic Evolution* (1890).

[5] *The Survival of the Unlike*, 15 (1896).

disappear in the animal creation, it has tended with equal strength to persist and to augment itself in the plant creation. Its marked development among plants began with the acquirement of terrestrial life, and with the consequent evolution of the asexual or sporophytic type of vegetation. Normally, the higher type of plant bears its parts more or less equally upon all sides, and the limit to growth is still determined by the immediate environment of the given individual or of its recent ancestors. Its evolution has been acephalic, diffuse, or headless, and the individual plant or tree has no proper concentration of parts. For the most part it is filled with unspecialized plasma, which, when removed from the parent individual (as in cuttings or grafts), is able to reproduce another like individual. The arrangements of leaves, branches, the parts of the flower, and even of the seeds in the fruit, are thus rotate or circular, and in the highest type of plants the annual increments of growth are disposed in like fashion; and it is significant to observe that in the compositae, which is considered to be the latest and highest type of plant-form, the rotate or centrifugal arrangement is most emphatically developed. The circular arrangement of parts is the typical one for higher plants and any departure from this form is a specialization, and demands explanation."

In England, rabbits are held in check, though with some difficulty. If the repressive factors are removed, as in Australia, the rabbits adapt themselves to the situation and multiply so as to become a veritable pest. In the same way the Russian thistle spread through the Northwest some years ago. An insect will often adapt itself to changed conditions to such an extent as to take on new habits.[1] "An early naturalist, traveling in Colorado, found a striped beetle feeding upon wild solanums or nightshades. The insect came to be in demand among collectors, and it is said that handsome prices were paid for specimens for museums. In the course of time the settlers grew potatoes in Colorado and the insect took a fancy to them and spread rapidly. It is now known as the Colorado potato-beetle. The first attacks were noticed about thirty years ago, but now the insect is a serious pest wherever potatoes are grown in quantity."

The displacement of equilibrium due to cultivating large areas to one crop has led to an enormous increase in the number of insects and fungous enemies in any given region.[2]

"The excessive ravages of insects in the United States are largely owing to the cultivation of their food-plants in extended areas. Two hundred years ago not even the wild crab, the earliest representative of the apple, existed in this country, and consequently there were no

[1] Cf. Bailey, *The Survival of the Unlike*, 184 (1896).

[2] Lintner, *First Report State Entom. N. Y.*, 10 (1882).

apple insects. Later when a few apple trees became the adjunct of the simple homes of the early settlers, those of our insects to which they offered more desirable food than that on which they had previously subsisted were obliged to wing their way often for many miles in search of a tree on which to deposit their eggs. If birds were then abundant, how few of the insects could accomplish such extended flights! But in the apple orchards of the present day—some of them spreading in almost unbroken mass of foliage over hundreds of acres—our numerous apple insects may find the thrifty root, the vigorous trunk, the succulent twig, the tender bud, the juicy leaf, the fragrant blossom, and the crisp fruit spread out before them in broad array, as if it were a special offering to insect voracity, or a banquet purposely extending an irresistible invitation.....Careful cultivation has made it the best of its kind; appetite is stimulated; development is hastened; broods are increased in number; individuals are multiplied beyond the conservation of parasitic destruction; facilities of distribution are afforded with hardly a proper exercise of locomotive organs; and when these almost useless members have become absorbed, as in the wingless females of the bark-louse and the canker-worms, the interlocking branches afford convenient passage from tree to tree."

As Bailey[1] says: "We, as horticulturists, are every year planting new invitations to insect and fungous attacks. If we take this extra risk, we must certainly prepare ourselves to meet it. Our fathers' weapons cannot avail against the horde of invaders which we are inviting to our doors. They are coming up out of the woods and the swamps and the bare fields to regale themselves at the banquet which we have spread.

"*Cultivation affords places of less struggle than organisms are forced to occupy under normal conditions.* Man disturbs the equilibrium or removes the pressure in some direction, and a multitude is waiting to spring into the void. The great potato fields not only provided food, but there were few other insects to dispute the possession of them; the Colorado solanum beetle saw his opportunity, and improved it. He has been a successful bug. This release of the natural tension, which cultivation affords, is to my mind the most potent factor in the increase of our little foes."

Temperature.

One effect of a lower temperature is obviously to produce a better protective coating on animals, while a higher temperature acts in the opposite way. I quote a few special cases from Darwin.[2]

"According to Roulin, the semi-feral pigs in the hot valleys of New Granada are very scantily clothed; whereas on the Paramos, at the height

[1] *The Survival of the Unlike*, 187 (1898).

[2] *Animals and Plants under Domestication*, 2nd Ed., 1, 81, 95, 102 (1890).

of 7000 to 8000 feet, they acquire a thick covering of wool lying under the bristles, like that on the truly wild pigs of France."

"Roulin asserts that the hides of the feral cattle on the hot Llanos are always much less heavy than those of the cattle raised on the high platform of Bogota; and that these hides yield in weight and in thickness of hair to those of the cattle which have run wild on the lofty Paramos. The same difference has been observed in the hides of cattle reared on the bleak Falkland Islands and on the temperate Pampas."

"Great heat seems to act directly on the fleece: several accounts have been published of the change which sheep imported from Europe undergo in the West Indies. Dr. Nicholson, of Antigua, informs me that, after the third generation, the wool disappears from the whole body, except over the loins; and the animal then appears like a goat with a dirty door-mat on its back. A similar change is said to take place on the west coast of Africa. On the other hand, many wool-bearing sheep live on the hot plains of India. Roulin asserts that in the lower and heated valleys of the Cordillera, if the lambs are sheared as soon as the wool has grown to a certain thickness, all goes on afterwards as usual; but if not sheared, the wool detaches in flakes, and short shining hair like that of a goat is produced ever afterwards. This curious result seems merely to be an exaggerated tendency natural to the Merino breed, for, as a great authority, namely Lord Somerville, remarks, 'the wool of our Merino sheep after shear time is hard and coarse to such a degree as to render it almost impossible to suppose that the same animal could bear wool so opposite in quality, compared to that which has been clipped from it; as the cold weather advances, the fleeces recover their soft quality.' As in the sheep of all breeds the fleece naturally consists of longer and coarser hair covering shorter and softer wool, the change which it often undergoes in hot climates is probably merely a case of unequal development, for even with those sheep, which like goats are covered with hair, a small quantity of underlying wool may always be found. In the wild mountain sheep (*Ovis montana*) of North America there is an analogous change of coat;[1] the wool begins to drop out in early spring, leaving in its place a coat of pelage quite different in character from the ordinary thickening—for instance in the horse, the cow, etc., which shed their winter coat in the spring."

The fact of there being wool-bearing sheep in the hot plains of India is not necessarily a contradiction of the general law, because the tendency to change may be counteracted by careful selection.[2] "M. Lasterye, after discussing this subject, sums up as follows: The preservation of the Merino race in its utmost purity at the Cape of Good Hope, in the

[1] Audubon and Bachman, *The Quadrupeds of North America*, 5, 365 (1846).

[2] Darwin, *Animals and Plants under Domestication*, 2nd Ed., 1, 103 (1890).

marshes of Holland, and under the rigorous climate of Sweden, furnishes an additional support of this my principle, that fine-wooled sheep may be kept wherever industrious men and intelligent breeders exist."

If we remove a plant to a climate where frosts occur earlier, the chances are very good that the plant will be killed before the seeds ripen. If the variety is to survive, an early-ripening form must develop. This actually happens with wheat.[1]

"Wheat quickly assumes new habits of life. The summer and winter kinds were classed by Linnaeus as distinct species; but M. Monnier has proved that the difference between them is only temporary. He sowed winter-wheat in the spring, and out of one hundred plants four alone produced ripe seeds; these were sown and resown, and in three years plants were reared which ripened all their seed. Conversely, nearly all plants raised from summer-wheat, which was sown in autumn, perished from frost; but a few were saved and produced seed, and in three years this summer-variety was converted into a winter-variety. Hence it is not surprising that wheat soon becomes to a certain extent acclimatized, and that seed brought from distant countries and sown in Europe vegetates at first or even for a considerable period, differently from our European varieties. In Canada the first settlers, according to Kalm, found their winters too severe for winter-wheat brought from France, and their summers often too short for summer-wheat, and they thought that their country was useless for corn crops until they procured summer-wheat from the northern part of Europe, which succeeded well."

Another interesting case is that of corn, also cited by Darwin.[2] "The tall kinds grown in southern latitudes, and therefore exposed to great heat, require from six to seven months to ripen their seed; whereas the dwarf kinds, grown in northern and colder climates, require only from three to four months. Peter Kalm, who particularly attended to this plant, says, that in the United States in proceeding from south to north, the plants steadily diminish in bulk. Seeds brought from lat. 37° in Virginia, and sown in lat. 43°–44° in New England, produce plants which will not ripen their seed, or ripen them with utmost difficulty. So it is with seed carried from New England to lat. 45°–47° in Canada. By taking great care at first, the southern kinds after some years' culture ripened their seed perfectly in their northern homes, so that this is an analogous case with that of the conversion of summer- into winter-wheat, and conversely. When tall and dwarf maize are planted together, the dwarf kinds are in full flower before the others have produced a single flower, and in Pennsylvania they ripen their seeds six weeks earlier than the tall maize. Metzger also mentions a European maize which ripens

[1] Darwin, *Animals and Plants under Domestication*, 2nd Ed., 1, 333 (1890).

[2] *Animals and Plants under Domestication*, 2nd Ed., 1, 341 (1890).

its seed four weeks earlier than another European kind. With these facts so plainly showing inherited acclimatization, we may readily believe Kalm, who states that in North America maize and some other plants have gradually been cultivated further and further northward."

The peach tree offers another good instance of acclimatization.[1]

"Mr. Crozier records testimony to the effect that peach trees in Michigan were injured no more at a temperature of twenty degrees below zero than they were in central Mississippi at a temperature of zero. Peach buds are injured at a much higher temperature at the south than at the north. Mr. P. H. Mell, Jr., director of the Alabama Polytechnic Institute at Auburn writes me that buds are often killed even at a temperature of 34 to 38 degrees above zero. This observation undoubtedly refers to the partially expanded buds, yet it is well known that at the north a considerable frost is required to kill the swelling buds. It is possible that all these instances of the peach should fall under the division of adaptation through modification of individual constitution; but as I cannot be certain, if indeed it is probable, that all these cases represent bud offspring, I place the statement here. If trees of the same variety show this difference in different latitudes, as they undoubtedly often do, then we have indisputable evidence of the acclimatizing of the individual."

Bailey's quotation from Cooper as to watermelons also has a bearing on this matter.[2]

"A striking instance of plants being naturalized, happened by Colonel Matlack sending some watermelon seed from Georgia, which, he informed me [Cooper] by letter, were of superior quality. Knowing that seed from vegetables which had grown in more southern climates, required a longer summer than what grew here, I gave them the most favorable situation, and used glasses to bring them forward, yet very few ripened to perfection; but finding them to be so excellent in quality as described, I saved seed from those first ripe; and by continuing that practice four or five years, they became as early watermelons as I ever had."

Changes in the colors of some butterflies can be obtained by varying the temperature during the pupal stage of development. While we are not able to prove that these changes are beneficial adaptations, it is interesting to note that these changes characterize the same butterflies in arctic and tropic regions.[3]

"Warmth acting on pupae of *V. cardui* (painted lady), gave an extraordinarily pale form, like those found in very different parts of the tropics. Cold, on the other hand, gave specimens with a very recog-

[1] Bailey, *The Survival of the Unlike*, 325 (1896).

[2] *Ibid.*, 154 (1896).

[3] Vernon, *Variations in Plants and Animals*, 237 (1903).

nizable darkening of the whole insect, such as is exhibited by a form found in Lapland."

We have no clue[1] at all as to the influence a low temperature has upon the production of wings in *Aphides*. "As long as the temperature is high and the moisture sufficient, plant lice are wingless; but if the temperature be lowered, wings begin to grow." The problem is an interesting one and should not be difficult to solve with the aid of the Theorem of Le Chatelier.

Light.

Since light tends to destroy any substance which absorbs it, it seems at first sight as though transparent, colorless plants and animals would be the surviving type in the intense light of the tropics. Light does tend to bleach organic colors; but the flaw in the reasoning is that we are dealing with living organisms.[2] It is easier for a man or an animal to develop a pigmented coating and thus eliminate the chemical action of light on blood[3] than for it to acquire the habit of living without red corpuscles. It is evidently better for a plant to develop chlorophyll and a healthy appetite for carbon dioxide than for it to be bleached by the light.

"Consequently we find that man is invariably covered with a pigment which acts as an armor to exclude the more harmful short rays, and moreover the amount of pigment is in direct proportion to the intensity of the light of the country to which his ancestors have proved their adjustment by centuries or millenniums of survival in health and vigor. It is a simple matter of mathematics to show that the intensity of light under the zenith sun in the tropics is the greatest, and that the amount of rays per unit of surface diminishes as we go north in proportion to a function of the latitude. In addition to this, the further from the tropics we go the greater is the layer of air which the rays must pass through and the more of them which are absorbed. Hence we can reach a latitude where there is insufficient light for plant growth even if there could be sufficient warmth. Yet man flourishes in these regions, and so do other animals. Hence we find the greatest pigment in the tropics among the Australians, New Guineas, Negritos, East Indians, and African Negroes, some of whom are nearly jet-black. As we go north from the tropics we find the complexions gradually lightening, being dark brown in Egypt, light brown in North African States, deep olive in the Mediterranean, olive in southern Europe, brunette in Central Europe, and blonde in the northwestern section of Europe, embraced by a curve passing through Northern France, Northern Germany, and Northwest Russia.

[1] Loeb, *The Dynamics of Living Matter*, 112 (1908).

[2] Cf. Eimer, *Organic Evolution* 136 (1890).

[3] Cf. Woodruff, *Effects of Tropical Light on White Men*, 10, 85 (1905).

"Undoubtedly the negro, while in the shade, is able to radiate heat better than whites, and this enables him to keep cool in the tropics, but puts him at a disadvantage in the north where the white man can keep warmer with less clothing and less fire in the house. But it is a secondary cause enhancing the first, because when it comes to a question of light and cold, nature makes no mistakes, but selects a color able to exclude the light. Hence in all cold, light countries, *i. e.*, steppes, plains, and the arctics, there is a pigmentation of a color in the lower end of the spectrum, red or yellow, with variations of brown, olive or copper. As a rule the color is markedly light yellow in cold, light countries, as in North China.

"In America we had every shade from the blackest Indians of tropical South America through all the shades of copper and brown to the very light, almost white Indians of the northeastern part of the United States, who had conditions very similar to those suited for the blondes of Europe. In Italy, Spain, and China, we find the same thing, for the men of the south are markedly darker than those of the north.

"The same law holds in France, Germany, Russia, Persia, and India: the north is decidedly blonder than the south, and the same is found in the British Islands, but in a much modified way. Even the Ainos in the north of Japan are said to be lighter than the Japanese.

"All these red and yellow colors undoubtedly enable the native to conserve his heat almost as well as the white man, and at the same time exclude the dangerous short waves."

In Africa, Eimer[1] found that in passing up the Nile valley from the Delta to the Soudan, the natives gradually became more and more dark-skinned, the further south they lived.

Woodruff[2] recommends that white men in the tropics should wear white outer gaments and black underclothes, which constitutes a pretty fair imitation of a dark-skinned Arab in a white burnous.

Vernon[3] points out "that the diminution or disappearance of pigmentation following upon withdrawal of light is best illustrated by reference to the well-known cave animals. Of these, one of the most interesting is *Proteus anguineus*, which is found in the subterranean caves of the Karst mountains about Adelsberg. This amphibian is almost white, but if kept for some time in the light, it gradually becomes pigmented. Pigment cells are, in fact, still present in its skin, and in all probability these are directly stimulated to exert their function by the action of the light." If Vernon had been familiar with the Theorem of Le Chatelier, he would have worded this last sentence very differently.

In the case of heliotropism, the animals turn automatically to or from

[1] *Organic Evolution*, 88 (1890).
[2] *Effects of Tropical Light on White Men*, 321 (1905).
[3] *Variation in Animals and Plants*, 250 (1903).

the source of light, depending on whether they are positively or negatively heliotropic. In some cases they also move automatically towards or away from the light. Loeb[1] says in regard to this:

"This automatic orientation is determined by two factors, first a peculiar photo-sensitiveness of the retina (or skin), and second a peculiar nervous connection between the retina and the muscular apparatus. In symmetrically built heliotropic animals in which the symmetrical muscles participate equally in locomotion the symmetrical muscles work with equal energy as long as the photo-chemical processes in both eyes are identical. If, however, one eye is struck by stronger light than the other, the symmetrical muscles will work unequally and in positively heliotropic animals those muscles will work with greater energy which bring the plane of symmetry back into the direction of the rays of light and the head towards the source. As soon as both eyes are struck by the rays of light at the same angle, there is no more reason for the animal to deviate from this direction and it will move in a straight line. All this holds good on the supposition that the animals are exposed to only one source of light and are very sensitive to light."

Loeb[2] has also shown that the heliotropism may sometimes be modified or even reversed by adding certain chemicals to the water. He has also shown[3] that some animals seek automatically the places where the intensity of light is a minimum, but that this is not negative heliotropism because the animals do not necessarily move along the path of the ray. In all these cases we have an application of our law, because the animals arrange themselves so as to minimize the state of stress.

It had always seemed to me a most mysterious thing that animals should be heliotropic, until it finally dawned on me that we are all of us heliotropic to a certain extent. Place a man out in an intense light and, if he cannot shade his eyes, it will take a pretty strong special stimulus to keep him from turning his back to the light. If his eyes happen to be weak, he will respond more promptly and more automatically to the light. He is negatively heliotropic to strong light. I am inclined to think that man is positively heliotropic to a faint light, because he would certainly tend to turn towards the point that he could see. We can also find an analogy to the case of the animals which congregated at the places where the intensity of light is a minimum. Place a man out on the desert in blazing sunlight and it will take a strong counter-stimulus to keep him from moving into any shade that he can find. Here the irritation is due to heat and not to light; but the man is not negatively

[1] *Darwin and Modern Science*, 264 (1909).

[2] *The Dynamics of Living Matter*, 131 (1906); *Darwin and Modern Science*, 265, (1909).

[3] Loeb, *The Dynamics of Living Matter*, 136 (1906).

thermotropic because he will move across the temperature gradient in order to reach the shade.

Of course the reflex action is not relatively so powerful with man as with the lower animals. In fact, Loeb[1] says that "it rarely happens that animals endowed with the mechanisms of associated memory react in such a machine-like manner to the elementary forces of nature as the heliotropic animals which we have discussed."

Vernon[2] points out that "if plants be allowed to grow in absolute darkness, they, as a rule, become very much elongated in form while their leaves are small and ill-shaped.....Sachs found that potato tubers grown in darkness for fifty-three days produced sprouts from 150 to 200 mm. high, while similar ones grown in daylight were only 10 to 13 mm. high. Again he found that the hypocotyl of the buckwheat (*Fagopyrum*) reached a height of 35 to 40 cm. in the dark, while it grew only to 2 or 3 cm. when freely exposed to light. K. Goebel has shown that if cactuses are cultivated in darkness, their form changes completely. The young shoots are rounded, and fail to show the angular irregularities of form which increase the surface capable of effecting assimilation under the influence of light."

Since the leaves especially are effective in the light, the absence of light will prevent normal development of the leaves and this seems to be the chief direct effect. If the plant does not have to develop leaves to any extent, there is more food available for the stem and the growth of the stem is thus really a secondary effect. The matter is still further complicated by the fact that the moisture content and the carbon dioxide content of the air were not kept constant during the two sets of experiments.

An increase in the intensity of the light is often accompanied by a decrease in the surface of the leaf and an increase in the thickness.[3] I think that it is a mistake to attribute this change to the action of light alone. It is more the combined effect of light and dryness, or of light and the higher rate of evaporation due to a higher temperature. With decreased surface and greater thickness there is less evaporation, one extreme of which is reached in the eucalyptus with its leaves turned edgewise. The assimilation of food is provided for by an increased thickness of the chlorophyll layer, because the more intense light can penetrate farther into the leaf.

We have seen that the pigment in the negro's skin is essentially protective in action. A thicker or coarser leaf may also be a protection against too intense a light. Rowlee[4] found that "intense light does

[1] *The Dynamics of Living Matter*, 135 (1906).

[2] *Variation in Animals and Plants*, 245 (1903).

[3] Vernon, *Ibid.*, 248 (1903).

[4] *Proc. 19th Meeting Soc. Promotion Agr. Science*, Boston (1898).

not kill thick, coriaceous, or succulent leaves with heavy cutinized external walls. . .doubtless owing to the screening effect of the heavy walls of cells containing much water."

We have not sufficient data to make it possible to say why an increase in the intensity of light causes the change from sexual to asexual reproduction in some algae and the reverse change in others;[1] but we can be quite certain that both changes are in conformity with the Theorem of Le Chatelier.

Moisture.

Vernon[2] says that "the effect of a dry soil and atmosphere is well shown by the characters of desert plants. These are stunted in growth, and are of a nearly uniform gray color, owing to their intense hairiness. The leaves are more fleshy, and there is a great tendency to the formation of spines. That these characters are, in part at least, the direct result of want of water is shown by the fact that they may disappear if water is supplied." The development of hairs is of great advantage to a plant in an arid climate, especially if there is any wind. The circulation of air, and consequently the rate of evaporation is impeded by the mass of hairs.

We get characteristic changes when plants, normally terrestrial, are grown in water.[3] "As regards the leaves, it is well known that when aërial and floating leaves are present on the same aquatic plant, they differ greatly in structure, and as a rule also in form, from the submerged leaves. In *Ranunculus heterophyllus* and *Cabomba aquatica*, for instance, the floating leaves are more or less rounded, while the submerged ones have dissected and filiform segments. In *Hippuris* (mare's-tail), the aërial and floating leaves are short, and in *Callitriche* rounded, but the submerged leaves of both are linear or ribbon-like. In all cases the submerged leaves are of a more delicate texture, more or less translucent, and of a brighter green color than the others."

This is a much more complex case than Vernon realizes. Submerged leaves do not develop the supporting frame of the aërial leaves. The delicate texture is, therefore, to a great extent a result of the supporting power of the water and not of its wetness. Since the supporting structure of the aërial leaf is not developed when the leaf is submerged, the leaf grows longer, just as the stem of the plant grows longer in the dark, because the leaves develop but slightly. The thinness of the leaf is probably chiefly a result of the decreased intensity of light. This is the best analysis that can be given at present, but it brings out clearly how slack people have been in controlling conditions.

[1] Loeb, *Darwin and Modern Science*, 230 (1909).
[2] *Variation in Animals and Plants*, 263 (1903).
[3] Cf. Vernon, *Ibid.*, 266 (1903).

The effect of excessive moisture or aridity upon plants is similar in type[1] to the effect of heat or cold on the pupae of butterflies.

"The relation of leaf-form to environment has often been investigated and is well known. The leaves of bog and water plants afford the most striking examples of modifications: according as they are grown in water, moist or dry air, the form of the species characteristic of the particular habitat is produced, since the stems are also modified. To the same group of phenomena belongs the modification of the forms of leaves and stems in plants on transplantation from the plains to the mountains or *vice versa*. Such variations are by no means isolated examples. All plants exhibit a definite alteration in form as the result of prolonged cultivation in moist or dry air, in strong or feeble light or in darkness, or in salt solutions of different composition and strength."

The last sentence in the preceding paragraph is interesting for what it does not say. There is no indication that Klebs has any inkling of the universal law underlying all these changes.

Food and Fertilizers.

It seems evident that an exuberant growth would be favorable to variability and to the development of sports. This is universally recognized to be the case. Thus Darwin[2] says: "Of all the causes which induce variability, excess of food, whether or not changed in nature, is probably the most powerful. This view was held with regard to plants by Andrew Knight and is now held by Schleiden, more especially in reference to the inorganic elements of the food. In order to give a plant more food, it suffices in most cases to grow it separately, and thus prevent other plants robbing its roots. It is surprising, as I have often seen, how vigorously our common wild species flourish when planted by themselves, though not in highly manured land; separate growth is, in fact, the first step in cultivation. We see the converse of the belief that excess of food induces variability in the following statement by a great raiser of seeds of all kinds. 'It is a rule, invariably with us, when we desire to keep a true stock of any one kind of seed, to grow it on poor land without dung; but when we grow for quantity we act contrary, and sometimes have dearly to repent of it.' According, also to Carrière, who had great experience with flower-garden seeds, '*On remarque en général les plantes de vigeur moyenne sont celles qui conservent le mieux leurs caractères.*' "

Under the heading of effect of cultivation, Klebs[3] says: "It is however a fact that if a plant is removed from natural conditions into cultivation, a well marked variation occurs. The well-known plant breeder,

[1] Klebs, *Darwin and Modern Science*, 235 (1909).
[2] *Animals and Plants under Domestication*, 2nd Ed., 2, 244 (1890).
[3] *Darwin and Modern Science*, 245 (1909).

L. de Vilmorin, speaking from his own experience, states that a plant is induced to *affoler*, that is to exhibit all possible variations from which the breeder may make a further selection only after cultivation for several generations. The effect of cultivation was particularly striking in *Veronica chamaedrys*, which, in spite of its wide distribution in nature, varies very little. After a few years of cultivation this 'good' and constant species becomes highly variable. The specimens on which the experiments were made were three modified inflorescence cuttings, the parent plants of which certainly exhibited no striking abnormalities. In a short time many hitherto latent potentialities became apparent, so that characters, never previously observed, or at least very rarely, were exhibited, such as scattered leaf-arrangement, torsion, terminal or branched inflorescences, the conversion of the inflorescence into foliage-shoots, every conceivable alteration in the color of flowers, the proliferation of flowers."

One more quotation will suffice, this time from Bailey.[1]

"Now let us endeavor to put ourselves in nature's place, if such a conception is possible, and to briefly follow an outline of her methods with plants. We shall find that variation is largely the result, so far as we can see, of excess of food supply. The seedsman knows that heavy lands make his seed-crops break into non-typical forms, and he therefore prefers, for most plants, a soil not very rich in nitrogen or growth production. Heavy soils make the dwarf peas 'viney,' and bud sprouts of curious leaves and flowers are wont to appear upon over-vigorous shoots."

Since conditions which tend to shorten the life of a plant or tree often cause the plant or tree to flower,[2] it follows that conditions which favor a rank growth are likely to be disadvantageous to the production of flowers. This is actually the case.[3]

"One extreme case, that of exceptionally early flowering, has been observed in nature and more often in cultivation. A number of plants under certain conditions are able to flower soon after germination. This shortening of the period of development is exhibited in the most striking form in trees, as in the oak,[4] flowering seedlings of which have been observed from one to three years old, whereas normally the tree does not flower until it is sixty or eighty years old.

"Another extreme case is represented by prolonged vegetative growth leading to the complete suppression of flower production. The result may be obtained with several plants, such as *Glechoma*, the sugar beet,

[1] *The Survival of the Unlike*, 169 (1898).

[2] Möbius, *Beiträge zur Lehre von der Fortpflanzung der Gewächse*, 7, 125 (1897).

[3] Klebs, *Darwin and Modern Science*, 232, 246 (1909).

[4] Möbius, *Beiträge zur Lehre von der Fortpflanzung der Gewächse*, 89 (1897). [The conditions are not given by Möbius—W. D. B.]

Digitalis, and others, if they are kept during the winter in a warm, damp atmosphere, and in rich soil: in the following spring or summer they fail to flower. Theoretically, however, experiments are of greater importance in which the production of flowers is inhibited by very favorable conditions of nutrition occurring at the normal flowering period. Even in the case of plants of *Sempervivum* several years old, which, as is shown by control experiments on precisely similar plants, are on the point of flowering, flowering is rendered impossible if they are forced to very vigorous growth by an abundant supply of water and salts in the spring. Flowering, however, occurs, if such plants are cultivated in relatively dry soil and in the presence of strong light. Careful researches into the conditions of growth have led, in the case of *Sempervivum*, to the following results: (1) With a strong light and vigorous carbon-assimilation in strong light, a considerably increased supply of water and nutritive salts produces active vegetative growth. (2) With vigorous carbon assimilation in strong light, and a decrease in the supply of water and salts, active flower production is induced. (3) If an average supply of water and salts is given both processes are possible; the intensity of carbon assimilation determines which of the two is manifested. A diminution in the production of organic substances, particularly of carbohydrates, induces vegetative growth. This can be effected by culture in feeble light or in light deprived of the yellow-red ray; on the other hand, flower-production follows increase in light intensity. These results are essentially in agreement with well-known observations on cultivated plants, according to which, the application of much moisture, after a plentiful supply of manure composed of inorganic salts, hinders the flower-production of many vegetables, while a decrease in the supply of water and salts favors flowering."

"Good manuring is in the highest degree favorable to vegetative growth, but is in no way equally favorable to the formation of flowers. The constantly repeated expression, good or favorable nourishment, is not only vague but misleading, because circumstances favorable to growth differ from those which promote reproduction; for the production of every form there are certain favorable conditions of nourishment, which may be defined for each species. Experience shows that, within definite and often very wide limits, it does not depend on the *absolute amount* of the various food substances but upon their respective degrees of concentration. As we have already stated, the production of flowers follows a relative increase in the amount of carbohydrates formed in the presence of light as compared with the inorganic salts on which the formation of albuminous substances depends.[1] The various modifications of flowers are due to the fact that a relatively too strong solution

[1] Klebs, *Künstliche Metamorphosen*, 117.

of salts is supplied to the rudiments of these organs. As a general rule every plant form depends upon a certain relation between different chemical substances in the cells and is modified by an alteration of that relation."

Vernon[1] cites some interesting cases in which changes of diet have apparently produced results in accordance with our law.

"John Hunter observed a most marked thickening and hardening in the stomach of a gull (*Larus tridactylus*) which had been fed for a year on grain. It is stated by Dr. Edmonston that a similar change takes place under natural conditions every year in the stomach of the common herring gull (*Larus argentatus*). Thus in the Shetland Islands, this bird feeds in the winter on fish, but in the summer frequents the corn-fields and feeds on grain. Dr. Edmonston has also noticed a somewhat similar change in the stomach of a raven which had been fed for a long time on vegetable food. Again, Menetries found that in an owl (*Strix gallaria*) the effect of vegetable diet was to change the form of the stomach and make the inner coat leathery.

"The converse experiment of feeding graminivorous birds on a flesh diet has been made by Dr. Holmgren. By feeding pigeons on meat for a considerable time, he found that the gizzard gradually acquired the qualities of a carnivorous stomach. Again Delage fed a fowl for three years on meat, and found that the muscular substance of its gizzard was considerably decreased. All these results, though apparently so unequivocal, have not passed unchallenged; for G. Brandes[2] who fed both flesh-feeding birds on grain, and grain-feeders on flesh states that he was unable to trace any adaption to the altered conditions in either case."

Since these alleged changes are directly in line with the cases, previously quoted, of the changes in butterflies and bog plants, it seems probable that the negative results are due to error. It is very desirable, however, that this point should be settled definitely one way or the other.

A very complicated case of the effect of the environment, and one which I shall not attempt to account for, is cited by Poulton.[3]

"Entirely new light upon the seasonal appearance of epigamic characters is shed by the recent researches of C. W. Beebe,[4] who caused the scarlet tanager (*Piranga eythromelas*) and the bobolink (*Dolichonyx oryzivorous*) to retain their breeding plumage through the whole year by means of fattening food, dim illumination, and reduced activity. Gradual restoration to the light and the addition of meal-worms to the diet invariably brought back the spring song, even in the middle of winter. A sudden

[1] *Variation in Animals and Plants*, 295 (1903).
[2] *Biol. Centralblatt*, 16, 825.
[3] *Darwin and Modern Science*, 297 (1909).
[4] *The American Naturalist*, 42, 34 (1908).

alteration of temperature, either higher or lower, caused the birds nearly to stop feeding, and one tanager lost weight rapidly and in two weeks moulted into the olive-green winter plumage. After a year, and at the beginning of the normal breeding season, 'individual tanagers and bobolinks were gradually brought under normal conditions and activities,' and in every case moulted from nuptial plumage to nuptial plumage. 'The dull colors of the winter season had been skipped.' The author justly claims to have established that the sequence of plumage in these birds is not in any way predestined through inheritance...., but it may be interrupted by certain factors in the environmental complex."

Secretions.

Under physiology and medicine mention has previously been made that many organisms give rise to products which are toxic to the organism and which must be removed. Brunton[1] points out that "an excessive quantity of their own products is usually injurious to cells and too much alcohol will stop the growth of yeast. At the same time these products are frequently very nutritious for cells of a different sort and alcohol furnishes a most suitable pabulum for the organisms which produce vinegar. Vinegar in its turn is toxic to the microbe which produces it, but serves again as a soil for another which gives rise to a viscous fermentation. By the successive action of these ferments a solution of sugar may produce, first, alcohol, secondly, vinegar and thirdly, ropy mucus. In this particular series each microbe produces a substance injurious to itself but useful to its successor. This is, however, not always the case, because a cell may produce a substance not only injurious to itself but injurious to other cells, and alcohol in large quantity not only kills the cells of yeast, but other cells as well. Similar conditions occur within living organisms where the cells composing the different parts are connected together and pass on the products of their life from one cell to another by means of the circulation of the blood and tissue juices. The secretions of one part may be, and indeed generally are, useful to other parts of the organism and so long as no part sins, either by deficiency or excessive action, the whole organism maintains a condition of health. But this is not always the case and health may be destroyed by (*a*) excessive, (*b*) defective, or (*c*) prevented action of one or more of the parts composing the body."

Vernon[2] has tested the influence of the excreta of adult echinoids upon larval growth. "Echinoids of known weight were kept for a known time in a known volume of water, so that on determining the absolute effect produced on larvae grown in this water it was possible to calculate the relative effect produced by unit weight of echinoids kept for unit

[1] *Darwin and Modern Science*, 174 (1909).

[2] *Variation in Animals and Plants*, 298 (1903).

time in unit volume of water. On growing larvae in water previously fouled by adult echinoids of their own species, it was found that, as a means of five observations, they were diminished in relative size by 2.6 per cent., while only 41 per cent. of the ova employed reached the larval stage. On growing them in water fouled by echinoids of other than their own species, the larvae, as a mean of five observations, were diminished by only 1.9 per cent., while 54 per cent. of the ova reached the larval stage; that is to say, the products of excretion of an echinoid act more adversely both on the death-rate and on the growth of embryos if these belong to its own species than if they belong to another species. At least this is the case with *Strongylocentrotus*, *Sphaerechinus*, and *Echinus*. With two other (physiologically) less closely related species, *viz.*, *Arbacia pustulosa* and *Dorocidaris papillata*, it was even found that the products of excretion, so far from acting adversely on growth, actually favored it. Thus *Strongylocentrotus* larvae grown in water fouled by these two species were increased in size by respectively 4.3 and 1.7 per cent., while respectively 81 and 50 per cent. of the ova employed reached the pluteus stage."

Vernon[1] points out also that "De Varigny actually found that snails grown in water in which other snails had already been growing several months were distinctly smaller than those grown in fresh water, and if the excreta of snails had been added as well, they were smaller still."

The experiments of Warren[2] show that water fouled by *Daphnia* becomes specifically injurious to *Daphnia*, "for when the *Daphnia* are fast disappearing, there may be a swarm of ostracods or copepods (still living healthily in the water)."

If we were to reason from these facts to the behavior of crops, such as wheat for instance, we should conclude that wheat unquestionably secretes substances which are toxic to itself and that the development of that crop or of a subsequent one would depend in part on the degree of the accumulation of the toxic substances in the soil. If the toxic substances were removed or destroyed sufficiently rapidly, no deleterious result would occur, but, otherwise, there would be one. We should also conclude that the secretions from the wheat would not necessarily be toxic to other crops. These *a priori* predictions seem to be confirmed by the facts.

Cameron[3] points out that "it has been found that as a general rule the continued growth of one crop in any soil results in a low crop production. Pot cultures have given even more pronounced results in the same direction. The explanation long accepted is that the soil has, as a result of

[1] *Variation in Animals and Plants*, 305 (1903).

[2] Vernon, *Ibid.*, 309 (1903).

[3] *J. Phys. Chem.*, 14, 425 (1910).

the continued cropping, become deficient in one or more of the 'available,' mineral nutrients. Pot experiments, where the garnered crop was returned to the soil and still diminished yield was obtained, throw doubt on this explanation. Still further doubt results from water cultures which, by growing a crop in them, become 'poor' for subsequent crops, although there is maintained in them an ample supply of mineral plant nutrients, and they are easily renovated by good adsorbers. These facts find a more satisfactory explanation as being due to the production in the nutrient medium of deleterious organic substances originating in the growing plant itself. This idea seems to have been advanced first by De Candolle, in 1832, to account for the beneficial results obtained by employing a rotation of crops. It appears to have been held by Liebig at one time, although he subsequently abandoned it in favor of the view that the benefits of a crop rotation are due to the several crops requiring different proportions of mineral nutrients, that the disturbance of the balance in the soil produced by one crop is not unfavorable to the growth of some other crop. Although lacking direct experimental confirmation, this latter view of Liebig's has long prevailed among agricultural investigators, partly by reason of his authority, partly by reason of the dominance of the plant-food theory of fertilizers, and partly by reason of the fact that the ideas of De Candolle, as originally advanced, include certain errors soon detected. The trend of recent investigations has been distinctly in favor of a modified form of the view of De Candolle. It has been recognized that other factors enter into crop rotations such as the elimination of associated weeds, various kinds of animal, insect and plant parasites, preparation of the soil by a deep-rooted crop for a shallow-rooted following crop, etc. It has come to be recognized that there are natural associations of plants and natural rotations of vegetation certainly determined by other than plant-food factors. Thus, in the eastern United States, wheat is followed by ragweed naturally, while across the fence cocklebur and wild sunflowers come in after the corn, the difference in vegetation being as sharply marked after the removal of the crops as when they still occupied the land. Analyses of the ragweed, for instance, although it is a shallower rooted crop than wheat, show that it takes from the soil as much of the mineral nutrients as does the preceding wheat crop. The investigation of Lawes and Gilbert on fairy rings showed that the continual widening of the rings cannot be satisfactorily explained by the comparison of the mineral constituents in the soil within and without the rings. Work at Woburn on the effect of grass on apple trees finds no other plausible explanation than that the growing grass produces in the soil organic substances detrimental to young apple trees. A number of similar cases have been recorded."

Climate.

When seeds are planted in a new locality, a great many conditions are varied simultaneously and it is difficult, usually impossible, to tell to what extent each factor causes the changes that actually take place or why any given change is beneficial. If we compare two varieties of the same plant, it seems reasonable to suppose, unless proof to the contrary is given, that the local variety is fairly well adapted to the local conditions, in which case one would expect the foreign variety to vary towards the local one. Darwin[1] cites a case of this sort.

The effect of the climate of Europe on the American varieties [of maize] is highly remarkable. Metzger obtained seed from various parts of America, and cultivated several kinds in Germany. I will give an abstract of the changes observed in one case, namely with a tall kind (*Breit-körniger Mais*, *Zea altissima*) brought from the warmer parts of America. During the first year the plants were twelve feet high, and a few seeds were perfected; the lower seeds in the ear kept true to their proper form, but the upper seeds became slightly changed. In the second generation the plants were from nine to ten feet in height, and ripened their seed better; the depression on the outer side of the seed had almost disappeared, and the original beautiful white color had become duskier. Some of the seeds had even become yellow and in their now rounded form they approached common European maize. In the third generation nearly all resemblance to the original and very distinct American parent-form was lost. In the sixth generation this maize perfectly resembled a European variety, described as the second sub-variety of the fifth race. When Metzger published his book, this variety was still cultivated near Heidelberg, and could be distinguished from the common kind only by a somewhat more vigorous growth..."

Bailey[2] draws the following conclusion in regard to American fruits and American climate. "American fruits constantly tend to diverge from the foreign types which were their parents, and they are, as a rule, better adapted to our environments than foreign varieties are. In less than a century we have departed widely from the imported varieties which gave us a start. At the expiration of another century we should stand upon a basis which is nearly if not wholly American."

Darwin[3] notes a similar case. "Mr. Meehan has compared twenty-nine kinds of American trees with their nearest European allies, all grown in close proximity and under as near as possible the same conditions. In the American species he finds, with the rarest exceptions, that the leaves fall earlier in the season and assume before their fall a brighter

[1] *Animals and Plants under Domestication*, 2nd Ed., **1**, 340 (1890).

[2] *The Survival of the Unlike*, 319 (1898).

[3] *Animals and Plants under Domestication*, 2nd Ed., **2**, 271 (1890).

tint; that they are less deeply toothed or serrated; that the buds are smaller; that the trees are more diffuse in growth and have fewer branchlets; and, lastly, that the seeds are smaller—all in comparison with the corresponding European species. Now considering that these corresponding trees belong to different orders, and that they are adapted to widely different stations, *it can hardly be supposed that their differences are of any special service to them in the New and Old Worlds;*[1] and, if so, such differences can not have been gained through natural selection, and must be attributed to the long-continued action of a different climate."

As a matter of fact, most of these changes are just what would be beneficial in a country having a hot, dry summer with a relatively long winter. If planted in a very moist place, the American elm develops some of the characteristics of the English elm.

Woodruff[2] has pointed out one marked case of adaptation to climate. "The shape and size of the nose and position of the nostrils are now fairly well proved to be a matter of selection of fittest variations. In the tropics where the air is hot and therefore rarefied, more of it is necessary and it is essential that there should be no impediment to the air currents, so that the nostrils are open and wide and the nose very flat. Such a nose is unsuited for cold countries as it permits masses of cold air to flood the air passages and irritates the lining membrane, so that the nose must be large and have much warming surface, and the nostrils therefore are slender slits to admit the air in thin ribbons easily warmed. The air being cold is concentrated, and less of it is needed than in the tropics and the slender nostril is no disadvantage. The nasal index or extreme width of nose divided by the extreme length, gradually increases as we go to warmer countries, where we find some races with nose index much greater than one thousand, *i. e.*, width greater than length. It is now many years since it was first pointed out that the open tropical nostril was one reason for so much pulmonary trouble of negroes out of the tropics. Hence there must have been a natural selection in cold countries of one kind of variations—large concentrated noses, and a selection in hot countries of the other extreme, so that the various types gradually arose.

"The great Biblical Pharaoh Rameses II had a prominent slender nose not now found in any Egyptians, and it is a positive proof of the recent arrival of some ancestor from the north. He was like Lord Cromer —a northern type ruling a native type."

Allen[3] has called attention to a correlation between climate and the color of birds. "The increase in color towards the south coincides with

[1] [The italics are mine.—W. D. B.]

[2] *Effects of Tropical Light on White Men*, 4 (1905).

[3] Vernon, *Variation in Animals and Plants*, 327 (1903).

the increase in the intensity of the sun's rays and in the humidity of the climate. The increase in color observed in birds on passing from east to west (in the United States) seems also to coincide with an increase of humidity, 'the darker representatives of any species occurring where the annual rainfall is greatest, and the palest where it is least.' This coincidence occurs not only in the birds of the United States to such a degree that Allen says he knows of no exception, but in Europe also. Thus birds from the Scandinavian coast are very much darker than in central Europe where the rainfall is only half as great. Allen says that this correlation of brighter and deeper tint with increased humidity is exhibited by the mammals of these districts, as well as by the birds."

Nonadaptability.

While the Theorem of Le Chatelier enables us to account for the direction of a change, it does not tell us whether a given stimulus will actually produce a change or under what condition the change will be a maximum for the same stimulus. We can make a fair guess at the answer by studying ourselves. We know that, as we get older, our tendency to resist change increases; our habits of body and mind become more fixed. We should, therefore, be tempted to conclude that the resistance to change increases as the organism becomes mature and that a given stimulus would probably have the most effect if applied at or before the earliest stages of development. The following quotation from Vernon[1] would seem to indicate that this was often true.

"Due reflection, will, I believe, incline one to infer that what is true for echinoid larvae is true for most multicellular organisms. In fact, it would seem to be a law of general application that the permanent *effect of environment on the growth of a developing organism diminishes rapidly and regularly from the time of impregnation onwards.*

"It is curious that this principle, enunciated by the author in 1900, should have been laid down by De Vries only a few months later, as the result of his observations on plants. Thus, judging from the effects of nutrition (manuring, planting out, good light and watering), he concluded that: (1) the younger a plant is, so much the greater is the influence of external conditions on its variability. (2) The nutrition of the seed, when developing on the maternal plant, has—at least very often—a greater influence on the variability than nutrition during its germination and later growth."

If the pressure on a liquid is made less than the vapor pressure for that liquid at that temperature, some of the liquid vaporizes, the temperature falls, and the liquid may be said to adapt itself to the new conditions. What would happen if the liquid were not adaptable? The easiest way to obtain a nonadaptable liquid is to place a Bunsen burner

[1] *Variation in Animals and Plants*, 199 (1903).

under it. The temperature rises until the boiling point is reached. The liquid then ceases to be adaptable. It volatilizes, it disappears, it becomes extinct so far as that particular region or flask is concerned. If a species cannot adapt itself to changed climate or other conditions, it does not volatilize; but it disappears, it becomes extinct. It may be a new point of view to consider the extinction of the mastodon as analogous to the distillation of water; but the two cases are really parallel, except in time.

It should be kept in mind that nonadaptability is not the only cause for extinction. A species might have enormous potential adaptability; but it would become extinct if the death-rate were too high in comparison with the rate of adaptation. This principle is made use of in the fight against weeds.[1]

"Weeds, like other plants, grow where they can find room; and the more room any plant can find, other things being the same, the farther and more rapidly it will spread over the earth. But room, used in this connection, does not mean, entirely, space vacant of other plants, but rather conditions of competition into which the given plant can fit itself with prosperity. Ground may be covered with a given plant, and yet a species of wholly different character and habits may thrive along with it. This is well illustrated in the growth of twining or climbing vines in dense thickets of shrubbery, or the practice, common even with the Indians, of growing pumpkins in cornfields. If weeds, then, are to be kept out of grounds, the land must not only be occupied with some other crops, but with a crop which will not allow the weed to grow along with it. In practice, it is impossible to select all crops from plants which so completely encumber the ground that no intruder can find a foothold; but this disadvantage is readily and almost wholly overcome by means of the rotation of crops—one crop in the rotation destroying what weeds may have crept in with the preceding ones. Thorough cropping of the land and judicious rotation of crops, therefore, are conditions against which no weeds can stand; and as these are the vital conditions, also, of successful agriculture, it may be said that weeds are never serious when lands are well farmed.

"The daisy-cursed meadows of the east are those which have been long mown and are badly 'run,' or else those which were not properly made, and the grass obtained but a poor start. The farmer may say that the daisies have 'run out' the grass, but the fact is that the meadow began to fail, and the daisies quickly seized upon the opportunity to gain a foothold; and just so long as the farmer persists in his accustomed methods, will the daisies usurp the land. The weedy lawns are those which have a thin turf, and the best treatment is to scratch the ground

[1] Cf. Bailey, *The Survival of the Unlike*, 194, 196 (1896).

lightly with an iron-toothed rake, apply fertilizer and sow more seed; in other words, augment the struggle for existence, and the weeds will go down before the June grass, and the grass plants themselves, because of the greater numbers, will be more slender and will make a softer turf."

Attitude of Biologists.

It may be asked to what extent biologists make use of the Theorem of Le Chatelier as a working hypothesis in studying the effect of external conditions. So far as I can learn, nobody makes any active use of it, and many biologists would deny the applicability of the theorem.

Darwin[1] began by attributing very little to the direct action of the climate, etc.; but later he stated that more weight should have been allowed to the direct action of the environment, *i. e.*, food, climate, etc., independently of natural selection. He says[2] that it is "probable that variability is directly or indirectly caused by changed conditions of life. Or to put the case under another point of view, if it were possible to expose all the individuals of a species during many generations to absolutely uniform conditions of life, there would be no variability." In spite of this he states[3] explicitly that long-continued action of a different climate has produced differences in American trees which are of no especial service to them.

Nägeli's[4] "extensive cultural experiments with alpine *Hieracia* led him to form the opinion that the changes which are induced by an alteration in the food-supply, in climate or in habitat, are not inherited and are, therefore, of no importance from the point of view of the production of species."

De Vries[5] is distinctly not prepared to admit that mutations are described by the Theorem of Le Chatelier.

"The origin of new species, which is in part the effect of mutability, is, however, due mainly to natural selection. Mutability provides the new characters and new elementary species; natural selection, on the other hand, decides what is to live and what to die. Mutability seems to be free, and not restricted to previously determined lines. Selection, however, may take place along the same main lines in the course of long geological epochs, thus directing the development of large branches of the animal and vegetable kingdom. In natural selection it is evident that nutrition and environment are the main factors. But it is probable that, while nutrition may be one of the main causes of mutability, environment may play the chief part in the decisions ascribed to natural selection. Relations to neighboring plants and to injurious or useful

[1] Cf. Schwalbe, *Darwin and Modern Science*, 125 (1909).
[2] Darwin, *Animals and Plants under Domestication*, 2nd Ed., 2, 242 (1890).
[3] Darwin, *Ibid.*, 2nd Ed., 2, 271 (1890).
[4] Cf. Klebs, *Darwin and Modern Science*, 225 (1909).
[5] *Darwin and Modern Science*, 77 (1909).

animals have been considered the most important determining factors ever since the time when Darwin pointed out their prevailing influence."

There is nothing very definite to be obtained from Klebs.[1]

"The dependence of *variable internal* on *variable external* condition gives us the key with which research may open the door. In the lower plants this dependence is at once apparent, each cell is directly subject to external influences. In the higher plants with their different organs, these influences were transmitted to cells in course of development along exceedingly complex lines. In the case of the growing point of a bud, which is capable of producing a complete plant, direct influences play a much less important part than those exerted through other organs, particularly through the roots and leaves, which are essential in nutrition. These correlations, as we may call them, are of the greatest importance as aids to an understanding of form-production. When a bud is produced on a particular part of a plant, it undergoes internal modifications induced by the influence of other organs, the activity of which is governed by the environment, and as the result of this it develops along a certain direction; it may, for example, become a flower. This particular direction of development is determined before the rudiment is differentiated and is exerted so strongly that further development ensues without interruption, even though the external conditions vary considerably and exert a positively inimical influence; this produces the impression that development proceeds entirely independently of the outer world. The wide-spread belief that such independence exists is very premature and at all events unproven.

"The state of the young rudiment is the outcome of previous influences of the external world communicated through other organs. Experiments show that in certain cases, if the efficiency of roots and leaves as organs concerned with nutrition is interfered with, the production of flowers is affected, and their characters which are normally very constant undergo far-reaching modifications. To find the right moment at which to make the necessary alteration in the environment is indeed difficult and in many cases not yet possible. This is especially the case with fertilized eggs, which in a higher degree than buds have acquired, through parental influences, an apparently fixed internal organization, and this seems to have predetermined their development. It is, however, highly probable that it will be possible, by influencing the parents, to alter the internal organization and to switch off development on to other lines."

Bailey is quite clear that the environment has a marked effect upon plants; but he is very far from formulating that effect, as the following quotations will show.[2]

[1] *Darwin and Modern Science*, 228, 235, 242 (1909).

[2] Bailey, *The Survival of the Unlike*, 32, 309 (1896).

"These differences [between individual plants] arise as a result of every impinging force—soil, weather, climate, food, training, conflict with fellows, the strain and stress of wind and wave, and insect visitors—as a complex resultant of many antecedent external forces, the effects of crossing, and also as the result of the accumulated force of mere growth; they are indefinite, non-designed, an expression of all the various influences to which the passive vegetable organism is or has been exposed; these differences which are most unlike their fellows or their parents find the places of least conflict and persist because they thrive best, and thereby impress themselves best upon their offspring."

"It is not too much to ask of climatology that it shall tell us why the northern climates develop saccharine elements and high colors, and why the Wisconsin-Minnesota area produces such remarkable waxen and pruinose tints. The influence of the climate is nowhere so easily traced, perhaps, as in the business of seed-growing. Every seedsman knows that certain climates are not only adapted to growth of certain seed crops, but that they exert a profound influence upon the character of the product grown by them. The study of all these inter-relations of climate and plant life falls into three subjects: Phenology, or the study of the periodic phenomena of plants, a subject which loses half its value when considered, as it usually is, without reference to the visible attending features of climate; acclimatization, or a consideration of the means by which plants adapt themselves to climates at first injurious; and secondary variations of plants induced by climate environment.

"The burden of my plea is twofold: First, while not discouraging the instrumental or conventional study of climate, I would encourage its study in terms of plant life. Second, it is essential that the synchronisms of local climate and the phenomena of plants be given the closest attention."

Sedgwick[1] is quite clear as to the direction of the changes; but I cannot see that he makes any actual use of this as a working hypothesis.

"It is a property of living matter to react in a remarkable way to external forces without undergoing destruction. The life-cycle, of which the embryonic and larval periods are a part, consists of the orderly interaction between the organism and its environment. The action of environment produces certain morphological changes in its organism. These changes enable the organism to come into what is practically a new environment, which in its turn produces further structural changes in the organism. These in turn enable, indeed necessitate, the organism to move again into a new environment, and so the process continues until the structural changes are of such a nature that the organism is unable to adapt itself to the environment in which it finds itself. The

[1] *Darwin and Modern Science*, 177 (1909).

essential condition of success in this process is that the organism should always shift into the environment to which the new structure is suited—any failure in this leading to the impairment of the organism. In most cases the shifting of the environment is a very gradual process (whether consisting in the very slight and gradual alteration in the relation of the embryo as a whole to the egg-shell or uterine wall, or in the relations of its parts to each other, or in the successive phases of adult life), and the morphological changes in connection with each step of it are but slight. But in some cases jumps are made such as we find in the phenomenon known as hatching, birth, and metamorphosis. This property of reacting to the environment without undergoing destruction is, as has been stated, a fundamental property of organisms. It is impossible to conceive of any matter, to which the term living could be applied, being without it. And with this property of reacting to the environment goes the further property of undergoing a change which alters the relation of the organism to the old environment and places it in a new environment."

This quotation is not what we want, because Sedgwick is considering the life-cycle of an individual, which is not our problem at all. It is good as far as it goes, however, and it is the best that I have been able to find.[1]

We get the opposite extreme with Bateson,[2] who says:

"To those who have made no study of heredity it sometimes appears that the question of the effect of conditions in causing variation is one which we should immediately investigate, but a little thought will show that before any critical inquiry into such possibilities can be attempted, a knowledge of the working of heredity under conditions as far as possible uniform must be obtained."

The cap seems to fit and I am quite ready to put it on. Bateson's argument is simply that a change due to reversion might be interpreted as due to a change in environment. This is a possible source of error, but it is one which can be eliminated by making enough experiments and by making experiments with different species of plants. It is hardly conceivable that a reversion to an albino variety, for instance, should coincide with a given change of environment in every experiment and with every kind of plant. On the other hand, it is always a good plan to do the easiest things first, partly because it takes less time to get results, but chiefly because the easy things usually throw light on the hard ones. We know that suitable changes in the environment, if made at a suitable time, will cause such changes in the organism that the next generation differs from the first. It is a very difficult problem to determine the intermediate steps; but it is a relatively simple one to de-

[1] Cf. also Bourne, *Science*, **32**, 738 (1910).

[2] *Darwin and Modern Science*, 95 (1909).

termine what change in the second generation is the result of a change in a single factor of the environment. This is a problem, which has not been attacked by the biologist in any systematic fashion, and it is a problem which will be greatly simplified by an intelligent application of the Theorem of Le Chatelier.

The view of the biologists seems to be that each generation always varies spontaneously from the preceding one to a greater or lesser extent, and that these variations are reproduced more or less completely in the succeeding generation. By the survival of the fittest we eventually get a race which is better adapted to the local conditions than the one from which we started.

The view that I have outlined is that the external conditions tend to produce such changes in the organism that the next generation varies in such a way as to be more adapted to local conditions. By the survival of the fittest and by the continued action of the external conditions, we eventually get a race which is better adapted to the local conditions than the one from which we started.

We reach the same conclusion whichever way we consider the matter. The two views are not mutually exclusive because it is quite possible to consider the variations due to the external conditions as superimposed on the spontaneous variations. If we are to decide between the two points of view, it must be on other grounds than qualitative results. To me, the phrase 'spontaneous variation' seems merely another way of expressing our ignorance. I do not believe in a variation without a cause. If we go back far enough, all variations must be the result of varying external conditions and the real problem is to show what part of any given variation in any given organism is due to the effect of external conditions on the preceding generation and what part is due to the effect of external conditions on still earlier generations. What we study under heredity, as the word is usually used, is the transmitted effect of varying external conditions upon the more or less remote ancestors.

Another objection to the biologist's point of view is that it has not worked out well practically. Being obsessed by the idea of spontaneous variation, he has very rarely taken the trouble to work out carefully the relation between each particular factor of the external conditions and the acquired characteristics of the organism which has become better adapted to its surroundings. If the biologist had had the Theorem of Le Chatelier as a guiding hypothesis, he would not have made this mistake and he would often have done better and more careful work.

I have tried to show that the Theorem of Le Chatelier is a universal law and that it is consequently of great value in enabling us to correlate old facts and to discover new ones.

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