a relation that the energy of atomic motion was concentrated on one electron and thus made possible its escape. However, the electrons are more probably in orbits in the atoms and the flexibility of this type of binding, coupled with the experimentally observed fact that the orbital momentum of electrons in atoms is not manifested in ionization processes,[31] makes it difficult, if not impossible, to explain the facts in a simple mechanical fashion. We can only conclude that there exists a mechanism in atoms which in *rare collisions by means of the interactions of the electrons in the atoms enables the relative energy of the atoms to be transferred to one of the electrons.*

The presence of a positive charge on one of the two colliding atoms at low velocities should affect the ionization by such a mechanism but slightly. As Franck[1] has stated it increases the energy necessary to cause ionization, as with the charged atom the electron must escape against an attractive charge of two units instead of one. Besides this minor influence the charge plays an important indirect rôle, in low velocity phenomena, in that it enables a molecule or atom to acquire its ionizing energy from an electrical field, an energy which it otherwise would practically never acquire at room temperatures as a result of the heat motions. Such an atom or molecule having acquired the energy through its charge is then able to ionize molecules itself, or perhaps is able by impact to impart its energy to a neutral molecule which can ionize slightly more effectively. In any case whatever its manner of producing ions, the function of the charge is but indirect enabling the ion *to acquire energy. It has little to do with the subsequent mechanism of removal of electrons* by the ion, thus clearly differentiating its ionizing mechanism from that of swiftly moving charged particles.

It is also conceivable that one ion may ionize by any two or even all three mechanisms simultaneously, although at high speeds the preponderating mechanism for an ion with electrons will be processes of Class 1, while as it slows down the processes of Class 2 and 3 will entirely predominate. At intermediate speeds probably all mechanisms are active and thus lead to some of the apparently contradictory results obtained.

We thus see that in terms of the three different mechanisms, the outstanding conflicting observations can be simply explained and it is seen that there is no essential contradiction even between the extreme views of Thomson and Franck; for we have seen that neither a proton nor a doubly charged helium atom can ionize below certain minimum velocities as classical theory demands that they should not, while hydrogen atoms, singly charged helium atoms and neutral helium atoms can be expected to ionize at low velocities albeit very ineffectively.

LEONARD B. LOEB

PHYSICAL LABORATORY,
THE UNIVERSITY OF CALIFORNIA

[31] Watson, E. C., *Phys. Rev.* 30, 479, 1927.

SPECIAL ARTICLES

CORRELATION BETWEEN ELECTROMOTIVE SERIES AND OXIDATION POTENTIALS AND PLANT AND ANIMAL NUTRITION

IN studying the distribution and the dominance of pasture plants, it was observed that there is a definite correlation between the dominance of certain pasture plants and the natural or native vegetation. An attempt was made to correlate the growth and dominance of the various plants with the soil acidity, but it was soon found that there is no very close correlation between acidity of the soil and the dominance of certain types of pasture plants.

Since no very definite correlation was found between the acidity of the soil and the growth and dominance of certain plants, an attempt was made to correlate plant growth with plant residues, particularly the basic nitrogenous materials, including ammonia, amines, etc., and here again only a partial correlation was found between the availability of the basic nitrogenous organic residues and plant growth.

The nitrogen carbon ratio in the organic residues probably affects the mobility of the nitrogen in the soil. There is a difference in the nitrogen carbon ratio in various plant residues. The difference in the nitrogen carbon ratio in peat soils illustrates the points in question. It has been found that some peat soils have a nitrogen carbon ratio as narrow as 1: 8, while others have a ratio as wide as 1: 70 or wider. This difference in nitrogen carbon ratio undoubtedly affects the availability of anionic nitrogen. It has been found that there is a close correlation between the calcium oxide content and the width of the nitrogen carbon ratio in peat soils. Where the nitrogen carbon ratio is narrow, it indicates that there is a relatively large amount of high oxidation potential mineral basic material present. And in such a situation it has been found that there is often an accumulation of toxic amounts of nitrates. But when the nitrogen carbon ratio is wide it indicates that there is a limited amount of high oxidation potential mineral basic material present. And where such a condition prevails it may result in a prolonged nitrogen starvation period, especially early in the growing season. Where the nitrogen carbon ratio is very wide such plants as some of the conifers, poverty grass (*Danthonia spicata*), certain species of Agrostis, etc., which may readily utilize cationic nitrogen, are apt to dominate in nature. Other plants, such as certain species of oak, hickory, poa, etc., seem to grow best when supplied with anionic nitrogen. It is not possible at present to say whether anionic nitrogen determines the growth response of plants or whether it is the nutritional complex commonly associated with available anionic nitrogen. Wide nitrogen carbon ratios would very probably have much less effect upon the mobility of the cationic nitrogen from organic residues. The basic nitrogenous materials from such residues undoubtedly function similarly to mineral bases in the soil colloidal complex. These organic bases may partially satisfy the basic needs of the soil colloids, but the oxidation potential of such materials is apparently not sufficient to produce optimum growth of many plants. The low oxidation potential of basic organic materials may partially account for the lack of close correlation between the hydrogen-ion concentration of a soil solution and plant growth. The desirable crop sequence in rotations and the succession of native plants on abandoned crop land, as well as the succession of plants on virgin soil, is probably closely correlated with the ability of various plants to utilize cationic nitrogen or non-ionized nitrogenous materials. Basic material is very often the limiting factor in many of our depleted soils. Nature has an abundant potential supply of basic material in the nitrogen of the atmosphere, but apparently many plants can not readily utilize low oxidation potential cationic nitrogenous materials.

After failing to find sufficient correlation between the acidity of the soil and the availability of the basic nitrogenous organic residues to account for the difference in plant growth and associations, an attempt was made to correlate plant nutrition with the electromotive series and oxidation potentials. As life is probably dependent upon a difference in electrical potential it was believed that the electromotive series and oxidation potentials, which are the best single expressions of the properties of ions, would correlate with plant growth. The entire chemical activity of the metals corresponds fairly closely with the above series. Here we found a very striking correlation between the electromotive series and the absorption of plant nutrients. Indeed the electromotive series may be the key to many of the perplexing problems in plant and animal physiology. The various ions differ very much in the voltage they produce. Such ions as K, Na and Ca produce high voltages, other ions, such as Mg, Al, Mn, NH_4, amines and other basic nitrogenous materials, produce medium voltages, while still other ions, such as Fe, H. As, Cu, Hg, etc., produce very low voltages. Various plants and animals apparently tolerate different potential levels. Many crop plants, such as alfalfa, sweet clover, celery, barley, millets, asparagus, beets, etc., seem to be tolerant of very high electrical potentials as, for example, the potentials produced by high concentration of such ions as K, Na and Ca, often encountered in semi-arid to arid climates. Other plants, such as blackberry, blueberry, cranberry, raspberry, strawberry, oats, buckwheat, red top, cotton, sweet potatoes, watermelon, etc., grow well at relatively low potential levels as, for example, the potentials produced by high concentration of such ions as Mg, Al, Mn, NH_4, amines, protein acid salt ions, Fe, H. etc. It is evident that a given H-ion or OH-ion concentration resulting from the presence of various acidic or basic materials may produce different oxidation potential levels or physiological gradients. The gradients produced by such high potential materials as K, Na, Ca, etc., would be different from the gradients produced by such low potential materials as NH_3, amines, etc. Hence a close correlation between H-ion concentration and plant growth could not be expected.

Cropping may deplete various soil types until they reach approximately the same biological fertility level as, for example, the fertility level suited for the dominance of pine, etc. Since the accumulation of basic nitrogenous materials is one of the important factors in the natural restoration of the productivity of soils, it is evident that the climax vegetation on different soils would be different, depending upon the ability of the soil colloidal complex to retain organic bases. Mass action resulting from the accumulation of organic bases may make available mineral bases that have a higher oxidation potential. The capacity of the soil colloidal complex to retain the organic bases may partially determine the climax vegetation. The above condition is probably one of the important factors controlling the more or less definite plant successions in the depletion and the restoration processes of various soil types. Therefore, certain soil types can not be restored above the pine fertility level while others may be restored to levels suited to the various hard woods.

It has been possible to trace the influence of the oxidation potential levels from plutonic magmas to the various igneous rock, thence to the soil colloids, and finally through the plant to the animal. The ash of certain plants, such as alfalfa, sweet clover, foxtail millets, etc., grown in semi-arid to arid climates may contain very large amounts of potash. Ionic potassium may produce a very high voltage and it is, therefore, very readily absorbed by plants. Under certain conditions the rapid absorption of the potassium or similar ions may exclude or limit the absorption of other desirable nutrient cations. The feeding of large quantities of plants with high potash content may seriously affect animals. Another striking example of the effect of a high oxidation potential material is the probable correlation between high potash content in fertilizers and tip burn in lettuce on certain high lime peat soils. It is necessary to have liberal amounts of potash to produce a satisfactory lettuce head, but if excessive amounts are added there is great danger of tip burn developing and this may result in a loss of the entire crop.

Selective or differential absorption of nutrients by organisms is probably largely determined by the oxidation potential of the various ions. The electromotive series and oxidation potentials are probably the key to the interpretation of the important works on antagonism and selective absorption by W. M. Bayliss, C. M. Child, G. W. Crile, D. R. Hoagland, J. Loeb, M. M. McCool, W. J. V. Osterhout, W. Stiles and numerous other investigators.

The bimodal growth or production curve so frequently met with in plant and animal physiology is probably closely correlated with the electromotive series and oxidation potentials. The hydrogen ion with an ionic velocity nearly five times greater than any other common nutrient cation very probably determines the mode on the acid side of the neutral point, and the hydroxyl ion with an ionic velocity nearly three times greater than any other common nutrient anion determines the mode on the alkaline side of the neutral point. These two high velocity ions greatly influence the absorption of other ions, and are thus very important factors in regulating the growth or development of organisms.

This paper is an attempt to outline briefly the significance of the correlation between the electromotive series and the oxidation potentials, and the nutrition of plants and animals. A more comprehensive statement of the whole subject will be presented in a later paper. It is very clear from the preliminary correlations which have been made that the electromotive series and the oxidation potentials afford a new and an important approach to the whole field of biology. Electrochemistry has illuminated the subjects of chemistry and physics. It will do likewise in the field of biology, when the biologist begins to appreciate more fully the relationship between electrochemistry and vital phenomenon.

H. P. COOPER,
J. K. WILSON

CORNELL UNIVERSITY

INHIBITION OF ENZYMATIC ACTION AS A POSSIBLE FACTOR IN THE RESISTANCE OF PLANTS TO DISEASE[1]

SPECULATIONS and investigations on the nature of disease resistance in plants have occupied the minds and efforts of plant pathologists since the inception of the science of phytopathology in the classic work of de Bary.[2] Fragmentary as is the evidence for the correlation of specific factors with specific internal resistance of certain species or varieties to particular parasites, it is sufficient to indicate that ultimate elucidation will probably be found in the domain of biochemistry.

During the course of an investigation which seeks to throw some light on possible bases for the resistance of sour orange (*Citrus aurantium* L.) and for the susceptibility of lemon (*Citrus limonia* Osbeck) to the bark diseases known as *Pythiacystis gummosis* and *decorticosis,* it has been found that the trunk bark of sour orange has a much greater inhibitory or paralyzing influence on the action of certain enzyms found in the dried mycelial powder of the causal fungi than does the trunk bark of lemon. This suggests the possibility that resistance to the invasion of the pathogens may be due to the inhibition of one or more of the enzyms of the fungi by some cellular product of the host, and that a sufficient decrease in this paralyzing power might permit the hyphae to progress rapidly, as they do in the bark of the susceptible lemon, and successfully parasitize the host.

Table 1 shows that the hydrolytic action of the diastase and invertase found in the dried mycelium of both *Pythiacystis citrophthora* and *Phomopsis californica* was inhibited more by sour orange bark than by lemon bark. Bark of tangelo, a hybrid of pummelo and tangerine, which has been found by inoculation tests to be very resistant to Pythiacystis, showed about the same degree of inhibition of fungus diastase and ptyalin as sour orange did. It is not to be expected that all enzyms would be similarly affected. Urease in fact was not thus inhibited. Other enzyms are being tried.

The "cultures" were made by placing in a 200 ml. Erlenmeyer flask 20 ml. of the substratum, 500 mgm. of the bark and 250 mgm. or 5 ml. of the enzym source. One ml. of toluol was added as a preservative, the flasks tightly stoppered, and the "cultures" incubated in the dark for 36 to 48 hours at 40 degrees C. At the end of the incubation period the "cultures" were filtered and a 10-ml. portion of the filtrate placed in 25 ml. of solution A of Fehling's reagent to stop enzymic action. Reducing sugars were determined by the Shaffer and Hartmann iodometric method[3] and the results calculated as milli-

[1] Paper No. 173, University of California, Graduate School of Tropical Agriculture and Citrus Experiment Station, Riverside, California.

[2] Bary, A. de, "Ueber einige Sclerotinien und Sclerotienrankheiten," *Bot. Ztg.* 44: 377–381, 1 fig.; 393–404, 409–426, 433–441, 449–461, 465–474, 1886.

[3] Shaffer, P. A., and Hartmann, A. F., "The Iodometric Determination of Copper and its Use in Sugar Analysis," *Jour. Biol. Chem.* 45: 349–390, 1920.