desired, tube and sterilize at fifteen pounds steam pressure for fifteen minutes. Should serum cystin dextrose agar be desired, sterilize the medium in a flask at the above pressure for the same time, then cool to 50° C., add 5 per cent. sterile rabbit's blood serum, tube and slant.

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SPECIAL ARTICLES

THE EFFECTS OF INFRA-RED, VISIBLE AND ULTRA-VIOLET IRRADIATION ON CHANGES IN ELECTRICAL POTENTIALS AND CURRENTS IN PLANTS

MANY theories have been developed to account for the effects of ultra-violet and infra-red radiations on tissues. We cite: (1) the activation of cholesterol in the skin, (2) the ionization of calcium and phosphorus in superficial tissues, (3) the electrical modifications produced in the proteins of the skin and consequent changes in hydrogen-ion concentration and (4) the presence of fluorescing materials in the skin which may act as absorbers of energy of short wavelength with reemission in the form of energy of longer wave-length which, in turn, is utilized by the tissues either as heat or in chemical changes.

The skin is the medium which separates the organism, whether it be an animal or a plant, from its environment. The skin, therefore, is the medium of reception of radiant energy and the seat of transformation or utilization of the incident energy. Since no changes of a physical or chemical character are produced in cells, tissues or organisms unless there is an absorption of energy, and since protoplasm exercises a pronounced absorption of energy of short wavelengths (such as ultra-violet rays) and of the shorter infra-red radiations which lie close to the region of the visible spectrum, we have felt that an investigation of the electrical changes produced in the leaves of living plants under various types of selective radiation might give some information regarding the physical and chemical changes taking place in plant tissues when exposed to these various kinds of energy.

Potentiometric changes produced by artificial sources of radiant energy.—Sunflowers were used in general for experimental purposes outdoors during the summer; poinsettias were found satisfactory for indoor investigation during the autumn and winter months. Ordinarily electrodes of thin tinfoil were used and attached to the leaves or stems of plants by means of acid-free kaolin after the method of Sen. In investigating potentiometric changes in leaves, both before and after irradiation, one electrode was fastened near the base of the leaf and the other one was placed at or near the tip of the leaf. Leads were then carried to a Leeds and Northrup potentiometer, using a high sensitivity galvanometer. Various spectral filters, such as Corning Glass Company filters of special make and transmitting only infra-red, red, green, blue and ultra-violet rays and so forth, respectively, were employed. Infra-red energy of long and relatively short wave-lengths could be removed from the sources of illumination by water chambers of sufficient depth and possessing quartz bottoms. The visible and infra-red portions could be removed by water cells and solutions of certain substances or by special mediums transmitting selected portions of the ultra-violet light only. The artificial sources of energy used were infra-red generators and arcs rich in ultra-violet irradiation.

The data obtained during the last three years definitely show that marked changes in electromotive forces in leaves are produced by irradiation with infra-red and ultra-violet rays. The potential changes under heat rays from an infra-red generator are usually rapid and values as high as 0.3 volt change in potential have been obtained. The potential changes produced by irradiation with an air-cooled quartz-mercury lamp have been similar to and in the same direction as those produced with infra-red irradiation. The visible portions of the line spectrum of air-cooled quartz-mercury arcs operated at 90 volts did not produce changes, except possibly small changes in the region of the short visible waves (violet end of spectrum). Irradiation with quartz-mercury arcs from which the infra-red energy had been removed by suitable water filters, hence allowing the incidence of visible and ultra-violet rays only, produced potential changes in the same direction as those produced by infra-red rays and of an order ranging from 0.005 to 0.10 volts. These data show that potentiometric changes are produced by infra-red and ultra-violet irradiation.

Potentiometric changes produced by ionized gases near arcs.—Ozone and oxides of nitrogen produced by the quartz-mercury arc or by other metallic arcs, operating at high voltages, through which air was drawn, the ionized or nascent gases then being conducted through suitable channels to the container surrounding the leaf under test, showed marked potentiometric changes and in the same direction as the changes produced by infra-red or ultra-violet irradiation. These observations lend support to the theory which we are advancing that ionization, due directly to ultra-violet light or indirectly to the ionized condition of the gas (air) which forms the medium surrounding the leaf, is largely responsible for the potentiometric changes observed.

Potentiometric changes produced by sunlight.—During the summer of 1929 series of experiments were conducted in which observations, covering periods of eighteen to twenty-four hours, were made simultaneously on the relative humidity, temperature, electromotive force (voltage) and intensity of illumination of sunlight (foot-candles), using sunflowers which were living and growing outdoors. From the data obtained it is apparent that there is a close correlation between changes in temperature and differences in electromotive forces developed in the leaves of sunflowers. Auxiliary experiments, in which relative humidity and temperature could be kept constant while admitting sunlight through ordinary glass windows with southern exposures, were conducted on plants living and growing constantly indoors. These auxiliary experiments showed that there was a definite correlation between the intensity of solar energy incident on the leaf used and the potentiometric differences developed. The conclusion, therefore, apparently is warranted that the changes in electromotive force are dependent on the infra-red portion of sunlight. The absorption of solar infra-red radiations by the atmosphere and the earth's surface produces changes in temperature. Plants also absorb such infra-red radiation. As a result, therefore, it is not the direct influence of temperature as such, but the absorption of energy from a body (the sun), which is an efficient source of radiant energy at a high temperature, that causes changes in electromotive force.

Changes in electrical current.—Voltages from 22.5 to 45 volts were applied at the electrodes attached to a leaf and the currents read with a micro-ammeter. In general, the values of the currents were of the order of 25 to 50 millionths of an ampere, indicating that the resistances of the leaves were approximately a million ohms each. The currents, under such condition, fall away asymptotically with time. When the approximately steady state of electrical current was reached, leaves were irradiated successively with various portions of ultra-violet, visible and infra-red radiations. The experimental data show that both ultra-violet and infra-red rays (from sources of fairly high temperature radiation) produce increases of current or corresponding decreases of resistance, whereas various selective regions of visible light produce little if any change. There is evidence, therefore, that stimulation by ultra-violet and infra-red rays produces an increase in ions in the leaf and that there may be a change in permeability of membranes.

Spectrophotometric changes.—The spectrophotometer built by Keuffel and Esser was used in the study of the changes in color produced in leaves when exposed to radiation of various qualities and quantities. The type of water-cooled attachment, devised by Brunsting and Sheard, carrying the magnesium carbonate block which serves as a standard for reflection of light, was employed in this work because it enabled us to obtain spectrophotometric measurements from living leaves, intact with the plant, over as many periods and under as many conditions as desired.

After a few minutes' exposure of a given area (usually 2 by 4 cm) on a leaf (intact plant) to infra-red irradiation it was found that considerable darkening of the exposed area occurred shortly after irradiation. The degree of this darkening increased with time until it finally reached a steady state. Repeated exposures of various leaves of different plants to irradiation with red, yellow, green and blue portions of the visible spectrum did not produce changes in spectrophotometric reflection. Ultra-violet rays, especially those below the limit of sunlight (practically speaking, 300 millimicrons), produced a definite bronze or brown-black effect in general. Hence plants, as well as human beings, get a browned and darkened epidermis by exposure to ultra-violet rays. Microscopic examinations showed that these effects were accompanied with a breaking down of the outer layers of cells of the affected areas.

CONCLUSIONS

(1) Marked changes in the differences of potential between the base and tip of leaves intact with plants can be produced by ultra-violet and infra-red radiations.

(2) No change in differences of potential in intact leaves can be observed under irradiation by selected portions of visible light or by the total visible energy of sunlight, with the possible exception of energy possessing wave-lengths lying at the extreme violet and red ends of the spectrum.

(3) In general, the difference of potential between the base and tip of the leaf, when the plant is kept continuously in darkness or subdued daylight, is such that the base of the leaf is relatively positive with respect to the tip of the leaf. The greatest difference of potential (base positive and tip negative) arises when the plant is kept in darkness.

(4) Under high artificial illumination or under noon-day sunlight, when the plants are housed behind ordinary window glass, the difference of potential decreases and the tip of the leaf may become positive relative to the base of the leaf.

(5) Very marked and rapidly produced differences of potential in leaves may be obtained by exposing the leaf (with electrodes protected) to gases drawn from the vicinity of quartz-mercury or other metallic arcs.

(6) From the data obtained relative to humidity, temperature, foot-candles of illumination and potential differences in leaves of plants (sunflowers) growing outdoors, it is concluded that these electromotive forces between base and tip of leaves are due chiefly to infra-red radiations.

(7) When an external and constant electromotive force is impressed on the leaf across the two electrodes, the values of the currents in the circuit including the leaf are increased by either ultra-violet or infra-red radiation or the values of the resistances are decreased.

(8) No measurable changes in currents under an impressed electromotive force are produced in leaves when exposed to various regions of visible light.

(9) Leaves may be darkened or tanned by ultra-violet or infra-red radiations. The character of the bronzing or tanning effect is apparently somewhat different in the two cases. Both ultra-violet and infra-red rays, however, possess the ability to fix the chlorophyll in the tissues, probably by disruption of cells and localized dehydration of surface tissues.

(10) From these experiments and other investigations which have been conducted on germination of seeds, growth of plants and development of chlorophyll, we conclude that the phenomenon of growth is evidenced, in part at least, by changes in electromotive force, and is largely dependent on and stimulated by the ultra-violet and infra-red regions of sunlight. The visible portions of sunlight are used, in all probability, for the development of chlorophyll.

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THE MANGANESE CONTENT OF THE MISSISSIPPI RIVER WATER AT FAIRPORT, IOWA

THE fact that the normal growth of plants, in many instances, depends on the presence of small amounts of certain metals is fast becoming apparent. Felix (1927)[1] reported that the application of copper improved certain muck soils on which onions and lettuce were raised. Brenchley (1910)[2] found that manganese stimulated the growth of barley, and Deatrick (1919)[1] found that manganese prevented chlorosis in wheat.

It was with these results in mind that the writer undertook to investigate the manganese content of the Mississippi River water at Fairport, Iowa. The Mississippi River furnishes the water for the fish ponds at this place. It was thought that possibly manganese might be a limiting factor in the production of algae in the fish ponds.

In Table I are given the results of some manganese

TABLE I

SHOWING AMOUNT OF MANGANESE IN PARTS PER MILLION. THE LETTER S REFERS TO SURFACE SAMPLES, THE LETTER B TO BOTTOM SAMPLES

Date	Parts per million	Date	Parts per million
5/24/29	S. .044	9/21/29	S. .120
			B. .120
6/12/29	S. .106	9/27/29	S. .080
7/2/29	S. .055	10/5/29	S. .128
			B. .100
7/16/29	S. .075	10/12/29	S. .096
			B. .088
8/7/29	S. .114	10/19/29	S. .080
	B. .084		B. .072

determinations made during the summer of 1929. The results show that while the quantity varies considerably from time to time, there is always an appreciable amount of manganese present. It does, therefore, not seem likely that manganese was a limiting factor.

The results shown in Table I were obtained from samples of filtered water, and they presumably represent the manganese that was in solution and not the total manganese.

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[1] Raber, "Principles of Plant Physiology," Macmillan, 1928.

[2] *Ann. Bot.*, 24: 571, 1910.

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