servations. The saving of the investigator's time is apparent because it is possible subsequently to measure rates at intermediate intervals without repeating laborious numerical computations.

The instrument consists of a base cut out at the center to receive a flanged rotatable disk. The center disk is held in place by being bolted to the indicator, Fig. 1. The exact center of this disk is marked by

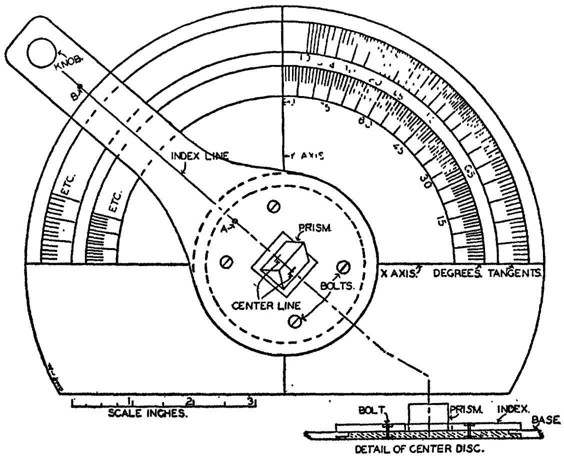

FIG. 1

crossed center lines on the under side, and an isosceles (or equilateral) triangular prism is placed odd face down on the upper side of the center disk in such a way that the lateral edge opposite the odd face is directly over the center. The main axis of the prism is perpendicular to the index line drawn on the under side of the indicator arm. A suitable opening for the prism should be cut through the indicator. All parts are made of transparent viscoloid.

The base is graduated with a protractor degree scale and with a tangent scale. Tangents to unity (45°) may be read directly to 2 parts in 100 and may readily be estimated to 1 part in 100. Above unity the magnitude of the tangents increases rapidly and the accuracy of the reading is proportionally less. The loss in accuracy does not appear greatly in the practical use of the instrument since many curves do not slope more than 60° and with greater slope the tangent may be obtained from the related function measured after the instrument has been rotated 90°. Increased accuracy may be obtained by increase in the size of the instrument and the number of divisions on the scales and by the use of a more transparent glass prism. When the slope of the curve is negative the tangent is read on the left-hand scale. (This scale is not completely illustrated in Fig. 1 because it is a mirror image of the scale on the right-hand side of the instrument.) The reading on the tangent scale is correct when the units of the abscissa and ordinate are equal; in other cases the readings must be multiplied by an appropriate factor.

To use the tangent meter place the crossed center lines directly over the point on the curve where the slope is to be measured, make the x- or the y-axis of the instrument parallel to the same axis of the curve by rotating the instrument and then turn the indicator arm until the image of the curve is seen through the prism to be a continuous line. Then the tangent to the curve at the point selected may be read on the tangent scale, or the angle that the tangent makes with the x-axis may be read on the protractor scale. When looking at the cross of the center lines from above the prism it is seen as two crosses, one at each side of the prism, due to the refraction of the prism (*cf.* Fig. 1). The tangent may be drawn to the curve by extending the line connecting two points made by pushing a pin through the holes A and B on the index line. For drawing tangents or normals to curves, where the operation is to be repeatedly performed, a convenient form of the instrument may be made by mounting a prism at the proper angle on a projecting section at the center of a straight edge.

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SPECIAL ARTICLES

THE GERMINATION OF SEEDS, GROWTH OF PLANTS AND DEVELOPMENT OF CHLOROPHYLL AS INFLUENCED BY SELECTIVE SOLAR IRRADIATION

THE energy in sunlight ranges from the infra-red (or heat) rays, through the visible from red to violet and on into the ultra-violet—the short rays of sunshine so necessary to prevent rickets. Are each of these regions of solar energy equally necessary as aids to germination, development, growth and maintenance of existence, or do quality (wave-length) and quantity (intensity) of energy enter as important factors? Are certain wave-lengths and intensities of radiant energy used by plants for one purpose, while other regions and intensities of energy perform a distinctly different function and service? Do certain wave-lengths of solar radiation promote growth, while other regions of solar energy retard it? Is the development of chlorophyll chiefly dependent on the infra-red, visible or ultra-violet rays?

We have endeavored to answer these and similar questions by making physical measurements on the quality (wave-length) and quantity (intensity) of the radiant energy used, the amounts of chlorophyll developed and so forth and by conducting biological experiments on the number of germinations, heights and weights of plants and areas of leaves.

Effects produced under quartz-containing glass, ordinary window glass, amber and blue glass filters.—Quartz-containing glass transmits the whole of the visible portion and a very considerable part of the ultra-violet region of sunlight; ordinary window glass deletes the shorter ultra-violet wave-lengths in large part; amber glass transmits only the longer wave-lengths while blue glass transmits only the shorter visible and longer ultra-violet wave-lengths of incident radiant energy.

Employing Pittsburgh amber No. 48, Pittsburgh blue No. 56, vitaglass (quartz-containing glass) and ordinary window glass, our experiments have shown: (1) In general, the number of germinations is the greatest under vitaglass or ordinary window glass, comparable under the blue filter and least under the amber glass. (2) The average height of stalks increases as we pass from the plants grown under ordinary window glass to vitaglass, to the blue filter and finally to the amber glass. (3) The areas of the leaves are the greatest under vitaglass, less under ordinary window glass, still less under the blue filter and least under amber glass. (4) The weights of plants (stalks and leaves) as grown under the four filters are in the order: vitaglass, amber, blue and ordinary window glass. (5) The lengths and weights of the roots are of the same order of magnitude and arranged in the same sequence as the lengths of stalks and weights of plants. (6) The development of chlorophyll for each gram of plant (not dried) is greatest under vitaglass and decreases in the sequence of ordinary window glass, blue and amber filters.

A comparison of these biological results with the data regarding the percentages of various types of solar radiation transmitted to the plants indicates that the growth is greater under either the longer or shorter wave-lengths of sunlight than it is under the full complement (practically) of sunlight. The infra-red transmissions of the four filters are comparable, therefore this region of solar radiation does not appear to be the controlling factor. Furthermore, the growth under amber or blue filters, which transmit from 30 to 40 per cent. only of the visible portion of sunlight, is greater than under vitaglass or ordinary window glass which transmit about 90 per cent. of the incident visible light. The growth is greater, therefore, under a portion of solar radiation than it is under the full complement of sunlight. A spectrophotometric study of the amber and blue filters shows that there is a relatively small transmission of energy in the green region of the spectrum. The inference (which is substantiated quite definitely by the experiments under the group of seven Corning glass filters) may be drawn that the green region of the solar spectrum, which is the region of maximal energy of sunlight, is inhibitory in character so far as growth is concerned. Or we may say that the infra-red and red regions of sunlight, at one end of the spectrum, and the blue, violet and ultra-violet at the other extreme of the solar spectrum, are vital and stimulating to growth. The development of chlorophyll, however, is practically the same under the amber or blue filters but is greatest under vitaglass or ordinary window glass. From these experiments, in which we have used vitaglass, window glass, blue and amber filters, it can not be stated, however, whether or not the development of chlorophyll is dependent on the total quantity of energy transmitted by the filters or on the quality (presence or absence of certain wave-lengths) of the incident radiant energy.

Effects produced under spectral filters transmitting chiefly one quality only of radiant energy.—In order to limit more narrowly the quality and quantity of solar radiation incident on any group of seeds or plants we have used a set of special filters[2] which transmit only ultra-violet, violet, blue, green, yellow, red and infra-red rays respectively.

Our results indicate that: (1) The number of germinations is greatest under the infra-red and ultra-violet portions of sunlight and least under the green region. (2) The average height of stalks is greatest in the infra-red and red regions at the one extremity of the solar spectrum and in the violet and ultra-violet portions at the other extremity of the spectrum, and least under the green and heat-absorbing filters. (3) The average weight of plant follows the same sequence as stated with reference to the average height of stalks. (4) The development of chlorophyll is greatest under the green portion of the spectrum and least under the infra-red and ultra-violet radiations.

A comparison of data relative to the quality and quantity of incident energy with the biological effects observed shows that a proportionately small percentage of ultra-violet light (since the ultra-violet content of sunlight is about 10 per cent. only, the visible 15 per cent. and the infra-red 75 per cent.) is as efficacious as the infra-red rays, if not more so, in stimulating and promoting germination and growth.

These observations are substantiated further by the results obtained by Sheard and Johnson on the

[2] Corning Glass Company 586 A, 586 A.W., 585, 584 J, 34 Y, 24, 554 FF and 392 H.

changes in electrical potentials and currents produced in plants by various types of radiant energy. In their experiments it was found that marked changes in potential differences (voltage) were produced by ultra-violet and infra-red radiations and that the electric currents obtained in leaves, when an external but constant electromotive force was impressed, were increased by both these types of radiant energy. Furthermore, these changes in potential differences between the base and the tip of leaves were found to be associated very definitely with the phenomenon of growth. No changes in potential differences or in electric currents were produced by the visible portions of sunlight or various artificial sources of radiation.

The development of chlorophyll is dependent chiefly on the quality of the incident radiant energy, namely, the energy in the green region of the visible spectrum. Little chlorophyll is found in plants grown under filters which transmit infra-red or ultra-violet rays only. A comparison of the energy of the incident light transmitted by these filters and measured with thermopiles shows that a transmission of 5 per cent. of the green region (through a green filter) produces a greater amount of chlorophyll for each gram of plant than is produced by a transmission of 40 per cent. of energy in the yellow or red regions of solar radiation obtained through yellow and red filters.

CONCLUSIONS

(1) The ultra-violet and infra-red portions of sunlight are stimulating to germination and enhance growth and development.

(2) The green portion of the solar spectrum, which is its region of maximal energy, is inhibitory to the processes of germination and growth.

(3) The development of chlorophyll is enhanced under the yellowish-green, green and greenish-blue regions of the spectrum.

(4) The least development of chlorophyll occurs under the ultra-violet and infra-red portions of the spectrum.

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SOME PRACTICAL RESULTS OF AN X-RAY ANALYSIS OF COTTON FIBERS

WHILE it has been known for some time that cotton fibers yield a typical cellulose X-ray diffraction pattern, comparatively little work has been done with this material. The explanation of this lies in the fact that in ramie fibers, for example, there is a much more perfect orientation of the colloidal micelles parallel to the fiber axis than is true in cotton, which appears to have a spiral arrangement. Ramie fibers have, therefore, been practically exclusively used in the brilliant X-ray work which has led to a final analysis of the crystalline part of cellulose. It is now definitely known that cellulose belongs to the monoclinic system and that the unit cell dimensions derived from X-ray patterns are: $a = 8.3$, $b = 7.9$, $c = 10.3$ A.U. The last named is the identity period along the fiber axis, with a monoclinic angle $\beta = 84°$. This small unit cell contains four $C_6H_{10}O_5$ groups. It has been further demonstrated that cellulose is built from long primary valence chains of the dehydrated glucose molecules and that a bundle of these long chains constitutes the colloid micelle or crystal grain. The measurement of the breadth of the X-ray diffraction interferences has proved that in various samples the length of the micelles, which is the same as the length of the primary valence chains, lies between 150 and 500 A.U., and that the cross-section dimension of the micelle, which is determined by the number of chains in a bundle, lies between 20 and 50 A.U.

It is this complete structure of cellulose which enables explanation of the physical and chemical properties of cellulose fibers. Up to the present time all the X-ray work has been devoted to fundamental studies of cellulose and practically nothing has been done in the practical sense of following growth or in classifying fibers of a particular kind. In the X-ray laboratory of the University of Illinois extensive independent and cooperative studies are in progress on wood and on cotton fibers. The first results in comparative studies of cotton fibers have been so promising and have so far exceeded the expectations that it has seemed wise to report in a preliminary note these findings on structural changes during growth and on classification of mature fibers.

A series of developmental stages of the fibers of *Gossypium hirsutum* representing growth intervals of eighteen, twenty-one, thirty-five and fifty days respectively have been studied thus far, by means of the diffraction method, utilizing the copper Kα radiation, the pinhold method and a bundle of parallel fibers as the specimen. The eighteen- and twenty-one-day samples represent the period of elongation in fiber growth. The thirty-five-day sample represents the early stages of wall thickening and the fifty-day sample the mature fiber at the close of its period of wall formation. The diffraction patterns for the four samples show a remarkable progression. In all cases the patterns indicate a crystalline condition which, however, is progressively more perfect with age. The eighteen-day sample pattern is distinguished by very broad and continuous rings indicating random orien-