AUTOMATIC RECORDING OF MOVEMENTS OF PLANT ORGANS

BY A. E. NAVEZ AND T. W. ROBINSON

(*From the Laboratory of General Physiology, Harvard University, Cambridge*)

(Accepted for publication, June 2, 1932)

In the study of many reactions of plants involving slow displacements of organs in space, one is often confronted with the necessity of keeping track of the successive positions occupied at definite moments by the organ considered as well as making a record of them free of personal bias. Photographic recording seems to be the most adequate procedure although it may present a certain number of difficulties. The chief difficulty has been, until lately, the necessity of operating for most cases under very dim red light, inactinic to the plants but unfortunately also to most photographic plates. Developments of the technique of supersensitization of panchromatic plates, following the work of Adams and Haller (1920), and Dundon, Schoen, and Briggs (1926), on the cyanins, has very considerably reduced this obstacle; and the possibility of finding on the market plates highly sensitive to the red end of the spectrum and in general rather uniform as regards speed and homogeneity provides an invaluable aid.

That such records, free from instrumental or personal aberrations, are needed even for very much investigated questions, is shown abundantly by the conflicting statements that one finds, for instance, in the literature of such subjects as geotropic curvature of plants. Different authors working on what often seems to be the same material, interpret their observations in quite different ways.

The study of the geotropic reaction in coleoptiles of *Avena* led us to develop the method here described. One could perhaps use the so called "time lapse" photographic process (Buder, 1926) using one of the highly perfected motion picture cameras. But we had it in mind to get a photograph of about natural size and often even enlarged directly on the record. In many cases also where measurement is important it may be very difficult to ascertain, in the time lapse photographs, the identity of position of the film in relation to sprockets or driving mechanism on successive exposures.

Finally, as the development of this work made apparent to us, the camera must be versatile in its possible ways of recording. For instance, we may need at some moment to record a phenomenon involving an upward curvature and at another moment a right-to-left bending.

All these reasons led us to set up the following device, which has proved highly successful in its operation. It is based essentially on the possibility of photographing under very dim red light to which the plant is insensitive, on a plate specially sensitized to the red end of the spectrum.[1]

If the light is turned on and off automatically at regular intervals of time, we may keep the shutter of the objective constantly open; of course the whole apparatus must be completely shielded from outside light.

The apparatus consists of the following parts (Fig. 1).

Camera.—A long extension camera of about 40 to 45 cm. working distance between focal plane of objective and ground glass, is provided with an objective (Zeiss Unar of f/5.n.a. and 155 mm. focal distance) which under these conditions is highly luminous and has enough depth of focus to take care of any possible motion of the plant organ (here, the coleoptile of oats) in planes different from the one perpendicular to the axis of the optical system. In most cases the iris diaphragm reduces the n.a. to f/9.0. Two types of plate holders are provided: the first is a standard type, taking a plate 83 × 108 mm. ($3\frac{1}{4} \times 4\frac{1}{4}$ inches); the second is built to take a plate 102 × 254 mm. (4 × 10 inches) in a brass frame which can slide easily between brass rails on a reinforced aluminum plate, the center of which is provided with a square opening, of the same size as the frame of the ground glass end of the camera. This special plate holder is built to fit the square end of the camera in a vertical or horizontal position, to permit taking records with a plate moving vertically or horizontally at constant speed. The displacement of the plate is obtained by means of a device described a little later.

With both types of plate holders the recording is done by turning on a source of dim, red light, inactinic for the plants, for short constant durations, at constant (but adjustable) intervals of time, the shutter being always kept open. It is

[1] We used extensively the Wratten and Wainwright panchromatic plates sensitized with neocyanine and later the same maker's hypersensitive panchromatic plates.

necessary to shield the recorder completely from all light for this reason. When the light source is turned off, the whole device is in darkness.

Light Sources.—We used glass cylinders, 65 mm. in diameter containing a saturated aqueous solution of fuchsin as a screen for a long 40 watt bulb of the show-case type (with a single filament). A light-tight cap holds the socket of the lamp in place and seals the mouth of the glass cylinder, reducing evaporation of the solvent. The outside of the cylinders is lacquered heavily with a black lacquer

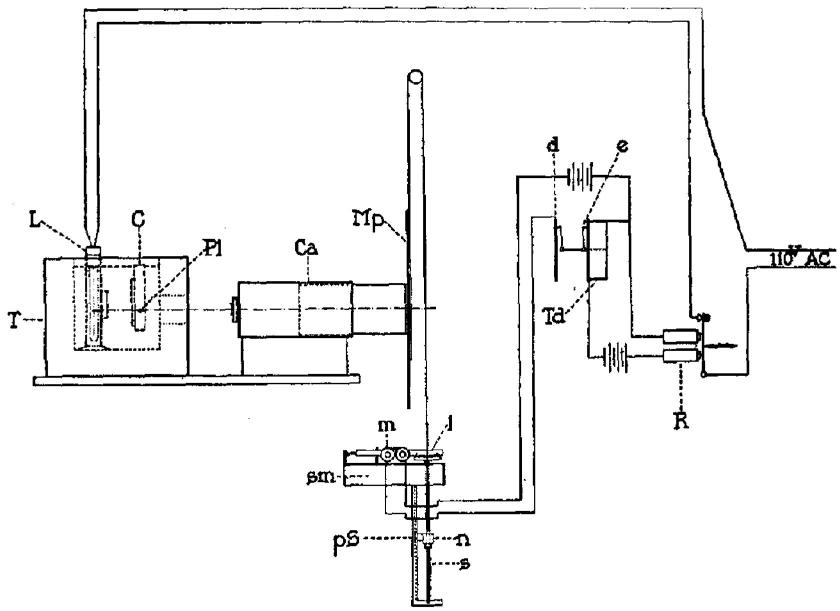

FIG. 1. The recording apparatus. *T*, thermostat with lamp *L* and cell *C* containing the plant *Pl*. *Ca*, photographic camera with moving plate holder *Mp*. *pS*, plate holder shifter with magnet *m* and curved lever *l*, conditioning the travel of the nut *n* along the micrometric screw *s*, put in movement by the spring motor *sm*. *Td*, timing device with contacts for exposure *e* and contacts for displacement of the plate *d*. *R*, relay.

to make it light-proof. One window 10 × 40 mm. is cut in the black cover of the cylinder. It is covered by a small frame holding a ground glass to diffuse the light. Two sources of light of this description are placed symmetrically in the thermostat tank, at about 9 to 10 cm. behind and to each side of the experimental plant. The plant is contained in a special cell whose back is made with a Corning G-24 plate (deep red filter), transmitting only light of wave lengths above 620 mμ. Care is taken to avoid direct penetration of the beams of light into the camera. As the sensitivity of *Avena* according to Blaauw seems to be almost nil at 530 mμ, and as no phototropic bending has been seen even after 2 to 4 hours' exposure, this lighting system is entirely satisfactory.

Relay System.—The lights are turned on and off through the medium of a clock whose minute hand is arranged to brush over copper strips sunk in a disk of hard rubber at intervals of 30° apart. Every passage of the brush over the strip of metal closes the circuit on a relay (operating on 2 volts) which is able to carry the load of the lighting circuit on its contact points. This relay prevents any pitting of the clock contacts, which would vary the duration of illumination. The same clock by means of an insulated extension of the minute shaft actuates also the automatic shifter of the long plate holder; the contacts for this circuit are entirely separated from the illuminating circuit and are adjustable so as to fall between times of exposure of the plate.

Plate Holder Shifter.—The carrier consists essentially in a long micrometric screw, one end of which is provided with a circular plate on which up to 20 pegs can be inserted; these are caught by a curved lever when no electrical current flows through the coils of an electromagnet. When the current flows through this magnet, the attracted lever liberates one peg and the circular plate turns until the next peg is stopped. This movement of the circular plate is determined by a powerful spring, strong enough to enable a nut to travel upward along the micrometric screw, being led by a tongue-and-groove arrangement in the stand supporting the screw. To a stirrup solidly made of fine steel rods fixed to the nut is attached a flexible, braided wire which passes over a pulley fixed to the ceiling. To the other end of the wire is attached the moving plate holder. Any amount of travel imparted to the nut allows the plate holder to move by the same amount.

As any number of pegs can be placed in the plate, and as a large number of electrical contacts can be inserted in the second circuit of the clock, the distance over which the plate can be made to move between each exposure may be varied from a fraction of a millimeter to about 11 mm.

Cell for Plant.—The seedling,[2] grown in sterile sawdust in a small glass tube 25 × 15 mm., is placed for experimentation in a container, the front of which is made of plate glass; the back is of a piece of Corning G 24 glass and the sides are of brass pieces soldered together to form a frame. The pieces of glass are cemented to the brass by Picëin.

The total capacity of this cell is about 480 cc.; this is slightly decreased by the presence of the movable brass mounting stand for the glass tube. The stand is so made as to permit rotation of the seedling around a horizontal axis by means of a 90° gear. With addition of a set of reducing gears this device can be used as a clinostat. Usually it is employed for orienting the seedling while the seedling is still vertical. Two brass pins soldered to the sides of the cell assure the correct position of the mounting for every experiment. A glass plate closes the cell after

---

[2] In most of the cases no marks are made on the seedling; sometimes we placed small India ink dots at known distances from the tip.

replacement of the mounting stand. It has been found very useful to coat the inner side of the front plate glass with one of the products sold for preventing condensation of water on glass surfaces, especially in the cases where one keeps the atmosphere of the cell saturated or nearly saturated with water vapor.

RESULTS

With the apparatus described it is possible to obtain two types of photographic record. The first, "the standing plate picture" is especially adapted for determination of time course relationships. For instance, in the case of a coleoptile of *Avena* it enables one to obtain clean-cut records of the time course of geotropic curvature. In

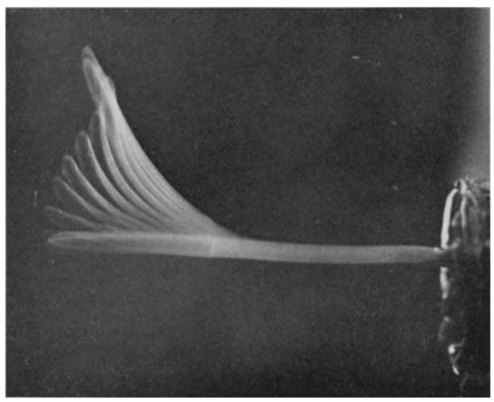

FIG. 2. A "standing plate" picture of the coleoptile of *Avena* bending geotropically; successive exposures every 30 minutes; 1.75 × natural size.

records of this type all successive images are superimposed one on top of another; all immobile parts will therefore be represented by one trace, in opposition to any moving part which will be reproduced as separate images placed one above or below another. Up to twenty-five successive exposures can be made on the same plate without blurring out the different individual exposures. Such an image describes automatically the course of events as related to time (*cf.* Fig. 2). It records successive positions of the motile portion of an organ in respect to a fixed portion, no motion being imparted to the plate; we then know the relation existing between these positions and time in a synthetic way. It dispenses with the necessary orientation of each exposure in relation to a common base line, an operation which is likely to introduce large errors. The second type, "the moving plate picture," permits an analysis of each successive position and the respective shape of the organ (Fig. 3). By means of a comparator it is then easy to detect very small changes in shape or position if one

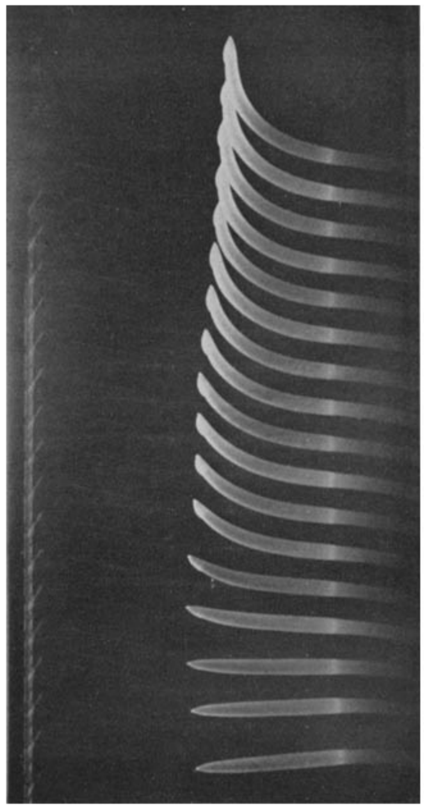

FIG. 3. A "moving plate" picture of a coleoptile of *Avena*. Exposures every 20 minutes. 1.7 × natural size.

has taken care to fix a pointer in the field. It makes possible, furthermore, the construction of composite pictures analogous to the one obtained by the standing plate method. It is especially well adapted to determinations of reaction times for geotropic excitation, as well as for recording growth of vertically oriented coleoptiles.

The two types of record supplement one another. Each has its special advantages. Both can be enlarged easily up to 9 or 10 diameters, which makes the total magnification up to twenty times. Measurements can be made in this way with an increased precision. The use of this method of recording will be demonstrated in an account of geotropic curvature of coleoptiles of *Avena*.

SUMMARY

An automatic photographic recording apparatus is described. It uses plates sensitized to the red end of the spectrum for recording movements of organs of plants which cannot be photographed in white light. It enables one to obtain two types of pictures:

1. A "standing plate" picture where the successive positions of the organ to be registered are superimposed on the same plate, no motion being imparted to the plate.

2. A "moving plate" picture where, by means of a clock-controlled plate shifter, each successive picture is entirely separate from the preceding one.

BIBLIOGRAPHY

Adams, E. Q., and Haller, H. L., 1920, *J. Am. Chem. Soc.*, **42**, 2661.

Buder, J., 1926, *Ber. bot. Ges.*, **44**, 47.

Dundon, M. L., Schoen, A. L., and Briggs, R. M., 1926, *J. Opt. Soc. America*, **12**, 397.