OPTICAL AND PHOTOGRAPHIC TECHNIQUES FOR THE SMALL-SCHOOL LABORATORY

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Most small schools and laboratories have more problems than money; this is often true of the large universities as well, but the small school is more handicapped when some special problem comes along because there is usually less likelihood of procuring equipment by interdepartmental exchange or loan. It is for this reason that the methods to be described are directed principally at the small school or laboratory.

It is rather remarkable that purely photographic measuring methods have not been more widely applied in research. Of course, there are many applications of photography in common use—to record images with the camera, shadowgraphs with the X-ray, spectrograms, and the like. However, the use of the photographic emulsion as a measuring element is still not extensive. Yet it can measure light-intensity, color, or any magnitude which can be expressed as either of these. It can measure things that the eye cannot see; and it can be applied to observe and record more closely, more accurately, and for longer periods than any individual observer.

The more flexible techniques of photographic measurement have been largely neglected; it is these that I want to describe today. There are a great many of them, and in the time allotted to me I can mention only a very few. I have chosen some which are more than usually varied, and which are especially susceptible to modification to other uses.

The motion-picture camera is often used to observe and to record the deflections of instrument pointers during tests; it is especially convenient for such things as aircraft tests, where the camera periodically records the indications of the entire instrument panel, and the films are later read visually. Prosperous laboratories often use recording oscillographic cameras to take down the data on electrical circuits. An early method of recording quantities with photographic means is shown in figure 1: a pointer-type instrument (which might be an electrical instrument, a pressure gage, or any instrument with an indicating pointer) which has had an opaque vane attached to its pointer and a light source so placed that the band of light passing through a slot in the dial is obscured by the vane as the pointer moves. The type of record produced is indicated on the slide—although of course the pattern does not show until the photographic paper or film is developed.

A record of this kind, or any variable-width record, is easily subjected to frequency or harmonic analysis. In many problems the periodicity of the magnitude being measured is important; the daily variation in earth-currents, the behavior of the tides or waves, the temperature variations in organisms, and many other phenomena are most interesting because of

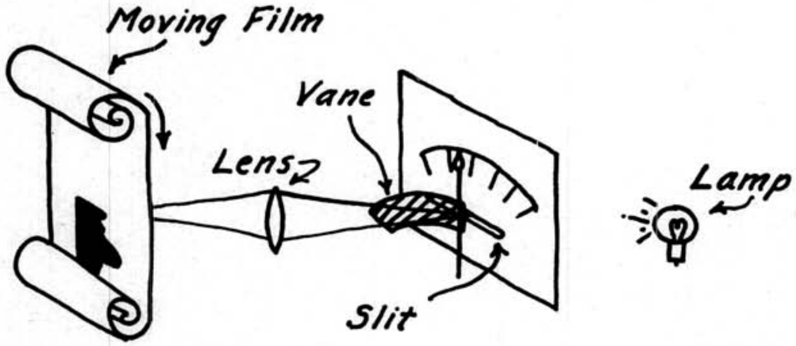
Moving Film
Vane
Lens
Lamp
Slit

Fig. 1

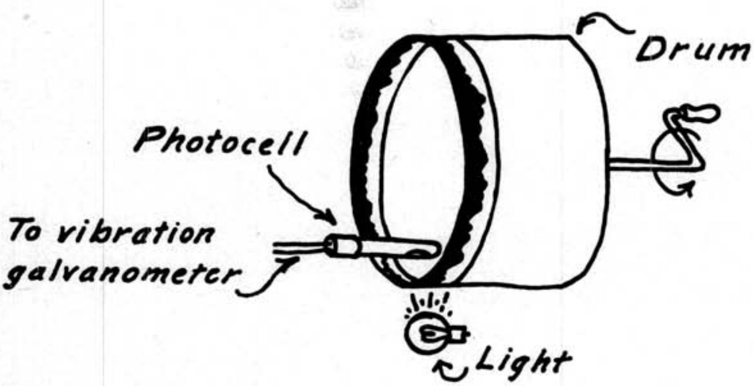
Drum
Photocell
To vibration galvanometer
Light

Fig. 2

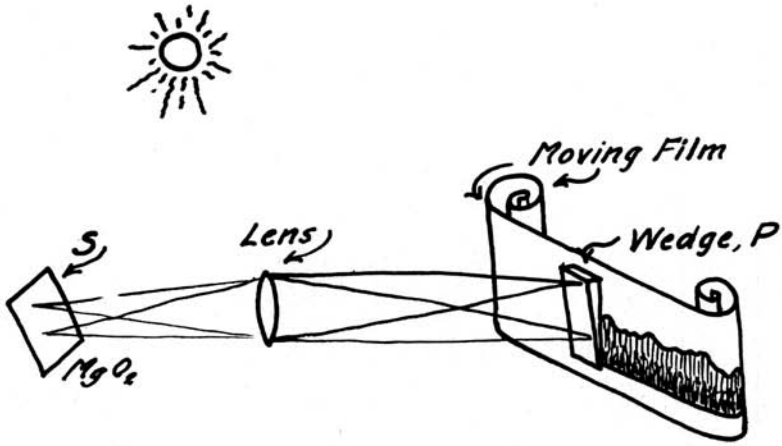

Fig. 3

their time-rate of change. Such a film record, taken over a period of days or even weeks, can easily be analyzed to determine what periodic variations may be present. It is only necessary to attach the strip of record to the edge of a cylinder which can be rotated (see fig. 2) while a light shines through the record and upon a photoelectric cell. The output of the photocell is then applied to some frequency-sensitive device; a tuned vibration galvanometer is ideal. When the speed of rotation of the cylinder is such that some component of the record comes by at intervals corresponding to the period of the galvanometer, a deflection will occur, and simple arithmetic is enough to determine the period of the phenomenon. Then other speeds of rotation can be tried until all frequency components desired are measured. Vibration galvanometers are not so common as they once were, but good results can be had with a simple tuned circuit and a vacuum-tube voltmeter or a cathode-ray oscilloscope, and these are becoming quite common in our physics laboratories.

This simple system is capable of many applications; there is a modification by which the periodic components may be evaluated by purely photographic means, but it is usually less convenient than the one mentioned. These systems, however, are only simple forms; they do not use the photographic materials in their most favorable manner.

In the following figures, there will be shown two sets of apparatus for recording sunlight and its characteristics; one records the average effective intensity, and the other both the intensity and the spectral composition or the color. The two pieces of apparatus were originally intended for use together, but can be used as individual items for their own purposes.

The first of these units (fig. 3) is for recording the effective intensity of daylight, continuously. It employs a clock-motor which moves a strip of 35 millimeter film at a rate of about 2 inches per day. Light

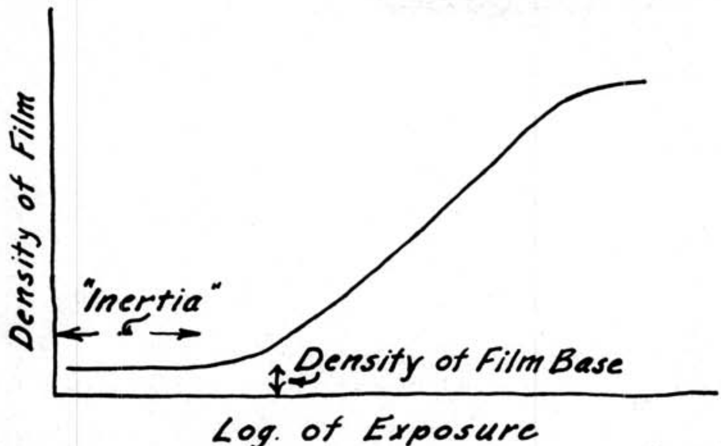

Fig. 4

from the sky falls on the surface S, which is of magnesium oxide, a neutral reflector; this light is reflected through the lens and through the gray wedge P_1 to where it falls on the film. The amount of light reaching the optical system depends of course on the intensity of the daylight, but the amount reaching the photographic film depends not only on that intensity but also on the density of the gray wedge. The over-all effect is that at some point along the length of the wedge the light intensity will be just enough to cause the beginning of darkening of the film. On one side of this point there will be perceptible darkening; on the other there will be no darkening. If a high-contrast film is used, this point is quite definite. A time-scale may also be applied to the film if that is desired.

Some of these things should perhaps be amplified before we go on to the next item. As most of us know already, the density of a photographic film (within its normal working range) is roughly proportional to the logarithm of the exposure. Below the working range there is an area where not enough light has fallen to produce a useful image. Actually, a certain amount of light must be received before any effect at all is produced; above this value the effect is proportional. This is called the ''inertia effect'' of the film, and it is this inertia or threshold point which is seen on the variably exposed film.

In figure 4 there is a curve showing the general shape of a density-versus-exposure curve for a film. What this means on the record is that the threshold point wanders across the film as the light intensity changes, and the boundary between clear film and gray film shows by its position the light intensity. It would be possible, of course, to permit the film to darken uniformly across its width, and to read its density with a microphotometer, except that most of us cannot afford a microphotometer. This system, in any case, makes a longer range of measurement possible.

The gray filter wedge used here is usually a piece of photographic film which has been partially exposed and developed; the exposure

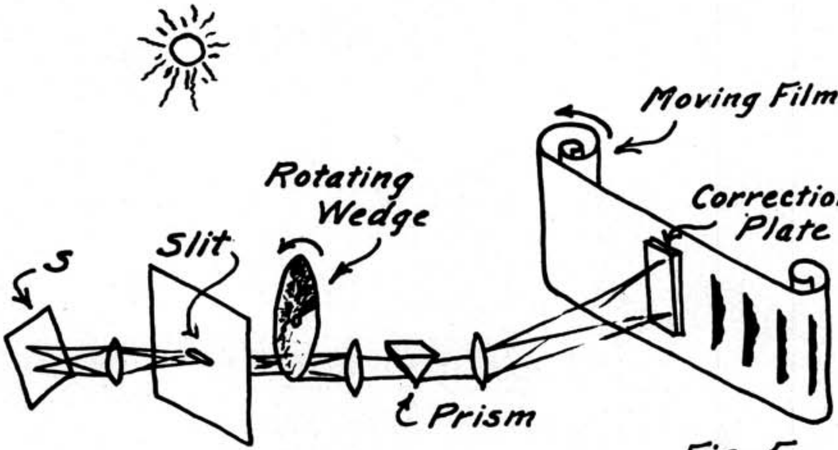

Fig. 5

is varied so that at one edge the wedge is clear and at the other edge quite dark. A density range of 0 to 3 corresponds to a range of 1000 to 1 in the amount of light transmitted. These filters can be made of gelatin, by squeezing a wedge of dyed gelatin between two thin glass plates, if neutral dyes are available. It is not difficult to make photographic wedges, but it is necessary first to prepare a curve like that in fig. 4, and then take data from it to calculate the exposures for the wedge. In all these procedures, conditions of exposure and of development must be controlled with some care.

The equipment for recording the color of sunlight is a little more complex. Again a clock-motor is used to drive the film, at about 2 inches per hour, but here a prism is used to spread a spectrum across the film, which must be panchromatic—approximately equally sensitive to all colors. The density of the various parts of the resulting band indicates the spectral composition.

To read this record, some device for measuring film density is required. The wedge method can be applied here; an easy way is to place a circular wedge over the lens, and rotate it about 10 revolutions per hour. This causes a uniform variation of intensity from very low to high, repeated every 6 minutes. The result is a series of repeated patterns along the film; the length along the film of the various elements of the pattern indicates the various intensities. The kind of pattern produced is shown in the figure; the actual films are easily read, but do not project well.

For ease in reading these records, it is desirable to equalize the frequency response, or the color sensitivity, of the film used. In figure 5 there is indicated a "correction plate" near the film plane. This plate equalizes the color response of the film. It can be made to match almost any commercially available film.

The actual response of a film to color is seldom uniform. Figure 6 shows a typical response curve; it is more sensitive to blue than the normal eye, and is also more sensitive to red. But within this range, the response may vary as much as 40

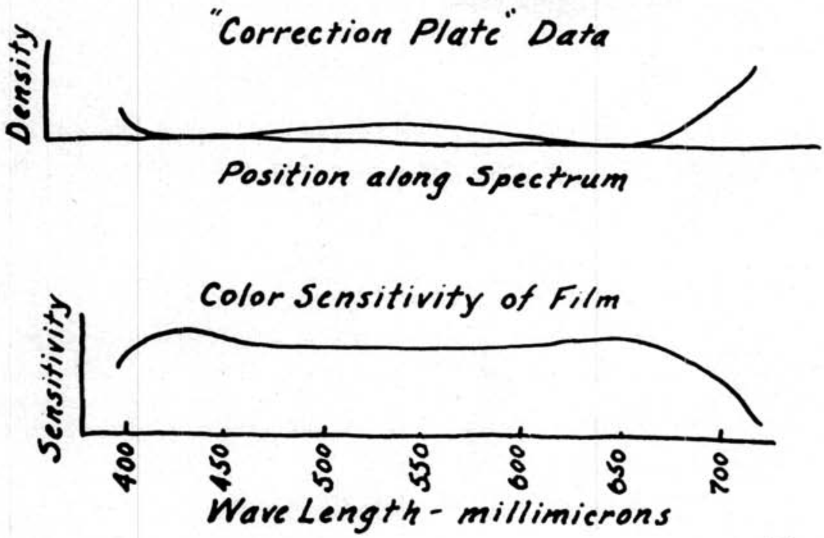

Fig 6

percent. This variation in response can be equalized by preparing a neutral density plate which matches the color curve for the film—that is, in the green, where the film is least sensitive, the correction plate permits most light to pass, but in the red range where the film is most sensitive, it cuts down the intensity. At any point, the sum of the two curves should equal the sum at any other point. The correction plate is placed close to the film; it is a neutral density filter, and its densities are adjusted according to the position of the color in the spectrum produced by the prism.

The optical quality required in these instruments is not very high; good results may be had with surprisingly crude optical systems. Reasonable care is required to avoid diffraction and reflection in unwanted places. The diagrams shown in the figures do not contain all the desirable operating details, such as the cylindrical lens just in front of the film in every case, but these details are obvious when construction is attempted.

The final accuracy to be expected from an instrument of this kind is not especially high, perhaps 5 to 10 percent. This is adequate for many purposes, particularly biological and agricultural studies. The range of intensities which can be recorded is extremely large; it is easy to handle a ratio of 10,000 to 1 because of the logarithmic scale. The actual method must of course be matched to the problem.

There are many other methods which might be described, such as force measurement either by Newton's rings or by the total-reflection method; the use of the Dove prism to extend the time range for recording with the cathode-ray oscilloscope; the photographic record from liquid-filled thermometers or manometers; and other types and classes of measurement. But these cannot be discussed in this paper; the few which have been selected will have to serve as examples of instances flexible enough to be applied in many other problems.