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TWO SIMPLE PHOTOMETRIC TECHNIQUES

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For many years, training in physics has been plagued by the fact that there is more material for the student to learn than there is time in which he may learn it. In recent years, too, the increasing commercial importance of atomic and nuclear physics has greatly increased the time allotted to their study, even in undergraduate courses.

That branch of physics called optics, although one of the oldest, is —with its close relative, photometry —still one of the most active. New developments appear every year or so, and a multitude of commercial applications are in use, with more appearing every day. As an attempt to provide more useful material, both on fundamental optical laws and on their applications in commerce and industry, two techniques are here described.

The law describing specular reflection is familiar to every student of physics; those laws describing diffuse reflection are much less so. Work in illumination and in photometry is based more upon diffuse than upon specular reflection. Measurements of specular and of diffuse reflection coefficients, made with ordinary and polarized light, can disclose many of the characteristics of materials—whether they are metallic or dielectric, their surface condition, as well as color, texture, and gloss. The simple equipment for such measurements may also be used to demonstrate many fundamental optical laws.

DEFINITIONS

The coefficient of specular reflection is usually defined as the ratio of the reflected intensity to the intensity of the incident light, whereas diffuse reflecting power is usually defined as the ratio of the entire reflected luminous flux to the incident flux. Consequently, a true measure of diffuse reflecting power requires measurement of all the light reflected over a 180° spherical angle.

TECHNIQUES AND EQUIPMENT

Let us first consider specular and diffuse reflection separately. Figure 1A illustrates the specular reflection of a pencil of light incident at the angle Θ. (The direction of the incident light is indicated by the dotted line, while the solid line represents the intensity of the reflected light plotted in polar coordinates with the point of incidence as origin.) In figure 1B the reflection of a similar pencil of light from a completely diffuse reflector (conforming to Lambert's Law) is shown; and in figure 1C the reflection pattern for a surface having both specular and diffuse reflectivities is drawn. This third condition is most often found in nature; neither perfectly specular reflectors nor perfectly diffuse reflecting surfaces are ordinarily found. (Smooth surfaces of magnes-

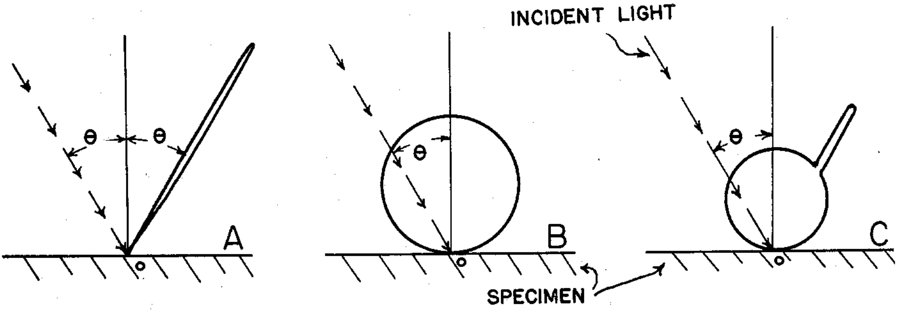

FIG. 1

ium oxide or carbonate, or even of plaster of paris, are often used as standards.) A curve such as that of figure 1C might be from a rather dusty mirror, or from a piece of matte paper coated with varnish.

It should be noted that these curves represent only the intercept on the plane of the incident light, while the actual pattern is a three-dimensional figure of some sort; that for figure 1B would be a sphere.

Figure 2 is a sketch of a simple apparatus by which these polar curves may be taken. It consists of two hinged arms, one carrying a light source with a collimator (which projects a slender pencil of light upon the test surface) and the other carrying a barrier-layer photoelectric cell, by which the intensity of the reflected light may be measured.

Details of construction may vary, but the essential points are these: a well-defined pencil of light must be produced; suitable masks and shields must be provided so that only light reflected from the specimen reaches the photocell; and the two arms should be so hinged that as they are moved the point of incidence at the specimen does not

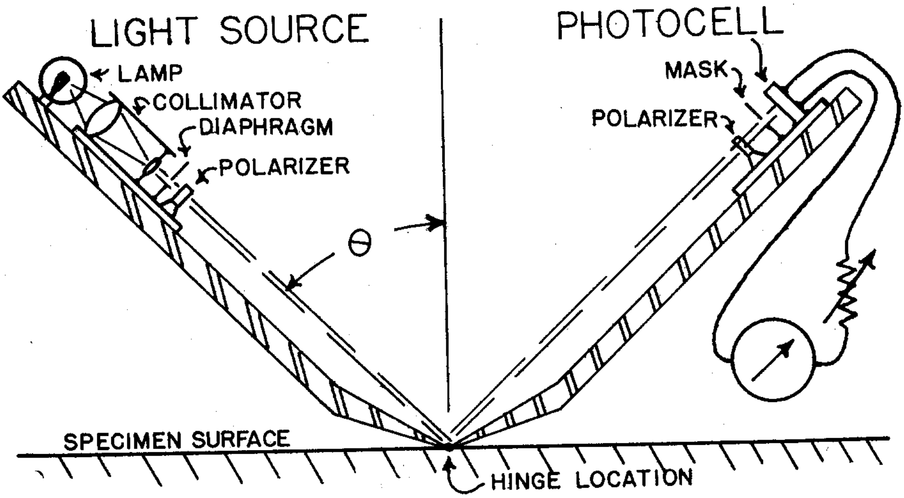

FIG. 2

change. (The hinge axis, therefore, should lie in the plane of the specimen surface, and also should be intersected by the light beam.) An automobile-type bulb will provide enough light to operate the apparatus if a moderate-sensitivity galvanometer is used. An aperture or diaphragm is placed just before the photocell, so that only the specularly reflected pencil of light passes to the cell.

Polarizing devices should be mounted on both collimator and photocell, to act as polarizer and analyzer respectively. Either may be used when measurements are made on dielectric materials, but it is convenient to have both for measurements on metallic surfaces.

In figure 3, the curves for reflected intensity versus reflecting angle are plotted for both metallic and glass surfaces; these curves also demonstrate the differences between well-polished and poorly-polished surfaces. Figures 3A and 3B were prepared by sweeping the incident beam and the light-receiving photocell simultaneously, keeping the angles of incidence and of reflection equal. Both ordinary and polarized light are used, the curve for ordinary light being the solid line, and for polarized light the dotted line. The two materials give curves which differ for these reasons: at normal incidence little light is reflected from the glass surface, much from the metallic surface; at the polarizing angle (about 57° for glass, and 70° to 80° for many metals) there is a decrease in reflected intensity in both instances—for glass the intensity drops to nearly zero while for metals the decrease is only perhaps 30 to 50 percent. These data can be used to explain the application of Snell's Law for both glass and metallic surfaces, there being nearly complete

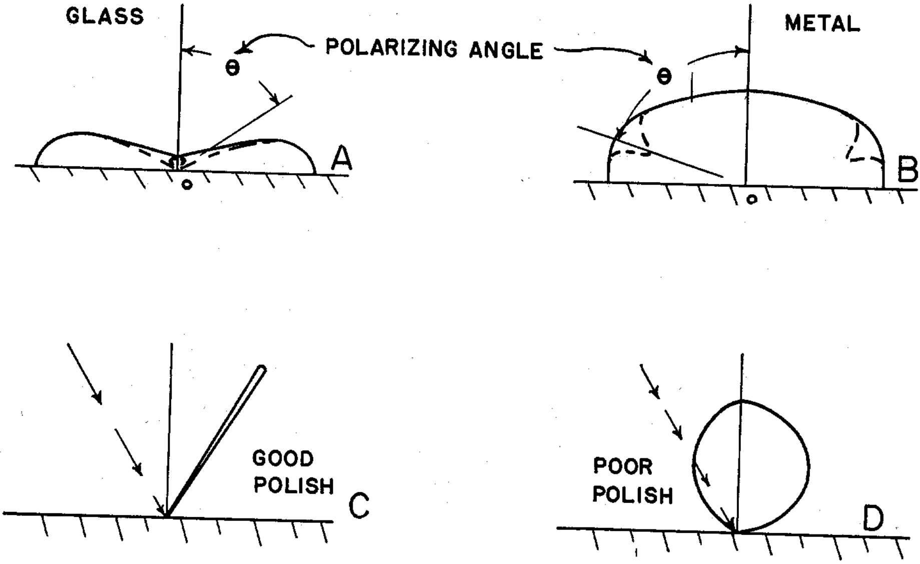

Fig. 3

plane-polarization for glass, while the effect at metallic surfaces is one of elliptic polarization.

The surface characteristics displayed by these data may be of value in identification of materials:

If the polar curve of reflected intensity looks like that of figure 3A, the material is probably a glass (or a plastic of similar optical character), though its color may be anything from transparent to jet black, and it may have any reasonable degree of polish. Its opacity does not obscure the measurement. If the glass is poorly polished, the reflected intensities will be lower than those for a good polish, but the shape of the curve will not change greatly. The drop in intensity at the polarizing angle will be less sharp, but the polarizing angle will still be about 57° for crown glass, and 58° for flint glass.

Conversely, if the shape of the curve remains essentially that of figure 3B, the surface is probably metallic in nature.

In order to determine the degree of polish, a fixed beam of light is used, incident at perhaps 45°, while the arm carrying the photocell is traversed, and the intensity of the diffusely reflected light is plotted at all angles except the incident angle (where the reflection is specular). An optically polished plate produces a pattern like that of figure 3C; a ground-glass surface produces a pattern much like that of figure 3D. This is essentially a measurement of gloss, or of surface smoothness; the gloss, or polish, of surfaces is important both from the technical and the commercial standpoint, though there is little useful information available on the subject and on apparatus for its measurement.

Comparative measurements, of moderate accuracy, may be made easier by providing another mask which is the converse of the one normally placed before the photocell, that is, a mask which intercepts the specular beam while permitting the diffused light to pass. It is then possible to make a reading with the first mask (of intensity of specular reflection) and one with the second mask (of intensity of diffuse reflection over a small solid angle) and to multiply their ratio by a factor determined by experiment, affording a measure of the gloss or polish of the sample. The accuracy of this measurement can never be very high, since it involves measuring only a small portion of the total light flux reflected by the sample. For a really high degree of accuracy, it would be necessary to use some form of integrating sphere to gather all this diffusely reflected light, but for many purposes the simple method described is adequate.

The same optical principles can be applied to another piece of equipment, much more convenient in use but less flexible in ability. It employs a source of collimated light projected through a small aperture in a barrier-layer photocell; the light which is reflected specularly returns along its original path and is lost, while the diffusely reflected light is gathered by an integrating sphere and applied to the photocell. The instrument is standardized by directing it at a standard diffuse reflector (as a magnesium oxide surface) and adjusting the galvanometer circuit until the deflection is

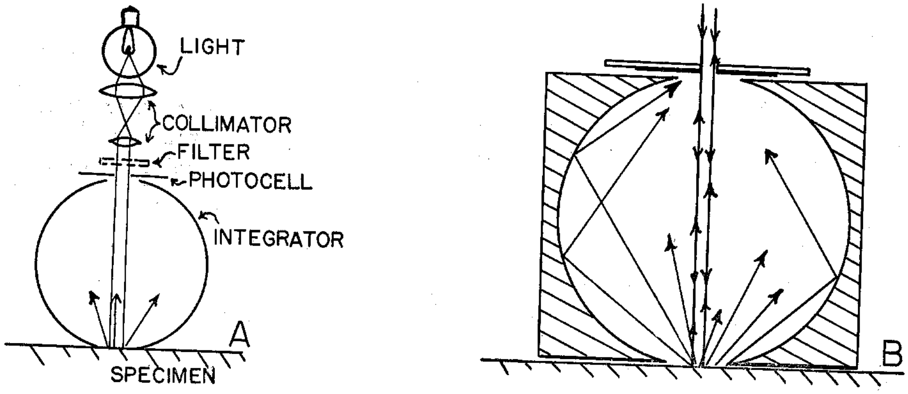

Fig. 4

100 divisions; then the deflection observed when the instrument is directed at an unknown surface indicates the diffuse reflecting power in percentage. Figure 4B shows the optical paths within the instrument in use.* Since light is applied only at normal incidence in this device, no measurements can be made with polarized light. Diffuse reflectivity, as well as color, is easily measured.

This instrument measures diffuse reflection of surfaces as described above, and is at its best when used on surfaces having low specular reflectivity. It can, however, be applied to glass containers to determine the whiteness or the color of the contents of the container; in this application the light reflected specularly from the glass returns through the aperture and is not measured.

Color is measured by introducing primary-color filters before the source of light; then the reflecting power of the specimen is measured for each of the three colors. If the three filters are mounted in a rotating disc, the three measurements may easily be made in a minute or so. For each color, the galvanometer is initially adjusted to 100 divisions, so that the reading is made in percentage.

As described, these instruments are not intended for high accuracy; the ordinary user may achieve perhaps two percent, although the sensitivity would imply higher accuracies. The care in design and construction is an important factor in affording accurate results. Usable data have been taken, however, with equipment employing automobile-type bulbs, inexpensive achromatic lenses as collimators, and pointer-type galvanometers with ½ microampere per division sensitivity. Since the barrier-layer cells operate best into rather high resistances, it has been convenient to employ a series-resistance adjustment. Satisfactory cells have been procured, with outside diameter of about ½ inch, and an aperture of ⅛ inch. The actual design of the integrating spheres has not been difficult; some of nearly cylindrical shape have been used, although a two-inch diameter spherical chamber produced the

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* In this connection, I am happy to acknowledge the assistance and cooperation of Antony Doschek, of Doschek Associates, Pittsburgh, Pennsylvania.

best results, with ½-inch apertures at opposite ends for the passage of light. A simple collimator has been made using two achromatic lenses, the first imaging the source at the center of the second lens, and the second imaging the field on the photocell.

APPLICATIONS

Some applications have already been mentioned; others are obvious. One, of more than usual interest, is the inspection of thin films, such as oxide films on metals.

As a specific instance, aluminum reflectors might be checked for polish during the polishing process. When the desired degree of polish is reached, a lacquer may be applied or the surface anodized to protect against corrosion and soiling. The degree of polish is easily determined by the diffuse reflectivity; the presence or perfection of an anodized or lacquered protective coating may be ascertained by examination by polarized light at the proper angle. The thin oxide film, practically invisible in ordinary light, is conspicuous under polarized light. An added advantage is that the surface is not contaminated during the measurement.

Similarly, glass (or other dielectric) coatings on metals may be inspected. Anomalous polar curves are occasionally found; usually they indicate an unusual surface condition.

The measurement of whiteness of paper, cloth, etc., has been mentioned—this is simply measurement of diffuse reflectivity. Smoothness of metal surfaces, color of pigments, stability of color of bottled products exposed to light, effectiveness of sandblasting on surfaces—these and other attributes may be measured with the two devices described.

The educational functions of the equipment likewise are evident; several optical principles may be demonstrated quickly and easily, and the applications of such methods in science and industry cited as examples, to add interest. The simplest points, such as the laws of reflection, Lambert's Law, and Brewster's Law, may be graphically illustrated; less familiar theory, such as the anomalous polarization effects at metallic surfaces and the resulting elliptic polarization, may be displayed.