Phase-Contrast in Polarized Light

In a recent communication, Hartley[1] indicated a simple arrangement for realizing phase-contrast in polarized light. It consisted of a quarter-wave plate cut in two and reassembled after 90° rotation, so that the dioptric rays and the diffracted rays, crossing respectively the two parts of the plate, are changed in phase with respect to each other. This same method was indicated by one of us[2] at the international conference of the Institut d'Optique, Paris, held in October 1946, and its efficiency has been tested since by experiment. We tested also another design which has the advantage of giving the exact phase-change needed and independently permits the weakening of the dioptric rays in a continuous manner so that it can be adjusted to optimum intensity. (In the last paragraph of his letter in *Nature*, Hartley indicated a modification of his design in order to obtain also the weakening of the dioptric rays ; in doing so, however, the correct phase retardation given by his first arrangement is lost.)

Our system is based on the following principle. The incident light is polarized by a 'Polaroid' screen before crossing the object. In the conjugate plane of the light source (which was a rectilinear slit in our experiment but which could have any other form, like a ring) there is a half-wave plate followed by a quarter-wave plate. The half-wave plate is cut into three, and the part to be crossed by the dioptric rays is rotated 45° to the rest of the surface (Fig. 1). In this manner the diffracted rays, and the dioptric rays after crossing this composite plate, have their vibrations oriented at right angles to each other, without any modification in phase. In crossing the quarter-wave plate placed behind, the convenient phase change between them is then obtained. The analyser (another 'Polaroid' screen) isolates the vibration components parallel to its principal direction[3].

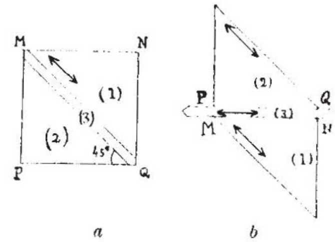

Fig. 1. (*a*) PLATE IS CUT INTO THREE PORTIONS, 1, 2, 3. (*b*) PORTION 3 IS TURNED THROUGH 45° AND INSERTED BETWEEN 1 AND 2

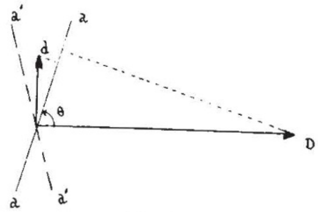

Fig. 2

Let D be the amplitude of the vibration in the dioptric rays, d that in the diffracted rays (Fig. 2) and θ the angle between the principal direction of polarizer (also the direction of vector D) and analyser. If $\theta = 90°$, the dioptric rays are suppressed and the system is equivalent to dark-ground illumination. If θ is less than 90° (position $a - a$ of the analyser) the resultant vibration will be : $D \cos\theta + d \sin\theta$, and the diffracted amplitude will add its effects to the dioptric amplitude. The system gives positive phase-contrast. If θ is greater than 90° (position $a' - a'$ of the analyser) the resultant vibration will be $D \cos\theta - d \sin\theta$ and the diffracted amplitude will be subtracted from the dioptric amplitude. We have negative phase-contrast. By rotating the analyser we can obtain zero intensity for $\cot\theta = d/D = \tan\varphi$.

If the diffracted light is produced by a small elevation of the object surface, the optical height z of this elevation will be given by the formula

$$z/\lambda = \frac{\varphi}{2\pi},$$

provided that $\varphi = \pi/2 - \theta$ remains a small angle.

In Fig. 3 are reproduced photographs taken for the three cases mentioned ; the object is a piece of plain glass on which appears a line of transparent varnish (1 – 1) and, crossing it, a small furrow made by a diamond point (2 – 2). The composite half-wave plate used was cut in a fine 'Cellophane' sheet and imbedded in Canada balsam between optically flat glass plates. The quarter-wave plate was an ordinary $\lambda/4$ mica plate. The photographs were taken in monochromatic light (mercury 5461 A.).

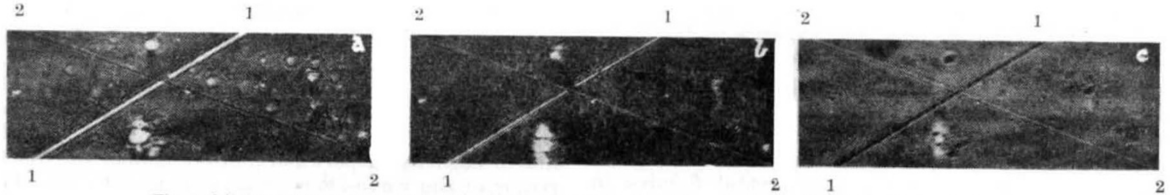

Fig. 3. (*a*) NEGATIVE PHASE-CONTRAST. (*b*) DARK-GROUND ILLUMINATION. (*c*) POSITIVE PHASE-CONTRAST

An ingenious method of combining variable phase-contrast with variable amplitude adjustment has been indicated by Osterberg[4], who separates the vibrations of dioptric and diffracted light by a cut and reassembled 'Polaroid'.

In all these systems[5] it is essential that the composite plate used be of equal optical thickness over its whole surface. We believe that this condition is more easy to obtain and to control for birefringent mica or 'Cellophane' sheet than for 'Polaroid'. A variable change of phase could be achieved in our design by replacing the quarter-wave plate by a Bravais compensator.

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Oct. 17.

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[1] Hartley, W. G., *Nature*, **159**, 880 (1947).

[2] Kastler, A., communication at the Colloque sur les Images Optiques, Paris, October 1946, *Revue d'Optique* (in the press).

[3] French Patent No. 534,779, May 17, 1947.

[4] Osterberg, H., *Opt. Soc. Amer.*, **36**, 710 (1946).

[5] Taylor, E. W., *Proc. Roy. Soc.*, A, **190**, 422 (1947).