Colour effects obtained with polarized light

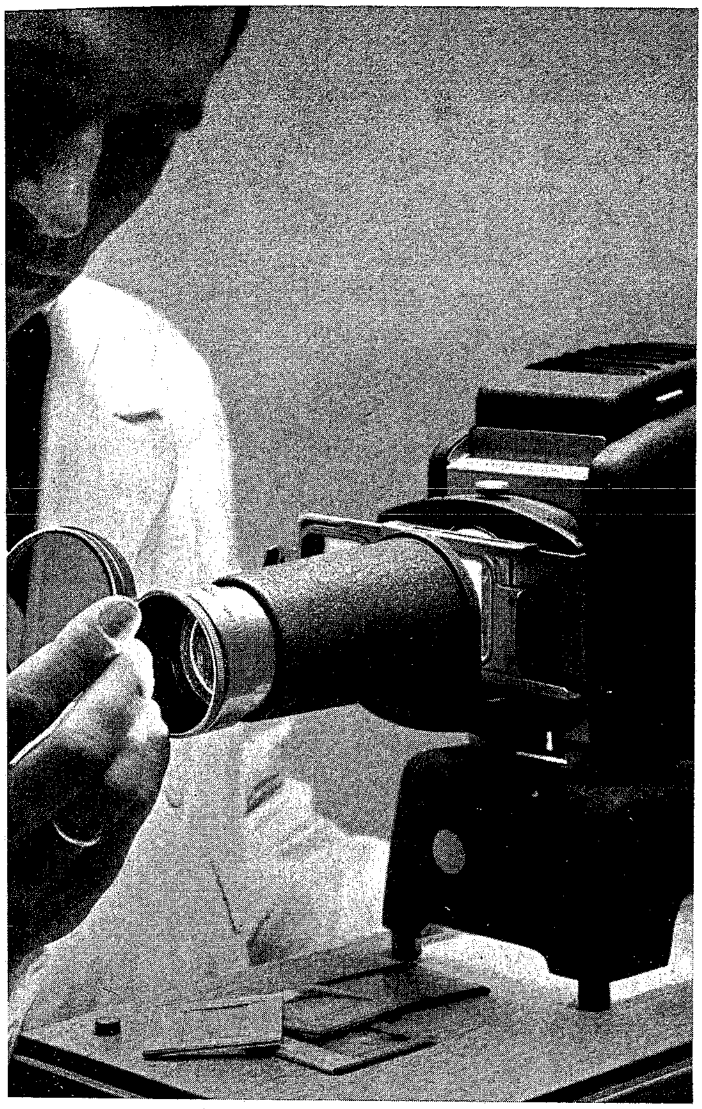

Fig. 1. The effect of double refraction can best be seen by projecting the slides with the cellophane strips on a screen. Between the condenser and the slide frame a polarizing filter is permanently mounted. A second polarizing filter is placed in front of the projection lamp. By letting this filter rotate about its axis, the colour variations appear.

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by Dr. Ir. J. Bergmans

What is the explanation of the colour effects obtained by Mr. Munari? What is polarization? These are questions many a reader will be asking himself. We have asked Dr. J. Bergmans, lecturer at the Technical High School, Eindhoven, to give in simple terms an explanation of this phenomenon.

Light travels along straight lines. We can imagine a great number of planes intersecting the line of propagation of light in the manner shown in fig. 2. Ordinary (unpolarized) light consists of an enormous number (approx. 6.10^{14} per second) of vibrations, all perpendicular to the line of propagation of the light and occurring in *all* the planes which can be constructed through the line of propagation.

The essential characteristic of unpolarized light is the fact that the vibrations are distributed wholly at random (that is without any direction of preference) over all these planes. As soon as there is a preference for certain planes, we are no longer dealing with ordinary light, but with light that we might call "somewhat polarized".

There are devices for converting, with relatively little loss of light, ordinary light into light with the strongest possible polarization.

This linear polarized light has the following characteristics:

a) along every line of propagation (in popular terms: along every ray of light) vibrations are propagated which occur in one plane only;

b) in a beam of linear polarized light, the afore-mentioned vibration planes are parallel to each other for all light rays.

Because these devices transmit of each vibration the resolved one, parallel to the afore-mentioned planes, and only obstruct the resolved one, perpendicular to this, one may theoretically expect a maximum transmission factor of 50%. Since plates of polarizing material have become commercially available (e.g. polaroid filters) the application of polarized light has become much easier. These plates are manufactured with transmission factors up to 38%. The polarization effect is easily made visible by placing two small plates of such material on each other in various positions, while a beam of light is sent perpendicularly through the two plates. When the directions of polarization of the plates coincide, more than 15% of the original luminous flux will remain in the beam after it has passed through the two plates. If, however, we rotate the plates in relation to each other, the light transmission decreases, slowly at first, then to a much more marked degree, so that when the rotation is 90%, only 0.05% of the light is transmitted. The position which the two plates then occupy in relation to each other, is called the "crossed position": their directions of polarization then are at right angles to each other and the one plate precisely keeps back the light which is transmitted by the other. This destruction of light thus appears extraordinarily effective. All the same, it is not impossible to obtain good light transmission again while retaining the "crossed" position of the two plates. This is accomplished by inserting *between* the two plates sheets of transparent material, as a result of which the light transmission may be completely restored. Without altering the cross position of the polarization filters in any way, we can increase or decrease the amount of transmitted light by rotating the inserted sheet. An ordinary piece of cellophane wrapping from a packet of cigarettes will usually demonstrate this effect quite clearly. It is obvious that the material characteristic demonstrated here is totally different from that of the polarization filter. For with such a sheet of cellophane one cannot possibly convert ordinary light into polarized light. And yet the property of the little piece of cellophane has something to do with polarization.

The transparent materials which we use for this purpose (practically all sorts of plastic) have the property of "double refraction". This corresponds with the characteristic of the polarization filters, in so far that the double refracting plates also have a preference direction for the transmission of light vibrating in various planes. The difference is, however, that with a polarization filter, the transmission *factor* for the light vibrating in the different planes varies, whereas in double refraction the transmission *factor* is constant, but the transmission *velocity* of the light vibrating in different planes, varies.

With ordinary (unpolarized) light, one cannot observe this characteristic: the material is quite transparent and absorbs almost no light. However, as already mentioned, with polarized light there appears to be something very peculiar. To permit the making of calculations for these phenomena, the concept of "retardation" has been introduced, which means that the light vibrating in a certain plane is retarded by the lowered transmission velocity in relation to the light vibrating perpendicular to this. The distance by which the light vibrating in one direction lags behind the light vibrating in the other direction is of the same order of magnitude as the wave length of the light: both are measured in fractions of microns. Usually we do not speak of a certain retardation *distance*, but of the retardation *angle*. For here we use the same notion as for the theory of electric alternating currents: a phase difference between the two currents is indicated by the angle difference between the vectors, which are characteristic for each of these currents. It will now be clear that a same retardation *distance* for light of different wave-lengths, results in a different retardation angle.

When polarized light passes through various double-refracting media, which, as far as their properties are concerned, are oriented in different directions (in popular parlance: several cellophane sheets, laid on each other at different angles) then it is the *retardation angle* which is decisive for the changes in the polarization direction of the transmitted light. This angle appears to be strongly dependent on the wave-length of the light. The different spectral colours from which white light is made up, are thus transmitted with different velocities and different angles of refraction. Because of this, we can insert between two crossed polarization filters, uncoloured, transparent, double-refracting sheets which impart a beautiful colour to the light passing through the filters. These colour effects are especially striking when several layers of this material are placed on each other under different angles. When a design built up from this double refracting material is rotated between two fixed polaroid filters, the colours of the components of the design change, resulting in surprising and beautiful effects. One can also keep one of the polarization filters and the design made up of double-refracting material immobile in relation to each other and rotate the second polarization filter. This method also produces changes of the colours in the components of the design. The greatest possibilities of variation are obtained when a design of several layers (oriented in different directions) is projected on a screen while at the same time the two polarization filters between which the design is placed are made to rotate at different speeds. In this way the reciprocal position of the design and the two polarization filters is constantly changing, thus producing the greatest possible variation of colours and tints.

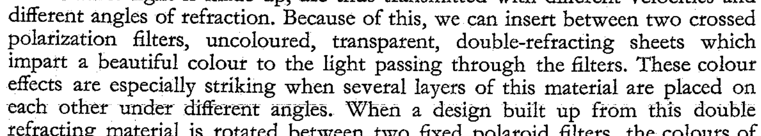

Fig. 2. Light vibrations, perpendicular to the line of propagation, and in all planes through that line.