PHOTOGRAPHY OF DIFFRACTION AND POLARISATION EFFECTS.

IT was natural that such a subject as physical optics should call forth the best skill of mechanicians, and science owes a debt to their beautiful instruments; but the very excellence of these has perhaps filled the worker with too much awe and made him feel that wave interference can only be observed in a great laboratory. The present object is to give details of simple arrangements which enable all such phenomena to be seen and photographed.

Diffraction.—The general appearance of the apparatus is shown in Fig. 1. It may be seen at the Victoria and Albert Museum. The middle stand carries a square piece of soft wood blackened, 3 inches square, $\frac{3}{16}$ inch thick, with a $\frac{3}{4}$ inch square cut out of the centre. A dozen or more of these wooden squares should be made, as holders for the various objects which cause diffraction. It is desirable to have some sheet aluminium and rolled brass, the thickness in each case about No. 30 standard wire gauge. Several objects can be made of aluminium and attached with pins to the centre of the wooden squares: a single edge; a rectangular edge for Grimaldi's crested fringes; two straight edges with adjustable distance, the adjusting edge of aluminium being made to slip under two clips of aluminium pinned down, one on either side. The pins should be cut short to about the thickness of the wood; a slight tap with a hammer rivets them. Let three of the 3-inch squares have the central

FIG. 1.

hole covered over with aluminium and let pinholes of various sizes be made; the aluminium is easily cut with scissors and pierced with a needle; when the hole is less than $\frac{1}{8}$ mm. the phenomenon is different from that given by larger holes.

Put thin microscope cover glass on the aperture of two or three wooden squares, and with the smallest speck of liquid glue attach shot of various sizes to the glass. This affords the easiest means of seeing Arago's famous experiment, a bright centre in the shadow of an opaque circular disc.

Other suitable objects are needles of various sizes, needle eyes and needle points. Fig. 2 shows diffraction by a fine and a thick needle. The centre of the shadow is a line of light in both cases; it is the finer needle which has the broader central line. For the same cause the central light broadens towards the points, and the centre of the shadow of a quartz fibre is very broad indeed. On one side of a needle place a strip of aluminium; this causes the interior bands to disappear at this position. To one side of a needle, along half its length, apply a piece of microscope cover glass; this shows Arago's crucial experiment to prove that the velocity is less in glass than in air. It is imperfectly described by saying that the fringes are shifted towards the glass side. There is another system of fringes, narrower and more in number as if from a broader needle; the central line of these is shifted towards the glass. The experiment is rather difficult; the edge of the glass gives trouble; it must be placed just over the thickness of the needle, and the needle had better be thin.

Perforated zinc and wire gauze easily give good effects; the former has series of rings in the spaces, and the centre can be made white or any colour with a small movement of the object;

FIG. 2.

also there are fine hexagonal rulings all over the geometrical shadow. The wire gauze gives bright Scotch plaids of any clan, when moved over a range of about two inches.

Some of the most beautiful effects which can be produced are shown in Fig. 3. The diffracting objects were small groups of four and five circles, circular lines of light photographed on glass, each group being $\frac{1}{16}$ inch diameter. They were made years ago for another species of diffraction, that as studied by Fraunhofer, Schwerd and Herschel, in which a telescope is focussed on to a distant point of light and various screens are placed on the object glass. Our present view is that of Fresnel, in which waves starting from a point, almost mathematical, of light are diffracted or broken by an interposing body.

A word more as to the holder of the objects. In the bottom of the 3-inch squares of wood, Fig. 1, is a slot; this slot is placed over a screw fixed in the top of the oblique bar in the middle stand; a nut on the screw clamps the square and allows adjustment in a vertical plane. The lower end of the oblique bar, which is 3 inches long, has a stiff joint on to the upright, which is 9 inches high; the stiff joint makes an easy adjustment for height.

On the left of Fig. 1 is a wooden screen 16 inches high, 9 inches broad. At a height of 10 inches is a hole $\frac{1}{2}$ inch in diameter; on either side of this let there be a brass spring which will allow one of the 3-inch squares to be slipped under it. The square should have a sliding strip of aluminium, with three pin-holes ranging in size from the smallest that can be made. Sometimes an adjustable slit should be placed here. A convex lens condenses lamplight or sunlight on to this aperture, whether pinhole or slit; this is the source of light.

Towards the right hand in Fig. 1 may be seen an eye-piece for

FIG. 3.

direct observation or a camera for photographing the effects. The distance for either of these is about 2 feet from the wooden screen which carries the source of light. The eye-piece is Beck's B microscope Huyghen's eye-piece. Any simple holder

can be made to serve, but it is useful to have a sliding tube in a brass upright and at the top a V which is above a stiff joint. On this V the eye-piece can be held with an elastic band; or an eye-piece of different breadth, or a Nicol's prism may be so fixed. Most of the effects may be well seen if a lamp is used for the source of light. It is easier to observe in a room which is rather dark, for then the space between screen and eye-piece need not be

FIG. 4.

covered up. Sunlight may be reflected by a hand-mirror into a darkroom through an open door. The lens which condenses on to the pinhole can be moved a little until it is seen that a pencil of light is just covering the lens of the eye-piece; then the object can be adjusted so as to be also covered by this pencil. Of course, the effects as seen directly by the eye are far more beautiful than the photographs. The object is about 18 inches from the pinhole. With good sunlight there are often groups of brilliant jewels, in which the emeralds and the rubies are made to change places by a small movement of the object. For producing Arago's bright spot with an object so broad as a threepenny piece, the distance from the pinhole to the eyepiece must be about 36 feet.

In photographing the phenomena the same eye-piece is fitted on to the front of a camera, instead of the usual lens; the camera can be placed on a box and adjusted to the right height with books or paper. If there is good sunlight, about 30 seconds' exposure is suitable for an Ilford ordinary plate. There is no question of focus; to whatever position the back of the camera is drawn out the figures are equally in focus. There is a series of folds or zones of light and shade, and prismatic colours which are often crossing one another and suffering interaction of their waves, so that if these zones are cut at various positions there is infinite change of form and colour. If the same eye-piece is used in a telescope or a microscope it will focus the sun or a diatom on to a screen; and when the screen is moved back the image is still in focus; but in these cases the reason is different, for the pencils of light emerge in parallel rays and make clear images at all positions.

Some of us who are fortunate have been inspired in early life at some well-known school of optics where there was the best

FIG. 5.

teaching and the best instruments; then we descend to our own rough contrivances. There is a third stage, when we watch for examples of wave interference with no apparatus at all. In looking at distant lamps at night-time several forms of Grimaldi's fringes can be seen by moving the eyelids over the eye; with care it is possible to see interference from the light reflected along the eyelashes, and there are fine figures of endless variety

which can be produced by slowly lifting the eyelid so as to draw a film of moisture across the eye. Some are similar to the figures of Michelson's refractometer, and all these are probably of the character of thick plates.

Polarisation.—It has often been considered that the rings and brushes made by oblique pencils through crystals can only be seen with elaborate instruments; but according to the method here described all polarisation effects of which the writer has any cognisance have been photographed. It is convenient to cut the cork mounts of the crystals so as to be round, about $\frac{1}{4}$ inch diameter. Place one of these on the top of the same microscope eye-piece, from which the cap has been removed; if the microscope is at hand, it forms a convenient holder. No objective is put on. A Nicol's prism may be inserted at the bottom of the tube. This, however, is not necessary, for the reflection from the plane mirror under the stage polarises almost as well. A cardboard tube, which fits the eye-piece, may be used instead of the microscope. In this case, cut a hole in the side of the tube at the further end and reflect up polarised light by a piece of microscope cover glass fixed on cork with black sealing-wax. A long pin run through the tube and the cork makes easy adjustment for this reflector.

For an analyser a tourmaline is desirable, as light in colour as possible. The artificial tourmalines are best, but they are now difficult to procure. The tourmaline is placed above the crystal section which is already on the top of the eye-piece. Perhaps the cap of the eye-piece will hold these two steady when they are turned to the right position. It is safer to twist thin copper wire round the top of the tube so as to have a small hook on either side; a thin india-rubber band from hook to hook over

FIG. 6.

the tourmaline holds them securely. It is only necessary to place the tube through the front of a camera from which the lens is removed so as to have the figures projected on the photographic plate. Sunlight is best to work with. Sodium light gives a field covered with fine detail, but does not make effective lantern slides.

Fig. 4 shows the calcite cross; Fig. 5 shows calcite circularly polarised and circularly analysed, or circularly polarised and plane analysed. One of the most attractive of polarisation crystals is Bertrand's prism. It is so cut that light entering directly through one side is internally reflected along the optic axis; it then emerges owing to a similar internal reflection. These reflections polarise and analyse; moreover, the first reflection preserves both the ordinary and extraordinary rays. The result is that by placing this one crystal without polariser and analyser on the eye-piece the black-cross and the white-cross systems both appear at once, as seen in Fig. 6. The interest does not end here; with a slight tilt, made by a shaving of cork under one side of the prism, the white and black crosses change places, with certain other changes of detail in the figures; and there is another tilt which will give two white-cross systems.

If Fig. 6 is to be projected on to a screen on a large scale, the crystal is placed at the focus of a convex lens on to which sunlight is turned, or else at the focus made by the condensers of a lantern when the light is drawn back; this is sufficient without a focussing lens. In both cases the heat may injure the crystal unless about $\frac{1}{4}$ inch of water is placed between the lens and the crystal. The ordinary crystals of calcite and nitre must have a Nicol on one side and a tourmaline on the other, and be placed at the focus as before. W. B. CROFT.