'X-RAY MICROSCOPE' EMPLOYING LAUE REFLECTIONS

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PRINCIPLE OF THE METHOD

THE refractive index for X-rays is very nearly equal to unity, so that refractive focussing of X-rays by lenses, as for ordinary light, is practically impossible. However, total reflection of X-rays takes place at small glancing angles (of the order of a few minutes of arc for ordinary wavelengths)[1] and utilising this phenomenon, X-ray focussing devices have been constructed.[2,3] Since the image obtained from a single concave mirror is highly astigmatic, two mirrors with their planes of reflection at right angles are employed, and images, having a magnification of upto 30 with a field of view of about 0·5 mm. have been obtained. Kirkpatrick[4] has also suggested a possible method of refractive focussing, which has not been tried, but does not appear to be promising owing to the large absorption in most materials.

The present note deals with a new method of obtaining focussed images, utilising the Laue reflection from crystallographic planes. As its very name implies, the Laue reflection obeys the optical laws of reflection with respect to the plane concerned; but it differs from ordinary reflection in that for a particular angle of incidence θ only a small range of wavelengths near selected values, given by the well-known formula $n\lambda = 2d \sin \theta$ will be reflected. Thus, if white X-rays are incident on a thin cleavage flake, a portion of the rays would be reflected in the same direction as ordinary light would be, if incident on the same angle as the X-rays. Suppose now that the lattice planes in the crystal are bent into the form of a concave spherical surface, and that we have a point-source of X-rays along the axis of the "concave mirror". Then, a certain fraction of the incident X-rays would be reflected and *the whole of this* would converge again to a point. Thus, an enlarged or diminished image is formed by X-rays at exactly the same place as the optical image obtained by illuminating the object with ordinary light. Apart from the aberrations of the mirror, the only contributor to the "background illumination" of the image is the Compton scattering from the crystal flake, which is comparatively weak, being incoherent.

EXPERIMENTAL ARRANGEMENT

The above ideas were tested by means of a very simple experimental arrangement. The essential part is a crystal plate, whose lattice planes have been distorted to form the surface of a sphere. This is obtained as follows: A thin cleavage strip of mica M (0·04 mm. thick) is fixed by means of wax on the circular brass flange F of a tube of inner diameter 1 inch (Fig. 1). On evacuating the inside of the tube,

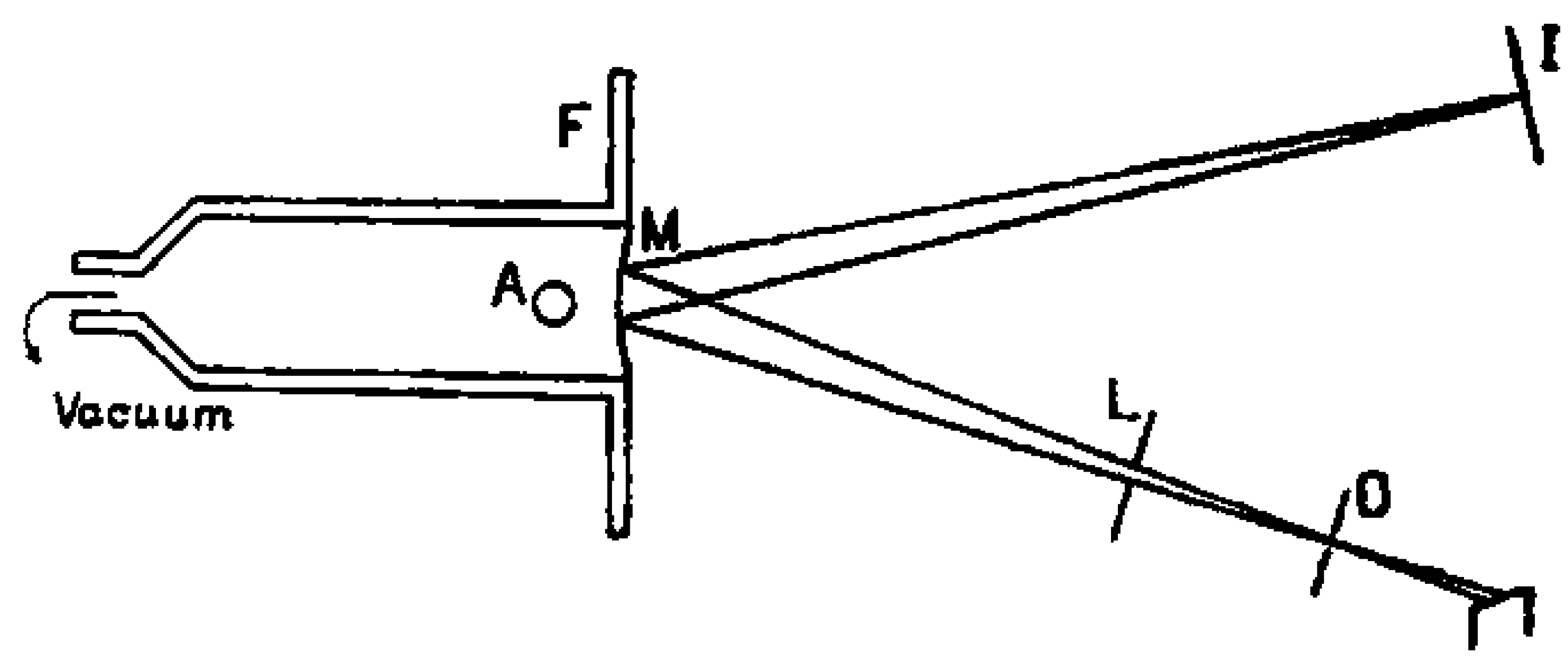

FIG. 1. Schematic Diagram of the Experimental arrangement.

the mica curves inwards, and if the central portion alone is utilised, then a fairly good optical image is obtained employing the mica as a mirror. In this way, a radius of curvature as small as 15 cm. (focal length 7·5 cm.) could be obtained. The difference of pressure on the two sides of the mica was of the order of 40 cm. Hg. The object O employed was a 100 mesh brass wire net, kept on an aperture in a lead screen. A lead aperture, L, was used to limit the beam diverging from O. The photographic film for recording the image I can be fixed on a stand sliding along an arm AI, which rotates about an axis A, which is also the axis of rotation for the tube bearing the mica mirror. Initially, the whole arrangement is removed from near the X-ray tube, the wire mesh is illuminated by ordinary light and the distances OM and MI suitably adjusted to get an image of the required magnification on a ground glass screen at I, to one side of the object. The arrangement is replaced near the X-ray tube and a photographic film is placed in the same position as the ground glass plate. With an ordinary demountable copper target X-ray tube working at 40 KV and 15 ma, exposures of the order of 30 min. are needed for a magnification of 4 and of the order of 6 hours for a magnification of 20.

RESULTS

Three photographs obtained in this way are reproduced in Fig. 2 *a, b, c*. They are all contact prints of the X-ray films and the magnifications are indicated in the caption to the figure. Fig. 2*a* shows that with a small field of view, the image is quite sharp and almost undistorted. The field of view in Fig. 2 b is fairly large of the order of 2 mm. diameter; but there is a certain amount of distortion owing to the unevenness of the mica surface. Efforts are being made to modify the technique of bending the mica to get rid of this. It is to be noted that the image is sharp even at a magnification of 20 (Fig. 2 c). In all the figures, the magnifications in the vertical and horizontal directions are not equal because the image is to one side of the object.

a b c

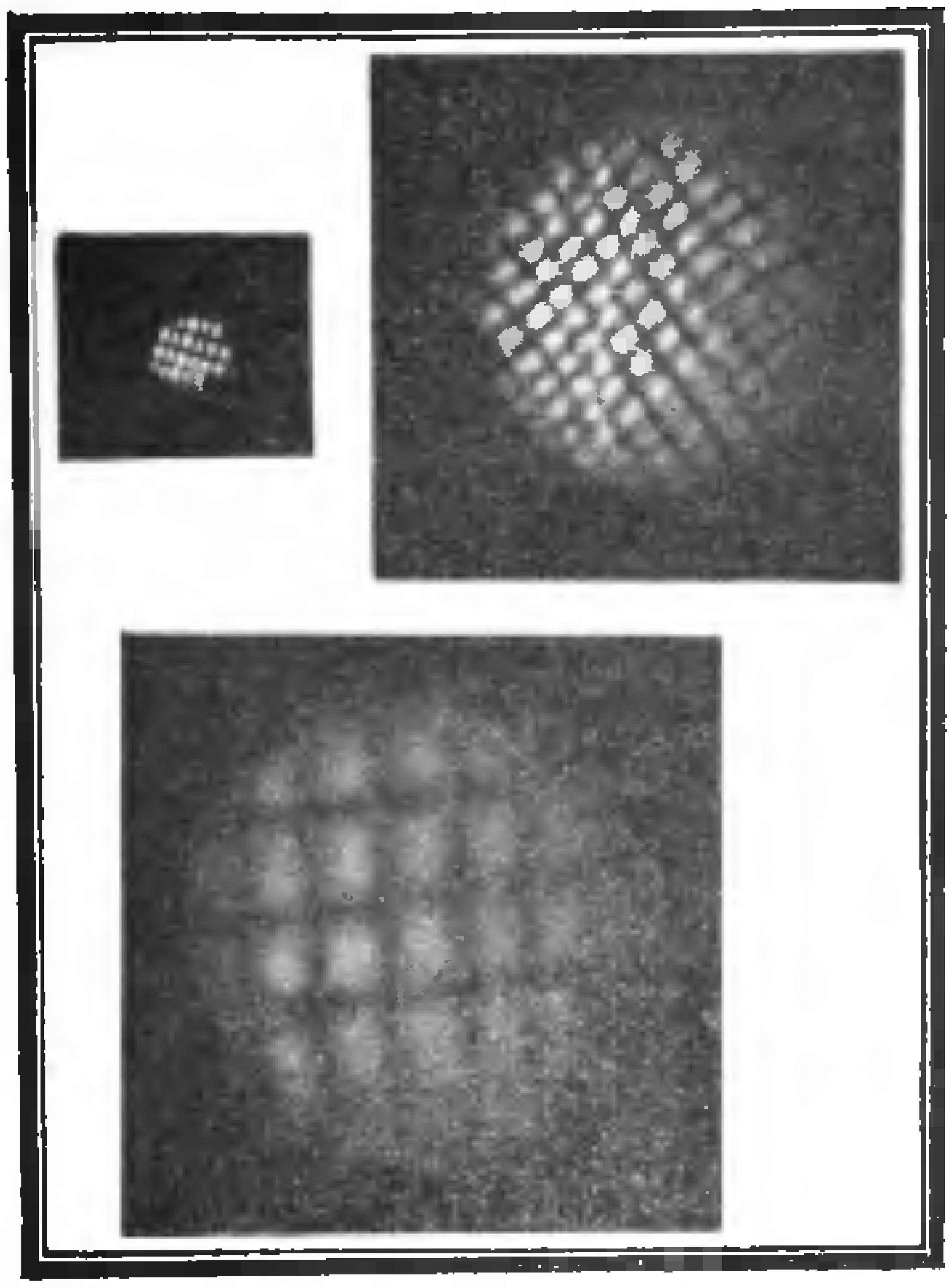

FIG. 2. Magnified images of a 100 mesh brass wire net, obtained by X-rays. The magnifications are for (*a*) ×3½, (*b*) × 6, (*c*) × 20.

Thus, it is clear that the new method of obtaining enlarged photographs with X-rays is workable and the exposures are not too large. The theoretical resolving power of this method is much larger than for the method employing total reflection. In the latter case, the limit of resolution is estimated to be about 3,000 Å for X-rays of wavelength about 1 Å.[5] Here, it should be very much smaller than this, if spherical aberration is made small, because diffraction alone would lead to a value of the order of the wavelength of X-rays. Therefore, it is necessary to devise suitable methods whereby the lattice planes could be curved to such a surface as to reduce spherical aberration. Two other possible methods of curving a crystal plate into a concave surface may be mentioned, though neither has yet been tried. One is to bend a circular plate pressed by means of two concentric rings from either side and the other is to deform it plastically to the required surface. The former is suitable for quartz and the latter for rock salt.

In any case, there seems to be little doubt that the design of the "X-ray microscope" considered here will have a resolving power better than that of the optical or ultra-violet microscope. Unfortunately, however, it does not appear to possess a large magnifying power. The focal length cannot be made less than about 5 cm., so that even a magnification of 50 in one stage would require a distance of 2·5 metres between the mirror and the photographic film. Higher magnifications in a single stage are thus ruled out. When we consider combinations of two mirrors as in a reflection microscope, a complication arises because in a Laue reflection, the wavelength of the ray reflected from the first mirror depends on the angle of reflection, and this has again to be incident at exactly the same angle on the second mirror. However, this strict condition can be satisfied by a combination of two annular mirrors with their axes coincident, but the theoretical study shows that the magnifications m_1, m_2 of the two mirrors are not independent. The total magnification $M = m_1 m_2 = m_1(2 - 1/m_1)$, so that $M \leqslant 2m_1$. Thus there is not much of an advantage in such a combination, in so far as magnification is concerned. However, it has the merit that the image is now along the axis and thus, there is no difference in the magnification in two perpendicular directions, as is the case with a single mirror.

Thus this instrument is not a suitable one for obtaining a very large magnification; however by using moderate magnification with X-rays and having further stages of enlargement optically, it is possible to obtain a resolving power better than the optical microscope. So also the greater penetration of X-rays would enable it to be used in circumstances where the electron microscope is inapplicable because of heavy absorption.

1. Compton, A. H., *Phil. Mag.*, **1923**, **45**, **1121**. 2 Kirkpatrick, P. and Baez, A. V., *Journ. Opt. Soc. Am.*, **1948**, **38**, **766**. 3. Lucht, C. M. and Harker, D., *Rev. Sci. Instr.*, **1951**, **32**, **392**. 4. Kirkpatrick, P., *Journ. Opt Soc. Am.*, **1949**, **39**, **796**. 5. Prince, E., *Journ. App. Phys.*, **1950**, **21**, **698**.