mum radius may be denoted by A. The minimum radius is then

$$A_m = \frac{\omega_0^2 A}{4\pi G\rho_0 - \omega_0^2}.$$

A period P of about 13 years is obtained if

$$\rho_0 = 1.5 \times 10^{-10}\ \mathrm{g/cm^3},$$
$$\omega_0^2 = 1.5 \times 10^{-17}\ (\mathrm{rad/sec})^2,$$

though, of course, certain other combinations of ρ_0 and of ω_0 would lead to the same period. The mass of a quasar is suspected to be of the order of 10^8 solar masses and, with the value of ρ_0 already quoted, it follows that A, A_m in light-years are given by

$$A = 7.2 \times 10^{-2}, \qquad A_m = 9.76 \times 10^{-3}.$$

These are small radii, as would be expected if all parts of the quasar's surface appear to a distant observer to vary in brightness simultaneously. Since the Schwarzschild gravitational radius of the configuration, $2GM/c^2$, is 3.1×10^{-5} light-years, the minimum radius is only some three hundred times the gravitational radius. These small dimensions, and the intense gravitational fields accompanying them, might lead to the conclusion that general relativity ought to be employed instead of classical theory. It is not necessary to do this, however, because in the corresponding problem of free gravitational collapse without rotation it can be shown that general relativity and classical mechanics lead to essentially the same conclusions. The absence of a pressure gradient is a more serious limitation which further study will no doubt remove.

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24 August 1964

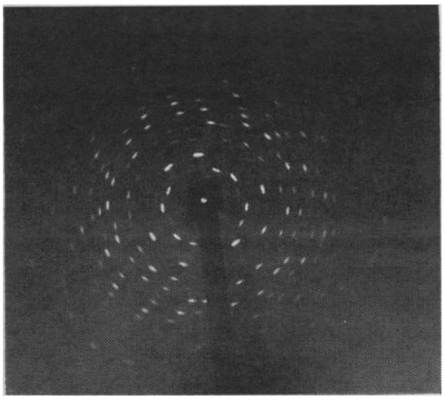
High-Voltage Laue X-ray Photography of Large Single Crystals

Abstract. *The perfection of relatively large single crystals can be tested by Laue transmission x-ray diffraction photographs by using much higher voltages for the x-ray generation than are used in conventional diffraction experiments. The technique can be used for determining the orientation spread of subcrystal units and for studying the loss of primary extinction due to occluded chemical impurities. An advantage of this method is its possible application to crystals inside polycrystalline or glass containers.*

Crystals that are large compared with the penetration of conventional electron or x-ray beams cannot be readily studied by diffraction techniques. Such large crystals can be subjected to a "surface" diffraction examination or to destructive studies by sectioning; these procedures are always tedious and usually unsatisfactory. Techniques in which more penetrating radiation is used may greatly simplify the study of large crystals. The application of neutron diffraction (*1*) for such purposes has already been discussed. The work described here illustrates the possibilities of high-voltage x-rays, up to about 200 kv, whose penetration depth is more than an order of magnitude greater than the x-rays used conventionally in diffraction experiments. The use of high-voltage Laue photography has been mentioned (*2–4*).

At accelerating voltages above those corresponding to the K-lines of the heaviest elements, there are no convenient monochromatic radiation sources of adequate brilliance for diffraction. Thus it is necessary to revert to the Laue technique, in which a stationary crystal is exposed to collimated polychromatic radiation. An advantage of high-voltage Laue photographs is that during exposure the specimen can be contained in a furnace or vacuum vessel made of polycrystalline or glassy material. Transmission Laue photographs taken with high-voltage x-rays (Fig. 1) are comparable in detail with conventional Laue pictures. They could be used for identification, orientation, or preliminary crystal perfection studies.

The collimation system (*2*) was placed as close as possible to a fine-focus (0.5 mm) x-ray tube. Exposures were of the order of 10 minutes on Ilford G x-ray film. The crystal specimen was adjusted so that the x-ray beam was perpendicular to the plane or axis of elongation of the specimens. The tangential elongation (Fig. 1) of the spots is largely due to beam divergence which can be measured by direct photography of the beam at different distances from the slit. For the slit used here, the incident-beam divergence from the central ray is about half of one degree, dependent slightly on wavelength. The radial dimension of the Laue spots depends on the size of the x-ray tube focal spot (the 0.5-mm microfocus tube was used for all illustrations), the specimen thickness traversed by the x-rays (*2*), and the divergence of the x-ray beam. To minimize spot broadening caused by divergence (*5*), the distance between the specimen and the film (measured along the diffracted ray) should equal the distance of the specimen from the effective point of divergence.



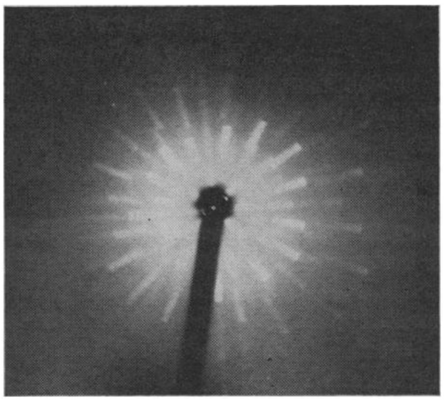


Fig. 1 (left). Laue photograph of a 0.5-mm thick germanium crystal cut perpendicular to the [111] direction; 150 kv x-rays parallel with [111], 8 ma, 10 minutes, 6 cm between slit and film. Fig. 2 (right). Laue photograph of a 2-cm thick aluminum crystal; 150 kv, 5 ma, 10 minutes, 6 cm between slit and film.

The increase in radial length of the spots, resulting from the greater thick-

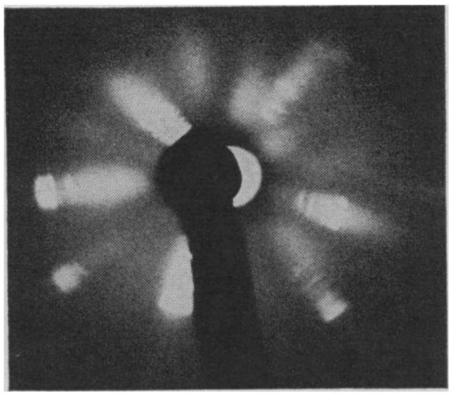


Fig. 3. Laue photograph of 1.5-cm thick potassium single crystal with appreciable orientation spread; 125 kv, 5 ma, 20 minutes, 10 cm between slit and film.

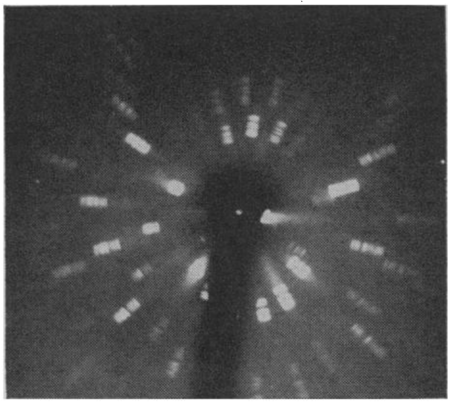


Fig. 4. Laue photograph of a 2-cm thick aluminum crystal grown by a Bridgman technique; 150 kv, 5 ma, 15 minutes, 10 cm between slit and film.

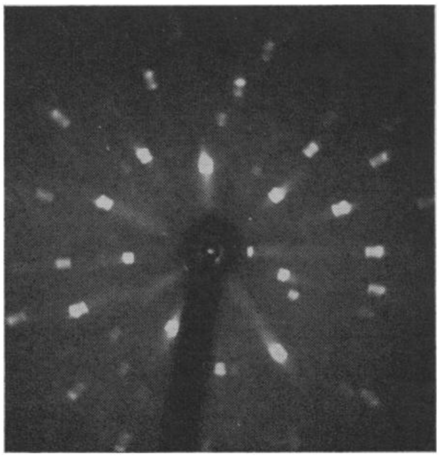


Fig. 5. Laue photograph of a 9 mm thick strain-annealed aluminum crystal; 150 kv, 5 ma, 5 minutes, 10 cm between slit and film.

ness of the crystal, is illustrated in Fig. 2, which shows a Laue photograph of a thick (2 cm) aluminum crystal. The crystal thickness in this instance is not negligible compared with its distance from the photographic film. The diffraction "spots" are therefore produced as radial streaks of length equal to the projected thickness of the crystal (*2, 3*), the direction of projection being parallel to the diffracted rays, and the plane of projection being the photographic film.

Appreciable misorientation within an apparently single crystal is recognized in the Laue photograph of a potassium crystal (Fig. 3). The streaks are longer than can be explained by the geometric effect discussed above, and their length is not simply related to the angle of diffraction. The detail in the individual streaks indicates the presence of subcrystals with large orientation spread. We have not ascertained whether the crystals grow imperfectly or whether they become deformed by handling.

The x-ray Laue photograph (Fig. 4) of an aluminum single crystal (2 cm thick) grown by the Bridgman method shows streaks of the predicted length for a nearly perfect crystal, so that considerable misorientation in subcrystals is excluded. However, there is detail along the streaks, presumably due to slightly misset mosaic "blocks" failing to produce streak intensity at one point and increasing it in another. The somewhat periodic fluctuation of intensity along the streaks at first seems surprising.

A very similar periodic structure in small crystals has been described by Guinier (*6*). Strain-annealed aluminum (*7*) does not show the intensity fluctuation to the same extent (Fig. 5). The increase in intensity at the ends of the streaks is a coherence effect (*2*) and corresponds to the predictions made by Kato (*8*) from the dynamic theory of x-ray diffraction for crystals of low absorbing power. Murdock (*9*) has previously observed the effect, but his explanation needs modifications in the light of more recent dynamic theory.

The high-voltage Laue technique may be applied to the study of the influence of impurities on the crystal diffraction. Primary extinction reduces the intensities of reflections of ammonium dihydrogen phosphate (ADP) crystals of high perfection. By contamination with Cr^{3+} ions, the perfection of the crystals is reduced and the intensities are correspondingly increased (Table 1). As is typical for primary extinction, the weak diffractions are not affected.

Table 1. Approximate integrated intensities of recorded Laue diffractions from section of an ammonium dihydrogen phosphate (ADP) crystal containing pure and chromium-contaminated portions (90 kv, 5 ma, 25 minutes, 20 cm between slit and film).

hkl	Intensities* (summed over all orders)	
	Pure ADP	Cr^{3+}-contaminated ADP
541	6.8	14.3
631	11.8	19.2

* Fluctuations between symmetrically equivalent spots (due to lack of precision in orientation, and other effects) range about ±25 percent from the mean.

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Crystal and Molecular Structure of Ferrichrome A

Abstract. *The crystal structure of ferrichrome A* ($C_{41}H_{58}N_9O_{20}Fe\cdot 4H_2O$) *has been determined by x-ray diffraction. The amino acid sequence in the hexapeptide ring is confirmed to be -Orn-Orn-Orn-Ser-Ser-Gly-, and the conformation of this ring is* trans *at each peptide linkage. The absolute configuration of the three hydroxamate rings at the iron atom is that of a left-handed propeller. Disorder is found concerning the positions of some of the side chains and one of the four water molecules.*

Ferrichrome A, a product of the metabolism of the smut fungus *Ustilago sphaerogena*, is a ferric hydroxamate and a cyclic hexapeptide consisting of residues of the amino acids glycine, serine, and ornithine (*1*). It is related