CHAPTER 6

LATTICE REORIENTATION IN INHOMOGENEOUS DEFORMATION

§ 14. Geometry, Crystallography, and Relation to Atomic Structure

1. Irregular Lattice Reorientation by Mechanical Stress

The lattices of the components of a classical twin are always inclined to one another at a definite angle and are rigidly joined at the surface of contact. The indices of the twin plane, the direction of twinning, and the twinning axis are small and are determined by the crystal structure. When crystals are mechanically stressed, reorientation of large regions of the lattice can occur as well as classical mechanical twinning and plastic deformation by slip; the orientation of these regions does not obey the rules of classical twinning. The angle through which the lattice is rotated depends both on the crystal structure and on the extent of the deformation. The plane of junction has a large (irrational, see § 1.3) index, and in general is not a plane of symmetry of the adjacent crystals. In individual cases the lattices are joined symmetrically along irrational planes of contact.

2. Historical

Lehman (1885) first reported the existence in minerals of regions joined at arbitrary and variable angles; these regions were considered as unusual twins. Friedel (1926) described the formation of imaginary twins. Mügge (1898) first distinguished between regularly oriented regions (twins) and irregularly oriented regions (kinks). He assumed that kinks are complex processes involving either classical mechanical twinning or plastic deformation by translation slip (§ 1.1). He also produced kinks by compressing crystals of various minerals. Brauns (1889) observed striations in natural rocksalt corresponding to the irrational plane (20.20.1) [close to (110)] but could not produce similar striations by deforming rocksalt crystals.

Elam (1928) found that rotated regions are produced by inhomogeneous pulling of monocrystals of aluminum and silver; he called these regions mechanical twins. He found a rotation of 66° around [121] in one aluminum specimen.

Brilliantov and Obreinov (1935, 1937) found that rotated macroscopic regions are formed by compressing flat rocksalt specimens; the orientation of these regions is different from that of the flat twinned layer. They called this effect irrational twinning. Star'tev (1940, 1941) and Klassei'-Neklyudova (1942a, b) carried out similar experiments at higher temperatures. Step'anov (1937) and Step'anov and Donskoi (1954) found that unusual platelike regions are produced by pulling rocksalt crystals with a fixed orientation at high temperatures; Step'anov called this effect plating.

Orowan (1942) produced very unusual reoriented regions (kinks) by bending a cadmium crystal longitudinally.

*The (110) planes act as glide planes in rocksalt.
Since 1949 kinking has aroused increasing interest. Kinking has been produced by compressing monocrystals of cadmium (Orowan, 1942), zinc (Hess and Barrett, 1949; Gilman, 1954), and titanium (Anderson, Jillson and Dunbar, 1953), and by pulling monocrystals of iron (Holden and Kunz, 1953), aluminium (Calnan, 1952), zinc (Washburn and Parker, 1952; Gilman and Read, 1953), tin (Jackson and Chalmers, 1953), bismuth (Berg, 1934), magnesium (Chaudhury et al., 1953), titanium (Churchman, 1955), and copper (Dichl, 1956) (see review by Urusovskaya, 1960). Kinking in crystals of thallium and cesium halides has also been studied (Klassen-Neklyudova and Urusovskaya, 1953, 1955, 1956a, b, 1960).

Pfeil (1927) and Barrett (1939) found band-shaped reoriented regions (deformation bands) in metallic monocrystals (α-Fe, AlMg).

High-resolution microscopy has shown that substructures (microblocks) occur in metallic monocrystals and polycrystals (see reviews by Cahn, 1950b, and by Gifkins, 1955). As well as causing slip traces, deformation of metals causes these microblocks to break up into smaller (about 1000 Å) disorientated blocks (Delise, 1953). The geometry of these effects indicates that most of them are connected with atomic processes.

3. Types of Lattice Reorientation: Irrational Twins, Kink Bands, Plates, Deformation Bands, Accommodation Bands, and Brilliantov-Obreimov Bands (Irrational Twins)

If a cleaved rocksalt plate (ratio of dimensions 1:10:10) is compressed along its short edge, ridges are formed on the sides (Fig. 147). Optical and x-ray measurements show that these ridges are rotated regions of the crystal (Fig. 148a, b) (Brilliantov and Obreimov, 1935). The angle between adjacent ridges varies from several minutes to several degrees, depending on the deformation. The boundary planes of adjacent rotated regions are not fixed in orientation; they are inclined to (110) by up to 1.5° if the deformation is carried out at room temperature (i.e., they have irrational indices) (Brilliantov and Obreimov, 1935). Figure 149a shows the side 1 (Fig. 147) of a compressed rocksalt crystal in reflected light. Figure 149b shows the surface 2 of this specimen in polarized light. Comparison of Fig. 149a and Fig. 149b shows that the ridge boundaries correspond to bright lines on the end face of the crystal; the lines are seen in polarized light on account of localized internal stresses at the boundaries of the rotated regions.

Kink Bands. Kink bands are produced by compressing crystals of kyanite, calcite, and mica (Mügge) (Fig. 150a-c), of cadmium (Orowan, 1942) and naphthalene (Perekalina, Regel', and Dubov, 1958) (Fig. 151a-c), and of CsI and a solid solution of TlBr and TlI (Klassen-Neklyudova and Urusovskaya, 1956a) (Fig. 152a-c). Kinks occur most frequently at the ends of specimens (Fig. 151c and 152b). Sometimes longitudinal compression produced one (Fig. 151a, 152a, c) or several kinked layers (Fig. 151b, c). The kinked layer in compressed monocryystals of naphthalene and of thallium and cesium halides forms an intermediate zone between two monocrystelline regions. This zone consists of many wedge-shaped regions rotated with respect to one another; the wedges are clearly seen in transmitted light.

Figure 152c shows a CsI crystal with one kinked layer and many slip traces both inside and outside the layer; the photograph was taken in polarized light. X-rays and polarized light were used to study the structure of the kink bands in thallium and cesium halides. The angle of rotation of the wedge-shaped regions with respect to the lattice of the original crystal changed stepwise from one wedge to the next; the wedge in the middle of the intermediate zone is turned through the greatest angle (up to 30-40°). Figure 153 shows a scheme for the formation of such an intermediate zone. The continuous lines are the boundaries of the wedge-shaped regions making up the kinked layer, while the dotted lines show the direction of slip traces in the deformed crystal. According to this scheme, the surfaces of the wedges during deformation tend to be perpendicular to the slip planes.†

Stepanov Bands (Plates). Plate-like regions (bounded by planes close to those of a rhombododecahedron) are formed by pulling rocksalt crystals in the [110] slip direction at 50-300°C (Fig. 154a) (Stepanov, 1937; Zankelies, 1962) has observed crystallographic slip in nylon 66 and 610, and also the formation of kink bands.† More precisely, to take the position of the bisector of the angle (close to 180°) formed by the lines of slip in adjacent regions of the kink (§ 14.4).