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8. CRYSTAL DEFECTS

Nothing is perfect.

An ideal crystal is one in which each atom has a definite equilibrium location in a regular array. Actual crystals are far from meeting this specification. Defects in the structure of a crystal, – missing atoms, extra atoms, atoms out of place, irregularities in the spacing of rows and atoms, the presence of impurities, and so forth – have a considerable bearing on its physical properties. Thus the behaviour of a solid under stress is largely determined by the nature and concentration of defects in its structure, as is the electrical behaviours of a semi-conductor.

The simplest category of crystal imperfection is the **point defect.** The **Figure 30** shows the three basic binds of point defect; the vacancy, the interstitial and the impurity.

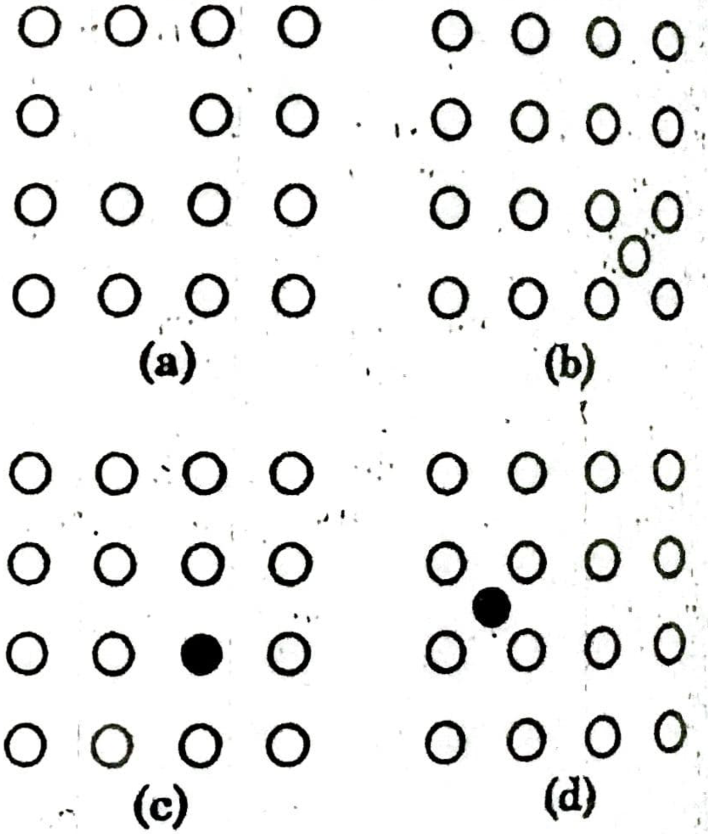

Fig. 30: Point defects in a crystal (a) Vacancy, (b) Interstitial (c) Substitutional impurity, (d) Interstitial impurity.

Both vacancies and interstitials, which require about 1 to 2 eV to be created, occur in all crystals as a result of thermal excitation, and their frequency accordingly increases rapidly with temperature. Of much importance is the production of defects by particle radiation. In a nuclear reactor, for instance, energetic neutrons readily knock atoms out of their normal locations. The result is a change in the properties of the bombarded material, most metals, for instance, become more brittle.

The existence of point defects in a crystal makes possible the diffusion of atoms within it—a surprising notion at first glance, though less surprising when we think of the bonding of dissimilar metals in such processes as soldering, brazing and galvanizing. When vacancies are present, diffusion occurs by the jumping of an adjacent atom into a vacancy to leave a new vacancy behind into which another atom may jump later, and so on. When interstitials are present, diffusion occurs as they migrate through the crystal. As we would expect, diffusion in a solid is strongly temperature-dependent, increasing from a usually negligible rate at room temperature to one not far from that characteristic of the corresponding liquid near the melting point.

A **dislocation** is a type of crystal defect in which a line of atoms is not in its proper position. Dislocations are of two basic kinds. **Figure 31** shows an **edge dislocation,** which can be visualized in terms of the removal of one layer of atoms and the subsequent accommodation of the array to the defect. In the **Figure** the bonds between atoms are represented by lines. The other kind of dislocation is the **screw dislocation.** We can visualize the formation of a screw dislocation by imagining that a cut is made part way into a perfect crystal and one side of the cut is then displaced relative to the other, as in **Figure 32.** The atomic layers spiral around the dislocation, which accounts for its name. Actual dislocations in crystals are usually combinations of the edge and screw varieties.

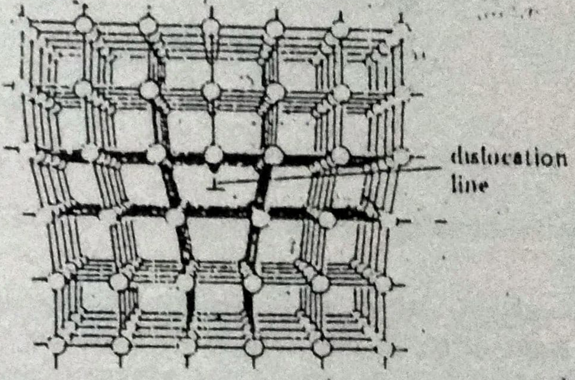

Fig. 31: An edge dislocation

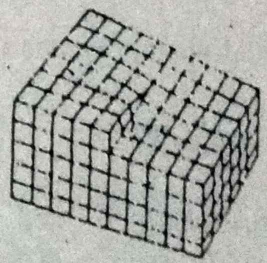

Fig. 32: A screw dislocation

When an applied stress exceeds its elastic limit, a material no longer returns to its original shape but is permanently deformed. Most metals can undergo substantial plastic deformation before fracture, a property called ductility. In other solids the plastic range is usually smaller. The elastic response of a solid is readily interpreted in terms of the bonding forces within it, which act like Hooke's law restoring forces for small displacements from the equilibrium configuration. But this direct approach fails to account for plastic behaviour. To slide one layer of atoms in a crystal past another layer — which would mean the breaking of vast number of bonds between atoms simultaneously — would need forces about a thousand times higher than those actually found.

The presence of dislocations makes it possible to understand why many solids can be bent, squeezed, or stretched into new shapes without breaking. Figure 33 shows how a crystal that contains an edge dislocation can be permanently deformed by a relatively modest pair of forces. The line of atoms below and to the right of the dislocation shift their bonds to the line of atoms directly above it when the forces are applied, which causes the dislocation to move one atom spacing to the right. The process is repeated until the dislocation arrives at the edge of the crystal, and the deformation is then permanent. The entire process is called **slip**, and the plane along which the dislocation moves is the **slip plane**. In slip, the atomic bonds holding one layer to the next are broken only one line at a time, not all at once.

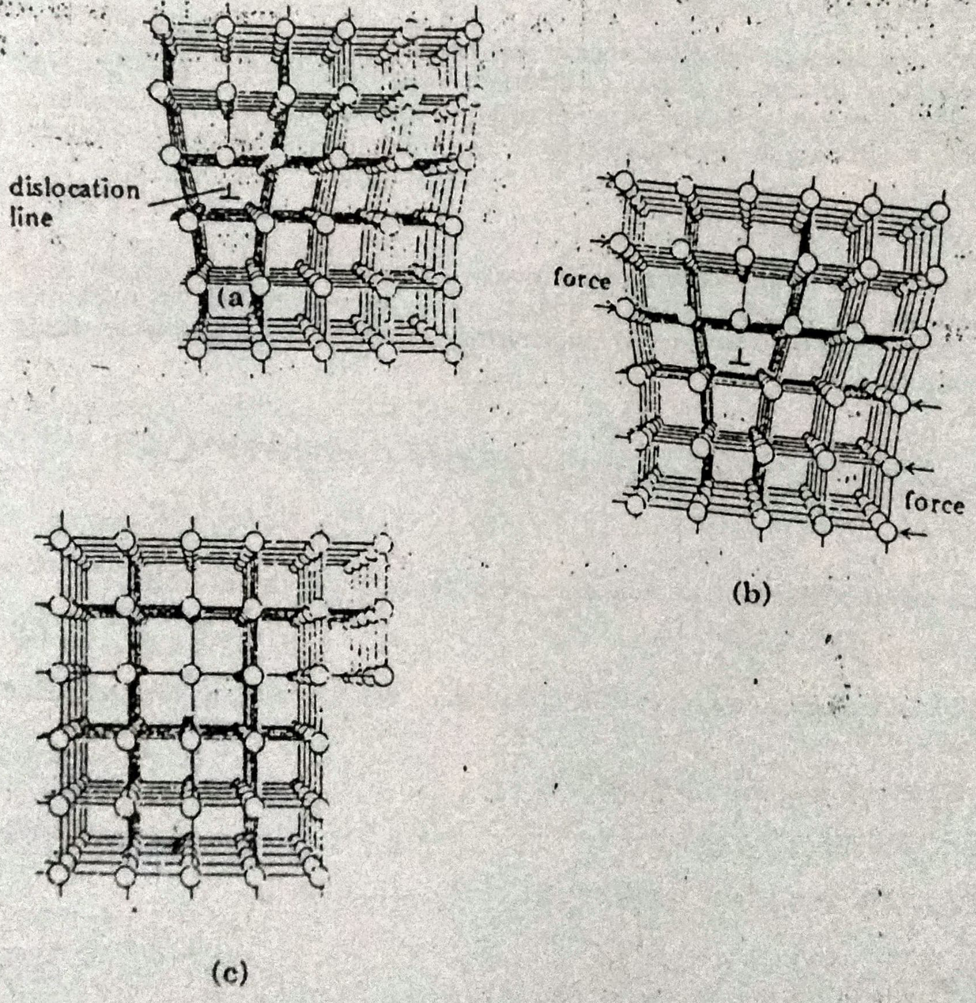

Fig. 33: Slip results from the motion of a dislocation through a crystal under stress. (a) Initial configuration of crystal. (b) The dislocation moves to the right as the atoms in the layer under it successively shift their bonds with those of the upper layer one line at a time. (c) The crystal has taken on a permanent deformation.