Twinning in metal crystals is usually accompanied by appreciable plastic deformation by slip near twin boundaries [1]. There is considerable hardening during twinning on account of the interaction of partial twinning dislocations with complete ones during the development of a layer [2]. As a rule, the twin boundaries in metal crystals are incoherent, so there are high twinning dislocation densities at the boundaries. The external stresses are balanced by long-range internal stresses in a loaded crystal, and the level of the internal stresses is determined by the dislocation structure of the crystal near the twins, together with the repulsion forces between dislocations of the same sign in dislocation groups at interfaces.

After the load has been removed, some of the twinning dislocations escape from the crystal (elastic detwinning [3, 4]), and the level of the internal stresses becomes less than that at which the twinning ceased. Repeated twinning in the same crystallographic planes begins on reloading at stresses less than the primary value [5], because the reconstruction of the dislocation structure needed for twinning has been produced partly by the primary loading. The instability in the dislocation structure means that one gets not only a reduction in the yield point on repeated motion of the twin boundaries but also partial or complete loss of the hardening resulting from the interfaces during the layer development in loading.

Here we examine the effects of the scale of unloading on the wedge twins in bismuth crystals.

Single-crystal specimens 3 x 2 x 15 mm were deformed in pure bending on an apparatus attached to the stage of a Linnik microinterferometer [6]. During loading and unloading, we measured the distances between the boundaries of a single twin in a cleavage plane. All the measurements were made on wedge twins with linear densities of twinning dislocations at the boundaries of $10^5-10^6$ cm$^{-1}$. The mean density of twinning dislocations at the interfaces was estimated by the method of [7]. The loading rate was 0.04 kgf/mm$^2$ / rain in most of the experiments.

Figure 1a shows a plot of $\sigma$ against $\Delta b$, where $\sigma$ is the stress in the twin plane and $\Delta b$ is the normal displacement of the twin boundaries. At a stress $\sigma_0$ (point a) the crystal is unloaded to a stress $\sigma_K$, which corresponds to 25% reduction in the stress in the crystal. Reloading from $\sigma_K$ to $\sigma_0$ leads to additional displacement of the twin boundaries by an amount $\beta_1$. Stress pulsations in the range $\sigma_K - \sigma_0$ are accompanied by cyclic hardening and stabilization of the position of the twin boundaries; a quantitative measure of the effect can be either $\beta_1$ or $\alpha = \Sigma \beta_1 / b_0$, the relative integral displacement of the twin boundaries during the cycling, where $b_0$ is the thickness of the initial layer. Parts Fig. 1b and c show similar diagrams for 50 and 100% unloading.
The ratio \( \alpha / \beta_1 \) is independent of the dislocation density at the boundaries within the limits of the experimental error, and is also independent of the extent of the unloading, the angle of the wedge, and the loading rate; the values were 3-4.0.

The absolute values of \( \beta_1 \) and \( \alpha \) are dependent on \( \Delta \sigma / \sigma_0 = (\sigma_0 - \sigma_K) / \sigma_0 \) (Fig. 2). The maximal values of \( \beta_1 \) and \( \alpha \) correspond to \( \Delta \sigma / \sigma_0 = (\sigma_0 - \sigma_K) / \sigma_0 = 0.7 \); the character of the \( \beta_1 (\sigma_K / \sigma_0) \) relationship is related to details of the unloading curve (broken line in Fig. 1a). Unloading to \( \sigma_K = 0.3 \sigma_0 \) is not accompanied by an appreciable reverse motion of the twin boundaries, and hence substantial loss of the twinning dislocations from the crystal.

Reduction in \( \beta_1 \) for \( \sigma_K < 0.3 \sigma_0 \) occurs because there is considerable reverse motion of the twin boundaries; as the reverse displacement has to be balanced out during the subsequent loading cycle, the boundaries of the twin are displaced less than they were relative to the position before unloading.

The nature of this effect is not fully understood. Plastic deformation by slip during unloading sometimes results in a step on the yield curve in the \( \sigma - \epsilon \) diagram, which is associated with blocking or complete dislocation [8]. Twin sublayers with plane-parallel sides do not show this property in calcite crystals during quasistatic loading [9]. The additional displacement of the boundaries is not related to creep at the twin boundaries, or to retention of the twin crystal for a long time at the maximum stress \( \sigma_0 \), because this leads to a reduction in the thickness of the twin that is less by an order of magnitude than that found during pulsating loading.

It has recently been found [10] that some blocking obstacles become insuperable on repeated motion of complete dislocations in planes in which those obstacles were easily overcome during the first motion. At the boundaries of the individual twins one gets the opposite effect; these surprising differences in the mechanical properties of complete dislocations and dislocation groups at twin boundaries are probably related to the different mechanisms of the structural changes accompanying the motion. The movement of a complete dislocation in the lattice is accompanied by displacement of regions of considerable local stress at the core of the dislocation; the motion or dislocation is retarded near an obstacle, and the dislocation may even be stopped at the obstacle for times from a fraction of a second to 10-15 min [10]. This time is sufficient for the obstacle to be strengthened on account of incoming diffusion of impurities in the stress field of the dislocation core. The obstacle becomes insuperable on repeated motion of the dislocation in the same plane.

The Burgers vectors of the twinning dislocations are 0.118 of the interatomic distance in bismuth, so twinning is accompanied by less local distortion; on the other hand, the overlap between the individual crystallographic planes of the obstacles does not result in twinning halting in other planes; one gets islands of untwinned lattice around the obstacles in the twinned volume [11].

Twinning dislocations form groups at obstacles on incoherent interfaces; the escape of some of the dislocations on unloading is accompanied by change in the force of dislocation interaction in these groups at the obstacles. During the subsequent loading cycle, the twin dislocations move again in the crystallographic planes in which the detwinning occurred; then their motion is usually facilitated because some of the structural changes in the lattice were produced by the primary twinning. For instance, the islands of untwinned lattice remain surrounded by packing defects of twin orientation on reverse motion of the twin boundaries during unloading. On second loading, all the partial dislocations forming a boundary acquire high speeds on reloading at the time when the dislocation density at the boundary attains the value before unloading, and the dynamic effect at the boundary breaks away some of the obstacles that oppose the motion of the twin boundary into the matrix. The increased dynamic effect may be ascribed to increase in \( \beta_1 \) and \( \alpha \) with the loading rate, as has been found from experiments with a variety of loading rates.

Increase in \( \alpha \) and \( \beta_1 \) in the range 0-0.7 (Fig. 2) involves an increase in the mean free path of the twinning dislocations in planes in which one gets detwinninig or unloading, and repeated motion of the dislocation is facilitated. For \( \Delta \sigma / \sigma_0 = 0.7 \) one gets detwinninig in 10⁶ crystallographic planes, which is sufficient to allow a dislocation group to accelerate and break away from the obstacles that restrict motion of the boundary into the matrix.

On reloading, one gets cyclic hardening of the twin boundaries, which may be related to increase in the long-range internal stresses near them [12] on account of plastic shear and regions adjoining the twin boundaries. If we assume that the motion of the dislocation group occurs in response to a difference.