STACKING FAULTS IN CLOSEPACKED METALLIC LATTICES

Part I. The Nature and Origin of Stacking Faults

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INTRODUCTION

In solid metals, the atoms or positive ions are held together by a cloud of free electrons and each atom tends to be attracted equally to all its nearest neighbours. The majority of metals crystallize therefore in highly closepacked structures.

A closepacked atomic lattice can be visualized as a regular pile of closepacked atomic planes. The atoms in each plane lie in three sets of lines (Fig. 1) which are physically equivalent and 120° to each other. If the letter A represents one such plane, the next plane can be put above it in two possible positions represented by letters B and C. Any arrangement or mode of stacking of planes of types A, B and C gives a closepacked structure, provided no two successive layers are alike. The closepacked metallic lattices normally exhibit either the ABCABC— or the ABABAB— sequence. The former is the so-called face-centred cubic (f.c.c.) structure adopted by common metals like aluminium, copper, gold, nickel and silver. The latter is the hexagonal closepacked (h.c.p.) structure exemplified by metals like cadmium, magnesium, titanium, zirconium and zinc. Cobalt is an interesting metal which exists in both modifications.

The f.c.c. and h.c.p. structures are the only two perfectly regular of the common closepacked structures. Any other sequence of layers, subject only to the condition that any two adjacent layers must be in different positions, is still closepacked, but has to be considered a faulty f.c.c. or h.c.p. structure. Any break in the sequences ABCABC— and ABABAB— is normally referred to as a "*stacking fault*". The existence of such stacking faults in metallic lattices was first detected in 1942 in the case of h.c.p. cobalt.[1,2] It is now known that stacking faults are introduced fairly commonly in metals by plastic deformation or phase transformation, and also during crystal growth. Such faults may be distributed randomly, clustered together or arranged more regularly in the lattice. They contribute to the anomalous broadening of X-ray reflections and have recently been recognized as playing an important role in the work hardening of metals.

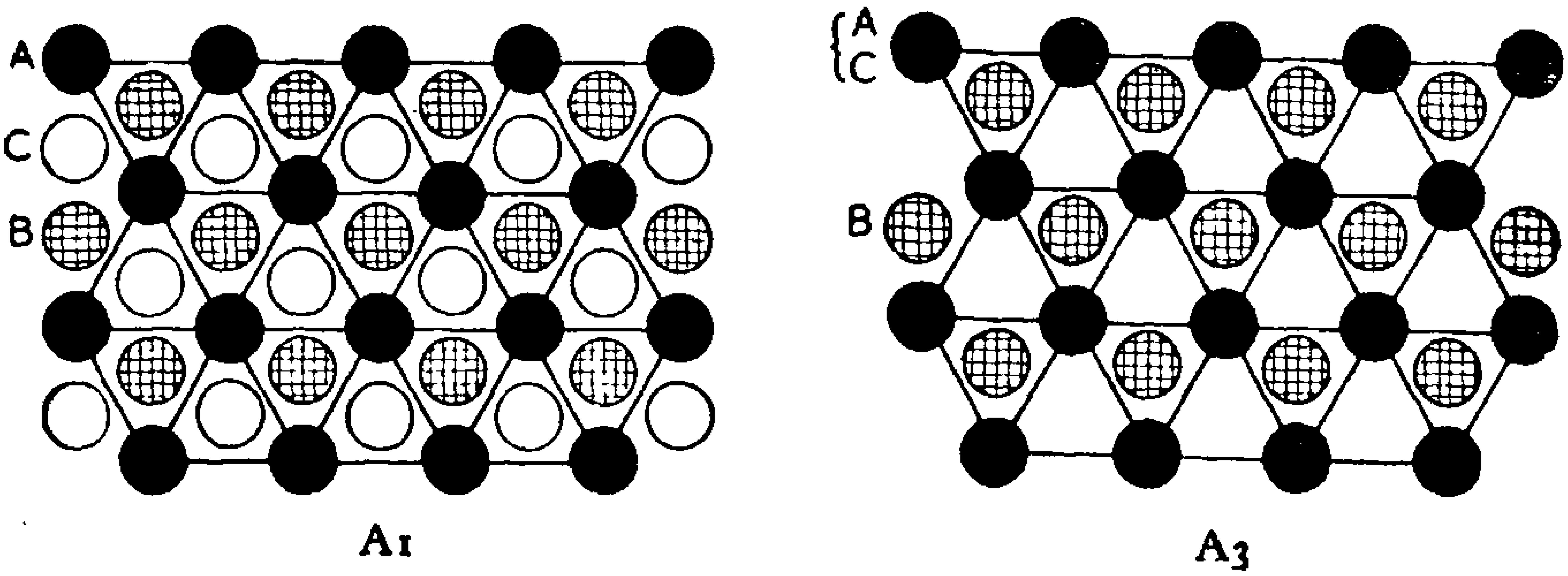

FIG. 1. Formation of closepacked lattices from closepacked atomic planes (B and C are the two possible positions for the plane above A. A_1 and A_3 are the f.c.c. and h.c.p. sequences respectively).

LAWS OF GROWTH AND DEFORMATION FAULTING

It is common practice to classify stacking faults in closepacked lattices into "*growth faults*" and "*deformation faults*". The differences between the two types are easily understood on the basis of simple laws for their formation.

The law of growth faulting for the f.c.c. structure is that each atomic plane is displaced relative to the two planes immediately beneath it, except at a fault where it is above the plane next but one below it. For the h.c.p. structure, each plane is above the layer next but one below it, except at a fault. Typical sequences of planes are thus:

ABCABCBACBAC	..	f.c.c. growth fault
ABABABCBCBCB	..	h.c.p. growth fault

The f.c.c. growth fault produces a twin orientation, an ABCABC— sequence being converted to a CBACBA— sequence. In the h.c.p. structure, however, owing to the different symmetry, the two halves have the same orientation and differ only by a translation. A growth fault introduced at each plane of the h.c.p. lattice produces the f.c.c. lattice and *vice versa*. There is thus a continuous transition between the two structures represented by an increasing number of randomly distributed growth faults.

The law of deformation faulting for both structures is that the lattices on either side of the fault have identical orientation, but the two halves are displaced parallel to the closepacked planes. Typical sequences of planes are thus :

ABCABCBCABCA .. f.c.c. deformation fault

ABABABCACACA .. h.c.p. deformation fault

For both structures, therefore, a deformation fault can be considered equivalent to a cluster of two growth faults on neighbouring atomic planes.

A deformation fault introduced at every plane of an f.c.c. lattice gives an f.c.c. lattice of twin orientation. Similarly, one h.c.p. sequence is converted to another h.c.p. sequence by including a fault in each plane. Thus there is no continuity between the two lattices as in the case of growth faulting. A random arrangement of growth faults in either structure produces therefore quite different X-ray diffraction effects from the corresponding structure with a random arrangement of deformation faults.

The laws postulated above implicitly assume that a stacking fault extends over the whole of an atomic plane. In reality, however, a fault may occupy part of a plane and be bounded by what are known as "imperfect dislocations" in the lattice. It is not possible with present experimental methods to establish whether stacking faults occupy part or whole of the atomic plane. The quantity that can be experimentally measured by X-ray methods is α, the frequency of faults or faulting parameter, which can be defined as the ratio of the total area of faults to the total area of closepacked planes. Such measurements are further based on the assumption that the faults are *randomly* distributed in the lattice.

Stacking Faults from Crystal Growth

If a closepacked lattice is built up by the successive growth of closepacked atomic layers in such a way that each layer forms from a fresh two-dimensional nucleus, there will be a finite probability of a layer going into the wrong position. When the kinetics of growth are such that the rate-limiting factor is the time to form the two-dimensional nucleus, the latter will spread rapidly over the plane after attaining a critical size. If a stacking fault is nucleated, it will occupy most of the plane. This is the situation envisaged in the law of growth faulting. It might arise during electrodeposition, growth from the vapour at high degrees of supersaturation and in certain types of nucleation and growth phase transformations. Fine twinning that can be observed in electrodeposited copper has been attributed to growth faulting.[3] Since these twins are visible microscopically, the faults seem to occur once in a few thousand atomic planes. X-ray diffraction effects become appreciable only at values of α corresponding to a twin thickness of less than a hundred atomic planes.

It is also possible, especially in transformations requiring long-range diffusion, that the rate of growth of a layer is small compared to its rate of nucleation. Growth faults will then form more readily, but will seldom grow to dimensions of the order of a whole plane. An aluminium-silver alloy with 30% silver prepared by condensation of the vapour has been found to contain both h.c.p. and f.c.c. phases together with a faulted structure at the junction of the two phases.[4] Growth faults have also been reported in vacuum-deposited pure silver,[4] but neither effect has been studied quantitatively.

Faulting Due to Martensitic Transformation

The formation of growth faults during martensitic transformations (*i.e.*, athermal, solid-state transformations involving simultaneous and co-ordinated movement of atomic planes in the lattice) has been clearly demonstrated in the case of h.c.p. cobalt[1,2] and h.c.p. lithium.[5] Quantitative estimation indicates that the faults are of the order of one in ten atomic planes in cobalt and even more in lithium. The faults in cobalt are of a rather complex nature and the results are often consistent only if the faults are assumed to be not completely random, but clustered together.[6]

The origin of faults during martensitic transformation has not yet been clearly understood. Such transformations are supposed to take place homogeneously with a macroscopic shear[7] and so, faults can arise only when transforming domains from different nuclei meet out of phase or when the transformation proceeds inhomogeneously in the regions between the macroscopically sheared layers already formed. The magnitude of the faults is far too much, however, to be explained this way. In h.c.p. cobalt, the most extensive faulting is observed in specimens which have been plastically deformed to assist the f.c.c. → h.c.p. transformation. Such specimens then contain both growth and deformation faults,[6] whose combined effects cannot be easily separated for reliable quantitative estimation of either.

FIG. 2. Streaks due to stacking faults in an oscillation photograph of a grain in a massive cobalt specimen (Ni K_α radiation, range of oscillation 15°).

ORIGIN OF DEFORMATION FAULTS

In 1952, exactly ten years after the first detection of stacking faults in a metallic structure, the suggestion was put forward[3] that a large part of the X-ray line broadening of cold-worked metals or alloys might be due to stacking faults. Evidence for the presence of deformation stacking faults in cold-worked closepacked metals is now available in the case of α-brass,[8] h.c.p. cobalt,[6] nickel and silver,[9] gold,[10] nickel-cobalt alloys,[11] copper and a number of its binary alloys[12] and a few martensitic steels.[13] The faulting parameter varies in such cases in the range 0·001-0·05. In some instances,[11-13] interesting correlations have been arrived at between the incidence of deformation fault and changes in electrical and mechanical properties.

Deformation faults are supposed to arise by the slipping or gliding of closepacked atomic planes over one another during mechanical deformation. In the case of an ABABAB— h.c.p. sequence, deformation faulting can occur only by both A and B planes gliding to the C positions. These are opposite so far as arrangement is concerned. but only require atom movements at 60° to each other and hence may be produced by the same shear stress.

DETECTION AND EVALUATION OF STACKING FAULTS

As pointed out earlier, the detection of stacking faults as well as the quantitative evaluation of the faulting parameter is possible only by X-ray methods. The effects of stacking faults on X-ray diffraction from faulted closepacked lattices have been worked out in detail by several authors and can be best understood in terms of the reciprocal lattices of the two closepacked structures. In Part II of this review, a simple, composite picture of the X-ray diffraction effects of the four types of stacking faults will be given. A clear understanding of these effects is absolutely necessary for both qualitative as well as quantitative determination of the faulting parameter.

In general, the presence of stacking faults is revealed by streaks (Fig. 2) in Laue and Oscil-

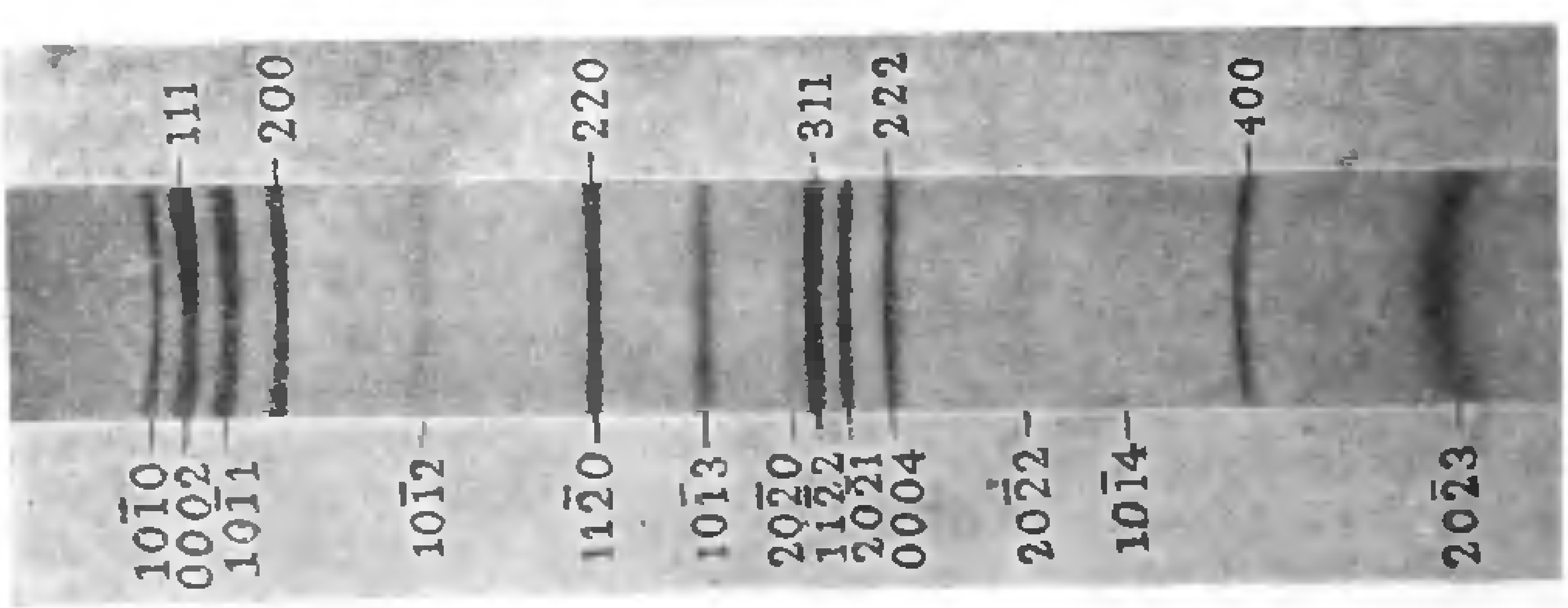

FIG. 3. Anomalous broadening of X-ray reflections in a Debye-Scherrer pattern of pure cobalt (Ni K_α radiation 9 cm. camera).

lation photographs and by the anomalous broadening of some lines (Fig. 3) in Debye-Scherrer patterns. These streaks and broad lines are easily detectable when the faulting frequency is greater than one in fifty planes The establishment of the actual type of faulting as well as the accurate measurement of the faulting parameter is, however, possible only through a detailed study of the nature of the streaks or line-broadening, as dealt with in Part II of this review.

(To be continued)

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ORIGIN OF RADIO BURSTS FROM THE SUN

AUSTRALIA has shared with Cambridge and Manchester in the advancement of the still young science of radio astronomy to a position in which it contributes seriously to many different branches of astronomy. A method of following the course of radio bursts from the sun—that remained for several years "special" to Australia is believed to be within sight now.

The originator of the method was Mr. J. P. Wild of the Radiophysics Laboratory, the Commonwealth Scientific and Industrial Research Organization. Mr. Wild's first apparatus was begun in 1948, and a second and much bigger instrument completed in 1952. By this time there was comparatively little activity on the sun, and often weeks would go by without anything of interest being recorded. However there was enough experience to enable the main kinds of radio burst to be distinguished and tentatively interpreted; during recent months there have been several bursts a day, and observations of a new kind have been made.

The main instrument consists of a trio of directional receivers, each capable of scanning a wide band of frequencies at half-second intervals. The frequencies covered a range from 40 to 240 megacycles a second, corresponding with a wavelength range from 1·25 to 7·5 metres. Records of intensity against time are displayed on a cathode ray tube, and in normal use are recorded photographically. For quick reporting of activity in connexion with the International Geophysical Year, a facsimile system has been introduced, similar to that used in transmitting pictures by radio.

The two most interesting types of radio burst differ greatly in their speed of development. In both there is a drift from higher frequencies to lower as the burst proceeds. But whereas a "slow-drift burst" may last for 10 minutes or so, a "fast-drift burst" is over with in a few seconds. The theoretical interpretation—plausible but so far unproved—is that the different frequencies observed correspond with natural frequencies of oscillation at different heights in the sun's atmosphere. Hence, it is suggested, an outpouring of particles from the sun's surface stimulates successive layers of its atmosphere to act as a source of radio waves, each at its own frequency, or a harmonic of it. In this way—provided that the explanation is correct—it has been possible to work out what the outward speeds of the particles should be, so as to correspond with the observed drift in frequencies.

In the case of 'slow-drift burst' the speeds deduced are usually from about 200 to 400 miles a second, and the disturbances can be followed—again if the explanation is correct—to distances above the sun's surface nearly as great as the radius of the sun. Such speeds correspond well enough with the interval between the bigger optical flares that can be seen on the sun and the beginning of auroal displays and magnetic storms that particle-streams. arriving from the sun, are thought with good evidence to cause on the earth. Also the "slow-drift bursts" are usually accompanied by big visual flares.

"Fast-drift bursts" are much more common. Sometimes one at a time, sometimes in small groups, they occur at the start of many flares, including small ones. Yet the speeds deduced are much higher—about one-third of the speed of light.