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Momentary bursts of cosmic radiation

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Continuous records of cosmic ray intensity made by means of ionisation chambers containing gas at atmospheric pressure or at a pressure of several atmospheres as in the apparatus designed by Kolhörster, Hoffmann, Millikan, Compton and others show occasional and momentary, but quite marked increases of ionisation. This singular phenomenon has been known ever since Hoffmann first noticed it in 1927; in fact, it is usual to call these instantaneous bursts of ionisation *Hoffmann Bursts*. Quite a number of cosmic ray investigators have studied the phenomenon of Hoffmann bursts and, in spite of a natural scepticism, which in the early days tended to attribute their origin to some instrumental defect or to some unsuspected form of ionisation by collision, it is now recognised that they are indeed genuine and effectively measure the sudden increases in the intensity of cosmic radiation. It has been established that Hoffmann bursts are more frequent at high altitudes than at sea level and some investigators (Hoffmann himself among them) have found that they occur even when the ionisation chamber is shielded all round by 5 to 20 cm of lead. The most frequent bursts correspond to an energy of 10^8 eV, but there are bursts of higher energy reaching 10^{10} eV or even more. The source of these high-energy rays, however, remains as obscure as that of cosmic rays in general.

Although almost from the time of the discovery of cosmic radiation the sun has at times been considered to be one of the possible sources, the sun's contribution has generally been regarded as extremely small, particularly because of the smallness (or even the absence) of a diurnal variation with solar time. But during the last two decades there have been at least 5 occasions on which the sun has unquestionably emitted bursts of cosmic radiation in association with flares of great intensity. On four of these occasions prior to 1956 the bursts were recorded simultaneously by Compton-Bennett and other types of cosmic ray recorders functioning at a number of stations in the middle and high latitudes, but never with certainty at equatorial stations, thus indicating that the energy of the cosmic ray protons of solar origin did not on these occasions exceed 5×10^9 eV. However, during the flare of 23 February 1956 the shielded (11 cm of lead) Compton-Bennett meter at Huancayo (geomagnetic latitude : 0°·6 S) also recorded a relatively large increase of about 18 per cent; this showed that the sun could at times emit cosmic ray protons whose energies were greater than $1{\cdot}5 \times 10^{10}$ eV. Thus the sun's contribution to the general intensity of cosmic radiation, though presumably small, can during intense flares be considerable; in fact, it seems very probable that every solar flare is accompanied by emission of cosmic rays, which may not in every case strike the earth if they are mostly protons ejected from the flare region in a more or less radial direction. But if there be some truth in this conclusion then there ought to be a fairly frequent correspondence between solar flares and some aspects of cosmic ray observations. The continuous records of cosmic ray intensity made at the Kodaikanal Observatory, Kodaikanal (geomagnetic latitude : 0°·6 N, altitude : 2343 metres above msl) during the last few years appear to indicate the existence of such correspondence in respect of the Hoffmann bursts.

A standard Kolhörster cosmic ray apparatus with photographic recorder has been in continuous operation at this observatory since March 1956. The ionisation chamber is shielded with 12·5 cm of iron all round. During the $2\frac{3}{4}$ years upto the end of 1958 some 90 cases of sudden but momentary increases of ionisation with the usual characteristics of Hoffmann bursts have been recorded by the Kolhörster apparatus which has behaved perfectly normally leaving no room for suspecting that the momentary increases of ionisation may have been due to some unsuspected instrumental defect. The possibility of these jumps being due to C.T.R. Wilson's "run-away electrons" is also excluded since none of these cases can reasonably be linked with reported local or nearby thunderstorms; for, the observations of almost all cosmic ray workers have indicated that the effect of thunderstorms on shielded recorders is rather to decrease than to increase the ionisation. The sudden increases of ionisation recorded by our shielded apparatus are, therefore, to be considered as genuine Hoffmann bursts due to the hard component of cosmic rays. In Table 1 we have collected data on solar flares, solar radio emissions and radio fade-outs along with information regarding the Hoffmann bursts registered on the cosmic ray records of this observatory. The information on solar radio emissions and flares and on radio fade-outs has been derived mainly from the monthly bulletins of C.R.P.L., Boulder, U.S.A. and the I.A.U. quarterly bulletins on solar activity; in some cases the required data are not yet available. As far as can be judged from the available data a great majority of the bursts follow solar flares after a time-lag of 10 to 100 minutes which agrees very well with the time-lag of 10 to 150 minutes actually observed in the five unmistakable cases of cosmic ray emission by the sun during flares. A striking feature of the cosmic ray bursts evident from the table is that many of them occur simultaneously (in a few cases with only a small time-difference) with some outstanding occurrences, such as noise bursts or noise storms. This appears to support the hypothesis put forward by Ehmert (1947, 1948) and again in a slightly different form by Kwal (1951) that the generation of solar cosmic rays, the radio-electric emission of the sun and the production of solar flares are all due to a process of acceleration of protons in the fairly strong magnetic field of sunspots. This is also consistent with the conclusion reached by Wild *et al.* (1954) that the so-called Type III bursts of solar noise produced during flares are due to particles moving with velocities ranging from 3×10^{9} cm/sec to 2×10^{10} cm/sec, for such fast-moving particles can be indentified with low-energy cosmic rays.

Another feature of the cosmic ray bursts collected in the table is that more than half of them were recorded at Kodaikanal during the night hours; but the solar flares, solar noises and radio fade-outs with which we believe them to be associated were recorded at various observatories necessarily during their day-light hours. This may, at first sight, appear to be rather strange. But there is really nothing untenable about this association. Some of the unquestionable cases of emission of cosmic rays during solar flares have shown the same peculiarity, thereby indicating that the cosmic rays emitted by the flare region are greatly dispersed by the local magnetic field of spots and are further deviated by the magnetic field of the earth so that they can strike the dark hemisphere of the earth.

It will also be noticed from the table that we associate the Hoffmann bursts recorded at Kodaikanal—a station almost on the geomagnetic equator—with solar flares of various importances ranging from 3 to sub-flares. One might be inclined to think that the very high-energy particles which could reach an equatorial station ought to have been produced only by flares of very high importance. But actual observation in absolutely unequivocal cases indicates that there is no proportionality between the importance of a flare and the energy of the cosmic ray particles or the importance of the geomagnetic storm for which it is responsible.

Although no certainty can be claimed in the very incomplete and uncertain state of our present knowledge of the mechanism of solar flares and of the physical process through which they emit both cosmic rays and radio radiation and cause geomagnetic storms, yet the data presented in our table appear to us to suggest that the momentary bursts of cosmic radiation recorded by the Kolhörster apparatus of this observatory are attributable to solar flares. If this view be correct, then one may also expect a similar correspondence to be apparent between solar flares and Hoffmann bursts recorded at other latitudes.

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