lines although the energy difference between them is only 1.1 kev.

3. RELATIVE INTENSITIES OF ELECTRON LINES AND MULTIPOLE ORDER OF THE RADIATION

Relative intensities of the conversion electron lines were measured for the five isomeric transitions studied. Corrections to the observed densities were made for fog, density-exposure, and for differences in film sensitivity for electrons of different energies. The resulting corrected values of relative intensities of electron lines is given in Table II and are to be considered only as approximate values.

For each of the five isomeric transitions the multipole order of the radiation was obtained by two independent methods. First, the half-life period of each element was checked with the reported value by observing the decay of the radiations from samples bombarded in the pile using an ion-chamber detector. These values of the half-life periods and the spectrograph values of the energies of the transitions were used together with Wiedenbeck's[20] curves to determine the multipole order of the radiation, assuming electric multipole radiation. Second, the ratio of the intensities of the K and L conversion electrons were used together with the theoretical curves of Hebb and Nelson[21] to find the multipole order of the radiation for each of the four isomeric transitions where both K and L conversions were observed.

Table III gives the values obtained for the multipole order assignments as well as a summary of the transition energy data. Axel and Dancoff[22] used some of these data in their recent analysis of isomeric transitions and reached similar conclusions.

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Cosmic-Ray Intensity Following a Solar Flare*

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Continuous records of the cosmic-ray intensity measured by a heavily shielded, high pressure ion chamber, were obtained during and following an intense solar flare (of importance 3+) and a subsequent intense magnetic storm. No increase in $C-R$ intensity was observed at or near the time of the flare, such as have been observed by others on similar occasions. At the peak of the magnetic storm there was a decrease of about 1.5 percent in $C-R$ intensity, with full recovery requiring 2 or 3 days. Unshielded $C-R$ telescope readings of low accuracy are included. These indicate that there were no prolonged alterations in the intensity (without shielding) of magnitude much greater than 14 percent associated with either the flare or the storm.

1. INTRODUCTION

In recent years there have been reported instances of changes in cosmic-ray intensity apparently associated with particular solar flares. For example, Forbush[1] reported that upon examination of 10 years of continuous records with ion chambers shielded by 11 cm Pb, three unusual increases were noted. These occurred on February 28 and March 7, 1942, and July 25, 1946. The first two consisted of sharp increases of about 7 percent which began within 18 minutes after radio fade-outs which were presumed to indicate solar flares. The third represented a sharp increase of about 15 percent beginning one hour after the commencement of a solar flare and fade-out. The peaks were very sharp, being represented on the graphs by only one or two points representing bi-hourly means, with the entire increase above indicated statistical deviations being represented by about 3 to 6 points. After a very few hours, the intensity returned to normal and not long afterward it dropped to some 7 or 8 percent subnormal in the first and third instances. The large subnormal dips followed a few hours after the sudden commencement of magnetic storms, and the upward return toward normal was slow, extending over several days. In the third case, the magnetic storm began 26.8 hours after the solar flare. The reliability of the observations of the

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[1] S. E. Forbush, Phys. Rev. **70**, 771 (1946); 1942 increases reported also by I. Lange and S. E. Forbush, Terr. Mag. **47**, 331 (1942).

initial increases is augmented by the fact that they were recorded simultaneously at stations at geomagnetic latitudes 50° N, 78° N, and 48° S, though not on one at 1° S, while the decreases accompanying the magnetic storms were recorded at all four stations.

The 1942 increases were reported also by Duperier[2] in England, though the increase noted by him on February 28 appears to have depended upon a single reading and to have amounted only to about one percent. The increase in cosmic-ray intensity following the solar flare of July 25, 1946, was confirmed both by Dolbear and Elliot[3] and by Neher and Roesch.[4] Using twofold and threefold coincidence counters with hourly rates of 30,000 and 65,000 at Manchester, England, Dolbear and Elliot found an increase of about 17 percent above normal, with the peak between 18.00 and 18.30 GMT, or between 2 and 2.5 hours after commencement of the flare. After the magnetic storm which followed, they observed a decrease of about 8 percent below normal, with a slow recovery during more than a week. Neher and Roesch, by means of an unshielded electroscope at Mount Wilson Observatory, noted an increase of 18 percent following the flare. They found that the increase had largely subsided in about 10 hours, but that the intensity was still 1 or 2 percent above normal when the magnetic storm began, after which they noted the usual decrease. They concluded that while the cosmic-ray increase attained its maximum about two hours later than the visual flare, the two began at about the same time.

Very recently Forbush, Stinchcomb, and Schein[5] have reported very large increases in cosmic-ray intensity accompanying the solar flare of November 19, 1949. Using ion chambers shielded by 12 cm Pb, they observed increases beginning at $10^h\ 45^m$ GMT and rising to 43 percent above normal at 11^h GMT at low altitudes at geomagnetic latitudes 50° N and 80° N, with no increase at 11,000 ft. altitude at $\Phi=0°$. At Climax, Colorado, altitude 11,500 ft., they report that the intensity under similar shielding increased to about 180 percent above normal in 15 min. and remained at least 100 percent above normal for about an hour, decreasing "exponential-wise" to near normal in about 7 hours. According to a verbal report by Dr. W. O. Roberts, Dr. Muller of Wendelstein Solar Observatory in Bavaria reported in a letter to Allen Shapley that he observed a solar flare of importance 3 beginning at 10^h 29 on November 19, attaining a maximum at 10:34, and subsiding at 11:19. Thus these extraordinary increases in cosmic-ray intensity appear to have begun only about 16 minutes after the start of the flare and to have attained their maxima about 26 minutes after the flare maximum, while persisting some 6 hours after the flare had subsided.

While the findings are largely negative, it appears that in view of the observations mentioned above it might be of some interest to report on the indications of recording apparatus which was in operation at Boulder, Colorado, altitude 5400 ft., geomagnetic latitude 49° N, during the large solar flare (of importance 3+) of May 10, 1949; it is unfortunate that the apparatus was not in operation on November 19, since Boulder is only about 65 miles from Climax and at nearly half its altitude.

According to a report by Dodson,[6] the flare of May 10, as observed at McMath-Hulbert Observatory, increased very suddenly in brightness, the principal outburst starting at $20^h\ 02^m$, reached a maximum at $20^h\ 11^m$, and was still bright at $22^h\ 20^m$. At the maximum, the brightest regions had 4 times the intensity of the undisturbed $H\alpha$-disk. Shapley and Davis[7] of the National Bureau of Standards reported concurrent bursts of radio noise. They stated that maxima were attained between 20:10.5 and 20:12.5, and that the intensity of the noise burst was about 290 times the normal energy output of the entire disk of the quiet sun on 160 megacycles, while on 480 megacycles it was probably 1000 times the background radiation.

Schein[8] has reported that during a balloon flight on May 11 an increase of 50 percent occurred in the rate of nuclear disintegrations at 95,000 ft. He attributed this unusual increase to the large solar flare observed "a few hours before the balloon flight took place."

2. EXPERIMENTAL PROCEDURE

The ionization-chamber measurements at Boulder were made with the same equipment, slightly modified, that was used in the measurements of a decade earlier. The thick-walled steel chamber was shielded not only by 5 inches of lead immediately surrounding it, but also by the building in whose basement it was maintained at constant temperature. It has been estimated[9] that the shielding afforded by the chamber walls and surrounding lead were roughly equivalent to 18 cm of lead, while that afforded by the building amounted to some 15 cm of lead for any direction and more than 40 cm for certain directions. In place of the air at 160 atmospheres used earlier, the ion chamber was filled with argon at 20 atmospheres for the recent observations. This yielded about the same cosmic-ray ionization current as the air at the higher pressure. The electrometer sensitivity was also increased somewhat so that bursts of 1.2×10^6 ion pairs produced deflections of 1 mm on the photographic record and were regularly read.

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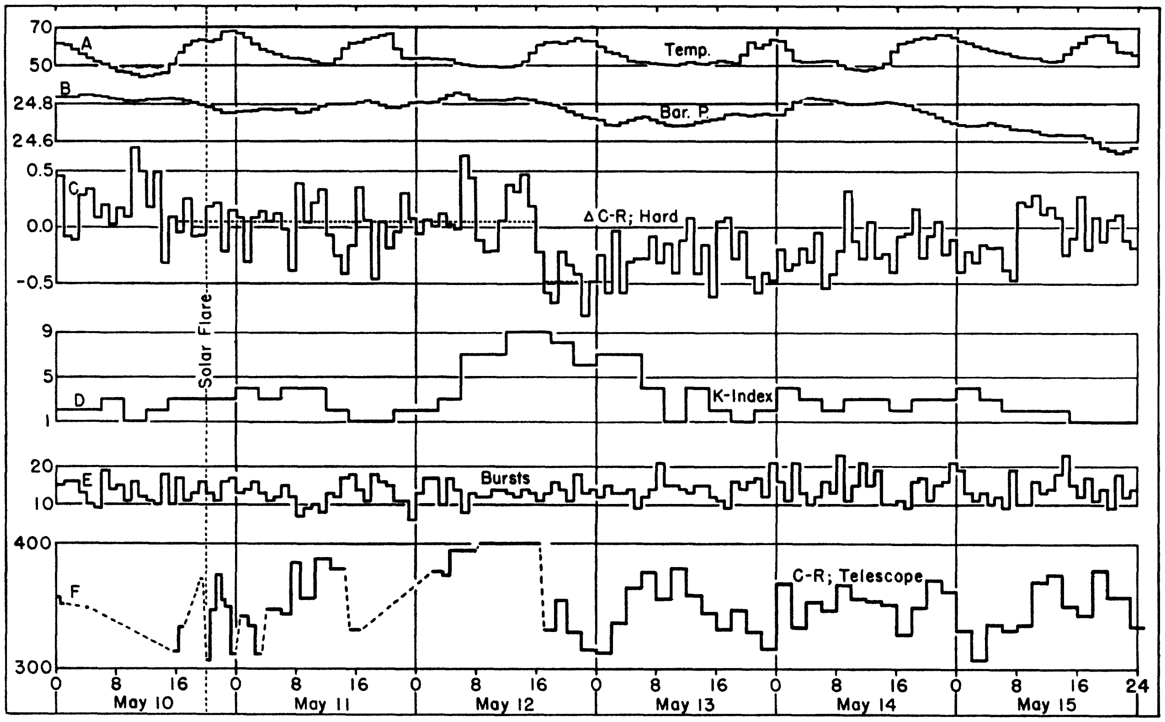

FIG. 1. For all curves the horizontal axis represents GMT. *Curve A* shows hourly average values of the out-door temperature in °F. *Curve B* shows hourly average values of the barometric pressure in inches of mercury. *Curve C* shows (as positive values) hourly average values of the excess of cosmic-ray ionization current over the steady compensating current, expressed in ion pairs per cc of the $C-R$ ion chamber per sec. This curve has been corrected for bursts and for barometric variations. *Curve D* shows magnetic K-indices at Cheltenham for successive 3-hour intervals. *Curve E* shows the number of bursts observed in each hour (59-minute collection interval) including all bursts greater than or equal to 1.2×10^6 ion pairs. *Curve F* shows the number of counts per hour with the telescope axis directed vertically or corrected for azimuth angle, but with no other corrections.

3. DISCUSSION

The data are represented in Fig. 1 for the (GMT) days May 10 to May 15, 1949, inclusive. Curve A, representing hourly means of out-door surface temperature in °F, shows that there were no unusual temperature changes. Curve B, representing hourly means of barometric pressure in inches of Hg, shows that the changes in barometric pressure were rather small and gradual. Hourly means of the excess of the cosmic-ray ionization current over the steady compensating current provided in an auxiliary chamber by gamma-rays from a radium capsule, expressed in ion-pairs per cc of the cosmic-ray ion chamber per sec., are designated in curve C. The values represented here were corrected for bursts (1 mm and greater) and for variations in barometric pressure. The analysis of data being in its initial stages, the barometric coefficient with the present set-up has not been fully investigated; a weighted average coefficient based on daily averages during a period of 10 months was employed.

The ion-chamber readings do not indicate any change (apart from the usual statistical fluctuations) at the time of the intense solar flare nor soon thereafter. Beginning at 17^h on May 12, 45 hours after the solar flare, there appears to be a definite decrease in $C-R$ intensity lasting several hours. For purposes of comparison, averages were determined for the 48-hour period from 16^h May 10 to 16^h May 12, and for the 9-hour period from 17^h May 12 to 2^h May 13. These averages are represented by dotted lines extending over the specified intervals in curve C. The difference between these averages indicates a decrease of 1.5 percent of the estimated average $C-R$ intensity for the 9-hour interval. The difference was found to be 3 times the standard deviation of the hourly values from the average for the 9-hour interval, but only 2.3 times the standard deviation for the 48-hour interval. It seems significant, however, that the $C-R$ intensity appears to have remained somewhat depressed for quite a long time. During the interval of 41 hours from 16^h May 12 to 9^h May 14, the $C-R$ current rose to the average value for the 48-hour interval preceding 16^h May 12 during only 3 hours, and then only barely so. In fact, curve C provides some indication that the pre-depression average may not have been fully attained until about 64 hours after the depression began.

That the decrease in $C-R$ intensity which began 45 hours after the solar flare was much more closely associated with an intense magnetic storm is shown by curve D. In this are shown the K-indices for successive 3-hour intervals determined at the Cheltenham (Maryland) Magnetic Observatory and supplied by the U. S. Coast and Geodetic Survey. A moderate storm is represented by K-index = 5, while moderately severe storms are represented by 6 or 7, and severe storms by 8 or 9. According to a report from the Tucson (Arizona) Magnetic Observatory, the storm represented by curve D had a sudden commencement at $6^h\ 41^m$ on May 12, had its maximum between 15^h and 18^h May 12, and ended at 7^h May 13. (A storm is considered to have ended when the K-index remains at 2 or less for a reasonable period, so the storm seems to have ended earlier at Tucson than at Cheltenham.) The range of H during the storm was 552γ at Tucson. The decrease in $C-R$ intensity is thus seen to have begun about 11 hours after the storm started and while the storm was at or near its peak.

Because solar flares are commonly associated with sunspots, as was the one of May 10, and because these are often followed by magnetic storms as was the case here, it may be of interest to compare the observations in this particular instance with the results of a statistical investigation by Broxon[10] of the relation of $C-R$ intensity to sunspots and magnetic disturbances by Chree's method of superposed epochs. Employing data obtained during a year and a half in 1938 and 1939, he found statistically that pulses in $C-R$ intensity were associated with inverse pulses in magnetic character and in sunspot area. The peaks of the $C-R$ pulses were found to lag the peaks of the inverse magnetic-character pulses by rather less than a day, while lagging the peaks of the inverse sunspot-area pulses by some 3 or 4 days. The peaks of the $C-R$ pulses represented deviations of about 0.6 or 0.7 percent from the average. $C-R$ disturbances accompanying magnetic disturbances have, of course, been recognized for quite a long while.[11] An interesting fact in this connection is that Duperier[2] observed a decided dip of 8 percent in $C-R$ intensity in England on March 27, 1945, when there was no magnetic storm.

Since many bursts were observed with the ion chamber, it was thought worth noting whether the rate of occurrence of these was affected by the flare or the following magnetic storm. Curve E represents the total number of bursts observed in each hour (actually 59 minutes of collection time) during the 6-day interval. The majority of the bursts were small ones, of course, near the lower limit of 1.2×10^6 ion pairs. The burst-frequency curve does not appear to show any particular response either to the flare or to the magnetic storm. Nothing noteworthy was detected with regard either to the frequency or magnitude of large bursts.

Because the ion chamber was heavily shielded, it is worth mentioning some readings taken concurrently with an unshielded $C-R$ telescope, even though this was not designed for the present purpose and the readings are consequently quite inaccurate. The telescope was mounted in a light wooden structure on the roof of a four-story building. The telescope was dual, with its arm shifting at intervals from zenith angles of 0° to 75° in 15° steps, provisions being made for independently recording (simultaneously) triple coincidences with no shielding and with two different amounts of shielding. Factors for reducing counting rates at different zenith angles to 0° were found by operating the equipment for long periods. These differed considerably from the $\cos^{-2}$ law only at the largest angle.

Curve F shows the number of counts per hour (reduced to the vertical) obtained with one arm of the telescope and no shielding during the 6 days. Readings given by the other arm were not included because of an apparent instability yielding obviously high and erratic readings; the arm employed appeared to be functioning normally. Because the shifting mechanism was not operating entirely satisfactorily, recordings represented somewhat varying time intervals. These are shown by the length of the line representing the mean counting rate in each interval. Because the camera did not function properly at times, there are gaps in the record indicated by dotted lines. The recorded values have not been corrected for barometric variations or anything but zenith angle. It will be noted that there was very little variation in barometric pressure during the first three days, and only the usual diurnal variations in temperature.

The unshielded telescope does not provide any clear indication of a change in $C-R$ intensity at the time of the solar flare nor soon thereafter. There do appear to be somewhat abnormally high values during the first two-thirds of May 12, followed by a decrease at 17^h on that day. The decrease is not to abnormally low values, however. Also the two longest readings at the highest values were at 75° zenith angle. The triple-coincidence rate is so small and the statistical fluctuations consequently so large that $C-R$ variations of a few percent could not have been detected reliably. Since the extreme variations during the 6-day interval were a little less than 14 percent from the mean of the extremes, it appears that any increase much greater than this and closely following the solar flare would have been detected, since the telescope was functioning at that time.

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Note added March 18, 1950: We have just received copies of papers by J. Clay, H. F. Jongen and A. J. Dijker [Koninklijke Nederlandsche Akad. V. Wetenschappen, Proc. **LII**, 897–914 and 923–926 (1949)] in which they report numerous correlations of $C-R$ fluctuations associated with solar flares, e.g., 30 cases of considerable increase (some extending to 3 or 5 percent) and 30 smaller ones during the year 1947, alone. For the intense solar flare of May 10, 1949, however, they observed no $C-R$ effect in a chamber shielded with 110 cm Fe, and an increase of only 1 percent in an unshielded chamber.

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