HEAVY SOLAR COSMIC RAYS
IN THE JANUARY 25, 1971 SOLAR FLARE

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Abstract. A detailed study of the charge composition of heavy solar cosmic rays measured in the January 25, 1971 solar flare including differential fluxes for the even charged nuclei from carbon through argon is presented. The measurements are obtained for varying energy intervals for each nuclear species in the energy range from 10 to 35 MeV nucleon\(^{-1}\). In addition, abundances relative to oxygen are computed for all of the species and as a result requires no spectral extrapolations. An upper limit for the abundance of calcium nuclei is also presented.

These measurements, when combined with other experimental results, enable the energy dependence of abundance measurements as a function of nuclear charge to be discussed. It is seen that at energies above about 10 MeV nucleon\(^{-1}\), the variations of abundance ratios are limited to about a factor of 3 from flare to flare, in spite of large variations in other characteristics of these solar events.

1. Introduction

The existence of multicharged nuclei in solar cosmic rays was first established as part of the early SPICE (Solar Particle Intensity and Composition Experiment) experiment. This experiment involved the launching of sounding rockets into large solar particle events to expose nuclear emulsion stacks to the incident particle radiation. Measurements of the relative abundances of these heavy, multicharged particles were made at energies above 40 MeV nucleon\(^{-1}\) several times in major solar flares occurring in 1960 and 1969 (see, for example Fichtel and Guss, 1961; Biswas et al., 1962, 1963; Bertsch et al. 1972). An outstanding result of these measurements at energies $\geq 40$ MeV nucleon\(^{-1}\) was the observation that the relative abundances of multicharged nuclei were constant within the experimental uncertainties from flare to flare in spite of large variations in such parameters as the flare size and proton to helium ratio. Furthermore, these abundance ratios were the same within experimental uncertainties as those measured in the solar atmosphere using spectroscopic methods.

This constancy was explained by the fact that rules of nuclear stability provide for the even-charged nuclei to be generally much more abundant than the odd-charged nuclei in the Sun and, consequently, the most abundant isotopes of multicharged nuclei observed in solar cosmic rays have charge-to-mass ratios that are almost the same provided the nuclei are fully stripped (the exception is iron which has a somewhat smaller charge-to-mass ratio). Since all particles with the same charge-to-mass ratio will have an identical rigidity at the same velocity, each species will be treated identically by electromagnetic forces irrespective of the complexity of the magnetic field. An exception to this would be the energy losses that a particle undergoes from Coulomb interactions, but this effect does not appear to be important, particularly for the...
propagation. The observed solar cosmic ray atoms will of course be essentially fully stripped at energies above about 15 MeV nucleon$^{-1}$ if they pass through even about a mg cm$^{-2}$ of matter (Heckman et al., 1963).

More recently, detailed solar particle abundances of multicharged nuclei have been measured with satellite borne detectors (Teegarden et al., 1973; Mogro-Campero and Simpson, 1972) at somewhat lower energies of about 20 MeV nucleon$^{-1}$. These measurements differed from the sounding rocket measurements in that the small geometric factors of the satellite instrumentation generally required that abundances be computed with data summed over the duration of a flare in order to reduce the statistical uncertainties, in contrast to the sounding rocket exposures which were exposures of about four minutes near flare particle flux maxima. These satellite results showed areas of disagreement with the previous sounding rocket results as well as variability in the abundance ratios from flare to flare.

In addition there have been recent measurements of solar cosmic rays at still lower energies ($\lesssim$10 MeV nucleon$^{-1}$) which show abundance ratio enhancements and variations which appear to grow larger as the energy of the measurements decreases. These measurements include data from plastic detectors flown on SPICE sounding rockets (Crawford et al., 1972; Price et al., 1973) as well as satellite measurements (Hovestadt et al., 1973).

The variability of solar cosmic rays has also been studied from the point of view of the ratios of charge groups, where the individual nuclei are unresolved (e.g., Bertsch et al., 1974). These observations include other SPICE exposures as well as satellite experiments (e.g., Bertsch et al., 1972, 1973a.; Armstrong and Krimigis, 1971; Armstrong et al., 1972; Braddy et al., 1973; Krimigis and Armstrong, 1973). While such observations address the question of solar particle abundance variations, they are unable to make detailed comparisons with solar spectroscopic measurements or to treat the question of the detailed Z dependence of the observed variations at low energies. Variations of the abundance of helium to medium (6 $\lesssim$ Z $\lesssim$ 8) nuclei both as a function of energy and as a function of time within a flare have been observed at energies below 10 MeV nucleon$^{-1}$.

In order to further study the processes of solar acceleration as a function of particle energy and charge, this experiment undertakes a detailed charge measurement near the maximum particle intensity in the January 25, 1971 solar flare. The even-charged nuclei from carbon through calcium are identified and differential energy spectra are presented for the nuclei where the statistical uncertainties are sufficiently small. The elemental abundances for these nuclei are then calculated in the common energy interval from 15 to 25 MeV nucleon$^{-1}$.

2. Experimental Procedure

Nuclear emulsion stacks exposed to the intense particle radiation of the January 25, 1971 solar flare at 1512 UT were analyzed. The stacks were carried above the atmosphere by a NIKE-APACHE sounding rocket launched from Ft. Churchill, Manitoba.