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ABSTRACT

A measurement of the isotopic composition of galactic cosmic ray neon in the energy range 70 to 260 MeV/amu has been made using the U.C. Berkeley HKH instrument aboard ISEE-3. A combination of high resolution and good statistical accuracy makes possible a precise determination of the local interplanetary neon composition. We find ^{22}Ne/^{20}Ne = 0.64±0.07 and ^{21}Ne/^{20}Ne < 0.30 in local interplanetary space. These ratios, when interpreted in using standard galactic propagation and solar modulation models, yield cosmic ray source abundances which are inconsistent with a solar-like source composition.

INTRODUCTION

Studies of the galactic cosmic ray (GCR) source nuclei at intermediate energies (~ 10-1000 MeV/amu) have shown that the composition of this material bears a strong resemblance to the composition of solar system material.[1] There are indications that differences between these two compositions may be related to charge-dependent selection mechanisms.[2] It is, therefore, important to examine the isotopic composition of the GCRs to see whether the pattern of composition similiarities persists. Of the elements for which measurements of isotopic composition have so far been made, the strongest indication of a GCR source composition different from solar system material occurs in the neon isotopes.[3-6] We present here the results of a new high-resolution measurement of the isotopic composition of GCR neon made using the U.C. Berkeley HKH instrument aboard ISEE-3. These data, interpreted using standard models for solar modulation and galactic propagation, imply a source in which the ^{22}Ne/^{20}Ne abundance ratio is significantly enhanced over that found in solar system material. Furthermore, we find that the observed enhancement cannot be explained in terms of a solar-like source composition with a large over-production of ^{22}Ne by spallation reactions during propagation.

OBSERVATIONS

The data used in this study were collected from launch (12 August 1978) through February 1979, omitting days when the count rate in the front Si(Li) detector indicated an enhanced flux of low energy particles. We have described the instrument and analysis techniques in another paper in this session and will only mention a few points of particular significance for our analysis of the neon composition. For this analysis we use particles stopping in any detector from D2 through D9. Furthermore, we restrict the analysis to those particles incident within 20° of the normal to the detector surfaces. This selection results in an energy interval of approximately 70 to 260 MeV/amu. In Figure 1 we show a histogram of the masses calculated for the 546 neon events in this range. Two well resolved peaks separated by 2.0 amu show the presence of substantial fluxes of both ^{20}Ne and ^{22}Ne. A separate ^{21}Ne peak has not been obtained and it is clear that the ^{21}Ne flux is significantly smaller than either the ^{20}Ne or ^{22}Ne fluxes. The absolute mass scale, fixed by the positions of the measured ^{12}C and ^{16}O peaks, yields neon masses which are in error by approximately 0.15 amu. This effect, which is still under investigation, does not affect the present analysis since the strong ^{20}Ne and ^{22}Ne peaks provide a correct renormalization of the mass scale. Also evident in Figure 1 is a low-level of background events. These are mostly due to particles whose incidence angles have been incorrectly identified. The majority of such events are eliminated by the requirement that the three measurements of a track's x and y coordinates be consistent to ±0.5 cm. This consistency criterion has not yet been optimized and we expect that further work will improve our rejection of this sort of background.

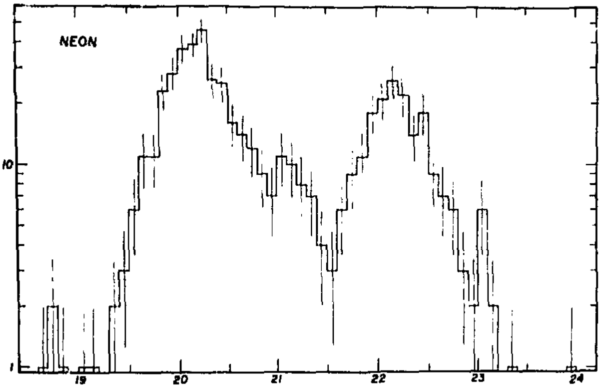

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Fig. 1

In order to obtain the relative abundances of the three neon isotopes we have performed fits to the ^{20}Ne and ^{22}Ne peaks using a number of different assumptions concerning the shapes of the tails and the nature of the background. We are able to obtain ^{22}Ne/^{20}Ne ratios in the range 0.56 to 0.60 and ^{21}Ne/^{20}Ne ratios less than 0.24. These ratios are obtained using equal intervals of particle range for each of the isotopes. In order to convert the abundance ratios to equal energy per nucleon it is necessary to know the spectral shapes. These shapes have not yet been obtained from the present investigation and previous measurements of the neon spectrum cannot be used due to the changing level of solar modulation. The correction factor should, however, be between 1.06 obtained for a flat spectrum and 1.11 obtained for a J = AT spectrum. We expect that the latter value is more appropriate for the present near-solar-maximum period and, hence, we have adopted this value. Thus, we obtain the following isotopic composition for neon in local interplanetary space:

$$^{22}\mathrm{Ne}/^{20}\mathrm{Ne} = 0.64 \pm 0.07$$
$$^{21}\mathrm{Ne}/^{20}\mathrm{Ne} < 0.30$$

The uncertainty on the ^{22}Ne/^{20}Ne ratio includes both statistical errors and our estimate of the uncertainty introduced by our peak fitting and background subtraction procedures. The upper limit on ^{21}Ne/^{20}Ne is a two standard deviation limit, taking into account these same uncertainties.

DISCUSSION

In Figure 2 we compare our measurement of ^{22}Ne/^{20}Ne with a number of other measurements.[3-6,8] There is reasonable agreement among the more recent experiments (i.e. those with the best mass resolution) indicating that the ^{22}Ne abundance is a substantial fraction of the ^{20}Ne abundance, contrary to expectations based on the assumption of a source with solar-like composition.

In order to compare the observed abundances with the predictions of standard source and propagation models, it is necessary to first apply a correction for the solar modulation undergone by the particles observed at earth. We have made roungh estimates of the size of this correction by assuming local interstellar spectra of the form $J \propto (E/M+U)^{-2.6}$ and using the force-field solar modulation approximation[9] characterized by a modulation parameter Φ (calculated using the mass-to-charge ratios of the neon isotopes and the rigidity-change parameter, ϕ, which results when a diffusion coefficient of the form $\kappa \propto \beta P$ is assumed). We have adopted a correction factor of 0.8 (corresponding to U = 400 MeV/amu and Φ = 330 MeV/amu) with an uncertainty of ±0.1 (corresponding to the extreme values obtained when U is varied between 0 and 931 MeV/amu and Φ is varied between 75 and 400 MeV/amu) to be applied to the local ^{22}Ne/^{20}Ne ratio.

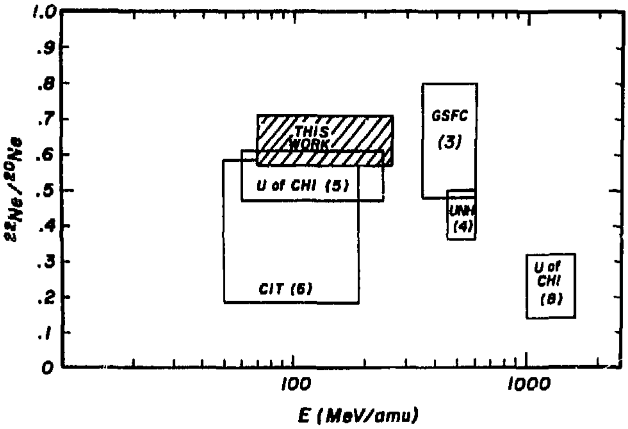

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Fig. 2
Boxes plotted show the ±1σ limits and energy ranges for the ^{22}Ne/^{20}Ne values reported by several groups. When only a mean mass was reported we have converted it to ^{22}Ne/^{20}Ne by using ^{21}Ne/^{20}Ne = 0.18.

In order to interpret the observed abundances in terms of a ^{22}Ne/^{20}Ne abundance ratio at the cosmic ray source, we have performed a calculation using the observed ^{21}Ne abundance as a tracer of the amount of interstellar material traversed by the cosmic rays.[10,11] This approach, which assumes that ^{21}Ne is absent at the cosmic ray source, will correctly take into account propagation through any exponential distribution of potential pathlengths. Thus our derivation of a source abundance ratio does not depend on a particular choice of the mean interstellar pathlength. In addition, ionization energy loss effects are included in a rough form by assuming a local interstellar spectrum of the form $J \propto (E/M+400 \text{ MeV/amu})^{-2.6}$ for all three neon isotopes. Total destruction cross sections on interstellar material (assumed to have He/H = 0.1 by number of atoms) are calculated using the Bradt-Peters form with coefficients given by Westfall et al.,[12] while partial cross sections are obtained from the Silberberg and Tsao formulas.

The validity of any propagation calculation depends on the accuracy of the partial cross sections used. A claim of an over-abundance of ^{22}Ne in the GCR sources must rest on our confidence that the partial cross sections for producing ^{22}Ne are not badly underestimated. ^{22}Ne production in the interstellar medium is dominated by contributions from β^{+}-unstable ^{22}Na. The cross sections for the production of ^{22}Na--widely used as a beam monitor--are well measured[13-15] and are reliably predicted by the Silberberg and Tsao formulas.[16-18] A preliminary report on other reaction channels leading to ^{20}Ne, ^{21}Ne, and ^{22}Ne by Regnier[19] indicates that the isotopic production ratios are also in close agreement with Silberberg and Tsao. We conclude that use of the Silberberg and Tsao formulas gives a reliable prediction of ^{22}Ne production at 400 MeV/amu.

The calculation of the secondary contribution to the observed neon fluxes involves computing a sum over all heavier species of the product of the equilibrium interstellar flux times the appropriate production cross section. The isotopic composition of elements heavier than neon is largely unmeasured, but preliminary indications[5,6] are that the composition of magnesium and silicon (the most important producers of neon) is not greatly different than expected from a source of solar-like composition. Therefore, we have used a local isotopic composition for $Z > 10$ species which is based on measured local elemental abundances[20-22] and a source distribution of isotopes within each element as given by Cameron[23] for solar system material. An exponential distribution of pathlengths with a mean of 5.5 g/cm^2 has been assumed and ionization energy loss has been neglected in this calculation. Note that this simplified treatment of the propagation of the parent isotopes should only slightly affect our results since all the elemental abundances which we use are the result of direct measurements.

Figure 3 shows the relation between the measurable local ratios, ^{22}Ne/^{20}Ne and ^{21}Ne/^{20}Ne, and the desired source ratio, ^{22}Ne/^{20}Ne. This calculation was done assuming that the particles which we observe at ~ 70-260 MeV/amu near earth had an energy ~400 MeV/amu in local interstellar space. The location of the point in Figure 3 indicates our best estimate of the local interstellar neon composition. The shaded area is bounded by our ±1σ limits on the local ^{22}Ne/^{20}Ne ratio and by our upper limit on the local ^{21}Ne/^{20}Ne ratio (both ratios corrected for solar modulation). In addition, there are uncertainties in the interstellar ratio due to the error in our correction to equal energy per nucleon and to errors in the solar modulation correction. The former uncertainty will be resolved when we obtain spectral information from these data. Some of the uncertainty in the modulation correction can be reduced by an improved calculation of this effect using parameters determined to be appropriate to the time period over which these data were taken, but a sizeable uncertainty will remain due to our incomplete understanding of the modulation process.

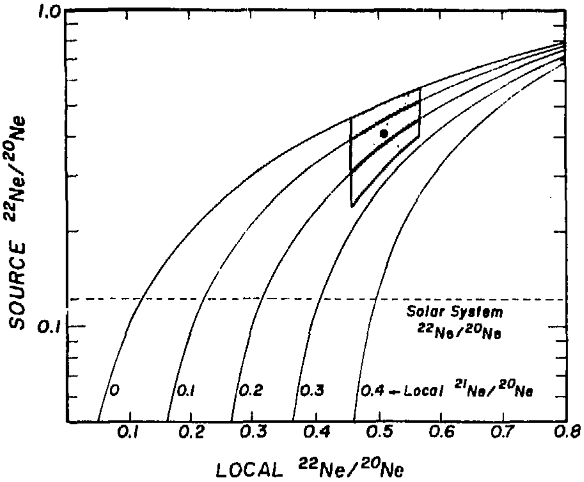

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Fig. 3

Besides the uncertainties involved in obtaining the interstellar abundance ratios, there are errors in the calculation of the source abundances due to errors in the parameters involved in the calculation. It has been shown[10,11] that the dominant source of error in the calculation is due to uncertainties in the fragmentation cross sections. In the present case, this should contribute an error of ~5-10% in the source ^{22}Ne/^{20}Ne ratio.

Also shown in Figure 3 is the ratio, ^{22}Ne/^{20}Ne = 0.122, found in solar system material. It is clear from this figure that the observed isotopic composition of GCR neon is incompatible with the assumption that the GCR source composition is similar to solar-system composition. We again emphasize that this conclusion is independent of any assumption about the mean interstellar grammage traversed, and that the cross sections which are most important for calculating the secondary yield of ^{22}Ne have been measured.

CONCLUSIONS

The neon isotopic abundances in the GCR present the first clear case of a cosmic ray source composition significantly different from solar system composition. Since a number of different processes can contribute to the synthesis of the neon isotopes, it is not yet clear how this difference is to be interpreted. There is now a definite need to examine models of galactic and stellar evolution and of cosmic ray acceleration in an attempt to understand the GCR neon composition. Emphasis should be placed on identifying observable effects on other abundances which would be implied by models capable of explaining the ^{22}Ne/^{20}Ne ratio.

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