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Elemental Composition, Isotopes, Electrons and Positrons in Cosmic Rays

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ELEMENTAL COMPOSITION, ISOTOPES, ELECTRONS AND
POSITRONS IN COSMIC RAYS

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This review discusses the papers presented at the 16th International Cosmic Ray Conference, Kyoto, Japan, dealing with the composition of cosmic rays (elements, isotopes, electrons and positrons). This paper should be considered complementary to Dr. G. Raisbeck's review where papers with major emphasis on nuclear fragmentation phenomena, the propagation and lifetime of cosmic rays, in the interstellar medium and source composition, will be discussed.

The following table classifies the papers discussed in this review in terms of categories of experimental measurements.

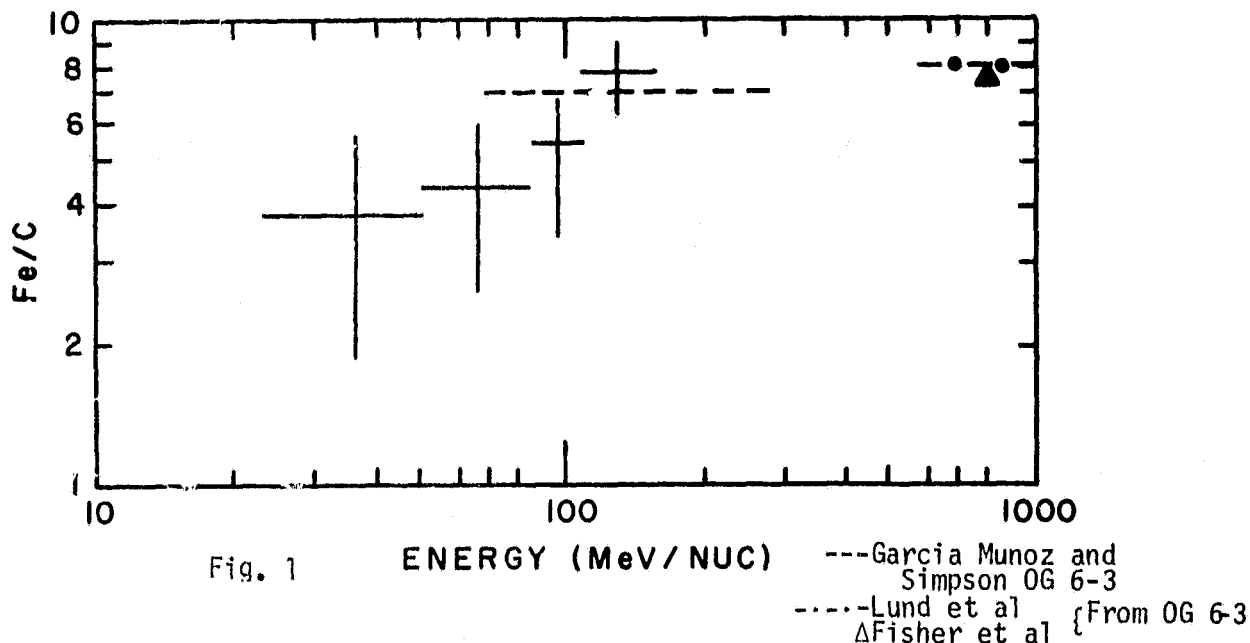
Table 1

<u>Type of Measurement</u>	<u>Energy Region</u>	<u>Experimental Objectives</u>	<u>Papers</u>
Elemental Composition and time variation etc.	<50 MeV/nuc	Anomalous component Low energy galactic CR phenomena	OG 6-1, 5, 6 OG 6-4
Fe and near Fe nuclei	>50 MeV/nuc to 10 GeV/nuc	Possible anomalies in this region Fe/Ni ratio and its variation with energy	OG 6-11, 12 OG 6-18
Trans IRON	>320 MeV/nuc	Ultra heavy nuclear composition	OG 6-10, 30, 28, 29
High energy spectra	>10 GeV/nuc	Energy distribution and spectral differences between different nuclei	OG 6-25, 26
Antiprotons	5.6-12.5 GeV/c	Antimatter detection	OG 6-34
Isotopes	30 MeV/nuc - 1 GeV/nuc	Comparison of C.R. source isotopic composition with other astrophysical sites	OG 7-2, 6, 13, 9, 10, 15, 18
Electrons, positrons and related papers	5 MeV - 1 TeV	Removal of existing experimental discrepancies, lifetime of electrons in galaxy, possibility of detection of individual sources, positrons as primaries, electron intensity inhomogeneities in the galaxy	OG 8-1, 2, 3, 4, 6, 8, 11, 13.

In this review wherever possible the bearing of the data on nucleosynthesis sites, supernovae, γ -process, comparison with solar system composition, multiplicity of sources and the energy dependence of composition will be commented upon.

Low energy region (<50 MeV/nuc)

In OG 6-4 McDonald et al. find that the Fe/C ratio measured at ~ 2 A.U. decreases from ~ 8 at 150 MeV/nuc to ~ 4 at 40 MeV/nuc as shown in figure 1.



If one accepts the view proposed by the authors that solar modulation produces only a negligible deceleration parameter for the period of this measurement, we have, probably, evidence for the ionization energy loss in the interstellar medium. When established, this result will have great bearing on the pathlength distribution in the interstellar medium and its shape at low path lengths.

In OG 6-5 Biswas et al identify the anomalous component detected in their Skylab experiment with the anomalous component detected in the interplanetary space. Figure 2 compares their results with the IMP and Pioneer satellites of Klecker et al 1977 and Webber et al, 1975.

In view of the similarity between the Skylab particles and the anomalous component they explain the entry of these particles into the magnetosphere and being detected where the geomagnetic cutoff would forbid their presence by the following model. The particles say O^{+1} ions (produced from neutral oxygen by the action of solar U.V. according to the model of Fisk et al (1974) or originating as O^{+1} from nearby stars (Durgaprasad, 1977) are accelerated to energies $E \sim 10$ MeV/amu by turbulent magnetic fields. They enter the high latitudes of the magnetosphere and on reaching the mirror points, some of the O^{+1} ions are stripped of more of their orbital electrons to form O^{+4} ions. As the stripped ions have lower rigidities, these ions remain trapped in the earth's magnetic field till they are removed by ionization losses (Blake and Friesen, 1977).

Figure 3 gives a sketch of the proposed process.

In OG-6 Biswas et al. propose an observational test for the current ideas of the origin of the anomalous component based on the detection of anisotropy of 3-30 MeV/nuc particles in the heliosphere. The test would be impossible to carry out as the low energy particles would become isotropised in the chaotic heliosphere. If one recollects the difficulties of detecting the anisotropy of muons of energy ~ 500 GeV, the problems with this approach could be appreciated.

Fe and Near Fe nuclei:

Durgaprasad et al. in OG6-11 report their study of the composition of nuclei in the Ca to Ni using the Skylab exposure of Lexan plates. They find an anomalously high Ca+Ti+Cr/(Mn+Fe+Ni) ratio at 60 MeV/nuc. If their results are compared to other results at higher energies (Figure 4) a rather marked energy dependence of the Ca+Ti+Cr/Mn+Fe+Ni is seen; the origin of this energy dependence is not clear. Here is a case where the experimental situation has to be made very certain before its significance can be comprehended.

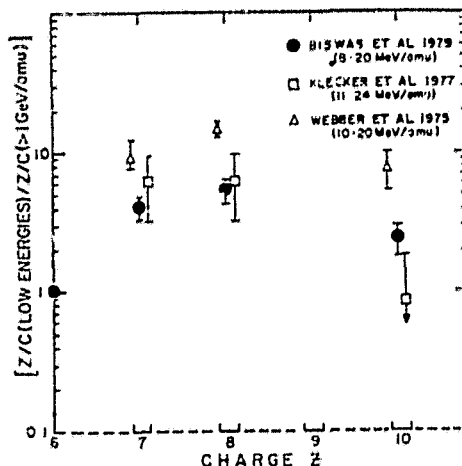


Fig. 2
PROPAGATION OF COSMIC RAY O⁺ IONS
IN THE MAGNETOSPHERE

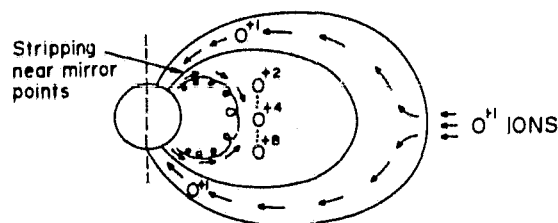


Fig. 3

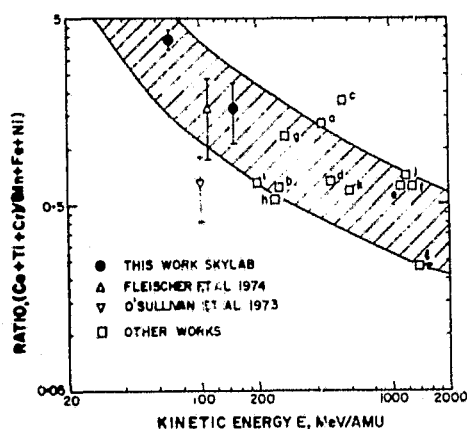


Fig. 4

Sequerios et al (UG 6-12) report their results from balloon exposure of Lexan sheets in the energy range 50 MeV/nuc to 300 MeV/nuc. The relative abundances measured by them after applying various experimental corrections are consistent with the results from other experiments using electronic detectors except for anomalously high abundances of ²⁵Mn and ²⁷Co. They discuss possible reasons for the discrepancy and one of the possibilities may be the spread of each rate-range measurements resulting in misidentification of charges. I think this result emphasizes the need for caution in comparison of results between

different detection techniques, in particular between Lexan and the electronic detectors.

Peter Meyer and Minagawa (OG 6-18) report high resolution measurement of the energy spectra from Fe and Ni in the energy range 1 to 7 GeV/nuc. This is the first report of the measurement of the differential spectra of Ni which is only $\sim 5\%$ of Fe in abundance. The spectra reported are $dJ/dE = (1.39 \pm .10) W(2.41 \pm .05) m^2 sr GeV/nuc$ for Fe and $dJ/dE = (1.06 \pm 0.01) W(2.3 \pm 0.1)$ for Ni. The Ni/Fe ratio is constant over this energy range contrary to the earlier results reported by Lund et al (1975) and their Ni spectrum is shown in Figure 5.

Trans Iron Region

Israel et al (OG 6-28) report their abundance measurements in the charge range $26 \leq Z \leq 40$ with their balloon detector of large geometric factor ($6.6 m^2 sr$). They find that the cosmic ray source composition in the charge range 26 to 40 is similar to that of the solar system, except for Zn which is underabundant. If one assumes the solar system abundance is represented C2 meteorites and one considers the higher ionization potential of Zn then cosmic ray source abundance of Zn may be consistent with that of the solar system. For sulphur also a similar effect has been noted. With the limited statistics available in this experiment they conclude that the abundances obtained by them are in better agreement with a solar system than either with γ -process abundance or with the He burning S process. They also remark that this conclusion does not necessarily contradict the observations that the abundances for $Z > 60$

(Shirk and Price, 1978) agree more with an γ process than a solar system mix. These $Z > 60$ nuclei are produced by r-processes in supernovae. The solar system mix of r and s processes below $Z = 40$ can be synthesized in supernovae and presupernovae stages of massive stars. Thus the results of ultra heavies may be consistent with acceleration of material synthesized in massive stars, either before or during the supernova explosions.

Doke et al in (OG 6-29) report the results of their balloon exposures of plastics x ray films and nuclear emulsions. They observe 7 tracks of nuclei $Z > 40$ for $E \geq 3.5 GeV/nuc$. Combining their results with that of Blanford et al. (1973) they find that the energy spectrum of nuclei $Z \geq 40$ is not inconsistent with that of Fe group and that of Shirk and Price (1978) for nuclei $Z \geq 65$ using the Skylab exposure.

In OG 6-30 and 10, Fowler et al. and Walker et al. present the results of their transatlantic balloon flights and preliminary results from their Ariel VI experiments. Ariel VI has been launched only on 2 June 1979 and the results for $Z > 65$ is shown along with the total sample from Bristol-Dublin balloon flights. As one can see from Figure 6 with the statistics of the measurements the preliminary results from Ariel VI are quite consistent with the higher data sample from the balloon flights. So far the highest charge detected is ~ 98 and no evidence yet for any super-heavies. The results suggest an actinide abundance $>$ solar system value along with a possible peak in the Pt region and γ -process signature.

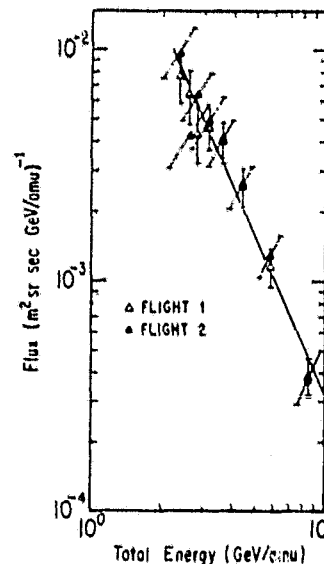


Fig. 5

Overall $Z_{\geq 88}/Z_{\leq 87} = .17/\pm .005$ while for Ariel VI alone the value of the above ratio = $2/16 = 0.13 \pm 0.10$.

Figure 7 shows the ultra heavy spectrum as obtained by Ariel VI in approximately one month's operation.

In Table 1 a summary of the situation with respect to actinide and super heavy abundances are shown and compared to several processes. More data will help in clearly identifying suitable nucleosynthetic processes acceptable to cosmic rays as can be seen in the table. Ariel VI is working very well and so we can hope to get significant information in this area soon. The HEAO-C ultra heavy experiment of Israel, Stone and Waddington is expected to be launched during the middle of September and so the combined results of Ariel VI and HEAO-C can be expected to provide definitive results in this crucial area of cosmic ray composition.

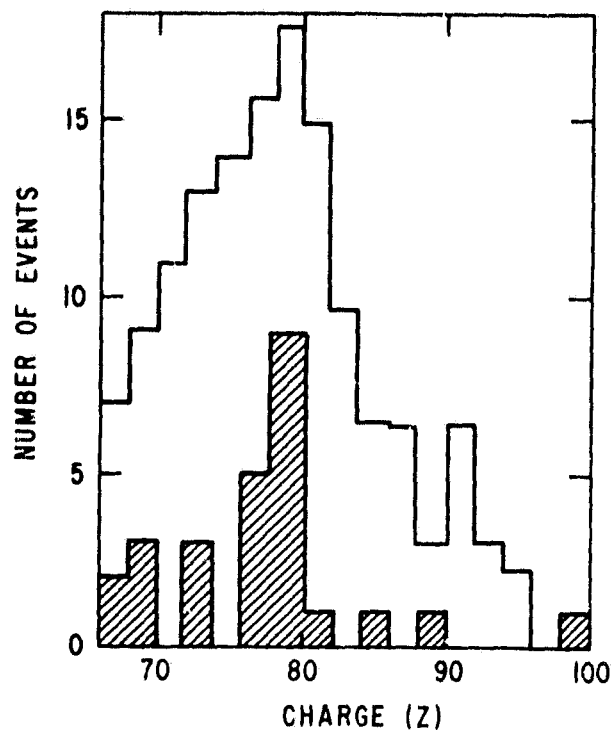


Fig. 6

High Energy Composition

In OG 6-25 and 26 Simon et al. report the results of the joint Max-Planck Goddard calorimeter balloon results. Their results on the more abundant nuclei such as oxygen extend up to 1 TeV/nuc whereas for Fe their results extend ~ 250 GeV/nuc. On a kinetic energy/nucleon representation the spectra of the elements show steepening with energy consistent with the propagation effects in a leaky box model (Ormes and Freier, 1978.)

Their results for Fe is shown in Figure 8. The statistics beyond 100 GeV/nuc is too limited, however, to rule out Goodman et al. 1979 who require the Fe spectrum to be a flat as $-2.36 \pm .06$. The results at lower energies are in agreement with the Fe spectrum reported by Meyer and Minnaga (OG 6-18, this conference.)

Antiprotons

Golden et al. (OG 6-34) have reported the results on their careful measurement with a superconducting magnet of the abundance of antiprotons in cosmic rays. This is a measurement where one has to understand one's instrument completely and pick up the small residual signal from the large amount of disturbing events. Having done this, they report a positive result for anti-protons. On the basis of 28 events they report that $\bar{p}/p = (5.2 \pm 1.5) \times 10^{-4}$ in the range 5.6 to 12.5 GeV/c. They conclude that all these antiprotons detected are consistent with being secondaries produced in the interstellar medium passage (5 g/cm^2 at 5 GeV reducing to 2 gm/cm^2 at 100 GeV).

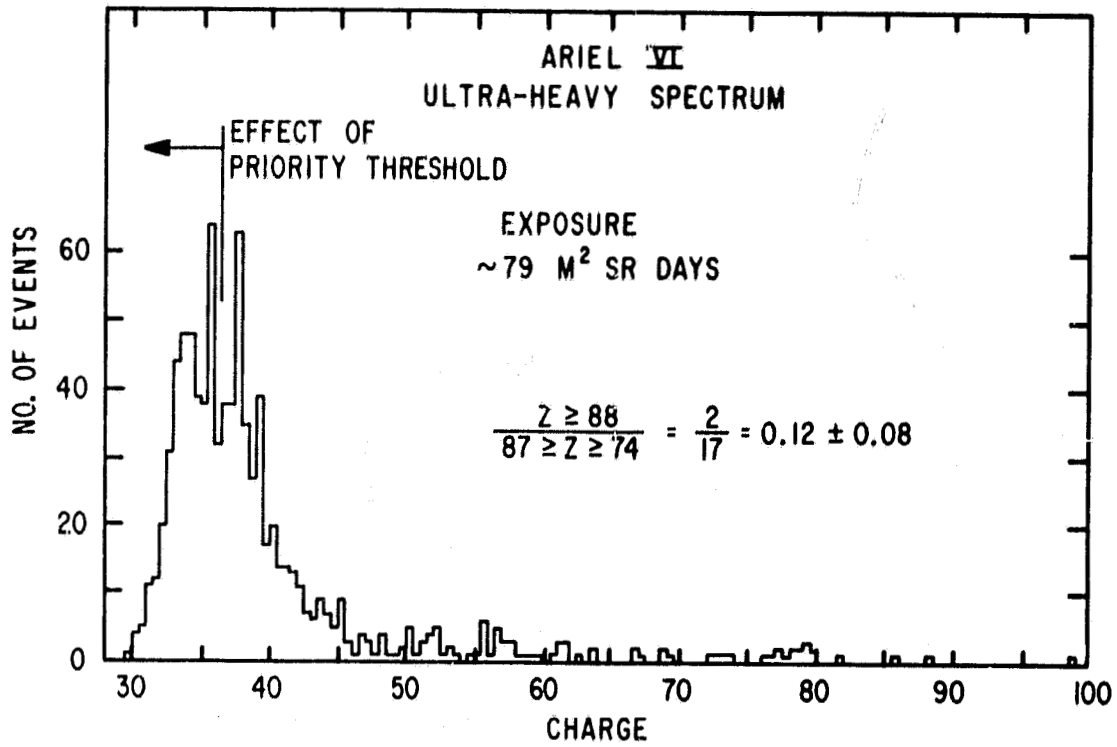


Fig. 7

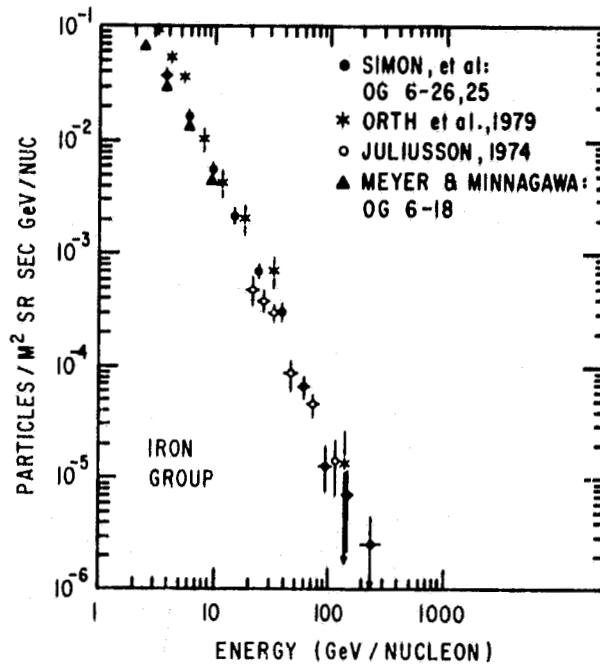


Fig. 8

TABLE 1
Actinide and Superheavy element abundances. The values in parentheses reflect preferential acceleration.

	$(Z \geq 88)/(74 \leq Z \leq 87)$	$(Z \geq 94)/(74 \leq Z \leq 87)$	$(Z \geq 110)/(74 \leq Z \leq 87)$
Berkeley Skylab data (1)	0.10 + 0.04	0.043 + 0.025	< 0.013
Bristol-Dublin balloon data (4)	0.17 ± 0.05	0.027 ± 0.018	< 0.012
Weighted average	0.14 ± 0.03	0.034 ± 0.015	< 0.006
Ariel VI	0.13 ± 0.10		
Propagated r-process (Sensbetu β -rates) (5)	0.07(0.09)	0.033	?
Propagated r-process (gross β -rates) (5)	0.13(0.19)	0.06	?
Propagated Solar System (5)	0.007(0.012)	0.00002	0
Implied Solar System r-process (5)	0.07(0.10)		
Indirect meteoritic evidence (5)			0.0002 - 0.006

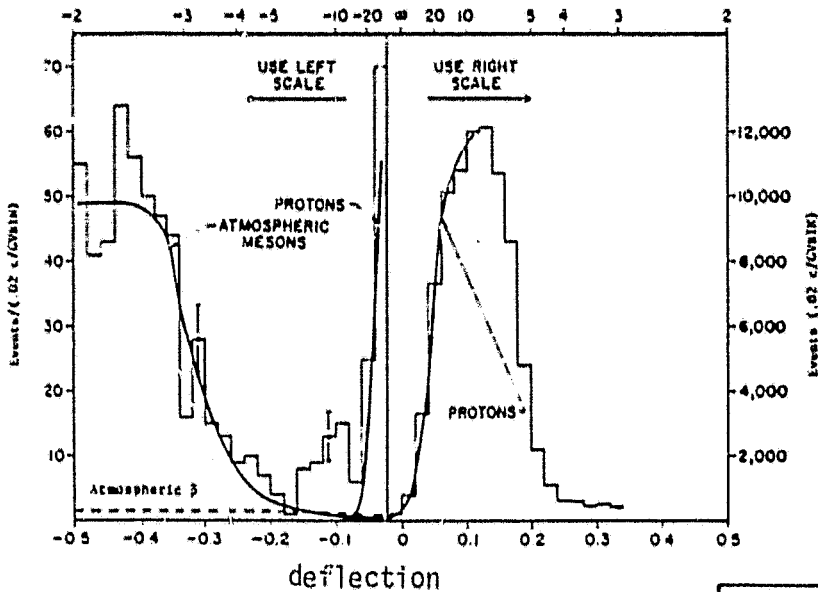


Fig. 9

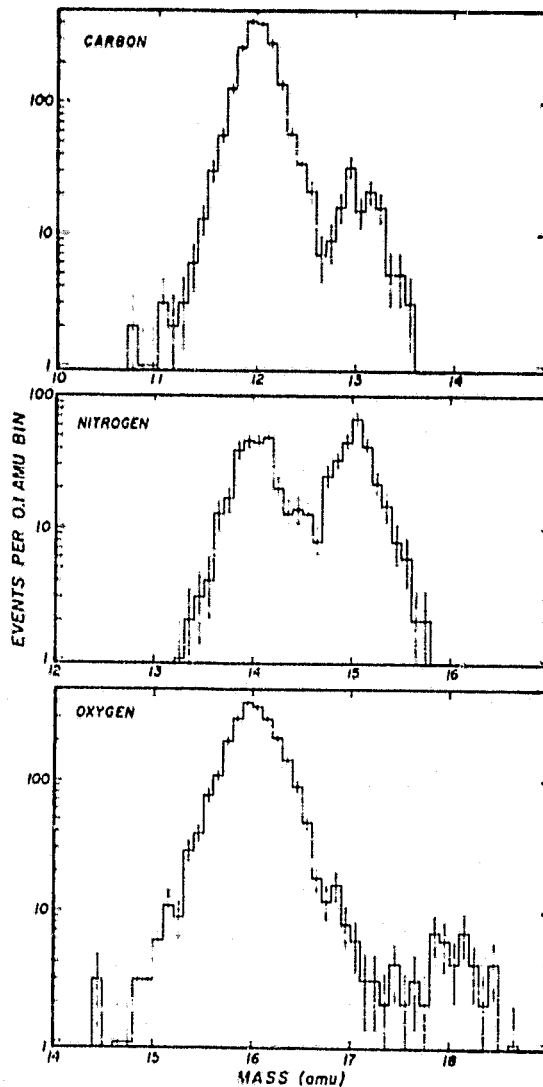
Their residual antiprotons and the discrimination they have attained is shown in Figure 9

Isotopes

Some of the most exciting measurements reported in this conference were in the area of isotopic composition. Compared to the last conference, the picture has become more detailed and definite in some areas and this field promises significant answers in the area of cosmic ray source phenomena.

CNO Region

Wiedenbeck et al. (OG 7-9) using their ISEE-3 instrument have concluded that cosmic ray source abundances in this element range are consistent with solar system abundance. For the $^{15}\text{N}/\text{N}$ their results are not inconsistent with the solar system value. However, a substantially larger value may also be permitted. Figure 10 gives an idea of the resolution obtained with their ISEE-3 semiconductor telescope in the CNO region with a drift chamber



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Fig. 10

for track definition.

Guzik et al.
(U. of Chicago
OG 7-6) using their
IMP-8 results and
Mewaldt et al.
(Caltech - OG 7-2)
come to similar
conclusions that the
cosmic ray source
in this area is
solar system like.
For $^{14}\text{N}/\text{N}$ Guzik et
al. deduce a value
0.03, considerably
lower than the
solar system value.

Some of the
most exciting
results in this
conference have come

from the Ne isotope studies. The early balloon results of Fisher et al. indicate that the Ne^{22} is overabundant in cosmic rays. The high resolution satellite measurements in ISEE-3, and IMP-8 have accumulated evidence to produce definitive evidence for the overabundance Ne^{22} compared to the solar system. An example of the excellent resolution obtained for Ne isotope identification is shown in Figure 11 which represents the results of the Caltech group (OG 6-2). In this figure the two separate mass determinations for the accepted events are plotted against each other. The following table summarizes the results in the Ne region.

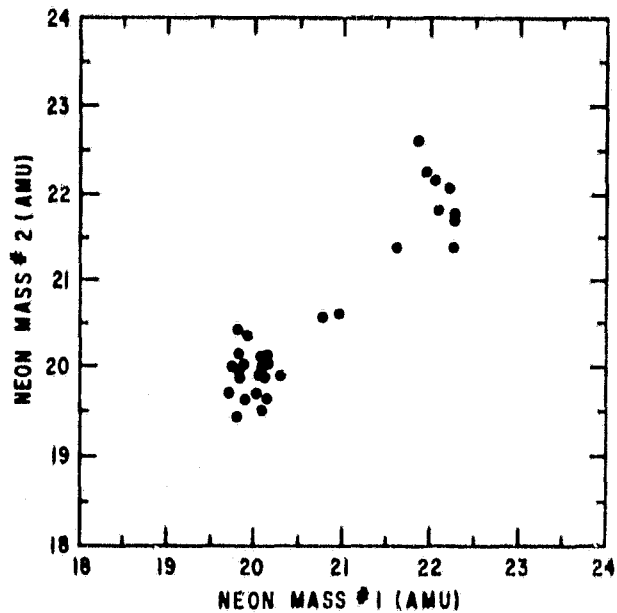


Fig.11

$\text{Ne}^{22}/\text{Ne}^{20}$ Observations

		<u>Paper</u>
Caltech	0.49 ± 0.39	OG 7-2
Berkeley	0.64 ± 0.07	OG 7-9, 10
Chicago	0.54 ± 0.07	OG 7-13
Webber	0.4 ± 0.02	OG 7-11

The average value compiled by Dr. Stone from all experiments (except mean mass measurements) = 0.49 ± 0.05 which translates to a source abundance of 0.37 ± 0.06 . Solar abundance for this ratio is 0.12. So the evidence for this ratio being non solar is becoming quite viable. Let us see what this tells us about the cosmic ray source.

As pointed out in OG 7-2 and OG 7-13 initial CNO elements are converted ^{22}Ne during hydrostatic helium burning and later reactions do not destroy them (Couch et al. 1973, Lamb et al. 1977). For heavier stars the reactions proceed as follows $^{22}\text{Ne}(\alpha, n) \rightarrow ^{25}\text{Mg}(n, \gamma) \rightarrow ^{26}\text{Mg}$ and so reduces Ne^{22} and increases Mg isotopes in the helium burned shell. The Mg isotopes and ^{20}Ne are produced in approximately solar system abundances during carbon burning reactions. So the mixing proportions of He burning and carbon burning regions and the interstellar matter prior to cosmic ray acceleration determines the Ne & Mg isotopic ratio. If large

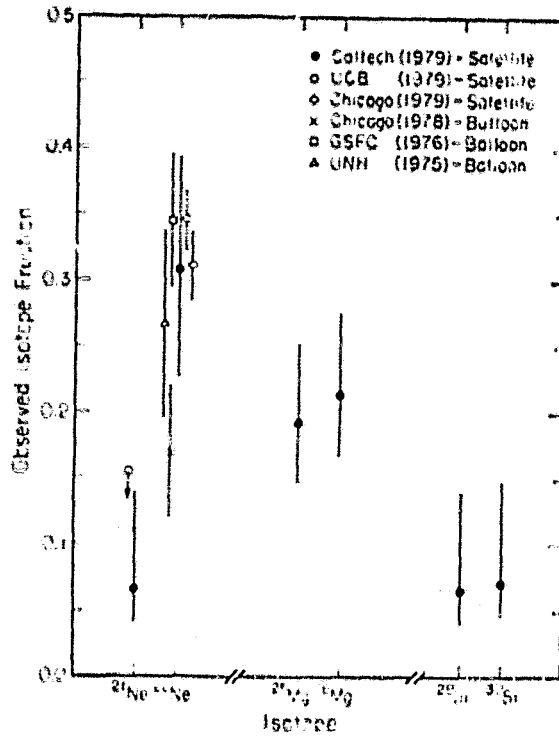


Fig.12 . A comparison of fractional isotopic abundances. The dotted lines are calculated for a solar system source. Data references: UCB (Greiner et al. 1979); Chicago 1979 (Garcia-Munoz et al. 1979) Chicago 1978 (Dwyer 1978); GSFC (Fisher et al. 1976); UNH (Prezler et al. 1975).

amounts of ^{22}Ne have been used up, the corresponding $^{25,26}\text{Mg}$ would be increased. So by considering the Ne and Mg abundances together one may have an idea of the evolution of stars that contribute to cosmic rays.

Let us review the isotopic evidence in the Mg region.

The results compiled in OG 7-13 by Garcia-Munoz et al. point to $^{26}\text{Mg}/^{24}\text{Mg} = .14 \pm .05$ at the cosmic ray source, essentially consistent with the solar system value of .14.

Table
 $^{26}\text{Mg}/^{24}\text{Mg}$

0.15 (+0.03)	Webber et al. OG7-11
0.22 \pm 0.07	Garcia-Munoz et al. OG7-13
0.36 +0.20	Mewaldt et al. OG7-2
-0.07	
0.18 \pm 0.04	Dwyer and Meyer OG7-18

Except for the $\sim 10\%$ deviation of Mewaldt et al. for both ^{26}Mg and ^{25}Mg , the other values are consistent with solar system value. In view of the important constraint this value can put on C.R. sources, it will be of interest to have more high resolution data to contribute to this question.

Dwyer and Meyer (OG 7-18) present results of the mean mass measurement of Ne, Mg and Si at 1 GeV/amu. For Mg and Si their results are consistent with solar system abundance. For Ne they look for energy dependence effects in the isotopic composition of Ne combining their results with other reported experiments. The results are not precise enough to indicate any energy dependence.

Fe Isotopes

During the Plovdiv conference there were indications that neutron rich isotopes (Simpson et al., 1977) were more abundant and this was in sharp contradiction to other results for, e.g., Tarle' et al. By this conference a general consensus appears to have emerged and the Fe isotopes have abundances quite similar to the solar system, as seen in Table 2.

Thus, to summarize the isotope findings except for the Ne isotopes, there is no clear experimental evidence so far for C.R. source composition differing radically from the solar system abundances, and the Ne²² overabundance suggests S.N. as an attractive possibility for C.R. origin.

Electrons and Positrons

In OG 8-1, Evenson et al., using the ISEE-3 spacecraft, study the electron spectrum between 3 and 200 MeV. They detect a number of short-term quiet time increases in the flux ascribed to Jovian origin, and the energy spectrum observed in 1978 is nearly identical to spectra observed by theOGO-V spacecraft in 1965.

Bland (OG 8-2) reports the results of balloon flight (200 MeV-1 GeV) during minimum solar activity in July 1977 and fit the electron data to a spectrum of the form $\frac{dn}{dE} = \frac{a+bE}{E^{3.5 \pm 0.03}}$. Their results agree with the measurements of the University of New Hampshire group during the last solar minimum (1965).

High Energy Electrons

In OG 8-3 Badhwar et al. present results on electrons and positrons from their balloon superconducting magnet studies. The ratio of $e^+/(e^+ + e^-)$ in the energy range (6-29 GeV) observed in 0.09 ± 0.01 consistent with the earlier measurements of Berkeley with more limited statistics up to lower energies. The positron spectrum could be represented as $(16 \pm 2) E^{-3} / \text{m}^{-2} \text{sr sec}$. For electrons the appropriate energy range is 6.05-57.8 GeV and the spectrum is $(183 \pm 7) E^{-3} \pm 0.1 / \text{m}^{-2} \text{sr sec GV}$. The authors remark that the results are slightly preliminary and that electron flux as a result of some efficiency evaluations may go up by approximately 25%, but is very unlikely to decrease from the stated value.

In OG 8-4 Müller and Prince make a careful reevaluation of the efficiencies involved in deducing the results from their Transition radiation balloon instrument. They conclude that the factors studied by them would not decrease the electron flux by sizable amounts and contribute to systematic uncertainties reported in this field between different observers.

Table 2
Fe ISOTOPIIC COMPOSITION

Isotope	Mewaldt et al. OG 7-2 (80-280 MeV/n) (*)	Webber et al. OG 7-12 (600 MeV/n)	Young et al. OG 7-14 (300-800 MeV/n)	Tarlé et al. OG 7-17 (~900 MeV/n) (*)	Scherzer et al. OG 7-15 (500-750 MeV/n) (**)	Solar System
⁵³ Fe	-	-	-	-	6	-
⁵⁴ Fe	0.09 ^{+0.09} _{-0.05}	4.8 ± 1.7	17.0	7.5	23	0.058
⁵⁵ Fe	<0.07	-	-	-	18	0
⁵⁶ Fe	0.91	92.2 ± 5.8	80.7	82.5	47	0.92
⁵⁷ Fe	<0.08	-	-	-	6	0.022
⁵⁸ Fe	<0.06	3.0 ± 1.6	< 2.3	10	-	0.003

* Source Composition

** At Detector Level

Tiara et al. (OG 8-8) presented results from balloon emulsion chamber results (U.S.-Japan collaboration). Combining the results of several flights, they have an exposure of $4 \times 10^5 \text{ m}^2 \text{ sr sec}$ and their study covers an energy region 30-1000 GeV. The differential spectrum is

$$\frac{dJ}{dE} = 1.7 \times 10^{-4} (100 \text{ GeV}/E)^{3.3 \pm 0.2} / (\text{m}^2 \text{ sr sec GeV}).$$

In Figure 13 the results from papers reported at this conference are shown, and probably for the first time a reasonable convergence amongst the results appear to be emerging.

Theoretical Papers Related to Electron Studies

In OG 8-8 Nishimura et al., following the general argument of Shen (1970) and Ramaty et al. (1970), discuss the possibility of observing structures such as bumps, or sharp cutoffs in the electron spectrum in the TeV region due to the small number of discrete sources contributing the general flux. Taking a list of nearby SNRs, their Monte Carlo calculations indicate that Loop 1 and Lupus loop are the most prominent sources of TeV electrons. In addition to the bumps, sharp drops in intensity are predicted in their calculation which might enable detection of these effects when measurements extend to several TeV electrons.

In OG 8-10 Webber et al. use the galactic radio noise data to estimate the interstellar electron energy spectrum. When this estimate is compared with measurements near earth, they find that considering the overall picture in the cosmic ray field such as e^+/e^- ratio and solar modulation, the higher electron intensity

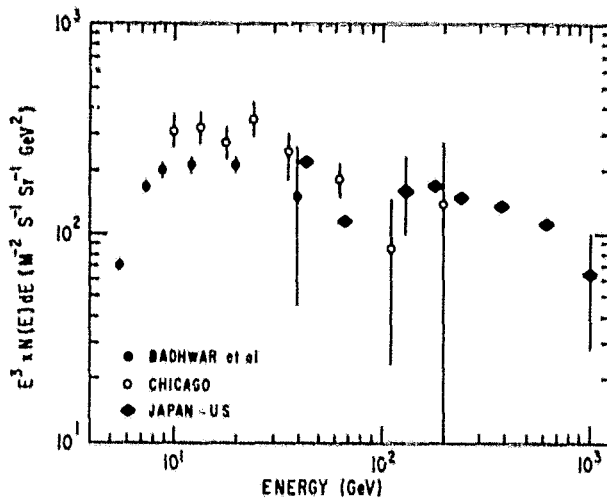


Fig. 13

to a cosmic ray age ~ 25 My. If the pathlength distribution is truncated at short pathlengths, there will be a pronounced decrease of the intensity of electron spectrum at high energies.

In OG 8-11, Lingenfelter and Ramaty point out the intense positron annihilation line radiation that has been detected from the region of the center of the galaxy and raise the possibility of primary positron contribution to cosmic rays.

Giler and Wolfendale in OG 8-13 discuss the pathlength distribution at low pathlengths and its relevance to electron data. They conclude that if the deficit of grammage below 1 g/cm^2 applies to electrons also, then it is possible to account for the electron energy spectrum with a differential production spectrum of the form $AE^{-1.84}$ and mean lifetime $\sim 4 \times 10^7$ years at 10 GeV.

In the last paper of the session OG 8-13 Strong and Wolfendale analyze the low frequency radio data and make some corrections for absorption based on the integrated diffuse $\text{H}\alpha$ and the spectral shape of external radio galaxies. As a result they arrive at an electron energy spectrum which relates to distances of some hundreds of pc. The local interstellar spectrum is inferred using the electron and positron data at the earth's neighborhood. Gamma-ray data is used to infer the electron spectrum several kpc away. Comparing these various electron spectra, they find evidence for the intensity and spectral exponent varying from place to place in the galaxy.

Acknowledgements

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measurements are more consistent in their estimates. However, when a specific propagation model is considered, the limits on the propagation parameters are found to be independent of which set of electron intensity measurements are used. For the leaky box model the preferred parameters are spectral index at injection = -2.24 energy loss parameter $b = (1.5 \pm 0.5) \times 10^{-16} (\text{GeV})^{-1}$, the pathlength energy dependence = $7.5 (E_0/E)^{0.33 \pm 0.1} \text{ g/cm}^2$ and interstellar hydrogen density 0.22 ± 0.08 atoms/cc corresponding

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