From a comparison between the emission and absorption spectra, all that can be stated is that the distance to Cyg X-3 is at least 11 kpc, but we cannot determine whether Cyg X-3 lies inside or beyond the arm at 11 kpc. A rough upper limit for the distance can be derived from the model of source expansion based on synchrotron theory[3]: in this model, the linear velocity of expansion would be of the order of the velocity of light at a distance of about 30 kpc, which can be taken as the upper limit.

From the emission and the absorption spectrum, we derive, as in ref. 1, a revised value of the column density of atomic hydrogen in front of Cyg X-3

$$N_{\mathrm{H}} = 1.6 \times 10^{22} \ \mathrm{cm}^{-2}$$

It is of interest to compare our H-line observations with the OH and H_2CO lines observations of Cyg X-3 published by Turner[4]. From his data, we estimate the peak optical depth in the 1,667 MHz line of OH to be $\tau_{\mathrm{OH}} = 0.06$ for the Cygnus feature. The corresponding optical depth at 21 cm as determined from Fig. 1 is $\tau_{\mathrm{HI}} \simeq 2.5$ at the same radial velocity, so

$$\tau_{\mathrm{OH}}/\tau_{\mathrm{HI}} \simeq 2.4 \times 10^{-2}$$

a reasonable ratio for the external parts of the Galaxy (compare refs 5 and 6). If we assume the same ratio to be valid for the arms at -45 and -68 km s^{-1}, the estimated OH absorption would correspond to 2×10^{-2} and 10^{-2} K in antenna temperature, with the 140-foot radio telescope used by Turner. This is well below the noise level of his OH observations.

The same situation occurs for formaldehyde. We estimate the peak optical depth in Turner's H_2CO observation to be $\tau_{\mathrm{H_2CO}} = 0.03$, so

$$\tau_{\mathrm{H_2CO}}/\tau_{\mathrm{HI}} \simeq 1.2 \times 10^{-2}$$

The estimated H_2CO absorption for the arms at -45 and -68 km s^{-1} is also very likely to be undetectable by Turner. Thus his results are quite compatible with our HI absorption measurements, and do not conflict with a distance ≥ 11 kpc for Cyg X-3.

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Charge Dependence of the Energy Spectra of Cosmic Rays

WHEN the abundance of elements in galactic cosmic rays is compared with the universal abundance[1], galactic cosmic rays are found to be very highly enriched in heavier elements. A similar enrichment has been reported recently based on comparisons of solar energetic particles and solar photospheric and coronal abundances (ref. 2 and J. D. Sullivan, P. B. Price and H. J. Crawford at the Solar Physics Division meeting of AAS, Univ. Maryland, April 1972). The high energy universe composed of suprathermal particles is apparently richer in heavy nuclei than the thermal universe. The reason for this has been sought in the possible preferential acceleration of energetic particles of higher atomic number Z (refs 3 and 4). We report new experimental results in the energy range 3 to 50 GeV nucleon^{-1} which indicate that the well known enrichment of heavy nuclei in cosmic rays is increasing with increasing energy.

The measurements were made with a balloon-borne ionization spectrometer having a total exposure factor of 1.57×10^3 m^2 sr s. The balloon floated at about 7.4 g cm^{-2} for 16 h. The detectors measured particle charge, trajectory and energy[5-7]. Charge identification accuracy is ± 0.3 at oxygen and ± 1 at iron, and energy is known to $\pm 20\%$.

Table 1 Spectral Data

Element group	Origin	Spectral exponent	Observed events > 3.3 GeV nucleon^{-1}
Li	Secondary	2.5 ± 0.2	116
Be	Secondary	2.8 ± 0.2	76
B	Secondary	2.76 ± 0.12	149
C	Primary	2.62 ± 0.05	614
N	Mostly secondary	2.68 ± 0.09	197
O	Primary	2.64 ± 0.05	560
$3 \leq Z \leq 5$ (L)	Secondary	2.78 ± 0.07	341
$6 \leq Z \leq 9$ (M)	Primary	2.64 ± 0.04	1,438
$10 \leq Z \leq 14$ (LH)	Mostly primary	2.58 ± 0.06	412
$15 \leq Z \leq 18$	Secondary	2.14 ± 0.15	54
$19 \leq Z \leq 22$ (Ca group)	Secondary	2.4 ± 0.2	55
$23 \leq Z \leq 28$ (Fe group)	Primary	2.12 ± 0.13	82

The spectral data are presented in Table 1, and represent the first differential spectra of many of these components above a few GeV nucleon^{-1}. At these energies solar modulation effects should be small and the spectra should reflect those in interstellar space. The secondary nuclei have spectral exponents slightly steeper than those of their closest progenitors as previously reported by Smith *et al.*[8] and Juliusson *et al.*[9]. We also note the pronounced change in going from the M group to the iron group and the behaviour of the LH group is consistent with this trend. These three groups all contain predominantly primary cosmic rays[10]. The pronounced change is illustrated in Fig. 1 where the ratio of M/(Fe group) is plotted as a function of energy. Lower energy data from various workers are consistent with the change in composition which we observe. If these spectra continue to higher energies, iron will become the most abundant nucleus besides protons and helium at ≈ 200 GeV nucleon^{-1}.

The difference in spectral exponents between carbon and oxygen and iron is about 0.5. This is much larger than the observed differences between primary nuclei and their secondary products which is about 0.2 and is probably due to propagation effects[9]. We believe that the enhancement of iron nuclei at high energies is due to effects occurring at cosmic ray sources. If propagation alone is to explain the differences between these primary spectra then they would have similar source spectra. The iron nuclei, which have on average passed through only 2 or 3 g cm^{-2} of matter[11], would have to be flattened more drastically than the carbon and oxygen which have passed through twice as much material[12]. If this were the case, all cosmic ray spectra would be steeper at higher energies.

As the amounts of matter are only a few grams at most, it is very unlikely that the propagation has modified the energy spectrum at the source drastically. Though Z-dependent interstellar acceleration or escape dependence on Z are possibilities, it is very likely that the differences detected represent source characteristics.

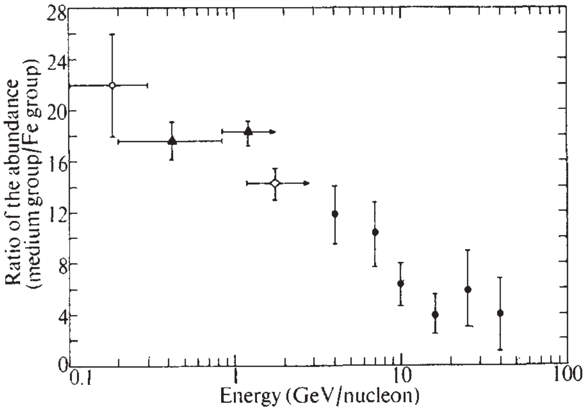

Fig. 1 The ratio of the abundance of the medium nuclei ($6 \leq Z \leq 9$) to the Fe group ($23 \leq Z \leq 28$) is plotted as a function of energy/nucleon. The open circle represents a satellite measurement, the remainder of the data was obtained on balloons and is corrected to the top of the atmosphere. ▲, Webber, Damle and Kish[12]; ○, Cartwright, Garcia-Munoz and Simpson[13]; ◇, Smith *et al.*[8]; ●, this paper.

With these provisos, we conclude that the source spectra of heavy nuclei are flatter than those of lighter nuclei. If all cosmic rays come from the same source then preferential acceleration of heavy nuclei is implied by this result. It does not seem that a Z-dependent injection process[3,4] can explain the data as the enhancement is most pronounced at energies well beyond any possible injection energy. The result would suggest a Z dependence of the acceleration process itself. Another possibility is that the spectral differences are due to different sources, and that the iron nuclei are produced in closer sources with flatter spectra.

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Evidence for Differences in the Energy Spectra of Cosmic Ray Nuclei

THE existence of differences in the energy spectra of the various cosmic ray nuclei at energies $\gtrsim 1$ GeV nucleon^{-1} would have important implications for the method of acceleration of the cosmic rays and their propagation in interstellar space. But only recently has it been possible to isolate and compare the spectra of particular charges or charge groups with the requisite statistical accuracy over a broad enough energy range.

It seems natural to expect that any spectral differences would be greatest for charges or charge groups widely separated in Z. Comparisons of the He/VH and M/VH ratios as a function of energy[1,2] (M nuclei: $Z=6$–9, VH nuclei: $Z=20$–28) give some indications that the spectral index γ (for power law spectra of the form $J(>E)=K/E^{\gamma}$) for VH nuclei was ~ 0.1 less than that for He or M nuclei in the energy range 1–20 GeV nucleon^{-1}, but these results were certainly not convincing.

As the charge measurements have improved it has been recognized that about half of the VH group nuclei are in fact nuclei with $Z=20$–25, and current models of cosmic ray propagation suggest that these latter nuclei are "secondary" nuclei produced by the fragmentation of Fe and Ni in interstellar hydrogen[3]. Of the VH group nuclei then, only Fe and Ni should be mostly "primary" or cosmic ray source nuclei. To look for possible spectral differences, perhaps related to the acceleration process in the cosmic ray sources, it seems more appropriate to compare ratios of mainly primary or source nuclei such as He, C+O, and Fe+Ni.

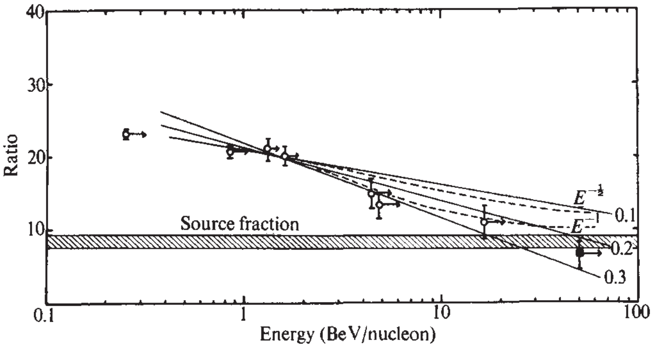

Fig. 1 Ratio of C+O to Fe+Ni nuclei as a function of energy. Open circles are these data plus those of ref. 2. Solid square is data from ref. 5. Solid lines are drawn for differences in the spectral exponent γ of 0.1, 0.2, and 0.3. Dashed lines are for escape length varying as $E^{-\frac{1}{2}}$ and E^{-1}.

In Table 1 we show data on the intensities of these nuclei measured at several energies from ~ 1 to 50 GeV nucleon^{-1}. Included here are previously unpublished data that we have obtained recently from balloon flights in Canada and Argentina using a large area, high charge resolution, double dE/dx· Čerenkov detector[4] covering the energy range up to $\gtrsim 5$ GeV nucleon^{-1}. Table 1 also includes some of our previously reported data[2], re-analysed to obtain the charge distribution in more detail, and recent data presented by Juliusson *et al.*[5] and Smith *et al.*[6].

The data in this table show a very interesting behaviour. The fraction of $Z=17$–25 to Fe+Ni nuclei changes from $\gtrsim 1$ at energies $\lesssim 1$ GeV nucleon^{-1} to values $\lesssim 0.2$ at the highest energies measured. We will return to this specific point shortly; first, however, consider what effect a variation of this type will have on the previously determined VH nuclei spectrum as compared with a spectrum of only Fe+Ni nuclei. As the Fe+Ni nuclei spectrum will have relatively fewer low energy particles than the corresponding VH spectrum, the