PROPAGATION STUDIES RELATED TO THE ORIGIN OF COSMIC RAYS

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Propagation of cosmic rays is discussed with the intent of deriving results relevent to the origin of cosmic rays. Starting from a brief description of the methods for demodulating the effects of the solar wind on the spectra of particles, we describe an accurate method for correcting for spallation effects on the cosmic-ray nuclei during their transport from the sources subsequent to their acceleration. We present the composition of cosmic rays at the sources and discuss its implications to their origin. We discuss briefly the effects of stochastic acceleration in the interstellar medium on the relative spectra of primaries and secondaries in cosmic rays and show that the observation of decreasing relative abundance of secondaries with increasing energy rules out such phenomena for galactic cosmic rays. The spectrum of cosmic-ray electrons is discussed in terms of contributions from a discrete set of sources situated at various distances from the solar system on the galactic plane. We show that unless there are at least 3.10^4 sources actively accelerating cosmis rays in the Galaxy the spectrum of electrons would have a premature cut-off at high energies. Finally we point out some important questions that need to be clearly resolved for making further progress in the field.

I. INTRODUCTION

We are at the threshold looking out at the nineteen eighties during which decade one feels hopeful that the problems posed by the discovery of cosmic rays early during this century would find a clear resolution. This confidence stems from the tremendous progress that took place during the seventies, not merely in the acquisition of data of excellent quality in the field of cosmic rays and many other related fields but also in the development of theoretical frame-work for the interpretation of the data. In this essay we shall review some of these developments and show how these studies have characterised the sources so well that their identification is imminent. A good part of this progress has been due to the age-old belief that cosmic ray sources should also be sources of high energy gamma rays and the recent disco-

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veries using the SAS-II ans COS-B instruments have stimulated much new thinking.

This is not a review paper but a personalised account of ideas in the field ; unfortunately we have not been able to cover all the important work in the field nor have we been able to give credit to the originators of several important ideas which have been worked on and developed further over the recent years. Here we wish to substantiate the thesis that bulk of the cosmic rays below air-shower energies ($\sim 10^4$ GeV/n) originate in a very large number of discrete sources ($\sim 10^5$) strewn about the galactic disc. The cosmic rays which are accelerated in these sources interact with the matter surrounding the sources before leaking into the interstellar space where they suffer further interactions before escaping into the intergalactic space. These interactions generate secondaries like Li, Be, B and also gamma rays which serve as excellent diagnostic tools. Since our view of the true cosmic-ray spectra at low energies in the interstellar space is obscured by modulation effects due to solar wind and magnetic field our presentation here follows the reverse sequence describing first the methods for demodulating the solar effects and then methods for correcting the effects of spallation etc to get the actual spectrum and composition of the particles at the site of their acceleration. We then discuss the implication of the source spectra and source composition. Finally, we point out that there are two questions related to the cosmic ray origin which stand out and which have to answered clearly before further progress can be made in this field. These questions are ;

a) Is the residence time of cosmic rays in the interstellar space a decreasing function of energy ?

b) What really are the physical processes involved which choose certain ions, in preference to others from the available matter, for acceleration to cosmic ray energies ? In other words what is the injection mechanism that is operative in cosmic-ray accelerators ?.

II. DEMODULATION OF SOLAR WIND EFFECTS.

While the available measurements of the energy spectra of comic-ray particles are confined to those performed with detectors on satellites and balloons at heliocentric distances of the order 1 AU, these spectra elsewhere in the solar systems and especially in the near interstellar space are of much astrophysical interest. In order to predict the spectra at various heliocentric distances, starting from the observed spectra near the Earth, account must be taken of the effects of particle propagation through the radially diverging magnetised solar wind plasma. These effects are usually described in terms of a spherically symmetric steady state established by the balance of the inward diffusion of particles with an outward convection combined with the associated energy losses (Parker 1966). Very recently this simple picture is undergoing a drastic change with the discovery that the 11-year modulation of the neutron monitor counting rates (representing the galactic cosmic-ray intensity at $\langle E \rangle \sim$ 5 GeV) are strongly correlated with the size of the polar coronal holes during the same period (Hundhausen et al. 1980). The correlation is so good that it establishes for the first time a connection between cosmic ray variations and a measurable parameter of the Sun, namely, the coronal holes which are known to be the sources of major streams of fast solar wind and establish a connection between interplanetary magnetic structure and the general magnetic field of the Sun. This correlation can be interpreted as non-spherically symmetric effects such as entry (Svalgaard and Wilcox 1976) and drift (Jokipii et al. 1976). This development is so recent that a full understanding of its consequences to the cosmic ray field will take some time and it may be worth while to consolidate the basic results obtained from solving the spherically symmetric transport equations of Parker (1966). These may indeed be adequate to correct for the relative modulation effects between isotopes of the same species at $E \gtrsim 300$ MeV/n. With these limitations the transport of the cosmic rays in the solar system is described by the equation

$$\frac{V}{r^2}\frac{\partial}{\partial r}\left(r^2 U_i\right) - \frac{K_i p^{\alpha_i}}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial U_i}{\partial r}\right) - \frac{2V}{3r}\frac{\partial}{\partial p}\left(p U_i\right) = 0 \tag{1}$$

Here, V = velocity of the solar wind

$K_i p^{\alpha_i}$ = diffusion constant for the species i

p = momentum per nucleon or per electron

and U_i = number density of particles at heliocentric distance r and momentum p.

Let the spectral observations near the earth be parametrised in the form

$$U_i(o,p) \equiv N_i(p) = \frac{N_i p^2}{\left(p_i^{\alpha_i+3/2} + p^{\alpha_i+3/2}\right)^{\nu}} \tag{2}$$

Then the solution at any r is given by (Cowsik and Lee 1977)

$$U_i(r,p) = \frac{N_i p^2}{\left(p_i^{\alpha_i+3/2} + p^{\alpha_i+3/2}\right)^{\nu}} \cdot M\left(\nu_i, 2, \frac{w\, x\, p^{3/2}}{p_i^{\alpha_i+3/2} + p^{\alpha_i+3/2}}\right) \tag{3}$$

Where M(a,b,z) = confluent hypergeometric function which equals one at z = 0,

x = r in units of the solar modulation boundary

and $w = (1 + \frac{2}{3}\alpha_i)\, r_0 V K_i^{-1}$

special cases of interest for this galactic cosmic-ray modulation are

$$\begin{aligned} \nu = 1 \qquad & U_i(r,p) = N_i(p)\,\frac{1}{\eta}\left(e^{\eta} - 1\right) \\ \nu = 3/2 \qquad & U_i(r,p) = N_i(p)\, e^{\eta/2}\left[I_0(\eta/2) + I_1(\eta/2)\right] \\ \nu = 2 \qquad & U_i(r,p) = N_i(p)\, e^{\eta} \end{aligned} \tag{4}$$

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where $\eta = \omega x p^{3/2} (p_i^{\alpha_i+3/2} + p^{\alpha_i+3/2})^{-1}$ and I_o and I_1 are modified Bessel functions.

Hopefully we will soon understand the effects of drifts adequately to have a full-fledged 3-dimensional solution including all effects. In the mean while the cosmic ray data obtained by various groups are of sufficiently high quality to warrant an uniform treatment of the modulation effects, that is generally agreed upon, to obtain the interstellar spectra.

III. CONSTRAINTS ON STOCHASTIC ACCELERATION IN THE INTERSTELLAR MEDIUM

The spectrum of particles in the interstellar space results from the combined effects of injection of particles by the sources and a variety of transformations these particles undergo before they escape from the Galaxy. Before discussing in detail the effects of nuclear spallation we wish to show that cosmic ray particles are not accelerated further in the interstellar medium stochastically by the socalled Fermi-mechanism (Fermi 1949). In this acceleration process cosmic rays grain energy through repeated collisions with magnetized clouds of gas that more about in the interstellar space. The interest in this process, in the context of galactic cosmic rays waned with the accumulation of radioastronomical evidence showing that the velocities of the interstellar clouds were too small and their relative spacing too large to accelerate cosmic rays significantly within the residence time of $\sim 10^7$ years. However the interest in the stochastic acceleration of cosmic rays in the interstellar space has been rejuvinated for two reasons : (1) Jokipii (1977) has considered the possibility that a spectrum of hydromagnetic waves may be present in the intestellar medium and these may provide for a rather rapid rate of acceleration ; (2) Axford et al. (1977) and Blandford and Ostriker (1978) have discussed the possibility that the shocks caused by the debris of supernova explosions extended to distances of $\sim$ 100pc and that these shocks coupled strongly to the cosmic-ray gas leading to $\sim$10% gain in the energy of the particles in each encounter. Now we proceed to show that if indeed such processes are effective the ratio of the fluxes of the secondary to that of the primary nuclei in cosmic rays will increase logarithmically with energy contrary to observations.

The energy spectrum of particles subject to Fermi acceleration is controlled by the well-known differential equation

$$\frac{\partial f}{\partial t} = -\frac{f}{\tau} - a\frac{\partial}{\partial E}(Ef) + KE\frac{\partial^2}{\partial E^2}(Ef) + I \qquad (5)$$

If particles are injected into the system at $t = 0$ with $E = E_i$ then setting $I = \delta(t)\cdot\delta(E-E_i)$ we get the Green's function of the problem to be (Cowsik 1979)

$$f(E,E_i,t) = \frac{1}{2\pi E}\left(\frac{E}{E_i}\right)^{\frac{K+a}{2K}} \exp\left[-(\ln E - \ln E_i)^2/4Kt\right]\cdot \exp\left[-(\delta + \frac{1}{\tau})t\right] \qquad (6)$$

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with $\delta = (K+a)^2/4K$. Now the spectrum of cosmic rays, F, in the steady state is obtained by integrating the eq. 6 over time.

$$F_{1,2}(E,E_i) = \left[4K(\delta+\tfrac{1}{\tau})\right]^{-1/2} \frac{1}{E}\left(\frac{E}{E_i}\right)^{\frac{K+a}{2K} \pm \sqrt{(\delta+\frac{1}{\tau})/K}} \tag{7}$$

The + sign in the exponent obtains for $E < E_i$ and the - sign for $E > E_i$. It is convenient to rewrite eq. 7 as

$$F_{1,2}(E,E_i) = \frac{A}{E}\left(\frac{E}{E_i}\right)^{\eta \pm \gamma} \tag{8}$$

Notice here that acceleration occurs irrespective of the sign of a, the term emphasised by Fermi. The second order term causes the particles to spread rapidly in 'lnE' space and thus plays an essential role in the acceleration process.

If during this acceleration process the particles traverse matter they will generate secondary particles through nuclear interactions. An example of this process is the generation of elements like Li, Be and B in the interactions of the cosmic ray carbon nuclei. If ξ be the production rate of the secondaries S above the production threshold E_{th}, we may write in the steady state

$$0 = -\frac{S}{\tau} - a\frac{d}{dE}(ES) + KE\frac{d^2}{dE^2}(ES) + \xi F(E,E_i) \tag{9}$$

Noticing that eq. 8 solves the homogeneous part of this equation we get

$$\begin{aligned} S &= \int F(E,E_p)\,\xi\, F(E_p,E_i)\,dE_p \\ &= \int_{E_{th}}^{E} F_2(E,E_p)\,\xi\, F_2(E_p,E_i)\,dE_p + \int_{E}^{\infty} F_1(E,E_p)\,\xi\, F_2(E_p,E_i)\,dE_p \\ &= \frac{A^2\xi}{E}\left\{\ln\frac{E}{E_{th}}\, E^{\eta-\gamma} + \frac{1}{2\gamma} E^{\eta-\gamma}\right\} \end{aligned} \tag{10}$$

Thus the ratio of secondaries to primaries has the behaviour

$$\frac{S}{F} = A\xi\left\{\frac{1}{2\gamma} + \ln E/E_{th}\right\} \tag{11}$$

In Fig. 1, this theoretical expectation is compared with the observations taken from a recent compilation of Ormes and Frier (1978)

Whereas the stochastic processes develop logarithmically increasing L/M ratios the observations indicate a fall off at high energies thus ruling out the effectiveness of the stochastic acceleration processes in the interstellar medium. These results has been generalized to processes where τ, a and K are arbitrary functions of energy, with essentially the same conclusions (Cowsik 1980).

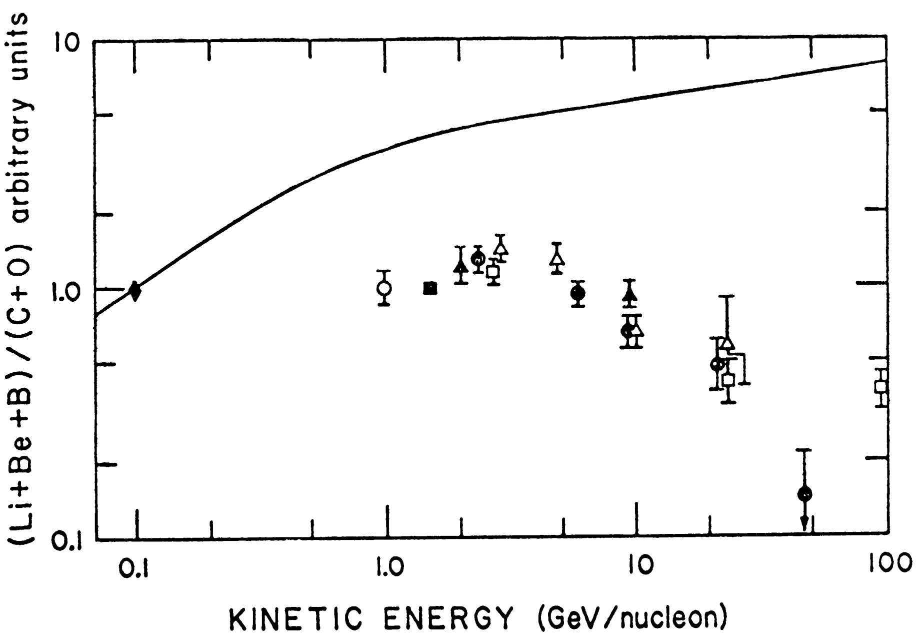

Fig. 1 - The predictions of the Fermi-theory are compared with the observations of L/M ratio in cosmic rays. The strong discrepancy rules out effective stochastic acceleration in the interstellar medium.

IV. NUCLEAR SPALLATION EFFECTS DURING PROPAGATION

The basis transport equation for cosmic ray nuclei is a second order partial differential equation (Ginzburg and Synovatskii 1964). This is in general too complicated to handle and Cowsik et al. (1966, 1967) introduced the concept of vacuum path length distribution which gave the probability that a cosmic ray particle survived for a time t after injection when all interactions were switched off. Since then invariably all calculations of the abundances of cosmic rays including effects of spallation and losses of energies due to ionization have been performed using this technique. However, this technique has mainly two difficulties : first, in this approach unless the pathlength distribution is an exponential or a convolution of exponential distributions the primary, secondary and thertiary nuclei can not be proven to have the same path length distribution. Second, the exact calculation of all the nuclear abundances in cosmic rays becomes extremely cumbersome. Since all nuclei more massive than the particular one of interest can contribute to its flux through nuclear spallation or radioactive decay one has to propagate all the more massive nuclei through the path-length integral first. In this procedure the propagation of calculational errors and the effects of uncertainty in the cross-sections is more severe. For these reasons consider the equation where the loss of particles from the volume of interest is parametrised by a leakage life-

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time τ_i (Cowsik and Wilson 1973, 1975, Wilson 1979)

$$\frac{dN_i}{dt} = -\frac{N_i}{\tau_i} - N_i \beta c n_H b_i + \sum_{j>i} \beta c n_H \sigma_{ij} N_j + S_i \qquad (12)$$

Where N_i = density of nuclei of the ith kind
$1/\tau_i$ = escape probability per unit time
$\beta c n_H b_i$ = nuclear break up and decay probability
$\beta c n_H \sigma_{ij}$ = spallogenic and radioactive production rate of nuclei of the ith kind by nuclei of the jth kind
S_i = average source strength per unit volume.

Consider a diagonal matrix D_{ii} with elements $(\tau_i^{-1} + \beta c n_H b_i)$ and a triangular matrix T_{ij} with elements $\beta c n_H \sigma_{ij}$ for $j > i$ and zero for $j < i$. Defining $M_{ij} = T_{ij} - D_{ij}$, we can write

$$\frac{dN_i}{dt} = S_i + M_{ij} N_j \qquad (13)$$

The relative constancy of cosmic rays over geologic times (see Honda 1979 for a review) allows us to assume a steady state ie. dNi/dt = 0 and write for the abundances of cosmic rays at the sources simply as

$$S_i = - M_{ij} N_j \qquad (14)$$

If we wish to calculate the expected composition N_j for any assumed source composition S_i, we can use

$$N_j = -(M^{-1})_{ji} S_i \qquad (15)$$

If cosmic rays are sequentially contained in ν regions each characterised by a transformation matrix M^{α}_{ij} we have

$$S_i = \left\{ \prod_{\alpha=1}^{\nu} M^{\alpha} \right\}_{ij} N_j \qquad (16)$$

This corresponds to the vacuum pathlength distribution

$$f(t) = C \sum_{\alpha=1}^{\nu} \frac{(-1)^{n_\alpha} t^{n_\alpha - 1} e^{-a_\alpha t}}{\prod_{\substack{\beta=1 \\ \beta\neq\alpha}}^{\nu} (a_\beta - a_\alpha)^{n_\beta} (n_\alpha - 1)!} \qquad (17)$$

Where n_α are the number of region with identical escape probability $a_\alpha = \tau_\alpha^{-1}$. A particular case of this was explicitly discussed earlier by Cowsik and Wilson (1973, 1975). This was called the nested-deaky box for cosmic rays.

Now, in the above equations τ_i are unknown. One usually assumes that τ_i are independant of the particle species and then one varies τ (and in some cases n_H also) till the abundances of certain elements such as Li, Be and B at the sources becomes a minimum or indeed zero.

The most important result that has come out during the last decade is that the relative composition of the cosmic rays at the sources do not show any sizeable variation with energy in the range 1-100 GeV, though τ itself seems to decrease beyond a rigidity of $\sim$10 GV/c or $\sim$5 GeV/n for the heavy nuclei (see Orth et al. 1978 for a recent discussion). One of the very important questions that faces us now is the way in which τ(R) is to be interpreted. Before discussing this question in the next section we will now proceed to discuss the implication of the source abundances of cosmic rays shown in Table 1.

Table 1 - Abundances of cosmic-ray nuclei at the sources derived using a pathlength distribution which has an exponential form but truncated below 1.3 gcm^{-2} (Silberberg 1980, Garcia-Munoz and Simpson 1979).

Element	C. Rays	Galactic	C.R./Gal.
He	3070 ± 200	(2.08 ± 0.46) X 10^4	0.148 ± 0.034
C	100 ± 1	100 ± 23	1.0 ± 0.23
N	6 ± 1	17.7 ± 7.7	0.34 ± 0.16
O	128 ± 3	177 ± 38	0.72 ± 0.16
F	0.7 ± 0.5	7.15	
Ne	16 ± 2	20.8 (1.7)	0.77 (1.7)
Na	2.7 ± 1	0.43 ± 0.07	6.3 ± 2.6
Mg	29.5 ± 2	8.08 ± 0.23	3.65 ± 0.27
Al	4.4 ± 1	0.65 ± 0.03	6.8 ± 1.57
Si	28.0 ± 2	7.69 ± 0.23	3.64 ± 0.28
P	0.6 ± 0.4	0.074 ± 0.015	
S	3.8 ± 0.6	3.46 ± 1	1.10 ± 0.36
Cl	0.3 ± 0.2	0.036 (1.6)	
A	0.8 ± 0.3	0.69 (1.7)	1.16 (1.8)
K	0.7 ± 0.3	0.028 ± 0.009	
Ca	3.7 ± 0.5	0.48 ± 0.05	7.71 ± 1.42
Fe	30.5 ± 0.2	6.77 ± 0.46	4.51 ± 0.43
Ni	1.7 ± 0.3	0.37 ± 0.046	4.59 ± 1.0

This procedure yields basically two parameters regarding the cosmic ray residence in the Galaxy. A path length distribution with an exponential fall-off with Λ = 5 g cm^{-2} with the path lengths below $\sim$1.3 g cm^{-2} cut-off, seems to fit the data best. The cut-off at short pathlengths is necessitated by having to fit simultaneously the secondaries of medium nuclei like C, N, O and those of the heavy nuclei like Fe. The nested leaky box model where cosmic-ray nuclei spend part of their time in a containment volume just arround the sources generates naturaly the low pathlength cut-off as due to the convolution of two exponentials. On the other hand the interpretation that typical sources are far apart faces the difficulty that in this case the source function for the secondaries is the product of the interstellar gas density and the steady state density of the primaries. Thus the secondaries can arrive at the earth even after passing through only a very short path length. Under these conditions one would not be able to fit the data over the whole range from Li to Fe.

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The second parameter which has come out of these studies particularly by studying the Be^{10} in cosmic rays is that the mean cosmic ray residence time in the Galaxy is longer than $\sim 10^7$ years. If it were any shorter the Be^{10} generated as spallation products would not have suffered radioactive decay to B^{10} sufficiently and we would have observed a much larger flux.

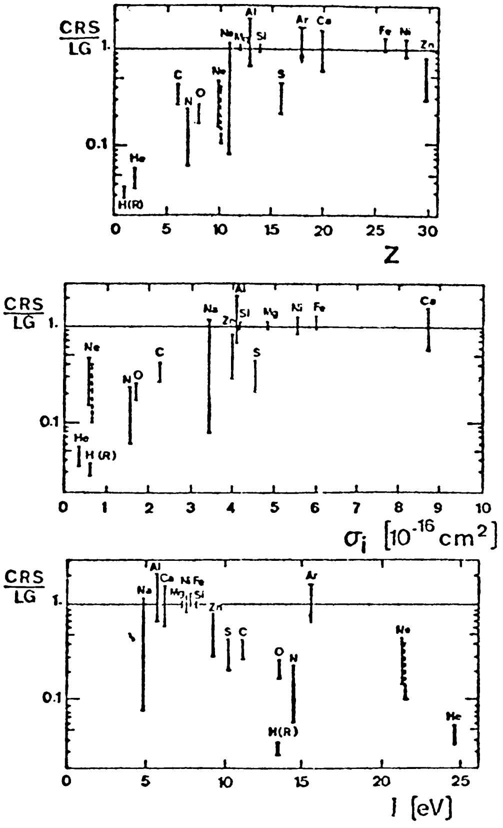

Fig. 2 - Ratio of the relative elemental abundances of cosmic rays at the sources to the local galactic abundances plotted as a function of nuclear charge Z, ionization cross-section σ_i, and the first ionization potential I.

The composition of the nuclei at the sources themselves tell us a lot. First, notice that the differences between the so-called local galactic abundances (Meyer 1979, Cameron 1973) and the composition of cosmic ray nuclei at the sources is within a factor of ~ 10 and selection effects based on atomic properties such as nuclear charge (Cowsik and Wilson, 1973) or first ionization potentials or ionizations cross-sections (Havnes 1971, Kristiansson 1974, Cassé and Coret 1978) could bring the two sets of abundances into correspondence. In Fig. 2 we show these correlations (Meyer, Cassé and Reeves, 1980).

The preliminary results from recent experiments indicate that the correspondance between the cosmic ray an universal abundances continues up to the heaviest elements. In fact these does not seem to be any evidence for usually high abundances of elements synthesised through the R-process thus severing one of the most important connections between cosmic rays and supernovae. In fact there are other factors in the composition of cosmic rays which further weaken the importance of supernova explosions as cosmic ray sources (Cassé and Soutoul 1975). The presence of the Fe-group of nuclei in the Galaxy is believed to be mainly due to explosive nucleosynthesis which provides proton-rich progenitors which decay either by electron capture or β^+ emission. The main decay schemes are

$$
\begin{array}{l}
{}^{55}Co \xrightarrow[18.2\,h]{ec\ \beta^+} {}^{55}Fe \xrightarrow[2.6\,y]{ec} {}^{55}Mn \\
{}^{56}Ni \xrightarrow[6.1\,d]{ec} {}^{56}Co \xrightarrow[77\,d]{ec\ \beta^+} {}^{56}Fe \\
{}^{57}Ni \xrightarrow[36\,h]{ec\ \beta^+} {}^{57}Co \xrightarrow[270\,d]{ec} {}^{57}Fe \\
{}^{59}Cu \xrightarrow[81\,s]{ec\ \beta^+} {}^{59}Ni \xrightarrow[8.10^4\,y]{ec} {}^{59}Co
\end{array}
\qquad (18)
$$

The electron capture is strongly inhibited once the nuclei reach high energies, as the atomic electrons would all have been stripped off. Thus the presence of ^{57}Fe and ^{59}Co in cosmic ray sources would indicate that the nuclei had electrons arround them for a considerable length of time before they lost them when they reached high energies. Just from the elemental ratios Fe : Co : Ni one can conclude that there has been a time delay of at least a couple of years between nucleosynthesis and cosmic ray acceleration. In fact if the preliminary indications of finite ^{59}Co in the sources is borne out by further experiments then one may conclude that the delay is longer than $2x(8.10^4 y)$. In view of such arguments the source of ions for cosmic ray acceleration is the average galactic matter rather than the newly synthesised matter in the supernovae. Since, however the heavy elements in the interstellar matter is depleated on to the grains, the conditions in the cosmic ray sources should be such as to sputter or ablate the grains before acceleration.

There is one important nuclide which does not seem to fit into this general scheme ; it is shown quite definitively that there is an excess of ^{22}Ne at the sources. At the moment the source of this anomaly is not clear though there are many suggestions ; see for example Audouze et al. (1980) and many other papers at this meeting.

V. SOME URGENT QUESTIONS

The analysis presented in the previous section has pointed out two basic questions which need an explanation before we can make further progress in the field. We discuss now these questions in turn.

V.1. Is The Residence Time Of Cosmic Rays In The Galaxy Dependent On Energy ?

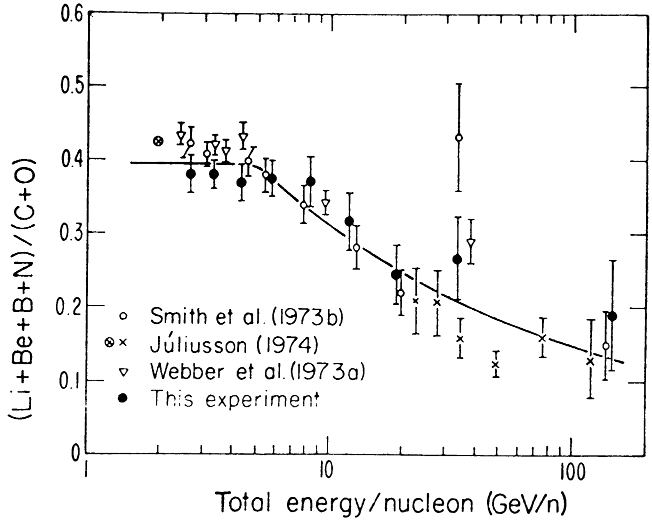

Fig. 3 - Energy dependence of spallation age (from Orth et al. 1978)

The energy dependence of the cosmic ray spallation age is shown in Fig. 3 taken from Orth et al. (1978). The most simple explanation for the fall off at high energies is that cosmic rays of higher rigidity escape from the Galaxy more effectively. An alterative explanation is that the residence time of cosmic rays in the Galaxy is indeed constant but the energy dependence of the L/M ration arises because of more effective trapping of low rigidity particles arround the sources as described in the nested leaky-box model (Cowsik and Wilson 1973,1975). A choice between these two alternate hypotheses is very important and we present here arguments relevant to answering this question.

Let us start with the first explanation in which the residence time of cosmic rays in the interstellar medium can be parametrised as

$$\tau(R) = \tau_0 \text{ for } R < 10 \text{ GV/c} \; ; \; \tau(R) = \tau_0 (0.1 R)^{-0.5} \text{ for } R > 10 \text{ GV/c} \quad (19)$$

Obviously this decrease in the residence time cannot continue beyond $\sim 10^4$ GV/c, as it would otherwise lead to too high an anisotropy for the cosmic rays. Thus τ(R) = constant, for R larger than 10^4 GV/c. Since the spectrum of the observed particles is the product of the injection rate and the residence time ie. F(E) $\sim$ f(E). τ(E), the observed spectra of particle would show kinks at $\sim$10 GV/c (E= 10 GeV for protons and electrons) unless the source spectra fortuitously have the inverse energy dependence. Indeed the observation of smooth proton spectrum between 1 GeV and 10^5 GeV (Sreekantan 1979) makes the simple explanation unlikely. In the nested leaky box model the more effective trapping of the particles does not change the average source function of the particles and with constant residence time in the galactic volume one expects no kinks in the proton spectrum. Also in this model the cut-off at short path lengths has a very logical and clear explanation. The expected flux of high energy nuclear gamma rays which would be generated if cosmic rays suffer nuclear interactions at the sources is also consistent with the observations (Cowsik and Wilson 1975, Cowsik 1979b). Though for these reasons we prefer the later explanation it is not without its own problems. It seems to predict too low a flux of positrons and antiprotons at high energy. If the preliminary observations of these extremely rare species of cosmic rays are confirmed, it might be the evidence of acceleration of these particles inside the sources.

V.2. Problem Of Sellective Injection Of Particles Into Cosmic Ray Accelerators.

Most processes of particle acceleration that have been discussed in literature rely on the assumption that there is an unknown mechanism that selects some particles from the available bulk matter and gives them an initial energy sufficiently large that their collision cross-section with the matter becomes sufficiently small for the acceleration processes to take over. Since the collision cross-sections drop rapidly with energy, under most astrophysical conditions the minimum injection energy E_i is in the range 1-30 MeV. Beyond this energy the particles are scattered by magnetic irregularities, and hydromagnetic and electromagnetic waves, rather than by the atoms, and so the particles tend to equalise their energy with the bulk motions of the fluid. This process clearly leads to the acceleration of the particles. But despite the fundamental importance of the initial injection process we have very little understanding of the basic mechanisms that are responsible. (Eichler 1979).

VI. THE ELECTRON COMPONENT AND THE MULTIPLICITY OF COSMIC RAY SOURCES.

The propagation of the electron component is very sensitive to the distribution of the cosmic ray sources because of the strong radiative losses suffered by the high energy electrons (Cowsik and Lee 1979, Giler,Wdowczyk and Wolfendale 1980). We may now consider a large number of discrete sources of cosmic rays situated all over the galaxy contributing to the spectrum that is measured. The highest energy electrons come from only the nearest sources as those electrons which leave distant sources with high energies rapidly radiate away their energy through synchrotron emission in the Galactic magnetic fields and by Compton-scattering of the microwave background. The theoretically expected spectral shape for various mean separation between the sources is compared with the observations of Hartmann et al. (1977) in Fig. 4.

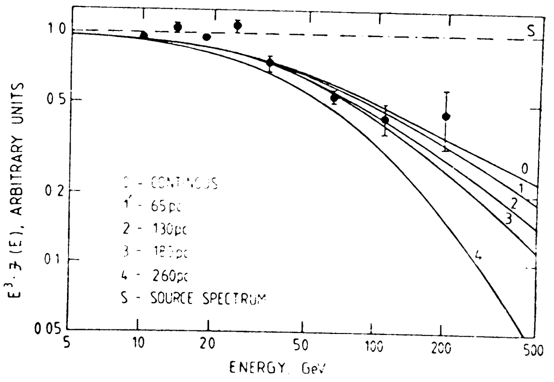

Fig. 4 : The spectrum of electrons summed over all the sources in the Galaxy ; the parameters represent typical spacing between the sources.

It is seen that unless the typical spacing between the sources is less than ~ 180pc the intensity of the high energy electrons cannot be accounted for. With such a typical spacing, within our Galaxy of radius ~ 15kpc, there are at least 3.10^4 sources actively accelerating cosmic rays. Thus there must be other sources of cosmic rays besides supernovae in the Galaxy.

VII. CONCLUSIONS

1. Cosmic ray source composition can be generated by atomic sellection effects operating on normal local galactic abundances.
2. There are probably more than 100,000 sources of cosmic rays in the Galaxy.
3. Cosmic rays suffer nuclear interactions in the vicinity of the sources generating secondary cosmic ray nuclei and gamma rays.
4. The processes of initial injection of selected ions into the cosmic ray accelerators needs critical study.

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