Chemical composition of the cosmic radiation and the electron component

Niels Lund
Danish Space Research Institute
Lundtoftevej 7, 2800 Lyngby, Denmark

In the following I have tried to summarize the important, new information presented at the XIV International Cosmic Ray Conference and to relate the new material to what was known earlier. I have, however, not attempted to review the field in depth; an excellent, up-to-date review has been published by Hillas (1975).

1. Positrons. Positrons may be injected into the cosmic radiation by several mechanisms, of which two are certain to operate in our galaxy, these are the decay of radioactive nuclei ejected from supernovae and the $\pi - \mu - e$ decay with the pions produced in interaction of high energy cosmic ray nuclei. More exotic mechanisms have been proposed, such as direct acceleration of antimatter electrons or electron pair production in the extreme electromagnetic fields occurring near a rotating neutron star or black hole (see f.i. Ames OG 9.1 - 6), but so far such mechanisms are not required to explain the available experimental data.

Mewaldt et al. (OG 8 - 1) report negative results of a search for low energy positrons ($E \sim 1$ MeV) which might originate from radioactive decays. The upper limit quoted by the authors is 2×10^{-3} positrons/cm^2 sec st MeV which is about an order of magnitude below the measured total electron flux at these energies.

Using a balloon borne magnetic spectrometer Hartmann and Pellerin (OG 8 - 2 and 8 - 3) have measured the electron and positron spectra between 20 and 800 MeV. For positrons no detectable flux above the background was observed below 200 MeV. Between 200 and 800 MeV the positron flux reported rises by a factor of two, while the electron flux remains almost constant. The ratio $e^+/(e^+ + e^-)$ at 800 MeV is about .25 according to these authors, which is somewhat highter than reported from other experiments (see f.i. Buffington et al., 1975). However, the energy region below 1000 MeV is strongly affected by solar modulation and considerable time variations are to be expected.

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Orth and Buffington in their contribution (OG 8 - 4, read by title only) consider the implications of a recent measurement of the positron flux above 4 GeV (Buffington et al., 1975). They conclude that high energy cosmic ray nuclei must have traversed about 4 g/cm^2 of interstellar gas in order to account for the measured positron flux. This is a surprising result because from the ratio of secondary to primordial nuclei in the cosmic radiation (e.g. ratios like (Li + Be + B)/(C + O)) a much smaller amount of traversed gas is inferred at energies around 100 GeV/nucleon, which is the energy range of relevance for the production of electrons and positrons above 4 GeV. So far the experimental data on the high energy positrons are of limited statistical weight and come from one experiment only, but if the discrepancy remains, it may suggest either an additional source of high energy positrons or differences in the propagation history for the proton and helium component in the cosmic radiation (which is producing most of the electron component) and the heavy element component.

2. <u>High energy electrons.</u> Three contributions to this Conference deal with the electron energy spectrum above 6 GeV (OG 8 - 6, 7 and 9). Despite considerable experimental effort, the results in this field still show a spread significantly outside the quoted error bars in the electron fluxes. Fig. 1 shows the new data presented at this Conference. The two dashed lines bracket earlier results from many groups which have not been plotted in the figure for the sake of clarity. It is evident that systematic errors are still present in some or all the new data. The root of the problem seems to lie in the following three experimental difficulties:

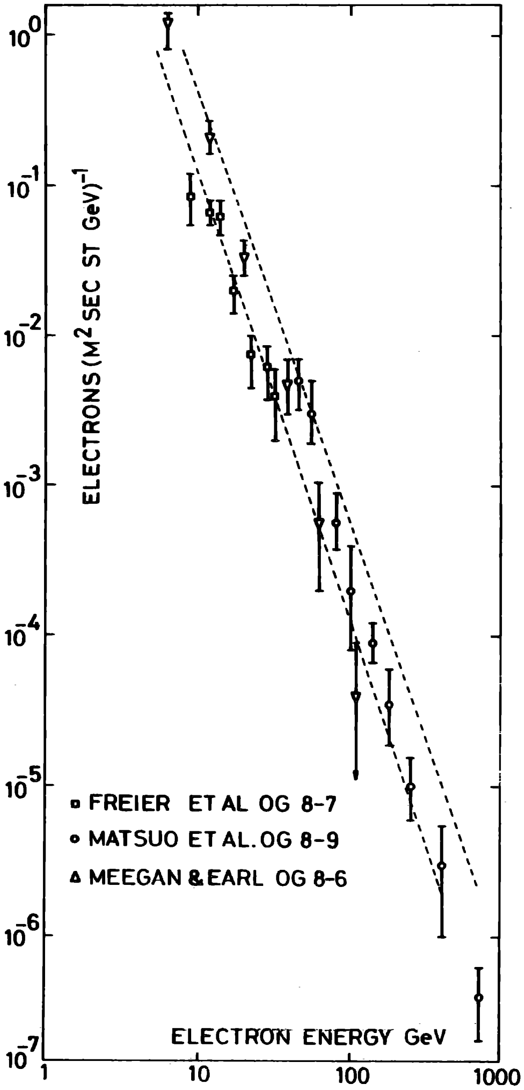

Fig. 1. The electron energy spectrum. The dashed lines bracket data points from earlier experiments.

a) The knowledge of the efficiency of the detector for recording the electrons as function of energy.

b) The rejection of protons simulating electrons.

c) The determination of the electron energy.

We can hope that the introduction of new detector techniques such as the use of transition radiation counters (Hartmann et al., T 3 - 11) or bremsstrahlung/magnetic deflection (Buffington et al., 1975) will improve the situation. For a recent review see Anand et al., 1975.

3. Antinuclei. Ivanova et al. (OG 6 - 24) have conducted a new search for antinuclei $Z^2 \geqslant 9$ using emulsion stacks exposed on space vehicles. They found about 7000 stopping heavy nuclei in their emulsions, but none of these terminated with the expected antimatter signature, an annihilation star. Correcting for the loss of efficiency of the method due to annihilation in flight, they quote an upper limit of 2.7×10^{-4} for the ratio of antinuclei to normal nuclei in the cosmic radiation at energies around 1 GeV/nucleon. Recently the Berkeley group (Smoot et al., 1975) have also improved their earlier upper limits obtained with a superconducting magnet spectrometer. Their upper limit is now 0.8×10^{-4} for energies between 2 and 16 GeV/n and 10^{-2} for energies between 16 and 50 GeV/n.

4. Fossil cosmic rays. The study of fossil cosmic ray induced tracks in lunar rock samples is an intriguing channel of information on the cosmic ray intensity and composition in earlier epochs. Krätschmer and Gentner (OG 6 - 22) report studies performed in one lunar sample with the aim of determining the relative abundances of the iron group nuclei at earlier times. Using artificially accelerated iron nuclei to calibrate the natural crystal samples, they find that the track length distribution of the fossil tracks is considerably broader and displaced toward shorter track lengths than that of the calibration events. However, this could be an effect of fading of the tracks with time as well as being caused by a larger proportion of lighter iron group nuclei (titanium and chromium) in the past. Independent evidence for the absence of fading or for the variation of cosmic ray composition with time seems to be required before firm conclusions can be drawn from these studies.

5. Ultraheavy cosmic rays. An important addition to our knowledge of the composition of the ultraheavies ($Z > 30$) was presented by Price and Shirk (OG 6 - 9). A 1.3 m^2 lexan array was exposed on board Skylab for 253 days. In this single exposure 83 particles with $Z \geqslant 65$ were recorded. The charge resolution is considerably improved over earlier balloon data as shown in Fig. 2, and the significant difference between a solar system composition with a prominent lead peak ($Z = 82$) and the observed cosmic ray composition, where the dominating element is platinium ($Z = 78$) is confirmed with the new data. This difference indicates that cosmic rays are accelerated from material which contains a much larger fraction of nuclei synthesized by the rapid neutron capture process than does ordinary solar system matter, where the products of the slow neutron capture is dominating.

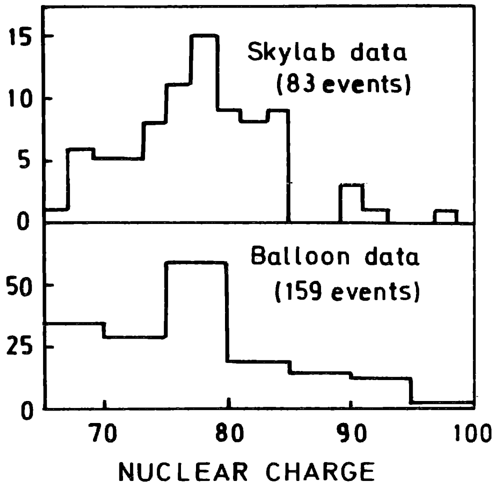

Fig. 2. The charge spectrum of the superheavies as obtained in the Skylab experiment and the 1973 balloon data total.

6. Chemical composition. 18 papers have been presented at this Conference dealing with the chemical composition of the elements from lithium to nickel. Most of these papers address themselves to the problem of variations in the composition with energy. Rather than trying to present a summary including all the specific results quoted, I have concentrated on two problems which illustrate well the new developments in the field.

At the Denver Conference in 1973 it was clear that the cosmic ray propagation history is not the same at all energies. Through the work of several groups it was demonstrated that at energies beyond 3 GeV/n, the abundance of the light secondary nuclei in the radiation (Li - Be - B - N) relative to the primordial nuclei C and O was decreasing by a factor of 3 to 4 in the energy interval from 3 GeV/n to 100 GeV/n. It was, therefore, inferred that, at the high energies, the cosmic radiation passes through much less matter before it escapes from the galaxy than at lower energies, therefore creating much less secondaries. At the Denver Conference conflicting evidence was presented as to whether this variation in the escape pathlength continued down below 3 GeV/n, to-day the new data from several groups are in agreement that the relative abundance of the secondary nuclei continues to rise down to the few hundred MeV range. Fig. 3.

It was also noted in 1973 that ratios between primordial nuclei such as C/O and Fe/(C + O) were changing with energy, but again there was disagreement as to the magnitude of the variations and it seemed possible to account for the observed variations in terms of the propagation effects revealed through the changing secondary to primordial ratios.

From the data presented at this Conference, it now seems excluded that propagation effects can account for all of the variations observed between the primordial elements. To illustrate this point, I have combined data from five groups on the ratio silicon to carbon. Fig. 4. It can be seen that over the energy range from 0.5 to 4.0 GeV/n, the ratio Si/C changes by about 50%, out of which 15% can be explained as due to the reduction in traversed matter indicated by the variation in the (Be + B)/C ratio shown in Fig. 3.

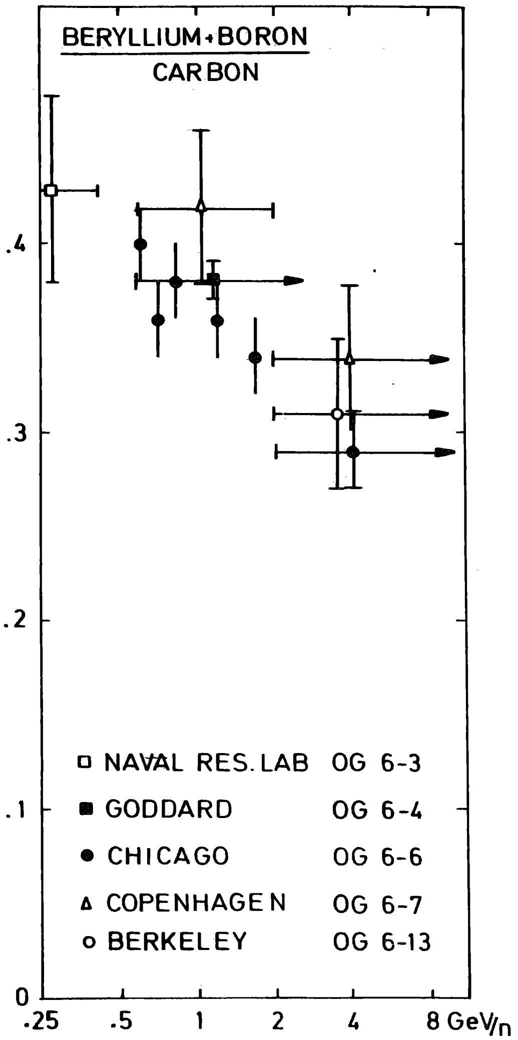

Fig. 3. The energy dependence of the ratio (Be + B)/C.

Variations of the relative abundances of the primordial elements could mean that several discrete sources with different composition and different energy spectra are contributing to the radiation observed at the Earth. Another possibility is illustrated by the discovery of strong variations in the solar particle composition from one solar flare to the next. If the cosmic ray sources accelerate the particles in flare-like bursts, with possible variations in composition and energy spectrum from burst to burst, then variation in primordial element ratios with energy may result even for particles originating in one individual source. Whatever the correct explanation, it is clear that more care is required when we talk about "the chemical composition of cosmic rays". Integral flux values become much less meaningful when the energy spectra for the individual elements are not all the same. More emphasis must be placed on obtaining reliable and detailed energy spectra for individual elements, grouping of elements must be avoided as far as possible, since important effects may be masked, particularly if primordial and secondary elements are combined.

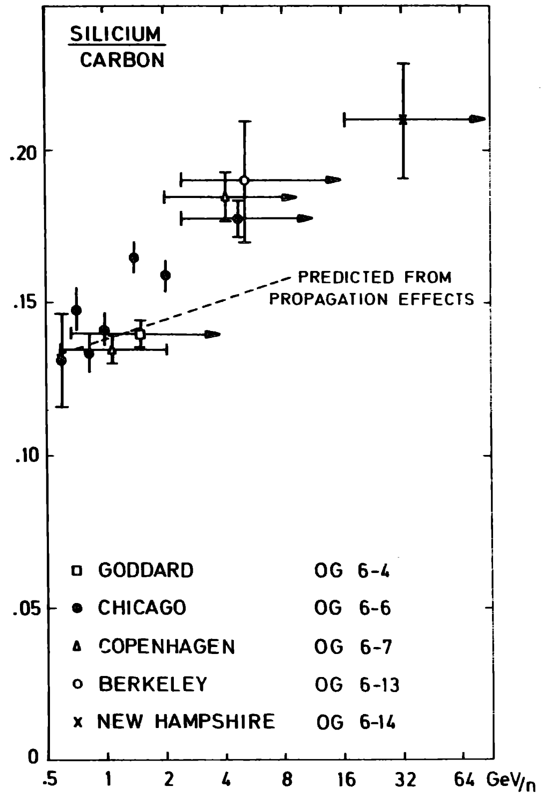

Fig. 4. The energy dependence of the ratio Si/C.

Some thought should be given to the problem of how to present the energy spectra of the individual elements so as to facilitate comparisons. Power law spectra are very hard to compare even when drawn next to each other, and plotting ratios of elements soon lead to anarchy, since each new ratio introduces a new reference spectrum. I would suggest to use as a standard a method already employed by Hillas in his review article (Hillas, 1975), where each spectrum is multiplied by $E^{2.5}$, which is the equivalent of using a pure power law spectrum as standard reference.

The fact that one common prehistory now seems excluded for even the primordial elements in the cosmic radiation of course leaves extra room for playing with the propagation models. One attempt to exploit the new possibilities is presented by Rasmussen and Peters (OG 6 - 7b). They consider the possibility that cosmic rays are confined within the galaxy and are removed by nuclear interactions only. They compensate for the increased abundance of all secondary nuclei resulting from the "infinite" pathlength by postulating a "local" source of the same composition as the distant source, but so close by that essentially no matter lies between the solar system and this local source. The source composition they arrive at, is not much different from the source composition in the leaky box model, except for the fact that no (or very little) protons are required in the source of the new model. Some doubts were expressed in the discussions at the

Conference as to whether the "local source" model can adequately account for the observed electron and positron fluxes, but the notion of a local source (or several local sources) contributing significantly to the cosmic radiation in the vicinity of the sun is certainly important and will probably remain in future theories of cosmic ray origin and propagation.

Much more valuable work and important information than summarized here was presented at the Conference, particularly on the subject of the chemical composition. However, I have restricted myself to the result of most general significance, which, in my opinion, is the evidence as presented above that the cosmic ray source composition is changing with energy.

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