subdivide it into smaller groups; the ideal situation would be to deal with the group, element by element, by charge but for reasons of difficulty in charge resolution and low flux this has not been possible yet. A subdivision is, however, possible and yields results of interest as has been shown by Daniel and Durga Prasad from Bombay. They have been able to carry out this subdivision because they have good statistics in their experiment (1200 tracks due to nuclei with $Z \geq 3$) as pointed out by Dr. Waddington. They divide the H-nuclei (which effectively lie from $Z=10$ to $Z=28$) into three subgroups: H_1, H_2, H_3 groups constituting $Z=20$-28, 16-19 and 10-15 respectively. With this subdivision they have been able to investigate the abundance of H_1, H_2, and H_3 nuclei at the top of the atmosphere using the experimentally determined growth curve in the atmosphere for extrapolation. They show that the H_2 group ($Z=16$-19) is much less abundant, and rather rare, in the primary radiation. This may be of interest to astrophysicists. If spallation reactions are important, one would expect to build up fairly smoothly lower species from higher species and whilst in the case of individual elements, as emphasised by Professor Peters, processes such as radio active decay may be important so that input is made by out put leading to effective small "reservoirs" this seems difficult in the case of a wide band of nuclei. The matter therefore appears to me to be an important one to pursue.

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III-1-21. Isotopic Composition

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I will begin by repeating a comment made to me quite a few years ago—"most experimental papers in physics raise more questions than they answer". I am afraid such may be the case here, presuming of course that the new results to be presented are correct.

My principal task in this report is to summarize the papers presented on isotopic composition in the plenary session. This is a new and interesting field and I must apologize beforehand if I seem to take up most of the time with the work done by Appa Rao at Rochester on He^3-He^4 but it is so far the principal work in this field.

First we must consider the reason, apart from the always prevailing one, to satisfy one's inherent curiosity, why we are concerned with the isotopic composition of the cosmic radiation. The importance of a detailed knowledge of the chemical composition was pointed out a long time ago by Bradt and Peters with particular emphasis on the observation of the relative intensity of elements whose cosmic abundance is very low (*i.e.* the light element, Li, Be, and B problem). In this case, it was believed possible to infer crucial information on the history of cosmic rays by observation of their abundance relative to the heavier elements ($Z \geq 6$) if one made the reasonable assumption that they are produced by the nuclear reactions of heavier elements in their traversal of the interstellar gas from the sources to their observation at the top of our atmosphere. This is an example of what we may call a "cold" reaction which can contribute to the observed composition of the cosmic radiation. Ideally one seeks other cold reactions which contribute to the composition as observed of earth and thus obtain by a joint extrapolation information on both the history and source composition of cosmic rays.

There are also what we may call the "hot" reactions, *i.e.* of the thermo-nuclear type which are evolved in the process of stellar evolution and which may also contribute in a unique fashion to the chemical composition and thus yield important clues as to the nature of the source and the processes taking place there.

Additionally, we must also take cognizance of the fact that if there is an appreciable distribution of isotopes within a given charge group, it can influence measurements made with non-mass sensitive detectors and this is an additional reason for investigating the isotopic composition.

Thus, in first approximation we may summarize the reasons as

A: To obtain information on Cosmic Ray history and source abundances by joint extrapolation

B: To obtain information on the type of reactions contributing to the chemical composition

C: To assess the influence on measurements obtained with non-mass sensitive detectors.

Before I proceed further I must emphasize the nature of some of the terms I shall use. There exist some source or sources of cosmic radiation which inject into the interstellar space of our galaxy. This gives rise to what I shall refer to as the Galactic Cosmic radiation and is characterized by a differential energy spectrum and chemical composition and is denoted by $J^{G}_{A,Z}(E)$. We do not observe this. We know that strong modulation effects influence the cosmic radiation so that the observations on earth, $J^{E}_{A,Z}(E)$, need to be modified to obtain $J^{G}_{A,Z}(E)$. We do not yet really know how to go from J^{E} to J^{G}. I should also like to emphasize that J^{G} as I use it, is not J^{∞}; it is the spectra in the galaxy in the vicinity of our solar system and which is modified by it in the various ways that have been much discussed in this Conference.

Now to get to the experimental results which now exist. At Rochester Dr. Appa Rao has investigated the relative abundance of He^3 in the doubly charged component utilizing two large emulsion stacks flown at high altitudes a year apart. The method used for mass separation was that of multiple coulomb scattering versus range—the so called constant sagitta method. This method requires the particle to stop in the emulsion detector and as such then is restricted to a determination of mass on a sample of particles whose energy is such as to be stopped in the detector. Thus our results are valid for a rather narrow range of rigidity or energy, whichever is appropriate for expressing such relative abundances and which is not yet clear.

To demonstrate the validity of our method of mass separation we exposed a stack of emulsions to the 925 Mev (total kinetic energy) He^4 beam at the Berkeley synchrocyclotron and applied our measurement scheme to two classes of particles. (First slide) (Fig. 1, III-1-14). The first shows the distribution in $\bar{D}$ (the measured parameter) for those He^4 which come to rest without interaction. Note the single peak which occurs at the expected value for this parameter. Next we selected a class of events, denoted as alpha-in alpha-out in which there emerged from an interaction a doubly charged particle (at small angles) with about the same velocity as the incident He^4. This class of events should be enriched in He^3 by stripping reactions and we expect to obtain a double-valued distribution in $\bar{D}$ showing the existence of both He^3 and He^4 in this sample. The next slide, (2) (Fig. 2, III-1-14) shows the histogram of the results; there is the peak corresponding to He^4 at the same value as obtained in the previous slide and another peak corresponding to He^3 at about the predicted position. With these results we felt sufficient confidence in our procedures to proceed with them on the Cosmic Ray exposures.

This method has been applied to two different emulsion stacks, flown at high altitude and at high latitude about one year apart. Both flights occurred on quiet days. The first exposure (CR-I) was at geomagnetic latitude 55°N on July 30, 1957 and the second exposure (CR-II) was flown from a geomagnetic latitude of 61°N on August 3, 1958. In both flights the emulsion stack was rotated into position at flight altitude so that no ascent correction is required. CR-I floated at an altitude of 8.5 gm/cm² of residual atmosphere for 8 hours and 51 minutes and CR-II floated at an altitude of 3.8 gm/cm² for 8

Table I.

Stack	$He^3/(He^3+He^4)$ Energy/nucleon	Interval in *Mev*	$He^3/(He^3+He^4)$ Magnetic Rigidity	Interval in *Bv*
CR-I	0.38 ± 0.09	(200-400)	0.42 ± 0.11	(1.3-1.6)
CR-II	0.31 ± 0.08	(160-355)	0.33 ± 0.08	(1.05-1.48)

hours and 30 minutes. CR-I consisted of 150 G-5 stripped emulsions $10''\times12''\times400$ microns and CR-II also consisted of 150 G-5 stripped emulsions $8''\times10''\times600$ microns.

In each stack a line scan was performed using ionization (the discrimination is illustrated in slides) as a criteria and the tracks were required to stop in the stack with a range greater than 4.5 cm for CR-I and 4 cm for CR-II. (The histograms of $\bar{D}$ obtained for CR-I and CR-II are shown in slides 3 and 4) (Fig. 5, 6 in III-1-14) This introduces a differential bias between He^3 and He^4, the direction depending on whether one compares relative intensities on the basis of energy per nucleon or magnetic rigidity. In addition there is a correction to be applied for interactions within the stack. We present in Table I the results, as extrapolated to the top of the atmosphere, for the ratios of He^3 to He^3+He^4 along with the corresponding interval of energy or rigidity. No correction has been applied here for secondary production within the atmosphere, but it is estimated to be less than 4%. We note that no particles were observed below the geomagnetic cut-off.

Before proceeding on to a discussion of what these results may mean I should like to briefly report on other work on this problem. Mrs. Aizu and collaborators have carried out a similar analysis on a very high altitude stack ($\sim$1.5 gm/cm^2 of residual atmosphere). Their results are in a preliminary form and I have not yet had an opportunity to study them. As I understand it they find *He* nuclei well below geomagnetic cut-off-in fact about half of their sample is below cut-off. For that part of their sample above cut-off they find an upper limit of 18% for the ratio $He^3/He^3+He^4)$ and a value of $8\pm8\%$ for the ratio. I have also been informed by private communication that Dr. Mulvey and the Oxford group have done this problem using Ionization-range as the method of discrimination. This was performed on emulsions flown in the same container as our CR II and they have found an approximate value of 25% for the ratio under investigation. I have no details as to what corrections if any have been applied.

Let me now return to a discussion of the Rochester results, assuming their correctness. (Clearly we should like independent verification). The first question that arises is whether this surprisingly large amount of He^3 represents a feature of the galactic cosmic radiation or is a reflection of some temporal variation within the solar system. We are clearly not in a position to give a meaningful answer to this since our observations are in a rather restricted energy range and span only 1 year apart. In this context I should note the observations of Fireman on the presence of H^3 in solar proton beams; he has observed in at least one case H^3 with about an intensity of 0.5% relative to protons. We have made some rough estimates of how this could contribute to He^3 assuming optimum storage and a reasonable frequency of such events and it does not appear to be at all appreciable. In fact it is difficult to account for the high intensity of He^3 we observe by injection from the sun or as production from local interactions.

If we assume our results are not time dependent we can obtain a further estimate of the ratio at the top of the atmosphere by extrapolation to 0 gm/cm^2 using the ratio from the two different flights. This is shown in slide (6) (See Fig. 7, 8 in III-1-14) and yields a value of 0.25.

For the purpose of further analysis we now assume a ratio of $He^3/(He^3+He^4)$ of about 30% and that this represents a feature of the galactic cosmic radiation.

Before proceeding further one must make assumption as to the average source composition and the origin of the He^3. As a limiting case we assume that the He^3 is all produced by nuclear interactions of He^4 and higher Z nuclei in their passage through the interstellar material. We assume a source composition in which no He^3 nuclei are present and in which medium nuclei ($C \leq Z \leq 9$) are 8% as abundant as He^4. We can then construct a growth curve on the basis of a one dimensional diffusion model. The parameters for this were obtained by using data obtained from N-α interactions and using charge symmetry for the He^4-P reactions and for the higher nuclei data from spallation studies; the major contribution comes from He^4-P reactions. We have assumed that all H^3 appears eventually as He^3. The growth curve so obtained is shown along with that calculated by Hayakawa and his collaborators in slide (7) (See Fig. 9 in III-1-14) and from this we infer (with the stated assumptions) that the amount of material traversed is about 12-15 gm/cm^2 of Hydrogen. This is clearly at variance with the results on Li, Be and B which indicate (under similar assumptions) about 3 gm/cm^2 of Hydrogen traversed. However, one should note that these results correspond to an energy per nucleon of around 3 Bev while our results on He^3 are for a very low range of energy/nucleon. In this respect we note that there does exist some evidence as reported by Dr. Koshiba that the relative amount of Li, Be and B compared to the higher Z nuclei increases with decreasing energy. This is the direction we should expect this ratio to go in view of our results. What we wish to emphasize in the necessity of comparing such ratios at similar energy/nucleon or perhaps rigidity.

There is another limiting case, quite opposite to the assumptions used above and which was considered quite some time ago by Professor Singer. This model assumes the initial injection into the interstellar medium of only very heavy nuclei and has as its consequence that the observed chemical composition results principally from nuclear reactions with Hydrogen. This model yields a ratio of $He^3/(He^3+He^4)$ in accord with our observations and must be given consideration. However in such a model one has also to take into account the variation with energy which has not yet to my knowledge been done.

We have considered three possibilities: (a) the source of cosmic rays contains a finite abundance of He^3 and the path length is that defined by the relative number of light nuclei as observed at 3 Bev/nucleon; (b) low energy nuclei travel through more matter than high energy nuclei; (c) helium nuclei travel through large amounts of matter than higher charged nuclei. (a) implies He^3/He^4 at the source is about 1/2. (b) implies that the amount of matter traversed is inversely proportional to the momentum per nucleon. (c) imples that if the shape of the differential spectra of helium and higher charge nuclei are the same, that ionization loss must then play a role in shaping the spectra.

Since both (b) and (c) above stress the role of material traversed and the shape of the galactic differential energy spectra we have investigated how the lack of identification of He^3 in measurements of He differential spectra can influence the shape and also the role ionization loss might play in shaping differential energy spectra.

First we have considered the effect of non-recognition of isotopic structure. If a detector is used to measure differential energy-spectra that is not mass sensitive, it is possible that this lack of sensitivity can yield a maximum in a spectra that does not have one, or enhance an already existent maximum. We illustrate this in slides (8) and (9) for the doubly charged component. We assume in both cases a ratio of $He^3/He^4=50\%$ and that each component has the same rigidity spectrum. In the first case the spectrum is monotonically falling and in the second it has a maximum. The curves show the resultant spectra obtained by a mass-insensitive detector for different types of measurement (*e.g.* velocity, range, energy/nucleon). A similar calculation has been done for the singly charged component in which an admixture of 5% H^3 with protons has been arbitrarily assumed. This is shown in slide (10). We wish here merely to emphasize that isotopic structure can yield appreciable effect—not that it is responsible for the spectral shapes observed but that eventually it must be assessed and taken into account.

We have also investigated the influence of ionization loss on the shape of the galactic spectrum. Such a model of course presupposes no acceleration in the interstellar medium and that some existing spectra is injected. We assume a differential spectrum of the form K $(A, Z)/\epsilon^{2.5}$ subjected to ionization loss in the interstellar medium (ϵ is energy per nucleon). We have carried out the calculation for various particles and for models in which a constant amount of matter is traversed and also for a model in which the amount of matter traversed is inversely proportional for the momentum dependent model to the momentum per nucleon. The emergent differential spectra are shown in slides (11), (12), (13) and (14) for He^4, C^{12}, Al^{27} and Co^{40} respectively. The normalization is to the number of grams traversed at 3 Bev/nucleon. The relatively slow variation of the position of the maximum with increasing Z is somewhat surprising and points out the necessity for quite careful experimental measurements. Such a model of ionization loss is not at all incompatible with the current observations on the shape of the differential energy spectra of the multiply charged component of the cosmic radiation. Whether it has any real validity must of course await the carrying out of detailed experiments on spectral shape as a function of Z.

Let me now report on a different aspect of isotopic composition—the work of K. Ito and H. Hasegawa on the isotopic abundance of carbon. This is relevant with respect to "hot" reactions and can in principle yield information relevant to the type of thermonuclear processes occuring in cosmic ray sources. Specifically they investigate the ratio of C^{13}/C^{12} produced in different thermonuclear cycles and a method for discriminating between C^{12} and C^{13} experimentally in nuclear emulsions. Slide (15) (See Fig. 1 in III-1-15) presents the relevant data here. The upper part shows the variation of C^{13}/C^{12} as a function of the type of thermonuclear reaction which itself is related to different stellar types while the lower part portrays the method of isotopic discrimination. The method depends upon a difference in nuclear interaction and exploits principally the fact that for C^{13} nuclei, neutron stripping to C^{12} should be a most likely process while the analogous does not hold for C^{12}. They are thus able to relate the ratio of C^{13}/C^{12} to the number of C→C and C→B interactions observed in emulsion and the cross-sections for these interactions. As the partial cross-sections are not too well known they show in slide (16) (See III-1-15) the relative ratio C^{13}/C^{12} as a function of the number of C→C/C→B events in terms of the value of the parameter $\Omega=(C^{13}\rightarrow C)/(C^{12}\rightarrow C)$. These curves and the calculations so far have not taken into account the beam adulteration which of necessity must arrive due to both the traversal through the interstellar gas and the residual atmosphere above the detector. It is clear however that this suggestion points the way to definitive means to obtain relatively unique information presuming that one can obtain with sufficient precision the necessary cross-sections and has sufficient information about the Cosmic Ray history to make the appropriate corrections.

In summary it would appear as if we are on a new threshold which may be quite definitive in yielding information about the history and the nature of cosmic ray sources. It is clear that the problems posed will be most challenging to solve.

Discussion

Koshiba, M.: 1. The ratio of, could be, He^3 to He^4 does not change with the range. That is, there is no reason to delete Mrs. Aizu's data in compiling the data. The observed value of this quantity 18/105 (energy range 200 Mev/n—300 Mev/n) and the true value of He^3/He^4 would probably less than this.

2. The use of the ionization loss as the main process of shaping the spectrum gives a serious discompatibility with our observation.

Kaplon, M. F.: 1. I would repeat my caution that one must be careful in comparing results of different times particularly in that you did not have a cut-off operation.

2. Ionization loss is not incompatible you have very broad maxima and have averages over composition our calculations are not incompatible, one has to really measure spectra a function of Z.

Hayakawa, S.: The high Rochester abundance of ^3He seems to be inconsistent with the low flourine abundance just reported by Dr. Waddington. In this connection I would like to point out an effect which may be important for low energy heavy nuclei; Since the gyration radius of such low rigidity particles in the geomagnetic field is only of the order of 100 Km, the probability of tipping the earth's atmosphere may be considerable. This could increase the thickness of matter traversed by low rigidity particles and especially by low Z particles which do little suffer from the ionization loss.

Ney, E. P.: It seems to me that the results of the second experiments do not show resolution of the He^3, He^4 peaks and if this had been done first, you might have concluded that there was no He^3 in the cosmic rays.

I also feel that the implication that the non sharp cut-off in galactic cosmic rays is due to the mass mixture of He^3 and He^4 is extreme speculation. The same non sharp cut off occurs with solar protons in the earth's field and almost certainly cannot be explained the same way.

Kaplon: 1. We first did our experiment on the machine accelerated *He* which gave us the courage to go ahead.

2. We are not implying that the non sharp cut-off is due to isotopic mixture. Author, We are pointing out that the influence of isotopic composition on a non-mass sensitive detection is something that should be taken into accounts.

Messel, H.: How large is the neutron stripping correction you must apply to your He^4 result?

Kaplon, H.: We have used the following fragmentation coefficients for atmosphere

$$P^{\mathrm{air}}_{\mathrm{He^4-He^3}}=0.1 \quad : \quad P^{\mathrm{air}}_{\mathrm{M-He^3}}=0.5$$

The atmospheric correction is less than 6%.

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III-1-22. Concluding Remarks

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Taken together, the three papers presented in this session give a rather complete summary of our present knowledge of the nature of the galactic component of the Primary Cosmic Radiation.

As the speakers have pointed out, we are only at the beginning of a detailed investigation of the electric charge and energy spectrum of galactic electrons and of the energy spectrum and spatial distribution of galactic γ-rays.

The chemical composition of the nuclear component is now known with reasonable accuracy but only in a narrow energy interval. There is an indication that the details of the composition may be energy dependent in the nonrelativistic range and that even the gross features like the ratio of heavy nuclei to protons may be quite different among the primaries giving rise to air showers, than among those of lower energy which can be observed in emulsion. In principle it seems possible to distinguish whether such changes in composition if present, are due to the fact that sources of different chemical composition predominate in different energy intervals or whether the difference arises from the dependence of the trajectories of primary