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AN EXPERIMENTAL STUDY OF THE ISOTOPIC COMPOSITION OF COSMIC RAY NITROGEN AND OXYGEN

L. Jacobsson, G. Jönsson and K. Kristiansson

Department of Physics

University of Lund

S-223 62 LUND Sweden

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An investigation of the isotopic composition of cosmic ray nitrogen and oxygen has been made. As a detector we have used nuclear emulsions exposed in 1970 in a balloon flight from Fort Churchill. The mass determinations are made on particles stopping in the emulsion stack and are based on the relations between residual range and track width measured with a nuclear track photometer. Our results extrapolated to the top of the atmosphere are

$$\frac{^{15}N}{^{14}N+^{15}N} = 0.30\pm0.11; \quad \frac{^{17}O+^{18}O}{^{16}O+^{17}O+^{18}O} = 0.10\pm0.05$$

1. Introduction. Knowledge of the isotopic composition of the heavy elements in the primary cosmic radiation is of great importance for the understanding of the origin of the radiation. In this report we discuss an experimental investigation of the isotopic composition of cosmic ray nitrogen and oxygen. As a detector we have used a small stack of nuclear emulsions which was exposed in a high altitude balloon flight from Fort Churchill, Canada, in June 1970 at a ceiling altitude of 2.6 g/cm^2. The stack consisted of 61 sheets Ilford G5 emulsions (size 10 cm x 10 cm x 600 µm). The degree of development is normal with a plateau blob density of 19 blobs/100 µm for singly charged particles. All pellicles have been area scanned for stopping heavy primaries.

The mean energy of the measured nitrogen nuclei is 320 MeV/nucleon and of the oxygen nuclei 330 at the top of the atmosphere. The energy interval covered by the detector is 220-450 MeV/nucleon.

2. Track width measurements. The mass determinations have been made on nitrogen and oxygen nuclei which stop in the emulsion. The mass of a nucleus has been determined from measurements of the relation between track width and residual range. The track width has been measured with a nuclear track photometer. The measured quantity is the light absorption caused by a section of the track when focused in a rectangular area defined by a slit system in the instrument. The slit system corresponds to an area 4 µm x 33 µm in the emulsion plane in these mass measurements. The light absorption measured can be interpreted as a photometric track width. All tracks have been measured in the residual range interval $0<R<17$ mm. Corrections for depth in the emulsion and dip angle and the plate normalization have been made according to standard procedures. The photometer has been described by Jönsson et al. (1970a). A short description is also given in paper OG7-8 of this conference.

Fig.1. The Charge spectrum

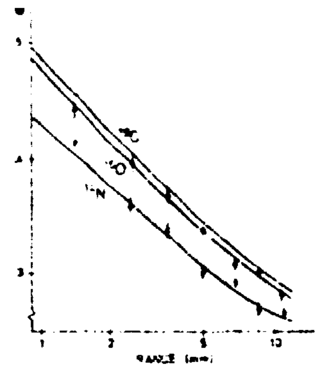

Fig.2. The track width-range relation for ^{14}N, ^{16}O and ^{18}O in the interval $1<R<12$ mm.

The selection of nitrogen and oxygen tracks is made in a preliminary measurement of the charge spectrum. Part of this spectrum is shown in Figure 1. The measured parameter $\bar{W}$ is equal to the mean value of the track width in the range interval $0<R<12$ mm. $\bar{W}$ is given in arbitrary units. The separation between the particle groups is sufficient to avoid mistakes in the selection of the tracks.

3. Track width - range relation. Figure 2 shows the relation between track width, W, and residual range, R, for ^{14}N, ^{16}O and ^{18}O. The difference in track width for the same range amounts to about 1.4% per mass unit both for nitrogen and oxygen. The experimental points show how the measurements of one ^{14}N track and one ^{16}O track are distributed along the mean curves. The distribution around the mean curves gives an idea of the precision in the track width measurements in relation to the distance between adjacent mass curves.

For particles of the same charge the relation between track width, W, mass, M, and residual range, R, can formally be written

$$W = f(\frac{R}{M})$$

The relation means that all particles having the same charge also have the same track width-range relation if the residual range is scaled by the factor 1/M. In the determination of the masses of the particles measured the scaling factors are computed by a least squares method in which the experimental W-measurements have been fitted to the W(R) relation for the charge in question. The details of the procedure of calculation are given in the paper by Jönsson et al. (1970b) and the method is also shortly described in paper OG7-8.

4. <u>Mass spectrum of nitrogen.</u> Figure 3 shows the distribution of the masses of 25 nitrogen nuclei. We have accepted particles whose zenith angle is less than 75° and dip angle less than 33° and which do not show any visible interaction in the emulsion stack.

The position of the mass scale in Figure 3 cannot be determined accurately from considerations about which stable and unstable nitrogen isotopes possibly exist in the mass spectrum. We have therefore determined the mass scale through an interpolation procedure based on the experimental track width-range relations for ^{12}C and ^{16}O. The starting point for this interpolation is the fact that the track width can be described by the ionization parameter restricted energy loss, REL, and that the W-REL relation is to the first approximation independent of the particle charge (Jensen et al. 1972).

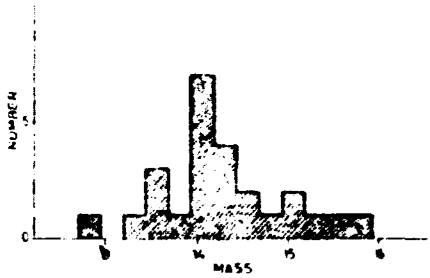

Fig.3. The mass spectrum of nitrogen.

The restricted energy loss for a particle with the charge number Z and the velocity βc is computed from the relation given by Barkas (1963).

$$REL = \frac{2\pi n Z^2 e^4}{\beta^2 m c^2} \left[\ln \frac{2mc^2 \beta^2 \gamma^2 w_o}{I^2} - \beta^2 - 2\ C(\beta) \right]$$

where w_o is the chosen energy limit for secondary electrons. I is the mean ionization potential of the atoms in the emulsion and $C(\beta)$ is a correction term which accounts for the density effect at high velocities and for the shell correction at low velocities. All other constants have their usual meaning.

It is reasonable that the value chosen for the parameter w_o corresponds to the effective maximum range for δ-rays which is covered by the slit in the photometer. We have chosen w_o = 20 keV and I = 331 eV. It should be stressed that the calibration of the nitrogen mass scale is very insensitive to the precise values for w_o and I.

Figure 4 shows the relation between track width W and restricted energy loss REL for ^{12}C and ^{16}O. The carbon points correspond to the residual range interval 1.3<R<7.1 mm and the oxygen points to the interval 2.0<R<10.8 mm. The point strings of the two charges nearly coincide in a large REL interval in spite of the different nuclear charge numbers in agreement with earlier measurements (Jensen et al. 1972). We have interpolated between the oxygen and the carbon points to fix the mass scale for the nitrogen isotopes in Figure 3. We have estimated the error in the position of the mass scale to be about 0.1 AMU.

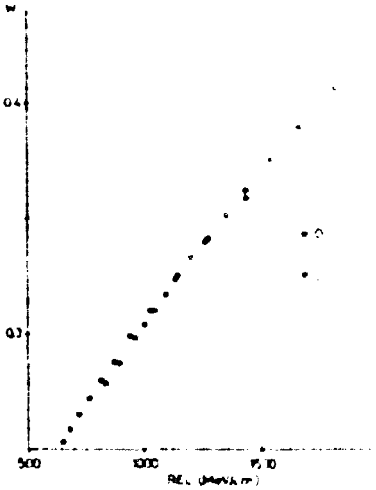

Fig.4. The relations between track width, W, and restricted energy loss, REL, for ^{12}C and ^{16}O.

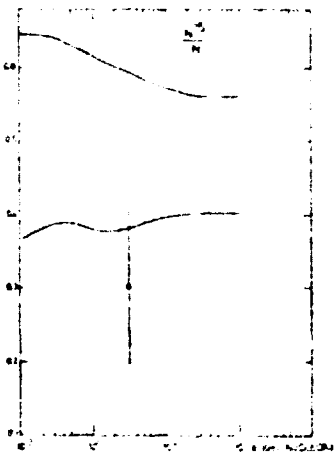

Fig.5. The calculated ratio of $^{15}N/(^{14}N+{}^{15}N)$ in the two cases described in the text compared with our experimental value.

5. Isotopic composition of nitrogen. The isotopic composition of nitrogen at the point of measurement ($^{15}N/(^{14}N+{}^{15}N)$ = 0.32) has been extrapolated to the top of the atmosphere with standard methods. The cross-sections have been derived from data in the paper by Silberberg and Tsao (1973) and from recent measurements of nucleus-nucleus cross-sections by Lindstrom et al. (1975). We have computed the fragmentation production in the interactions with the air nuclei from the observations reported by Lindstrom et al. that the cross-section of a nucleus-nucleus interaction can be factored into beam-fragment and target terms. The target factor is with good approximation proportional to $A^{1/4}$ where A is the target mass number. The cross-sections and the cross-section relations are valid for particles of an energy of about 2 GeV/nucleon. This may give rise to an error in our extrapolation of nuclei with an energy of a few hundred MeV/nucleon but this error is most probably small. The cosmic ray composition at the top of the atmosphere has been taken from Shapiro et al. (1973).

The isotopic composition at the top of the atmosphere is found to be $^{15}N/(^{14}N+{}^{15}N)$ = 0.30±0.11. The error given is only the statistical one based on the number of measured particles.

We have in Figure 5 compared our experimental quotient with the calculations by Meneguzzi et al. (1971). The upper curve shows the isotopic ratio at the top of the atmosphere calculated with the assumption that the source is devoid of nitrogen. The lower curve is based on the assumption that the source contains a normal stellar abundance of nitrogen. Our result strongly supports this assumption.

Our abundance quotient is appreciably lower than some early results reported by Webber (1971) and Beaujean and Enge (1972) for approximately the same energy. It is in better agreement with later results reported by Beaujean et al. (1973) and Webber and Lezniak (1974) which, however, showed larger errors in the mean mass determinations.

6. Isotopic composition of oxygen. Figure 6 shows the mass distribution of 78 oxygen nuclei. It is assumed that the main peak is an ^{16}O-peak. The standard deviation is about 0.5 AMU if the mass values of a nuclide are normally distributed. To estimate the number of $^{17}O+^{18}O$ among the measured particles we have proceeded as follows: We have calculated the number of ^{15}O and ligther oxygen isotopes which are produced in interactions in the atmosphere and in the emulsion and which can be assumed to exist in the measured mass spectrum. Then we have assumed that the ^{16}O distribution is symmetrical with equally large "tails" in the ^{15}O distribution and in the $^{17}O+^{18}O$ distribution. This gives the number of $^{17}O+^{18}O$ in the spectrum. At the point of measurement we have obtained the ratio $(^{17}O+^{18}O)/(^{16}O+^{17}O+^{18}O)=0.12$.

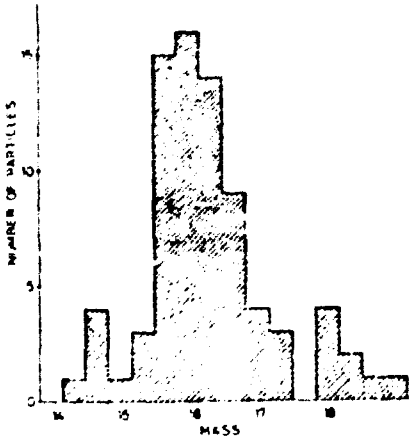

Fig.6. The mass spectrum of oxygen.

The mass spectrum has been extrapolated to the top of the atmosphere with the cross-sections computed in the same way as in the nitrogen extrapolation. The result is $(^{17}O+^{18}O)/(^{16}O+^{17}O+^{18}O) = 0.10\pm0.05$ or by mass representation $\bar{M} = 16.13\pm0.07$ AMU. Our result is in fair agreement with the result of the computations of isotopic abundances at the top of the atmosphere made by Tsao et al. (1973). These authors have obtained a 4.5% abundance of $^{17}O+^{18}O$ for relativistic oxygen whose path length through interstellar matter was taken to be of the form exp (-0.24x) with a linear rise between 0 and 1 g/cm^2. It was further assumed that the source composition of oxygen was the same as in normal stellar atmospheres.

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