# III-1-15. Isotopic Abundance of Carbon in Primary Cosmic Rays

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The isotopic abundance of carbon in primary cosmic rays is strongly related to the nature of sources of cosmic rays. If the Helium burning process occurs in the source such as a red giant, the ratio of the content of $^{13}C$ to that of $^{12}C$ is almost zero. If the sources are the general celestial objects where the CN cycle occurs, this ratio is about 1/4.6= 22%. If the rapid CNO cycle occurs under a certain condition which is realized at the earliest stage of the supernova explosion, this ratio can be about one or more (See Table I).

Table I.

| $^{13}C/^{12}C$ ratio | Nuclear reaction | Source |
|---|---|---|
| $\simeq 0$ | *He*-burning | Red giant |
| $\simeq 1/4.6$ | *CN*-cycle | General celestial object |
| $\gtrsim 1$ | Rapid *CNO* cycle | Supernova |

Previously it has been believed that it is almost impossible to determine this ratio because the mass difference between $^{12}C$ and $^{13}C$ is small.

Now, we propose a method to determine this ratio. The essential point of our method is to use the difference in nuclear nature of $^{12}C$ and $^{13}C$. Carbon 12 is very stable, while the binding of the last neutron of carbon 13 is weak. When $^{13}C$ collides, this neutron is easily stripped and the residual part of $^{13}C$ emerges as $^{12}C$. Therefore the cross section for one neutron stripping process of $^{13}C$ is unusually large, while it is not for $^{12}C$. How do we utilize this difference?

In order to do this, we should search for the events in which the primary carbon nuclei collide with the emulsion nuclei and fast carbon nuclei emerge. We do not know the mass numbers of observed carbon nuclei in each event. Suppose we get $N$(C-C) such event in all. Next we search for the events in which the primary carbon nuclei collide with the emulsion nuclei and fast boron nuclei emerge. Let $N$(C-B) be the number of such events. Then these observed quantities $N$ are connected with the primary carbon fluxes $J(^{12}C)$ and $J(^{13}C)$ by the following relation:

$$\frac{N(\text{C-C})}{N(\text{C-B})}=\frac{J(^{12}\text{C})\sigma(^{12}\text{C-C})+J(^{13}\text{C})\sigma(^{13}\text{C-C})}{J(^{12}\text{C})\sigma(^{12}\text{C-B})+J(^{13}\text{C})\sigma(^{13}\text{C-B})},$$

where $\sigma(^{12}C\text{-}C)$ and $\sigma(^{13}C\text{-}C)$ are respectively the cross sections of neutron stripping process for $^{12}C$ and $^{13}C$, $\sigma(^{12}C\text{-}B)$ and $\sigma(^{13}C\text{-}B)$ being the cross sections of fast boron emerging process for $^{12}C$ and $^{13}C$ respectively.

Here if we observe the number of events for primary carbon and know the respective cross sections, we can estimate the required ratio, $J(^{13}C)/J(^{12}C)$. The cross sections $\sigma(^{12}C\text{-}C)$ and $\sigma(^{12}C\text{-}B)$ are estimated from the results of the heavy ion induced reaction and of the fragmentation induced by protons with energies of the order of Gev. Also the cross section $\sigma(^{12}C\text{-}B)$ for the process in which incident $^{12}C$ turns in boron isotopes and that cross section $\sigma(^{13}C\text{-}B)$ for incident $^{13}C$ are nearly equal to each other. For $\sigma(^{13}C\text{-}C)$ we calculated analogously to the neutron stripping and Coulomb disintegration cross sections of deuteron by assuming that the $^{13}C$ is composed of $^{12}C$ and one neutron. These results are as follows:

$$\sigma(^{12}\text{C-C})=25\pm5\text{ mb},\qquad \sigma(^{13}\text{C-C})=75\text{ mb},$$

$$\frac{\sigma(^{12}\text{C-B})}{\sigma(^{12}\text{C-C})}=1.0\pm0.1,\qquad \frac{\sigma(^{13}\text{C-B})}{\sigma(^{12}\text{C-C})}=1.0\pm0.1.$$

It is important that $\sigma(^{13}C\text{-}C)$ is much larger than the other cross sections. Then, if $N$(C-C) is nearly equal to $N$(C-B), the flux of $^{13}C$ is much smaller than that of $^{12}C$. But, if $N$(C-C) is larger than $N$(C-B), it means that the flux of $^{13}C$ and that of $^{12}C$ are of the same order of magnitude.

More precisely, we can estimate by using the diagram. Fig. 1 shows the relation between the ratio of $J(^{13}C)$ to $J(^{12}C)$ and the ratio of $N$(C-C) to $N$(C-B). We chose the above numerical values for the cross sections in which the ratio $\sigma(^{13}C\text{-}C)/\sigma(^{12}C\text{-}C)$ is assumed to be 3. The cross hatched region represents the uncertainties in the cross sections. At

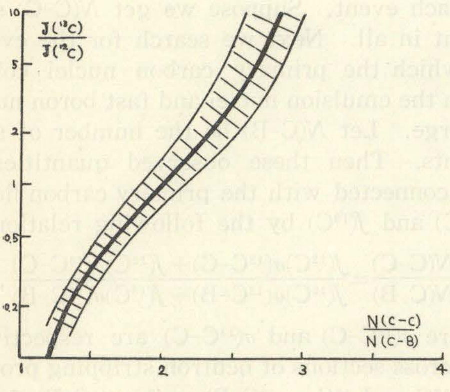


Fig. 1.

present the effect of these uncertainties is not negligible. But these uncertainties will become smaller as the experimental information regarding the nuclear reactions increases.

Strictly speaking, it needs to correct for the carbon isotopes produced as a result of the break-up of heavier nuclei through the interstellar matter of about 3 gcm$^{-2}$. In order to make this correction, we must know the fragmentation probabilities for producing secondary nuclei of mass number 12 and 13 from heavier nuclei. But this correction may be so small that the qualitative nature of the answer would be unchanged at all.

The purpose of our paper is not to give results but to propose a method. However, I would like to give some approximate results based on existing data. We collected the data thus far published and obtained a ratio $N$(C-C) to $N$(C-B) of about two. Then the ratio of the fluxes, $J(^{13}C)/J(^{12}C)$ is about one at the depth where the emulsions were exposed. If this is not far from reality, this may be additional evidence for the theory of supernova origin of cosmic rays.

## *Discussion*

**Daniel, R. R.:** I would like to mention about a method to detect high energy deuterons in the cosmic rays. This was suggested by the Bombay group and was published in Nuovo Cimento in 1960. The method makes use of the characteristics of the interactions produced by high energy deuterons in nuclear emulsions. We have shown that in about 30% of deuteron interactions, only the neutron is involved in the collision process and the proton emerges with very small deviation with respect to the deuteron direction. This is $\leq 1°$ for primary energies $\geq 5$ Bev/nucleon. We have also shown that at equatorial latitudes we can detect deuterons if they exist with a relative intensity $\geq 5\%$ compared to protons. This limit arises mainly from the background events due to protons in which a secondary emerges within this angle. However correction for this can be made from experimental results on protons from machines. We have already made some special exposures for this experiment in India and preliminary work is nearly completion. Results will be available in a few months time.