Measurement of isotopic cross sections of ^{12}C beam fragmentation on hydrogen at 3.66 GeV/n

A. Korejwo[1]**, M. Giller**[1]**, T. Dzikowski**[1]**, J. Wdowczyk**[1]**, V. V. Perelygin**[2] **and A. V. Zarubin**[2]
[1]*Division of Experimental Physics, University of Lodz, 90-236 Łódź, Poland*
[2]*Laboratory of Particle Physics, Joint Institute for Nuclear Research, Dubna, Russia*

Abstract

An experiment with ^{12}C beam fragmentation on liquid hydrogen target was performed on the magnetic spectrometer ANOMALON, equipped with Cherenkov charge detector, on Dubna Synchrophasotron at the projectile energy 3.66 GeV per nucleon. Charge resolution of 0.26 e (except hydrogen nuclei) and mass resolution of 0.11÷0.18 amu have been achieved. Isotopic and elemental fragmentation cross sections are obtained for fragments from Z=1 to Z=6. Decayed cross sections are also calculated.

1 Introduction

It is well known that cosmic ray nuclei collide with the interstellar gas (mainly hydrogen) during their propagation in the Galaxy. Knowledge of cosmic ray fragmentation cross sections for particular isotopes is necessary to draw astrophysically important conclusions about their path lengths and life time in the interstellar space. In particular, the dependence of cross sections on energy in the GeV/n region has to be measured if we want to know how the propagation characteristics change with energy. In this paper we present results of a measurement of the isotopic fragmentation cross sections of carbon ^{12}C on a hydrogen target at the energy region not measured so far, i.e. 3.66 GeV/n.

2 Experimental set-up and data collection

In this experiment the fragmentation of ^{12}C projectiles on hydrogen target was studied. The experiment was performed on the Anomalon set-up [1,2] located at the Synchrophasotron's slow extraction beam VP-1 in the Joint Institute for Nuclear Research in Dubna (Russia). The Anomalon magnetic spectrometer (Fig. 1) is based on a system of multiwire proportional chambers (MWPC) and an analyzing magnet SP-40. It also includes a Cherenkov hodoscope for determination of fragment charges, a trigger system consisting of scintillation and Cherenkov detectors, and a beam monitor. The target consists of a 0.94 g cm^{-2} liquid hydrogen contained in a mylar tube with total wall thickness of 0.067 g cm^{-2}.

The multiwire proportional chambers constitute a coordinate detector destinated for determining tracks of charged particles. The first MWPCs (1÷3) determine the parameters of the beam particle (^{12}C nucleus) track. Next group (MWPCs 4÷7) measure fragment tracks before the magnet, whereas MWPCs 8÷10 determine tracks behind the magnet.

All the detectors were gated by trigger system on time intervals of 100 ns with a time delay chosen for each chamber separately. Voltage of the proportional chambers was chosen so as

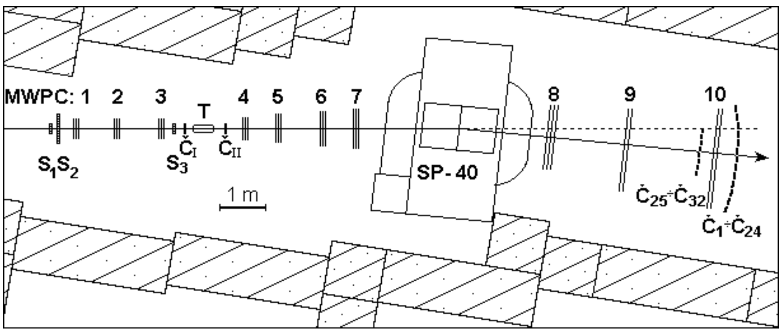

Fig. 1: Experimental set-up ANOMALON – top view;
MWPC 1÷10: multiwire proportional chambers,
$S_1 \div S_3$: scintillation counters,
$\check{C}_I$, $\check{C}_{II}$, $\check{C}_1 \div \check{C}_{32}$: Cherenkov detectors,
T: liquid hydrogen target,
SP-40: analyzing magnet.

to favour detection of nuclei with Z=3÷6. The axis of MWPCs 8÷10 and the Cherenkov hodoscope is deflected from the primary beam direction by 80 mrad. Cherenkov hodoscope consists of 32 detectors. The radiators are made of plexiglass.

Magnetic field is set to assure the deflection angle for primary beam particles the same as the angle of deflection between the main and the second axis of the spectrometer and is about 1.2 T. Nuclei are deflected in the horizontal plane.

The wire chambers, the reading control system and the liquid hydrogen target were constructed in JINR [3-5]. Triggering and beam flux measurements were performed by scintillation counters S_1, S_2, S_3, and Cherenkov detectors $\check{C}_I$, $\check{C}_{II}$. Total number of registered events in the measurements is about 10^6 with the hydrogen target and $2{,}8\cdot10^5$ with empty target (for the background calculation).

3 Results

The charge spectrum of fragments obtained from Cherenkov detectors (channel width – 0.1 e) is shown in Fig. 2. The results are shown as squares, dashed line represents shapes of individual peaks fitted with Gaussian functions, continuous line – total fitted spectrum. The peak at the charge 2.7 e is interpreted as caused by two helium nuclei crossing the same Cherenkov detector simultaneously. A similar effect (but significantly smaller) is observed also at Z=3.6 (He and Li nuclei through one detector). We obtain that the charge resolution of the Cherenkov hodoscope is about 0.26 e for the fragments with $2 \le Z \le 6$.

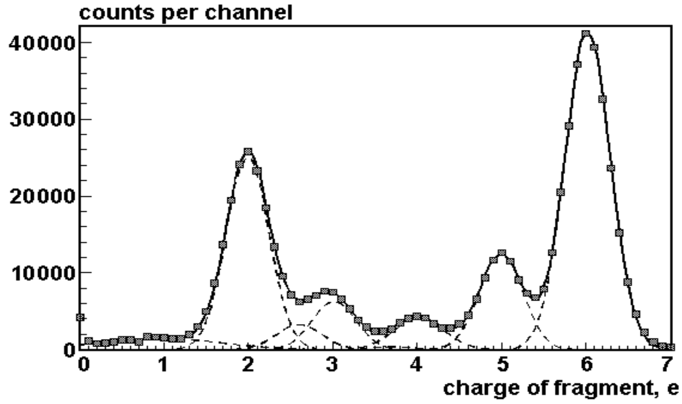

Fig. 2: The charge spectrum of fragments produced in the reaction ^{12}C+p (before subtraction of background).

Fig. 3 presents the angular distributions of carbon, boron, beryllium, and lithium isotopes. The results of measurements are shown as squares, dashed lines represent fitted shapes of individual peaks, continuous line – total fitted spectrum. Because of the uncertainty of charge determination, these spectra are contaminated by other (neighbouring) elements. For instance, in the case of boron isotopes spectrum, the peak marked as ^{10}B contains a contribution of ^{12}C. Mass resolution for the fragments is in the range 0.11÷0.18 amu.

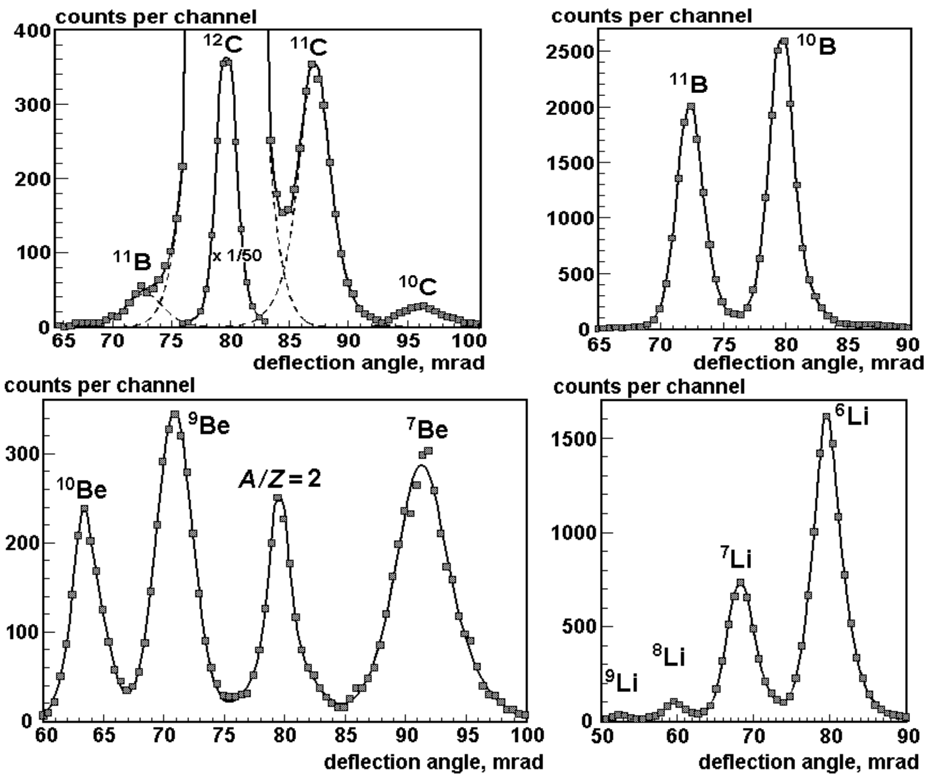

Fig. 3: Angular distribution for isotopes of carbon, boron, beryllium, and lithium.

4 Fragmentation cross sections

Isotopic cross sections (Tab. 1) were calculated taking into account numbers of registered nuclei, target parameters and counts of trigger detectors and normalized using the value of the inelastic cross section of the ^{12}C+p reaction equal (250±2) mb [6].

Determination of the total number of nuclei of a particular isotope was performed from partial isotopic data (including only Z values near the integer numbers) with use of the functions fitting the angular distribution, and recalculated allowing for the fact, that the charge spectrum for any Z contains a sum of isotopic counts for the same Z.

Tab. 1: Isotopic cross sections for the ^{12}C fragmentation on hydrogen target at the energy 3.66 GeV per nucleon.

reaction $^{12}C\rightarrow$	σ mb	$\Delta\sigma_{stat}$ mb	$\Delta\sigma_{syst}$ mb
^{11}C	29.2 ± 2.5	2.5	0.3
^{10}C	3.6 ± 0.5	0.5	0.04
^{9}C	0.24 ± 0.05	0.05	0.003
^{12}B	0.12 ± 0.05	0.05	0.003
^{11}B	27.7 ± 0.7	0.3	0.6
^{10}B	12.3 ± 3.0	3.0	0.3
^{8}B	0.44 ± 0.04	0.04	0.01
^{10}Be	4.2 ± 0.6	0.16	0.5
^{9}Be	6.7 ± 0.9	0.37	0.8
^{7}Be	10.1 ± 1.3	0.23	1.3
^{9}Li	0.25 ± 0.06	0.05	0.03
^{8}Li	1.47 ± 0.23	0.11	0.20
^{7}Li	12.5 ± 1.8	0.25	1.7
^{6}Li	19.8 ± 2.7	0.5	2.6
^{6}He	0.87 ± 0.31	0.29	0.11
^{4}He	159 ± 21	1.2	21
^{3}He	24.8 ± 3.2	0.40	3.2
^{3}H	88 (± 31)	8	~30
^{2}H	138 (± 41)	10	~40
^{1}H	143 (± 42)	14	~40

Tab. 2: ^{12}C fragmentation elemental cross sections at the energy 3.66 GeV per nucleon.

reaction $^{12}C\rightarrow$	σ mb	$\Delta\sigma_{stat}$ mb	$\Delta\sigma_{syst}$ mb
C	33.0 ± 2.7	2.6	0.35
B	40.6 ± 3.1	3.0	0.9
Be	21.0 ± 2.7	0.46	2.6
Li	34.0 ± 4.6	0.6	4.5
He	185 ± 25	1.3	25
H	360 (±120)	19	~110

Experimental errors were computed separately as statistical (including errors concerning the discrimination of contributions of isotopes with the same A/Z) and systematical. The systematical errors are due mainly to uncertainty of track reconstruction efficiency (varying with Z), other factors being negligible.

In this experiment there is no simple correlation between the number of registered nuclei and the statistical error of the corresponding cross sections because of contribution of nuclei with other charge and the same A/Z ratio. For instance, in the case of ^{10}B, the value of statistical error of cross sections which is considerably greater than for ^{11}B, is mainly due to the statistical error of the ^{12}C contribution in the peak marked as ^{10}B (Fig. 3), while ^{11}B peak contains no contamination of other nuclides.

With a much better accuracy than absolute cross sections we could determine ratios of the cross sections for isotopes with the same Z. Of particular interest are isotopes of Be, for which we obtained $\sigma_{^{10}Be}/\sigma_{^{9}Be} = 0.627\pm0.042$ and $\sigma_{^{10}Be}/\sigma_{^{9}Be} = 0.416\pm 0.018$.

The cross sections for production of elements from hydrogen to carbon shown in Tab. 2 are obtained by summing up the isotopic cross sections presented in Tab. 1.

In Tab. 1 and Tab. 2 are also shown the statistical ($\Delta\sigma_{stat}$) and systematical ($\Delta\sigma_{syst}$) errors of fragmentation cross sections.

5 Decayed cross sections

Decayed cross sections and their uncertainties can be simply calculated using the data collected in Tab. 1 and Tab. 2. They are considerably greater than the direct ones only in the case of ^{11}B (56.9 and 27.7 mb respectively) and ^{10}B (15.9 and 12.3 mb). Decayed cross section for boron production is a sum of values for ^{11}B and ^{10}B, i.e. 72.8 mb.

6 Comparison with other experiments

The values of isotopic cross sections of ^{12}C fragmentation obtained in several experiments are shown in Fig. 4. The cross sections obtained in the present experiment (also for ^{10}C and ^{9}C production – not shown here) for Z>1 do not show any unexpected behaviour at 3.66 GeV/n, apart from the cross sections for the production of ^{1}H. This cross sections is considerably greater than that at 1.05 and 2.1 GeV/n. It indicates that a probability of proton emission increases with increasing energy. Some previous results concerning ^{3}H production were obtained in other experiments in which cross sections were calculated on the basis of tritium β-activity measurements [11, 12]. Values of cross sections determined in those experiments, not marked on Fig. 4, (17÷20 mb with errors of about 20%, at energies 2.1÷6.2 GeV/n) are a few times lower than those obtained in [1,2] and in this work. It might be caused by losses of tritium during chemical treatment of the target.

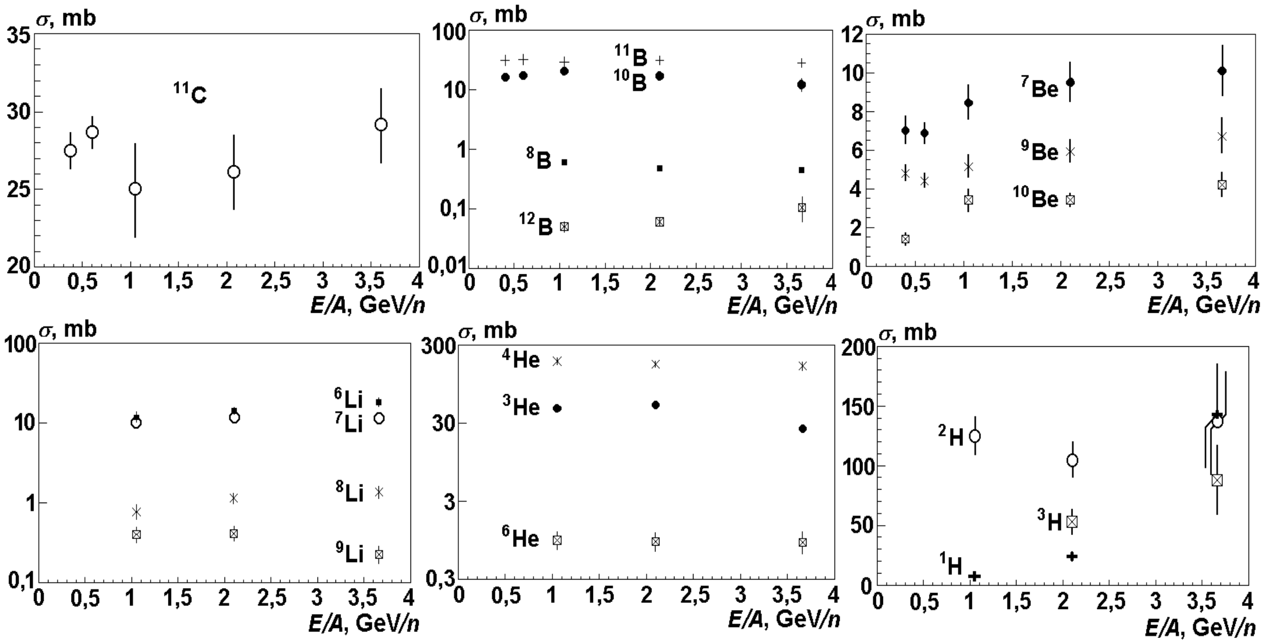

Fig. 4: Cross section for carbon, boron, beryllium, lithium and helium isotopes produced in ^{12}C fragmentation on hydrogen. Values at the energies 0.403 GeV/n – from [9], at 0.6 GeV/n – from [10], at 1.05 and 2.1 GeV/n – from [7,8]; at 3.66 GeV/n – this work.

References

[1] A. V. Zarubin et al.: JINR B1-1-93-444, Dubna (1993)
[2] Yu. T. Borzunov et al.: JINR Rapid Comm. **1/81** (1997)
[3] V. V. Vishnevski et al.: JINR 13-83-15, Dubna (1983)
[4] T. V. Bespalowa et al.: JINR 10-81-412, Dubna (1981)
[5] Yu. T. Borzunow et al.: Prib. i Tekh. Eksp. **3** (1984) 30
[6] B. M. Bobchenko et al.: Yad. Fiz. **30** (1979) 1553
[7] P. J. Lindstrom et al.: LBL 3650 (1975)
[8] D. L. Olson et al.: Phys. Rev. **C28** (1983) 1602
[9] W. R. Webber, J. C. Kish: Proc. 19th ICRC (La Jolla, 1985) **3** 87
[10] W. R. Webber et al.: Phys. Rev. **C41** (1990) 547
[11] L. A. Currie et al.: Phys. Rev. **101** (1956) 1557
[12] L. A. Currie: Phys. Rev. **114** (1959) 878