UNIVERSIDADE DE SÃO PAULO

INSTITUTO DE FÍSICA
CAIXA POSTAL 20516
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by

M.M. Coimbra, N. Carlin Filho and A. Szanto de Toledo

Instituto de Física, Universidade de São Paulo

and

P.M. Stwertka, M.G. Herman, N.G. Nicolas and T.M. Cormier

Dept. of Physics and Astronomy and Nuclear Structure Research Laboratory, University of Rochester, Rochester, N.Y., U.S.A.

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ON THE USE OF ENERGY-AVERAGED CROSS SECTIONS FOR NUCLEAR SPECTROSCOPY: ^{26}MG STATES IN THE CONTINUUM*

M.M. Coimbra+, N. Carlin Filho+ and A. Szanto de Toledo
Instituto de Física da Universidade de São Paulo
Departamento de Física Nuclear, Laboratório Pelletron
Caixa Postal 20516, São Paulo - BRASIL

and

P.M. Stwertka, M.G. Herman, N.G. Nicolas and T.M. Cormier**
Dept. of Physics and Astronomy and Nuclear Structure Research Laboratory, University of Rochester, Rochester, N.Y., U.S.A.

A B S T R A C T

Energy averaged cross sections for the $^{12}C(^{18}O,\alpha)^{26}Mg$ reaction were studied. Over 80 states between $E_x(^{26}Mg)$ = 5 and 20 MeV were observed for many bombarding energies in the range $E(^{18}O)$ = 46 to 50 MeV. Broad, non-correlated structures observed in the excitation functions prevent the application of Hauser-Feshbach analysis for spin spectroscopy to this particular data set. By implication, our results cust doubt on the previously suggested backbend in the ^{26}Mg Yrast sequence.

NUCLEAR REACTIONS: $^{12}C(^{18}O,\alpha)^{26}Mg$, $E(^{18}O)$ = 46 - 50 MeV, measured $\sigma(E)$, $\theta_{lab} = 10^{\circ}$, ^{26}Mg deduced levels.

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The investigation of highly excited states in the continuum of medium weight nuclei has been of special interest in the recent years due to the suitability of Heavy Ion Compound Reactions for the selective population of high spin states[1-4]. Several techniques have been systematically exploited for nuclear Yrast spectroscopy. Particle-particle correlations[5)] have been studied in a few cases and permit unique spin assignments typically through $J \simeq 8\hbar$. In many more cases the analysis of angular distributions within the Hauser-Feshbach formalism has led to a number of tentative spin assignments in some cases reaching $J = 12\hbar$. The application of this latter method must be carried out with proper attention to the statistical characteristics of the reaction mechanism. In practical cases this generally limits the method to reactions with high channel spin or to the observation of very high spin states near $\theta_{cm} = 90^{\circ}$. Either of these conditions guarantees that a large number of fluctuating amplitudes contribute to the observed cross section with a consequent damping of the Ericson fluctuations of the cross section. Even in the most favorable cases, a careful statistical fluctuations analysis reveals that spins inferred with this method are correct at the 75% probability level. The prudent approach, therefore, has been to regard spins assigned in this manner as reliable within $\pm 1\hbar$.

An alternative approach has been applied in cases where the channel spin is low. Excitation functions measured at relatively forward angles are used to produce energy averaged cross sections which when compared with Hauser-Feshbach predictions can be used to infer unknown spins. Aside from the obvious fact that this method must be carefully calibrated against a large set of states of known spin it is essential that the experimental energy averaging interval be large compared to the characteristic width of the Ericson fluctuations (Γ). A typical experimental procedure, therefore, has been to choose a beam energy stop size comparable to the fluctuation width such that each measured point is statistically independent. In cases where the fluctuation width is not directly measured, extensive systematics (ref. 6) can be used to estimate Γ.

The structure of ^{26}Mg at high spin is a subject of particular interest due to the reported occurence of a backbend in the Yrast sequence at the rather low spin $J = 6\hbar$ while no corresponding backbend is observed in ^{24}Mg through $J = 10^{+}\hbar$ and possibly $J = 12^{+}\hbar$. The ^{26}Mg backbend was proposed in Ref. 7 based on spin assignments made using energy averaged cross sections for the $^{12}C(^{18}O,\alpha)^{26}Mg$ reaction in the range $43.2 < E(^{18}O) < 45.9$ MeV. Motivated by the striking reported difference between ^{26}Mg and ^{24}Mg we have reinvestigated the $^{12}C(^{18}O,\alpha)^{26}Mg$ reaction using a wider energy averaging interval so as to improve the energy averaged cross sections. We have also expanded the range of excitation energies studied to $E_x(^{26}Mg) \leq 20$ MeV.

In the present work we report the observation of $\sim$ 80 excited states in ^{26}Mg (see figure 1). A self supporting, natural C target of $\sim$ 10 $\mu g/cm^2$ thickness was bombarded with an ^{18}O beam from the University of Rochester Tandem Accelerator. Alpha particles were observed in the focal plane of a split-pole magnetic spectrograph by means of a $[\Delta E - E]$ position sensitive proportional counter. The energy calibration was performed using the low lying ^{24}Mg states from the $^{12}C(^{16}O,\alpha)$ reaction as well as previously known low lying ^{26}Mg states by means of the $^{12}C(^{18}O,\alpha)$ reaction. The overall resolution was of the order of 60 keV (see figure 1).

Excitation functions were measured for most of the observed transitions in the 46 MeV $< E(^{18}O) <$ 50 MeV bombarding energy interval, in $\Delta E(^{18}O) = 300$ keV steps (see table 1 and figure 2). It is important to notice that this step value is comparable to the Ericson width (see figure 2 a-c).

Absolute cross sections were obtained by remeasuring, at the University of São Paulo Pelletron accelerator, the $^{12}C(^{18}O,\alpha)$ spectra as well as the $^{12}C + ^{18}O$ elastic scattering at bombarding energies near the Coulomb barrier using $\Delta E - E$ silicon detector telescopes. The alpha continuum of the spectra was used to normalize the spectrograph with respect to the telescope spectra.

Averaged absolute cross sections were obtained for most of the transitions and are listed in Table 1. These cross sections were compared to the values published in reference 7 and show serious discrepancies for most of the reported levels. These discrepancies are not, however, the result of an overall cross section normalization error in either experiment. Indeed, the total cross section for all states $E_x \lesssim 12$ MeV are in acceptable agreement. Inspection of the excitation functions in fig.2a-c immediatly reveals the origin of the average cross section discrepancy between Ref. 7 and the present work. Most of the observed transitions exhibit broad structures in their energy dependence with $\Gamma >> \Gamma_{Ericson}$. Noting in particular that the cross section scale in fig.2a-c is logarithmic, it is clear that the measured average cross sections will depend sensitively on the energy interval chosen. In several cases the widths of the broad structures approach a significant fraction of the entire energy interval studied.

The origin of these broad structures, which for the most part are uncorrelated from channel to channel is unknown. For the present purpose, it is sufficient to note that their presence indicates non-statistical contributions to the $(^{18}O,\alpha)$ reaction. Similar broad structures have already been reported in the reactions $^{10}B(^{16}O,\alpha)$[8], $^{12}C(^{15}N,\alpha)$[9] and $^{12}C(^{16}O,\alpha)$[10].

The influence of the broad structures on the analysis of the present data for spin assignments in ^{26}Mg is shown in fig. 3. Here we plot the observed energy averaged cross sections versus excitation energy in ^{26}Mg. The solid error bars on each point reflect the experimental uncertainties in the measured cross sections while the narrow vertical bar reflects the observed variance of the experimental excitation functions. In the present case, where structures with widths comparable to the entire energy interval are observed, it is more appropriate to regard the observed variance as the uncertainty in the energy averaged cross section.

An uncertainty in the energy averaged cross section is related within the Hauser-Feshbach formalism to an uncertainty in the spin which can be assigned to a particular state. The relevant theoretical factor is the reaction selectivity

$$s = \frac{d}{dJ}\,\sigma(E_x, J)$$

which measures the sensitivity of the cross section to variation of the spin J.

For the present reaction, the selectivity is only moderate with the result that the uncertainties shown in fig. 3 correspond to a rather broad acceptable spin range for most states. Indeed the present data contain no new information on the location of high spin states in ^{26}Mg. Furthermore, the spin assignements made in ref. 7 using the same reaction reported here can not be supported by the present data.

We conclude that the presence of a backbend in ^{26}Mg is in doubt and deserves further investigation.

We emphasize that the present results are not universal. The break down of the utility of energy averaged compound nucleus cross sections for high spin spectroscopy occurs in the present case as a result of the rather low selectivity of this reaction. Some reactions, eg. $^{12}C(^{16}O,\alpha)$ exhibit a selectivity nearly 10 times that encountered here. In such cases the broad oscillations reported here are much less significant.

Level Number	E* (MeV)$^{a)}$	E* (MeV)$^{b)}$	$\langle d\sigma/d\Omega\rangle_{exp} \times 10^{-2}$ (mb/sr)
3	5.47 ± 0.01	5.473	1.49
4	5.71 ± 0.02	5.716	0.77
5	6.14 ± 0.03	6.126	
6	6.62 ± 0.02	6.616	1.31
10	7.37 ± 0.03	7.41	1.86
13	7.98 ± 0.03	7.944	3.81
14	8.21 ± 0.02	8.188	4.43
16	8.66 ± 0.03	8.694	5.28
17	8.93 ± 0.02	8.918	1.99
18	9.13 ± 0.02	9.156	3.39
19	9.37 ± 0.06	9.30$^{c)}$	5.00
20	9.60 ± 0.02	9.564	3.95
21	9.84 ± 0.02	9.841	2.74
22	10.02 ± 0.02	10.028	5.81
23	10.14 ± 0.02	10.118	
24	10.37 ± 0.02	10.358	4.35
26	10.71 ± 0.03	10.74$^{c)}$	
27	10.96 ± 0.02	10.96$^{c)}$	5.09
28	11.16 ± 0.03	11.16$^{c)}$	5.44
31	11.72 ± 0.01	11.77$^{c)}$	2.17
32	11.92 ± 0.02	11.94$^{c)}$	5.71
33	12.06 ± 0.02	12.03$^{c)}$	6.61
34	12.20 ± 0.01	12.20$^{c)}$	2.91
36	12.51 ± 0.02	12.53$^{c)}$	
37	12.59 ± 0.02	12.63$^{c)}$	
38	12.75 ± 0.02		2.83
39	12.88 ± 0.03	12.88$^{c)}$	
40	13.04 ± 0.02	13.06$^{c)}$	6.66
B	13.21 ± 0.03	13.19$^{c)}$	4.64
41	13.31 ± 0.02	13.35$^{c)}$	5.01
42	13.54 ± 0.02	13.52$^{c)}$	11.41
43	13.83 ± 0.02	13.85$^{c)}$	
44	14.07 ± 0.02	14.08$^{c)}$	8.58
45	14.17 ± 0.03	14.14$^{c)}$	11.68
46	14.44 ± 0.01	14.50$^{c)}$	

Level Number	E* (MeV) a)	E* (MeV) b)	$<d\sigma/d\Omega>_{exp} \times 10^{-2}$ (mb/sr)
A	14.57 ± 0.02	14.56 c)	6.75
48	14.70 ± 0.02	14.70 c)	7.04
49	14.87 ± 0.03	14.86 c)	
50A	15.14 ± 0.03	15.14 c)	10.68
51	15.31 ± 0.03	15.35 c)	5.49
52	15.46 ± 0.02	15.46 c)	7.14
53	15.59 ± 0.03	15.56 c)	
54	15.84 ± 0.03	15.84 c)	4.88
55	15.96 ± 0.04	15.98 c)	12.70
57	16.32 ± 0.04	16.35 c)	11.25
58	16.42 ± 0.03		
59	16.60 ± 0.03		
60	16.75 ± 0.03		7.52
61	16.90 ± 0.04		13.15
62	17.12 ± 0.02		2.80
63	17.35 ± 0.04		5.59
64	17.50 ± 0.04		9.70
65	17.64 ± 0.04		
66	17.74 ± 0.05		
67	17.86 ± 0.04		10.40
68	18.01 ± 0.04		8.72
69	18.11 ± 0.05		
70	18.18 ± 0.05		9.20
71	18.22 ± 0.07		4.83
72	18.31 ± 0.06		11.23
73	18.54 ± 0.03		9.27
74	18.65 ± 0.06		2.99
75	18.72 ± 0.04		8.91
78	18.93 ± 0.05		
79	19.03 ± 0.09		
82	19.18 ± 0.04		12.83
83	19.27 ± 0.04		10.51

TABLE 1

a) Present work b) Values from Ref. 11 c) Values from Ref. 6

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FIGURE CAPTIONS

Figure 1. Typical background subtracted spectrum of the $^{12}C(^{18}O,\alpha)^{26}Mg$ reaction. The alpha continuum has been fitted by means of a 5^{th} order polynomial.

Figure 2a-c. Experimental excitation functions for some of the observed transitions.

Figure 3. Energy averaged cross sections for the observed tansitions to ^{26}Mg states. The solid error bars reflect the experimental uncertainties and the narrow vertical bars reflect the observed variance of the experimental excitation functions.

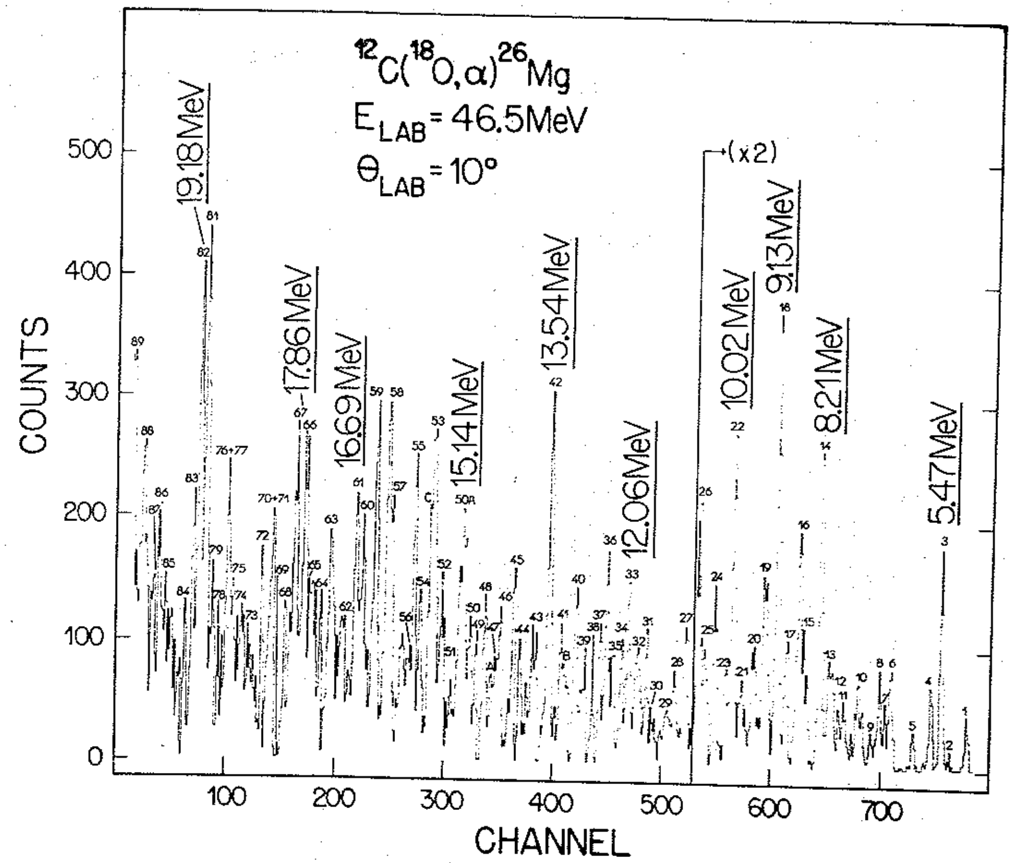
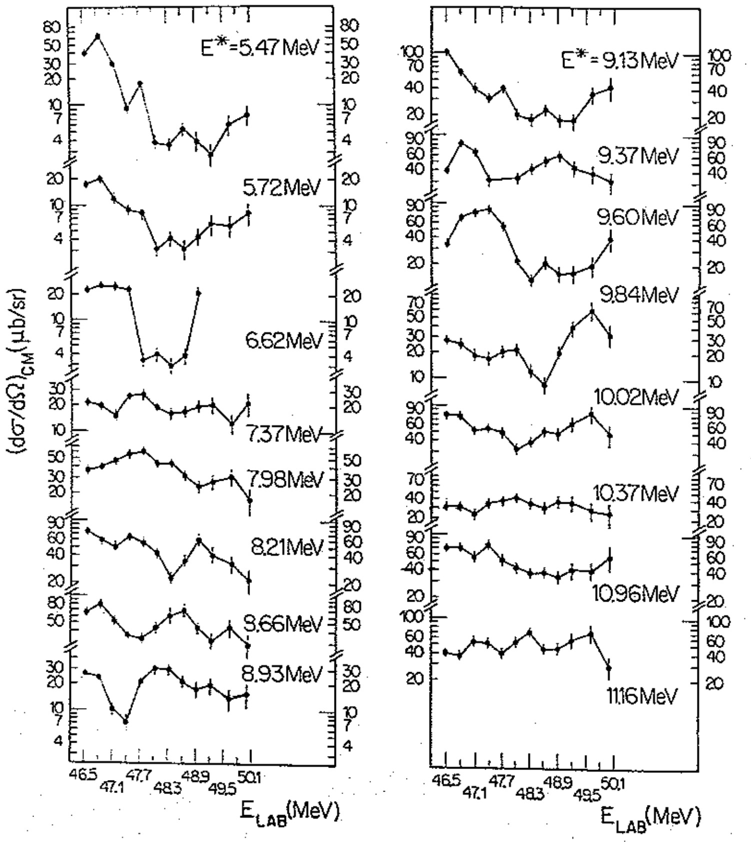
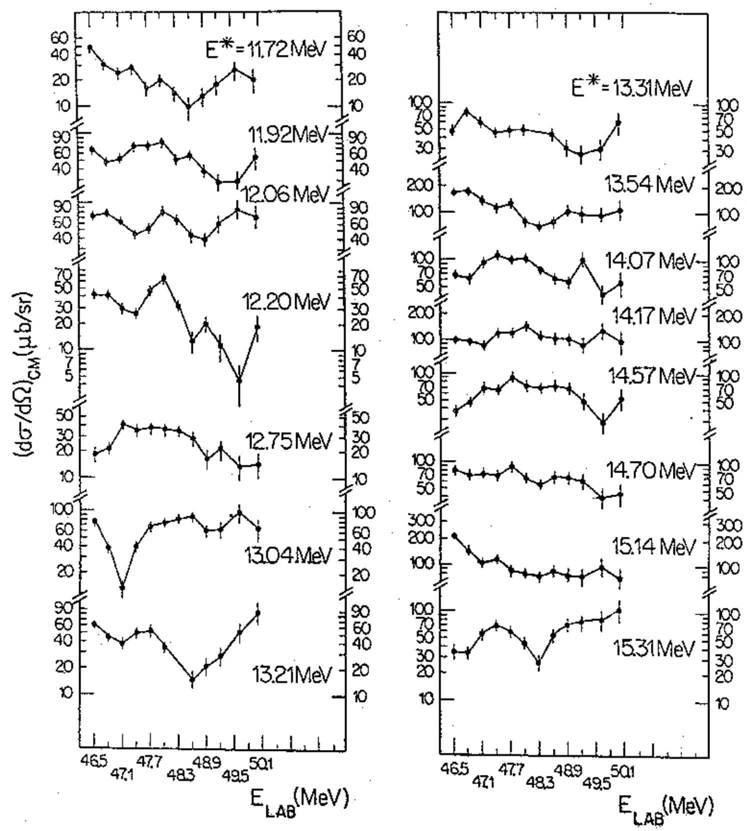


Fig. 1



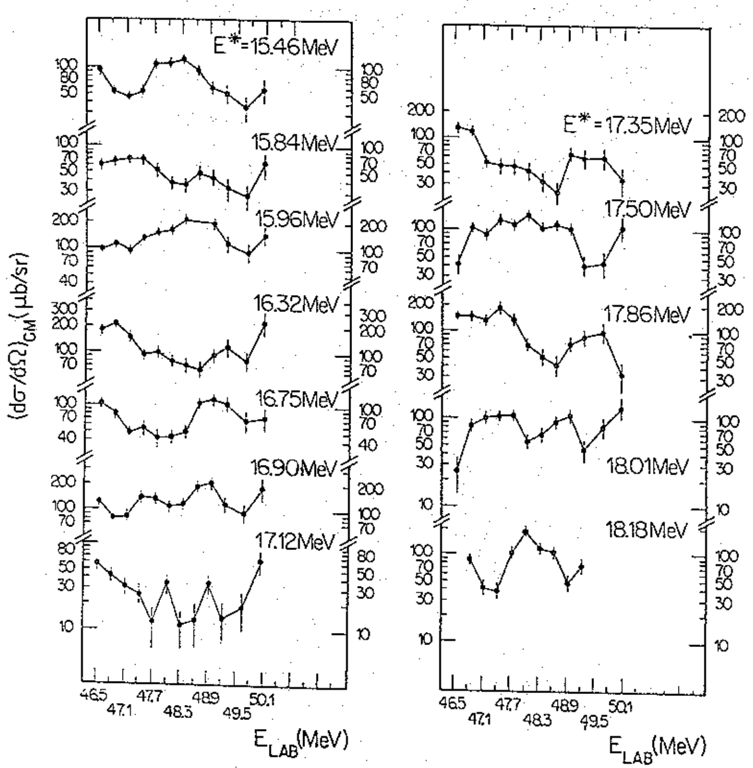
E* = 5.47 MeV
5.72 MeV
6.62 MeV
7.37 MeV
7.98 MeV
8.21 MeV
8.66 MeV
8.93 MeV
E* = 9.13 MeV
9.37 MeV
9.60 MeV
9.84 MeV
10.02 MeV
10.37 MeV
10.96 MeV
11.16 MeV
(dσ/dΩ)CM (μb/sr)
46.5
47.1
47.7
48.3
48.9
49.5
50.1
ELAB (MeV)

Fig. 2a



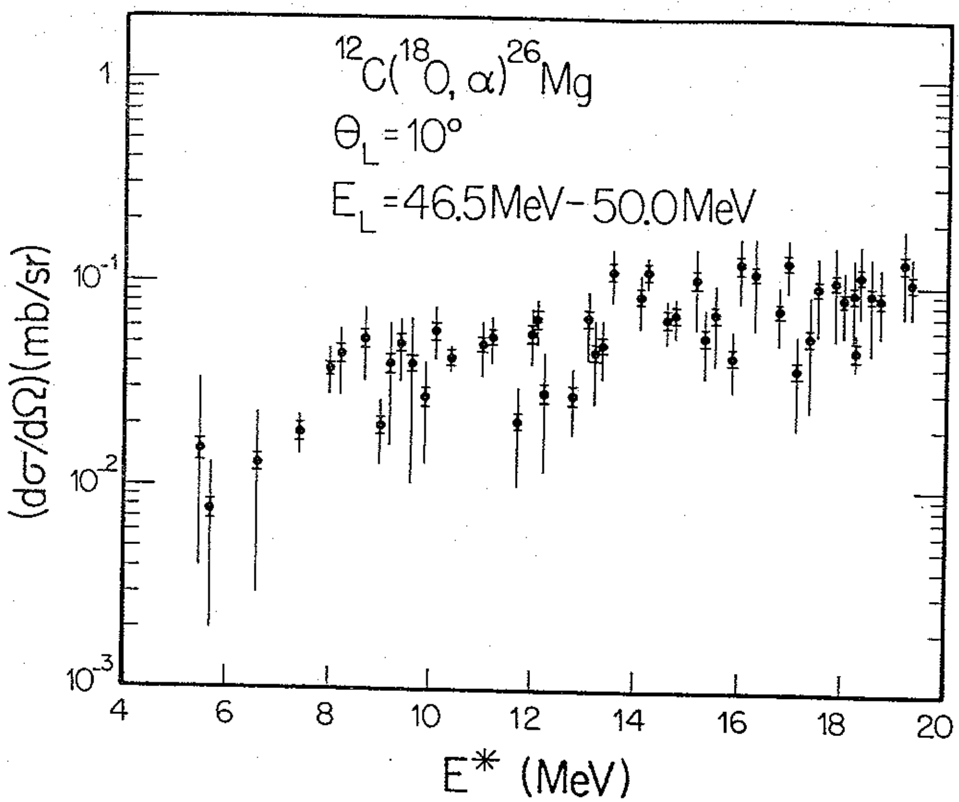
E* = 11.72 MeV
11.92 MeV
12.06 MeV
12.20 MeV
12.75 MeV
13.04 MeV
13.21 MeV
E* = 13.31 MeV
13.54 MeV
14.07 MeV
14.17 MeV
14.57 MeV
14.70 MeV
15.14 MeV
15.31 MeV
(dσ/dΩ)CM (μb/sr)
46.5
47.1
47.7
48.3
48.9
49.5
50.1
ELAB (MeV)

Fig. 2b



E* = 15.46MeV
15.84MeV
15.96MeV
16.32MeV
16.75MeV
16.90MeV
17.12MeV
E* = 17.35MeV
17.50MeV
17.86MeV
18.01MeV
18.18MeV
(dσ/dΩ)CM (μb/sr)
ELAB(MeV)

Fig. 2c



12C(18O, α)26Mg
ΘL = 10°
EL = 46.5MeV - 50.0MeV
(dσ/dΩ) (mb/sr)
E* (MeV)

Fig. 3