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# LETTER OF INTENT FOR AN EXPERIMENT ON MUON CAPTURE IN LIGHT NUCLEI LEADING TO EXCITED NUCLEAR LEVELS -

Milano Group

(E. Fiorini et al.)

## 1 - INTRODUCTION -

Capture of negative muons to bound nuclear states of well defined quantum numbers represents an unique mean to obtain informations on the four form factors $g^{\mu}_{A}, g^{\mu}_{V}, g^{\mu}_{P}, g^{\mu}_{W}$ and particularly on the induced pseudoscalar and weak magnetism ones(1-3). One can also investigate in principle $\mu - e$ universality, existence of second class currents, value of the Cabibbo angle and T-invariance. Moreover important results on nuclear structure can also be obtained.

Let us consider the muon capture to bound states:

$$(1) \qquad \mu^- + (A,Z) \longrightarrow (A,Z-1)^* + \nu_\mu$$
$$\hookrightarrow (A,Z-1)_{g.s.} + \gamma\text{-rays}$$

followed by the beta decay

$$(2) \qquad (A,Z-1)_{g.s.} \rightarrow (A,Z)^* + e^- + \overline{\nu}_e$$
$$\hookrightarrow (A,Z) + \gamma\text{- rays}$$

We would like to obtain the capture rates to the various excited levels of (A,Z-1) by measuring with a large Ge(Li) the deexcitation $\gamma$-rays, which are generally emitted promptly. If the half lifetime for beta decay is long enough the target would then be moved in a region with low background where the de-excitation of $(A,Z)^*$ would be measured and the total rate for processes (1) determined. The capture rate to the ground level of (A,Z-1) can thus been obtained by difference.

Our letter of intent is still very preliminary for the following reasons:

a) the design project of the experiment is not yet definitely fixed;

b) we have not yet decided if it would be preferable for us to run the experiment at CERN SCIP or at SIN;

c) the experiment has not yet subjected to approval of the Italian National Institute for Nuclear Physics (I.N.F.N.);

d) the experiment could not be run, in any case, before mid 1975.

We consider in the next section muon capture on five light nuclei with $0^+$ ground state (for the sake of simplicity). We want to stress however that our interest is mainly concerned with $\mu$-capture on $^{28}Si$, using a solid state Si(Li) detector both as target and counter$^{(4)}$.

## 2 - ANALYSIS OF $\mu^-$ CAPTURE ON FIVE LIGHT $0^+$ NUCLEI -

a) $\mu^- + {}^{12}_{6}C \longrightarrow {}^{12}_{5}B^* + \nu_\mu$ followed by

$\qquad\qquad\qquad\qquad \hookrightarrow {}^{12}B_{g.s.} + \gamma$-rays

$$^{12}B_{g.s.} \longrightarrow {}^{12}C + e^- + \bar{\nu}_e$$

As shown by the nuclear scheme of this "isobaric doublet" (fig. 1) three rather well established levels of $^{12}B$ exist, which decay promptly to the ground state. Upper levels are unstable under n emission. While the rates for capture to the various $^{12}B$ have not been measured separately, the total transition rate has been obtained in various experiments from beta decay of the ground state of $^{12}B$ to the ground state of $^{12}C$ (branching ratio of 97%). In particular E.J. Maier et al.$^{(5)}$ have measured the total rate of muon capture leading to excited $^{12}B$ levels, which amounts to about 10% of the total capture rate leading to bound $^{12}B$ states.

Measurements on $\mu^-$capture to the single excited states of $^{12}B$ could be done with a large Ge(Li) detector only if the stopping muon beam is intense and narrow. With $10^3$ muons per second stopping in a 2-3 gr cm$^{-2}$ thick carbon target, and a beam cross section of a few square centimeters one could detect a $\gamma$-ray from de-excitation of $^{12}B$ every minute. The measurement of the total rate for reaction (a) from de-excitation of the 4.43 MeV level of $^{12}C$ is ~~somewhat~~ less competitive with other experiments, since the branching ratios for decay to this level is only 1.3%. The counting rate would therefore be of about a count every 10 minutes, rather hard to detect, expecially if one takes into account that the low lifetime for beta decay (20.3 msec) makes almost impossible the mechanical transfer of the target to a region reasonably free from background.

b) $\mu^- + {}^{16}O \longrightarrow {}^{16}N^* + \nu_\mu$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow {}^{16}N_{g.s} + \gamma$-rays followed by

$${}^{16}N_{g.s.} \longrightarrow {}^{16}O^* + e^- + \bar{\nu}_e$$

$$\hookrightarrow {}^{16}O_{g.s.} \quad + \gamma\text{- rays}$$

As shown in fig. 2 the excitation energy of the three rather well established levels of ${}^{16}N$ is much lower than in the preceding case, making $\mu$ capture to excited levels more probable ($\sim 30\%$).

In addition the $0^-$ level at 0.120 MeV is metastable ($\tau_{1/2} = 5.4\ \mu$sec) thus allowing a detailed investigation on the time dependence of its decay to ${}^{16}N_{g.s.}$. The half lifetime for beta decay of ${}^{16}N$ (7.2 sec) allows the mechanical transfer of the target to a remote region where one can measure de-excitation of the 6.131, 7.115 and 8.870 MeV ${}^{16}O$ levels, to which beta decay occurs with branching ratios of 68%, 4.9% and 1.1% respectively. The experiment has in fact been carried out by various groups^(6-8)^, and a Ge(Li) detector has been used by J.P. Deutsch et al.^(8)^. We could improve these results by an order of magnitude due to higher intensity and larger detector and possibly measure capture rate to $3^-$ state at 0.296 MeV, for which only an upper limit exists at present.

c) $\mu^- + {}^{20}_{10}Ne \longrightarrow {}^{20}_{9}F^* + \nu_\mu$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow {}^{20}F_{g.s.} \quad + \gamma$-rays followed by

$${}^{20}F_{g.s.} \longrightarrow {}^{20}Ne^* + e^- + \bar{\nu}_e$$

$$\hookrightarrow {}^{20}Ne_{g.s.} \quad + \gamma\text{-rays.}$$

This capture, which has not been studied up to now, looks interesting due to the presence of reasonably established nuclear levels of ${}^{20}F$ (fig. 3) and to the fact that beta decay occurs only to the 1.63 MeV excited ${}^{20}Ne$ state, which totally decays to the ground level. The half lifetime for beta decay (11.4 sec) is large enough to allow the mechanical transfer of a liquid neon target; pneumatic transfer of high pressure gaseous or liquid neon seems also feasible, even if difficult. With a muon beam with a cross section of a few $\mathrm{cm}^2$ and an intensity of $10^3$ muons per second stopping in 2 cm of liquid neon the rate of detected gamma rays from excited $^{20}\mathrm{F}$ levels would be about 1 per minute, but the counting rate for de-excitation of $^{20}\mathrm{Ne}$ following beta decay should be about an order of magnitude higher.

The isotopic aboundance of $^{20}\mathrm{Ne}$ is rather high (90.92%). A $^{20}\mathrm{Ne}$ enriched target could however be used if one wants to eliminate the background from $\mu$-capture on the less favourable isotope $^{22}\mathrm{Ne}$. This is also true for the isotopes considered in d) and e).

d) $$\mu^- + {}^{24}_{12}\mathrm{Mg} \longrightarrow {}^{24}_{11}\mathrm{Na}^{*} + \nu_\mu$$

$$\hookrightarrow {}^{24}\mathrm{Na}_{g.s.} + \gamma\text{- rays followed by}$$

$$^{24}\mathrm{Na}_{g.s.} \longrightarrow {}^{24}\mathrm{Mn} + e^- + \bar{\nu}_e$$

$$\hookrightarrow {}^{24}\mathrm{Mn}_{g.s.} + \gamma\text{- rays}$$

Even in this case a number of reasonably well defined $^{24}\mathrm{Na}$ excited nuclear levels exist (fig. 4), and the ground $^{24}\mathrm{Na}$ state decays almost completely (99%) to the excited $^{24}\mathrm{Mg}$ level at 4.1225 MeV ~~level~~ which then decays to ground state via an intermediate level at 1.368 MeV. An unique feature of this "isobaric doublet" is however the very long half lifetime for beta decay of $^{24}\mathrm{Na}$ (15 hours). One could think to expose the Mg target to the $\mu^-$ beam for periods of up to 20 hours measuring the de-excitation of the excited levels of $^{24}\mathrm{Na}$, and then move the irradiated target to a low background laboratory even outside CERN (for instance the Mont Blanc laboratory), to measure precisely the $\gamma$ rays from the 4.1225 MeV state. In this particular case a very intense beam, like the internal muon beam at SIN, could be very useful if the pion contamination would be tolerable.

e) $$\mu^- + {}^{28}_{14}\mathrm{Si} \longrightarrow {}^{28}_{13}\mathrm{Al}^* + \nu_\mu$$
$$\hookrightarrow {}^{28}\mathrm{Al}_{g.s.} + \gamma\text{- rays}$$

$$ {}^{28}\mathrm{Al}_{g.s.} \longrightarrow {}^{28}\mathrm{Si}^* + e^- + \bar{\nu}_e$$
$$\hookrightarrow {}^{28}\mathrm{Si}_{g.s.} + \gamma\text{ rays}$$

This muon capture is promising due to the number of reasonably well known nuclear states in $^{28}$Al (fig. 5) and because beta decay occurs only to the excited $2^+$ state at 1.780 MeV. The lifetime for beta decay (2.3 min) allows a very easy mechanical transfer of the target to a remote region. What makes however in our opinion this process ~~as~~ the most suitable to study muon capture is the possibility to use a lithium drifted silicon solid state detector as an "active" target$^{(4)}$, which can detect the electron in the muon decay and in the beta decay of $^{28}$Al.

A very tentative sketch of the experimental setup is shown in fig. 6. A narrow muon beam defined by a counter telescope and collimators, is degraded in energy and stops in a Si(Li) detector ($\mathrm{Si}_1$). These detectors can be presently made in form of disks with a diameter of a few centimetres and with thickness up to 2 gr cm$^{-2}$, which are reasonable for a stopping $\mu$ target. Si(Li) have proved to be able to stand crossing by up to $10^{13}$ lightly ionizing particles without visible radiation damage$^{(4)}$. The "active" target is viewed by a large Ge(Li) ($\mathrm{Ge}_1$) protected by the anticoincidence counter AC. The $\gamma$-ray signals from $\mathrm{Ge}_1$ are transmitted to the analysis chain only if for a period of, say, 20 $\mu$ sec there is no further pulse from $\mathrm{Si}_1$. This procedure should eliminate $\gamma$-rays due to bremmstrahlung of the electron in $\mu$ decays (about 40% of the total stopping rate) and also many muon captures with neutron or charged particle emission, followed by nuclear breakup. In fact the pulses from $\mathrm{Si}_1$ couls be used to yield very interesting informations on the nuclear processes following $\mu$ capture.

After a few minutes of exposure to the muon beam the detector $\mathrm{Si}_1$ should be mechanically interchanged with a similar detector $\mathrm{Si}_2$ and placed in a remote, background free region, near a second Ge(Li) detector ($Ge_2$). Since de-excitation of the $2^+$ $^{28}$Si level at 1.780 MeV follows immediately $\beta$ decay from $^{24}$Al, one can make use of a $\beta - \gamma$ coincidence, sending the pulse from $Ge_2$ to the analysing chain only when accompanied by a suitable pulse from the Si(Li). Anticoincidence counters will probably be needed to shield against spurious counting both in position I and II of fig. 6.

## 3 - SOME DETAIL ON THE ORGANIZATION OF THE EXPERIMENT -

We are mostly interested to the study of muon capture in an "active" Si(Li) target and will refer here only to this experiment, since the others can be considered as "subproducts" of this one; apart possibly the experiment on $^{24}$Mg.

### i) Details of the $\mu^-$ beam -

The stopping $\mu^-$ beam should be narrow, with a cross section not exceeding a few cm$^2$. The pion or other contaminations should be lower than 1%. We would like to start the experiment with a stopping muon intensity of $\sim 10^3$ muons/sec in a target of 2-3 gr/cm$^2$ and increase further the intensity by an order of magnitude.

### ii) Measuring apparatus -

The group already owns a 90 cm$^3$ useful dimension Ge(Li) with associated electronics and a 4096 multichannel analyser. By buying the Si(Li) detector and buying (or better borrowing) some additional electronics we would be in position to carry on the first tests, since the long lifetime for beta decay of $^{28}$Al allows to move to the remote region both the Si(Li) and the associated Ge(Li) detectors together. To complete the experiment the group should buy a second Ge(Li) and buy or borrow the associated electronics, possibly including a second analyser.

### iii) SCIP - SIN alternative -

If the required intensity will be available at SCIP we would obviously prefer to start our experiment, or at least our tests, at CERN for obvious logistical and practical reasons. Moving to SIN would later allow to increase the intensity between one and two orders of magnitude, even if the experiment should be run parasitically in the extracted beam(9). The use of the SIN internal beam could be considered only for the exposure of the $^{24}$Mg target if the pion background would be tolerable.

(E. Fiorini)

on behalf of Milano Group

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FIG. 1

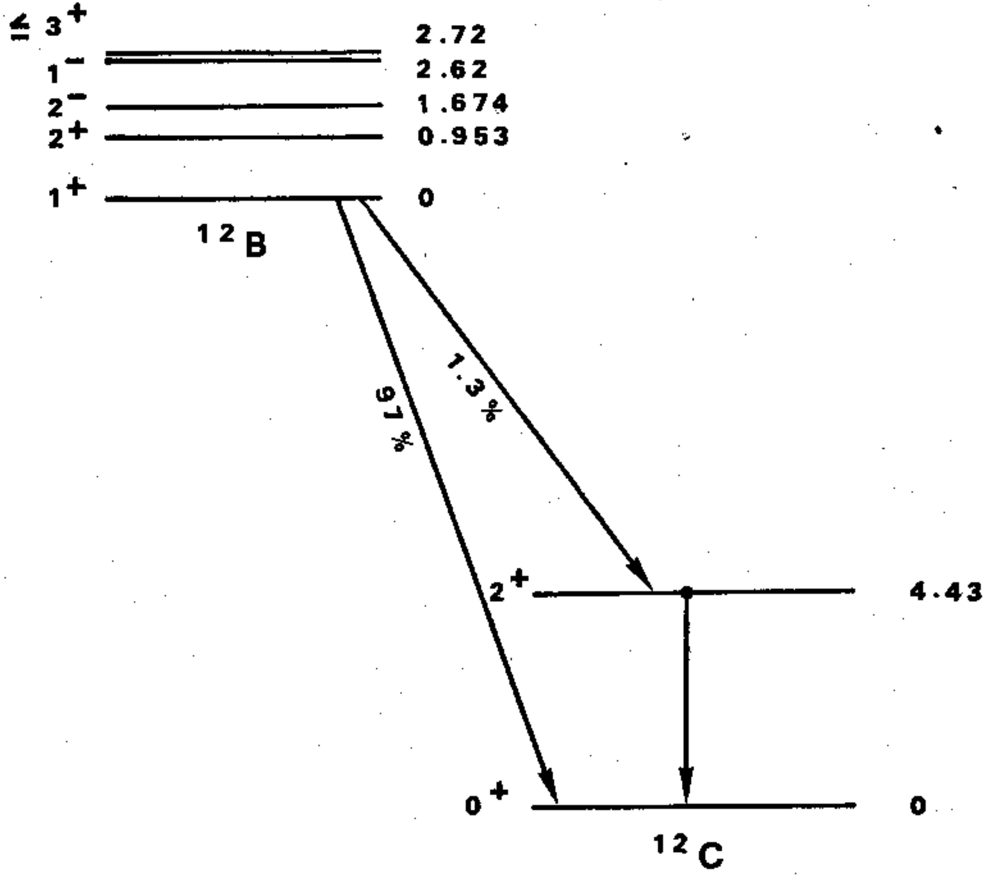


FIG. 2

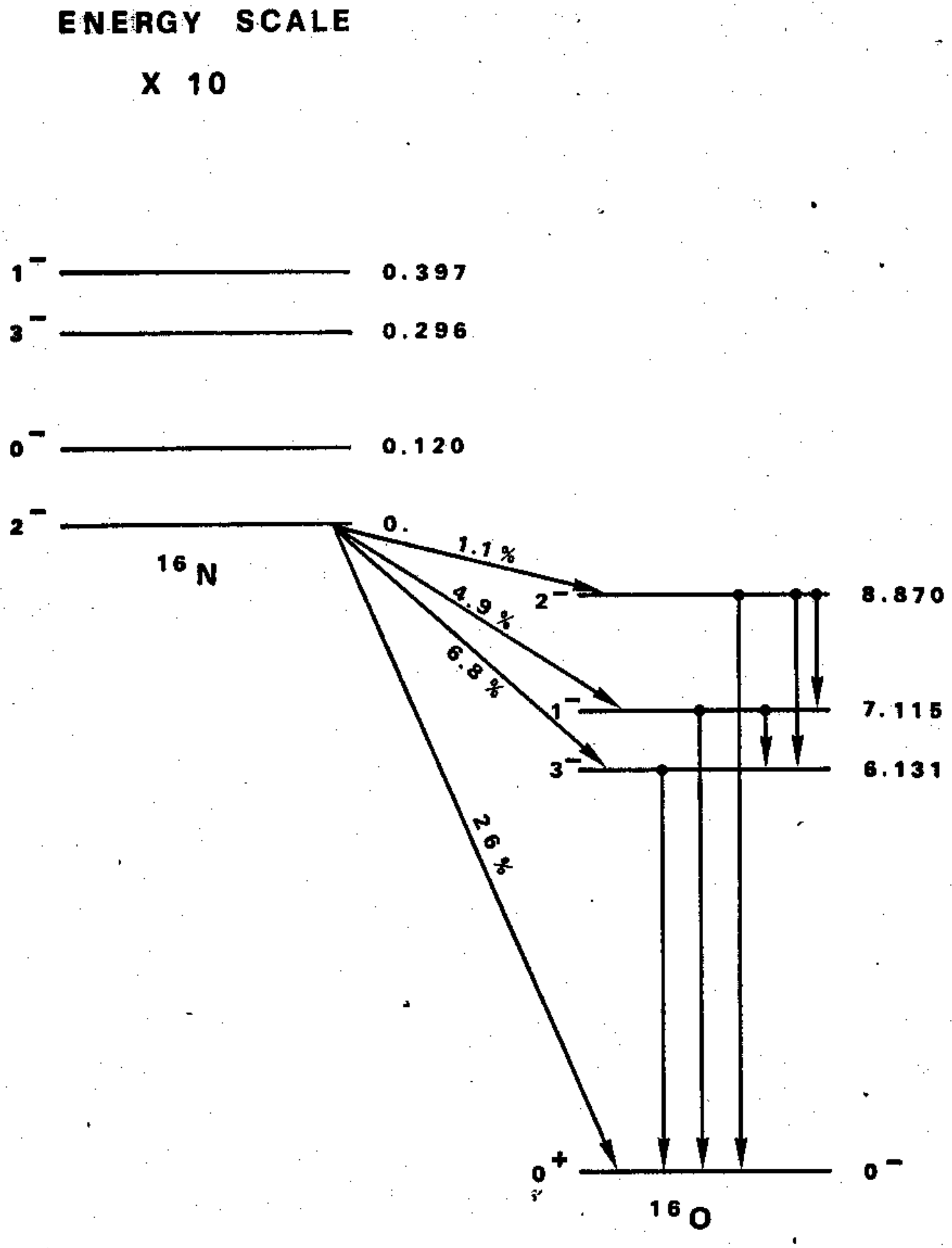
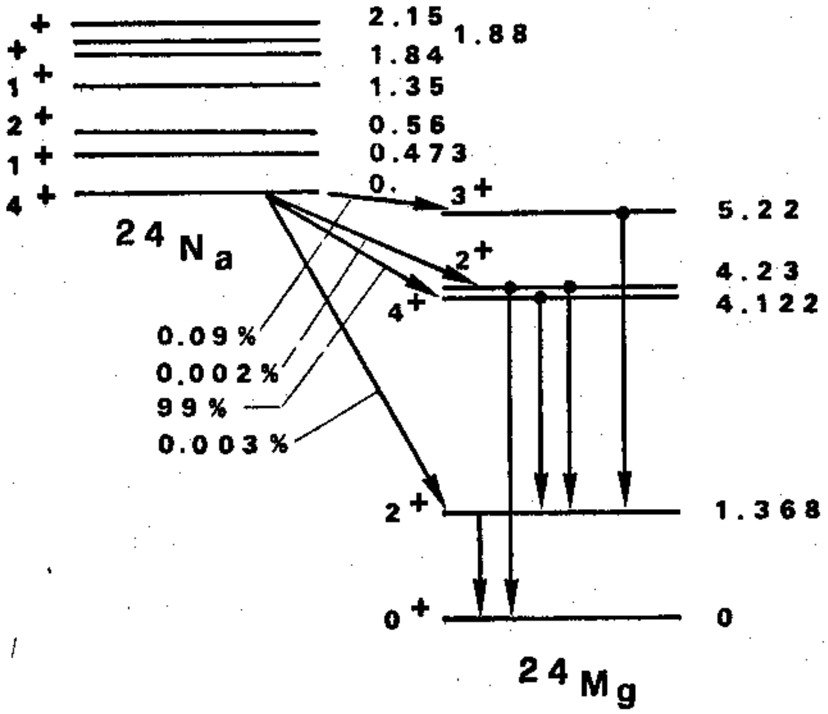

ENERGY SCALE
X 10
1⁻ 0.397
3⁻ 0.296
0⁻ 0.120
2⁻ 0.
16N
1.1 %
4.9 %
6.8 %
26 %
2⁻ 8.870
1⁻ 7.115
3⁻ 6.131
0⁺ 0⁻
16O

FIG. 4



+
+
1+
2+
1+
4+
2.15
1.88
1.84
1.35
0.56
0.473
0.
24Na
3+
5.22
2+
4.23
4+
4.122
0.09%
0.002%
99%
0.003%
2+
1.368
0+
0
24Mg

FIG. 5

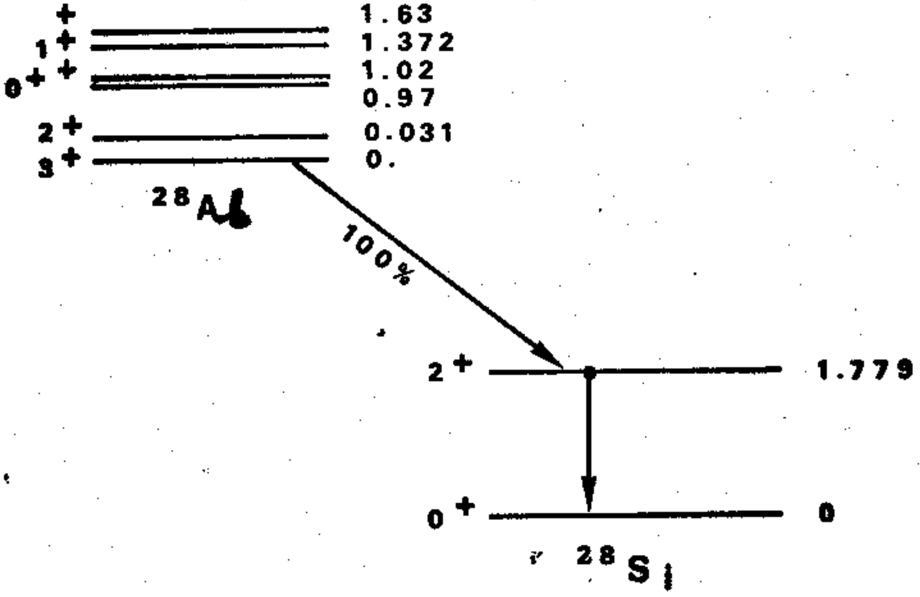


FIG. 6