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Beta-delayed Proton Decay of the $T_z = -2$ Isotope, ^{26}P*

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Abstract:

The $^{28}Si(^3He,p4n)^{26}P$ reaction at 110-130 MeV has been used to discover the odd-odd $T_z = -2$ nuclide $^{26}P(t_{1/2} \sim 20ms)$, which was predicted to lie on or beyond the proton drip line. Beta-delayed protons from its decay establish the mass excess of the lowest T=2 state in ^{26}Si as 5.936 ± 0.015 MeV. Possible beta-delayed two-proton emission from this isotope is discussed.

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Recent observation of the β^+-delayed proton decay of ^{22}Al established the existence of the first known member of the A = 4n +2, T_z = -2 series[1]. We wish to report our detection of the second such nucleus, ^{26}P. As stated in Ref. 1, these nuclei are of interest not only for isobaric analog state masses and beta decay information, but also because they are expected to define the limits of particle stability for proton-rich nuclides in this mass region. ^{26}P is actually predicted to be unbound to direct proton emission by most mass formulae.[2] As discussed below, this is not necessarily inconsistent with our observation of the β^+-delayed proton decay of this isotope. Also of considerable interest is the energetically possible decay mode of β^+-delayed two-proton emission for both of these T_z = -2 nuclei.

^{26}P was produced via the $^{28}Si(^3He,p4n)^{26}P$ reaction with 110-130 MeV $^3He^{+2}$ beams of 3-7 μA intensities from the 88-inch Cyclotron at the Lawrence Berkeley Laboratory. A single target, single capillary helium jet system was used to collect nuclear reaction recoils and transport them via a 70 cm stainless steel capillary (i.d. 1.3 mm) to a counting chamber arrangement similar to that described in Ref. 1. Recoil products were collected on a slowly rotating ($\sim$1cm/s) Al wheel that reduced β^+ background by removing long-lived activities. β^+-delayed protons were observed with the three element semiconductor particle telescope (110 μm ΔE1, 60 μm ΔE2, 1000 μm E) described in Ref. 1 except that for these experiments the solid angle subtended was increased to 2.3% of 4π sr. A standard slow coincidence network was used together with fast coincidences measured by time-to-amplitude converters (TAC). The timing resolution achievable was typically better than 10 ns (FWHM). Energy and TAC spectra were recorded event by event on a Mod Comp IV computer using the data acquistion and analysis program, CHAOS,[3] enabling use of several software particle identification techniques.

Proton spectra observed at 130, 110, and 60 MeV ^{3}He energies are shown in Fig. 1. The dominant features of each spectrum are due to β^{+}-delayed protons from the decays of ^{21}Mg, ^{25}Si and ^{29}S produced via (^{3}He,xα2n) reactions. At 60 MeV, which is below the threshold of 63.5 MeV for ^{26}P production, two previously unknown proton groups from ^{29}S decay (assigned by additional low energy bombardments on several targets) are observed at laboratory energies of 7.114 ± 0.015 MeV and 7.581 ± 0.015 MeV. At 110 MeV, a new group is observed at a laboratory energy of 7.269 ± 0.015 MeV in addition to the ^{29}S groups. In order to reduce the amount of ^{29}S ($t_{1/2}$ =187 ms) in the spectrum, another measurement was made A) at 130 MeV and B) with the wheel speed increased to $\sim$2 cm/s to discriminate against longer-lived activities. The resulting spectrum (Fig. 1(a)) shows that the ^{29}S contribution is reduced and the new group at 7.269 MeV is more pronounced. Also present is a group at 6.827$\pm$0.050 MeV which will be discussed further below.

A rough half-life of 20^{+35}_{-15} ms was determined for the 7.269 MeV proton group by varying the wheel rotational speed and observing the relative yields of the various activities present. This method could, in principle, yield a precise half-life measurement but does not do so here due to the low yield of ^{26}P (see below).

As shown in Fig. 2, the 7.269$\pm$0.015 MeV group can be attributed to the isospin forbidden decay of the lowest T=2 state in ^{26}Si (fed by the superallowed β^+-decay of the T=2 ground state of ^{26}P) to the ground state of ^{25}Al. (As noted below, this assignment is consistent with Coulomb displacement energy considerations.) The J^{π} assignment of 3^+ to the levels in this isospin multiplet is based on the measurement of the hyperfine splitting of the T_z=+2 member, ^{26}Na, by Huber et al[4].

The known energy difference between the ^{25}Al ground state and its first excited state[5] permits the calculation of the proton energy to be expected if decay to the first excited state also occurs. This energy is 6.835$\pm$0.015 MeV and is indicated in Fig. 1(a) and 1(b) with the arrow at the lower proton energy. Accurate measurements in this region of the spectrum are made extremely difficult by the high "background" caused by the following effects: A) a distortion to higher energies of the very intense lower energy proton groups caused by simultaneous detection of the proton and the preceding positron and B) the actual presence of some weak groups from $T_z = -3/2$ β^+-delayed proton emitters. The latter accounts for the two groups labeled a and b in Fig. 1(b), which are also observed in low energy bombardments of Mg targets and can be tentatively assigned to the decay of ^{25}Si. In Fig. 1(a), however, the ^{25}Si ($t_{1/2}$ = 218 ms) contribution is substantially reduced and the relative intensity of the peak observed at 6.827±0.050 MeV is consistent with a major component of that peak arising from decay of the ^{26}Si T=2 state to the first excited state of ^{25}Al.

In order to confirm the assignment of these proton groups to the decay of ^{26}P, the cross-bombardment $^{27}Al(^3He,4n)^{26}P$ was also investigated. Both the 7.269 MeV and 6.827 MeV groups were again observed, but their yield was reduced by a factor of five. (The yields of "background" activities were also substantially decreased.) This eliminates sulfur isotopes (in particular the unknown isotope ^{27}S) as a source of this activity. Coupled with the previous work described in Ref. 1, this shows that only ^{26}P can be a source of these proton groups.

The center of mass proton energy of the group decaying to the ground state of ^{25}Al, taken together with the ^{25}Al

mass[6], gives a mass excess of 5.936$\pm$0.015 MeV for the lowest T=2 state in ^{26}Si (an excitation energy of 13.080$\pm$0.015 MeV). An estimate of the Coulomb displacement between this analog state and the ^{26}P ground state can give an estimate for the latter's mass. A simple size correction (assuming an $A^{1/3}$ dependence) to the known T = 3/2, ^{27}Si* - ^{27}P Coulomb difference[7] gives a value of 11.013$\pm$0.038 MeV (the indicated error is only from known errors of the masses involved) for the ^{26}P ground state mass excess. This value indicates ^{26}P would be bound to direct proton emission by 104 keV. However, if one predicts the ^{26}P mass from a Kelson-Garvey type calculation[8] (all masses from Ref. 6), this indicates ^{26}P would be unbound by 73 keV. A significant Thomas-Ehrman shift is to be expected in ^{26}P and such a shift should cause the ^{26}P mass to be lower than that indicated by a Kelson-Garvey calculation (and would also affect our CDE estimate above). In order to provide a limit for the ^{26}P mass, we have used the barrier penetration code, COCAG[9], to estimate the maximum energy available for $\ell = 0$ proton emission which still permits beta decay to dominate. The conclusion from this is indicated in Fig. 2; ^{26}P can be up to 50 keV unbound and it would not significantly affect any of our observations.

A shell model calculation[10] by Wildenthal for the beta decay of ^{26}P using allowed branches to states up to 9 MeV in excitation in ^{26}Si and the superallowed branch yields a predicted half-life of 22 ms. (This should be considered an upper limit on the expected half-life since there will be some contributions from decays to levels above 9 MeV). Assuming a pure Fermi log ft of 3.19 (the Gamow-Teller contribution should be negligible[10]) and using the observed half-life of 20 ms gives a superallowed branch of $1.9^{+3.5}_{-1.4}\%$. Comparison of the ^{26}P yield to the other activities present in the ^{3}He bombardments indicates an effective cross section for the 7.269 MeV proton group of 1.8 nb (within a factor of three) which corresponds to a total production cross-section of $\gtrsim$ 100 nb.

As shown in Fig. 2, other decay modes, besides proton emission, are energetically possible for the analog state in ^{26}Si. Of substantial interest is the possible decay mode of two proton emission from the daughter analog state, following the superallowed beta decay of ^{26}P. This radioactive decay mode has been discussed by Gol'danskii[11] but has not so far been observed. The analogous decay mode for nuclides on the neutron-rich side of the valley of stability, β^--delayed two neutron decay, has been discovered by Azuma et al.[12]; however, detailed experimental information on the mechanism of two nucleon emission should be more readily available in studies involving charged decay products. Work is in progress to observe whether beta-delayed two proton emission arises in the decays of ^{26}P and ^{22}Al.

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Footnotes and References

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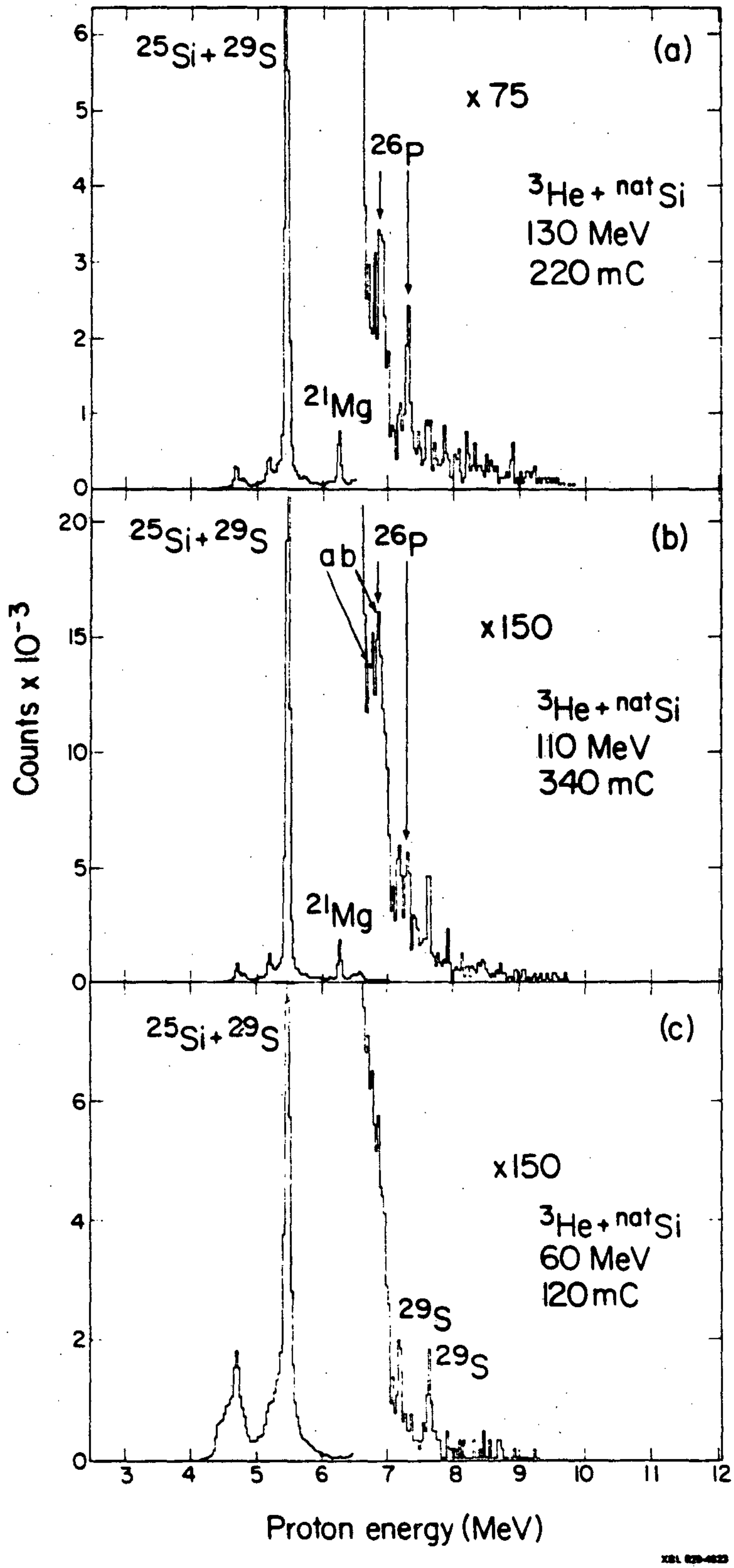
Figure Captions:

Fig. 1. Beta-delayed proton spectra observed following ^{3}He bombardments at (a) 130 MeV, (b) 110 MeV, and (c) 60 MeV. The spacing between the arrows labelled ^{26}P in parts (a) and (b) is calculated from the known energy difference between the ground state and the first excited state of ^{25}Al. See text.

Fig. 2. Proposed partial decay scheme for ^{26}P.



^{25}Si + ^{29}S
(a)
x 75
^{26}P
^{3}He + ^{nat}Si
130 MeV
220 mC
^{21}Mg
^{25}Si + ^{29}S
(b)
a b
^{26}P
x150
^{3}He + ^{nat}Si
110 MeV
340 mC
^{21}Mg
Counts x 10^{-3}
^{25}Si + ^{29}S
(c)
x150
^{3}He + ^{nat}Si
60 MeV
120 mC
^{29}S
^{29}S
Proton energy (MeV)

Fig. 1

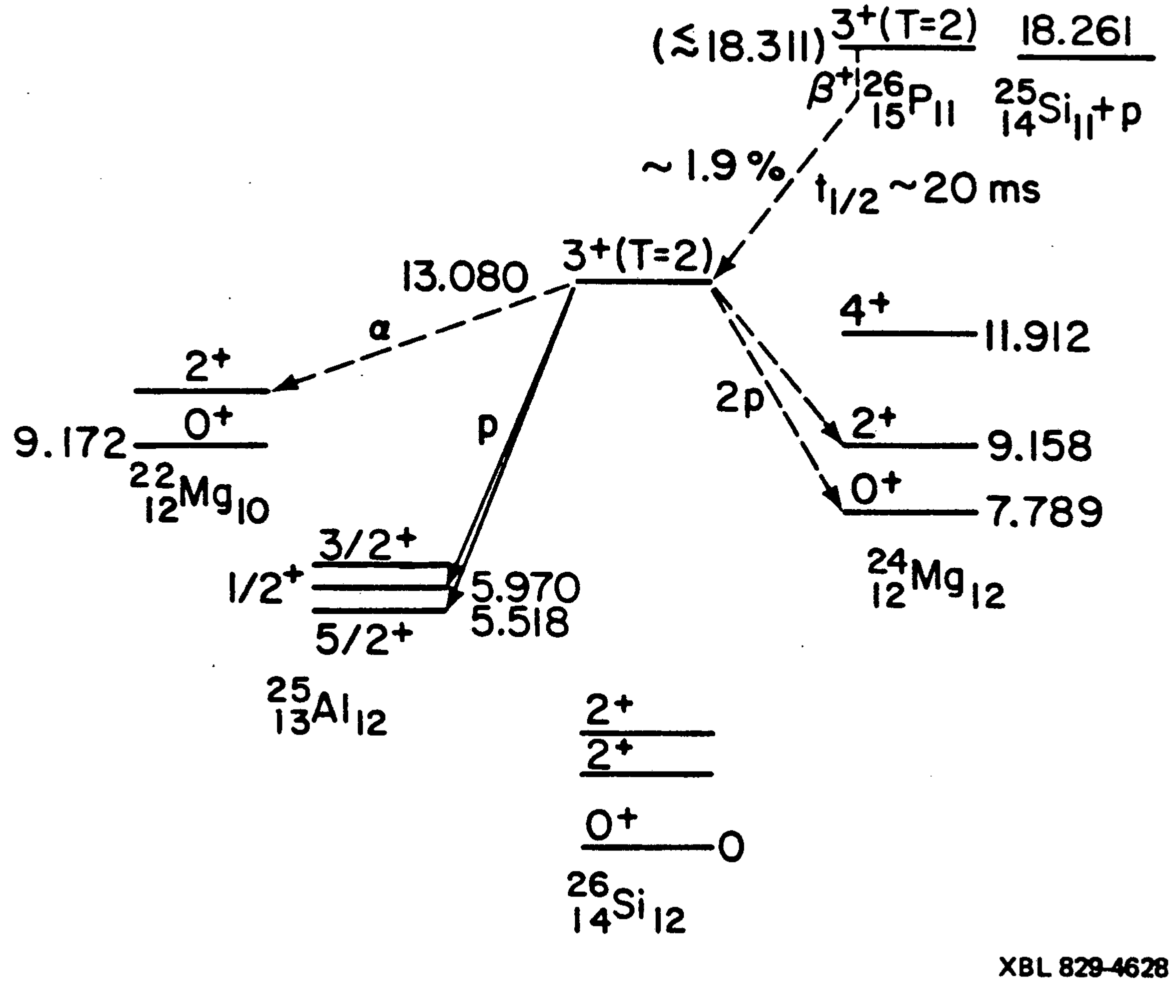

(≲18.311) 3+(T=2)
18.261
β+ 26 15 P 11
25 14 Si 11 + p
~1.9 %
t1/2 ~20 ms
13.080
3+(T=2)
α
2+
0+
9.172
22 12 Mg 10
p
3/2+
1/2+
5/2+
5.970
5.518
25 13 Al 12
4+
11.912
2p
2+
9.158
0+
7.789
24 12 Mg 12
2+
2+
0+
0
26 14 Si 12
XBL 829-4628

Fig. 2

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