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Author
Honkanen, J.

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J. Honkanen, M.D. Cable, R.F. Parry, S.H. Zhou,
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Beta-Delayed Two-Proton Decay of ^{26}P*

J. Honkanen[+], M. D. Cable, R.F. Parry, S. H. Zhou[++],

Z. Y. Zhou[+++], and Joseph Cerny

Department of Chemistry and
Lawrence Berkeley Laboratory

University of California
Berkeley, California 94720

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Abstract:

Beta-delayed emission of two protons has been observed in the decay of ^{26}P. A two-proton summed energy group at 4.914 MeV was assigned to the decay to the ^{24}Mg ground state following the superallowed beta decay of ^{26}P. The mechanism for two-proton emission has, in this case, been shown to be a sequential process.

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Beta-delayed emission of two protons has recently been observed for the first time[1] in the decay of ^{22}Al. Observation[2] of beta-delayed single proton emission from another odd-odd, $T_z = -2$ nucleus, ^{26}P, showed this nucleus to exist and furthermore indicated that the analog state in the beta-decay daughter, ^{26}Si, is unbound to two-proton emission by 5291 keV. We would like to report here the observation of beta-delayed two-proton emission from ^{26}P. As opposed to the complex beta-delayed two-proton emission of ^{22}Al, the particular ^{26}P decay observed is relatively simple and, as such, is well characterized by the experiments described below.

^{26}P ($t_{1/2}$~20 ms) was produced via the ^{28}Si(^{3}He,p4n)^{26}P reaction (estimated[2] total production cross-section ~100nb) by bombarding a natural silicon target with 110 MeV ^{3}He beams of 3–7 μA intensity from the 88-Inch Cyclotron at the Lawrence Berkeley Laboratory. A helium-jet system was used to transport the recoil atoms through a 70 cm long capillary into a measuring chamber, where the activity was collected on a slowly moving wheel. A specially constructed solid state particle telescope, described in more detail in Ref. 1, consisting of three elements (14μm ΔE1, 170μm ΔE2, and 500μm E) was used to observe beta-delayed protons at the collection point. The ΔE detectors were fabricated such that the surface contact on one side was divided down the center, effectively providing two two-element (ΔE1 and ΔE2) telescopes capable of detecting low-energy (1.0–4.5 MeV) protons in coincidence. The average angle between these telescopes was 40° with each side subtending 4.5% of 4π sr. The E detector, combined with either of these two-counter telescopes (referred to as "left" and "right"), was used to detect high-energy single proton groups as $\Delta E1$, $\Delta E2$, E coincidences. A schematic diagram of the experimental arrangement has been given in Ref. 1.

Figure 1 is a summed energy spectrum of the coincident protons observed in the "left" and "right" low energy telescopes with a 20 ns coincidence window following a 600 mC bombardment. In addition to two-proton groups from ^{22}Al decay, which was also produced in this bombardment, a new group at 4.914 MeV (laboratory energy) was observed. This group has been assigned to the decay of the ^{26}Si, T=2 analog state (fed by superallowed beta decay of ^{26}P) to the ground state of ^{24}Mg. Conversion of the observed laboratory energy to the center-of-mass energy (assuming the decay mechanism discussed below) agrees with the expected value of 5.291 MeV for this decay. An arrow at low energy indicates the expected location of the group corresponding to beta-delayed two-proton decay of ^{26}P to the ^{24}Mg first excited state.

Possible decay mechanisms for the emission of these two protons can be categorized as sequential or simultaneous emission. Sequential emission is a two-step process in which a proton is emitted to a level in an intermediate nucleus, which is unbound to subsequent emission of a second proton; therefore, the individual proton spectra should show specific proton groups corresponding to these transitions. Simultaneous emission can be further divided into a) independent or b) diproton (^2He) emission (an unbound proton pair coupled to a $^1S_0$ configuration). Gol'danskii has shown[3] for simple cases of decay that angular momentum barrier penetration considerations favor ^2He emission over independent simultaneous emission. The individual protons arising from ^2He emission are expected to be strongly correlated and would be emitted at a relatively small angle determined by the ^2He kinetic energy and the virtual $^1S_0$ state energy. In this case, the individual proton spectra should show a broad distribution centered around $E_{p_1}=E_{p_2}$.

Figure 2 presents the individual proton spectra in the "left" and "right" telescopes which comprise the 4.914 MeV two-proton group. These relatively simple spectra show coincident groups at laboratory energies of 3699±15 keV and 1210±15 keV, indicating a sequential decay through a single intermediate state. In fact, sequential decay is expected for this particular two-proton transition since this T=2 isospin multiplet should have[4] $J^\pi=3^+$, causing ^2He emission to the ground state of ^{24}Mg ($J^\pi=0^+$) to be spin-parity forbidden. Because the emission of the first proton causes a kinematic shift in the laboratory energy of the second proton (since the second proton is emitted from a recoiling nucleus), it is possible to determine the sequence of the decay by measuring the proton spectra at two different angles. Results of a second experiment performed with two separate telescopes (23μm ΔE1, 270μm ΔE2, 1000μm E) mounted at 120° and each subtending 3.5% of 4π sr show a kinematic shift for the 1.2 MeV individual proton group, which indicates that this group corresponds to the second proton in the sequential process. Thus the intermediate state in ^{25}Al would lie at 3714±21 keV excitation and might correspond to the known[5] $7/2^-$ level at 3695.7±0.5 keV. The proposed decay scheme for ^{26}P two-proton emission is shown in Fig. 3.

The observed coincidence counting rate for two-proton emission will be dependent upon the behavior of the angular correlation between the protons. For the decay sequence assumed above the angular distribution has been calculated (See Ref. 6) and is weakly peaked at $\theta = 90°$. Since the telescopes used all subtend very large solid angles, the angular correlation function also tends to be averaged out and is expected to contribute less than a 20% correction to the relative detection efficiencies. Also of interest is the relative intensity of the 4.914 MeV ^{26}P two-proton group to the 7.269 MeV ^{26}P single proton group (observed originally in Ref. 2). Effective cross-sections for these ^{26}P decay modes are only a few nb and so preclude collection of the high statistics necessary for a precise measurement of this 2P/1P ratio; however, this ratio can be determined to be about 1.5 (within a factor of two).

^{26}P beta-delayed two-proton emission has been observed to occur sequentially for the transition to the ground state of ^{24}Mg, as is expected from spin-parity conservation. Further experimentation is of interest to obtain information about the angular correlation of the two protons and to attempt to observe the decay to the ^{24}Mg first excited state. For this decay, ^{2}He emission is allowed and so might contribute. Comparison of the results of the relatively simple ^{26}P decay to the more complex spectra obtained from ^{22}Al decay is also proceeding.

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Footnotes and References

+On leave from: Dept. of Physics, University of Jyväskylä, Finland.

++Present address: Institute of Atomic Energy, Beijing, China.

+++On leave from: Dept. of Physics, Nanking University, China.

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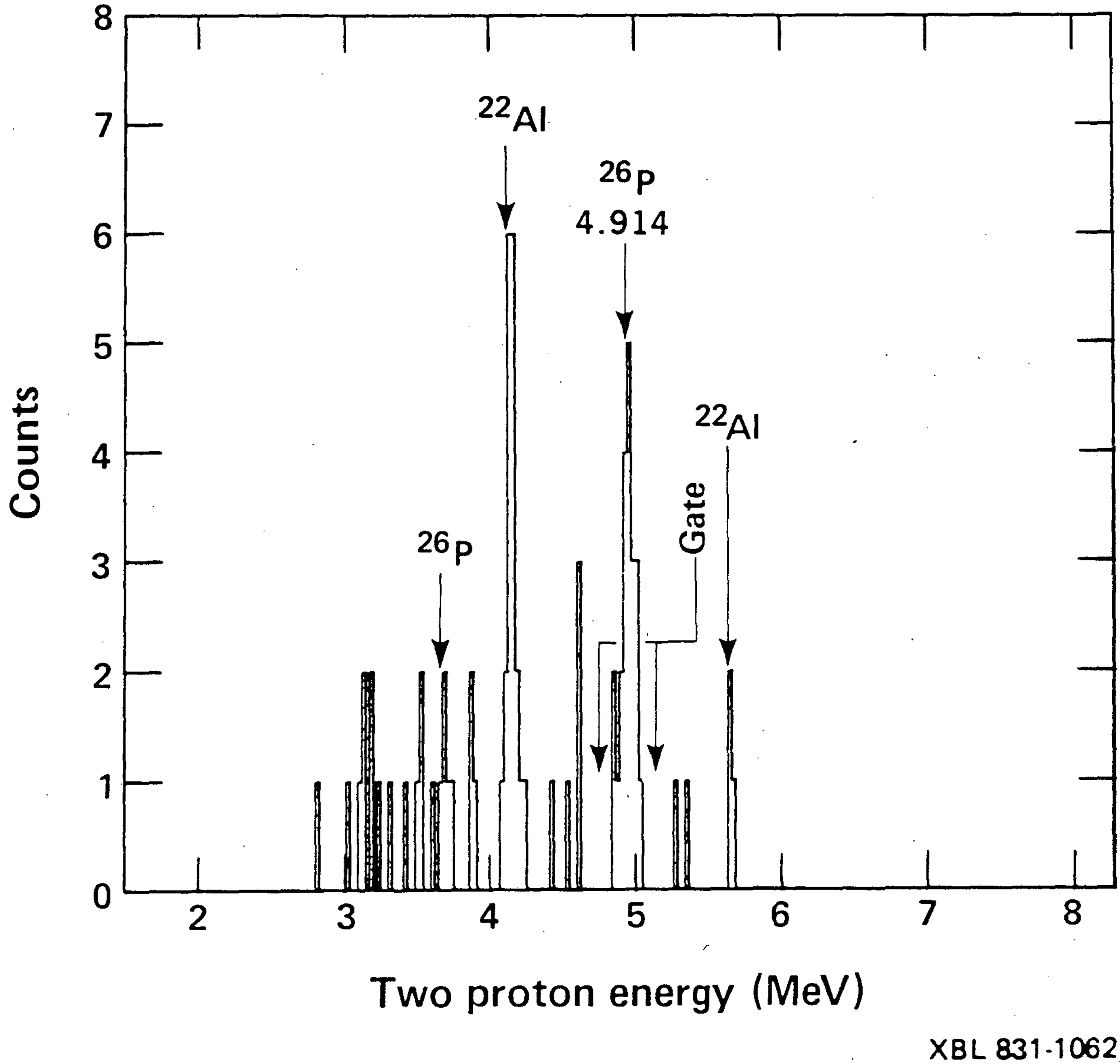
Figure Captions

Fig. 1. A summed energy spectrum for two-proton coincidences arising from 110 MeV ^{3}He bombardment of ^{28}Si. The spectrum is measured with two telescopes separated by an average angle of 40°.

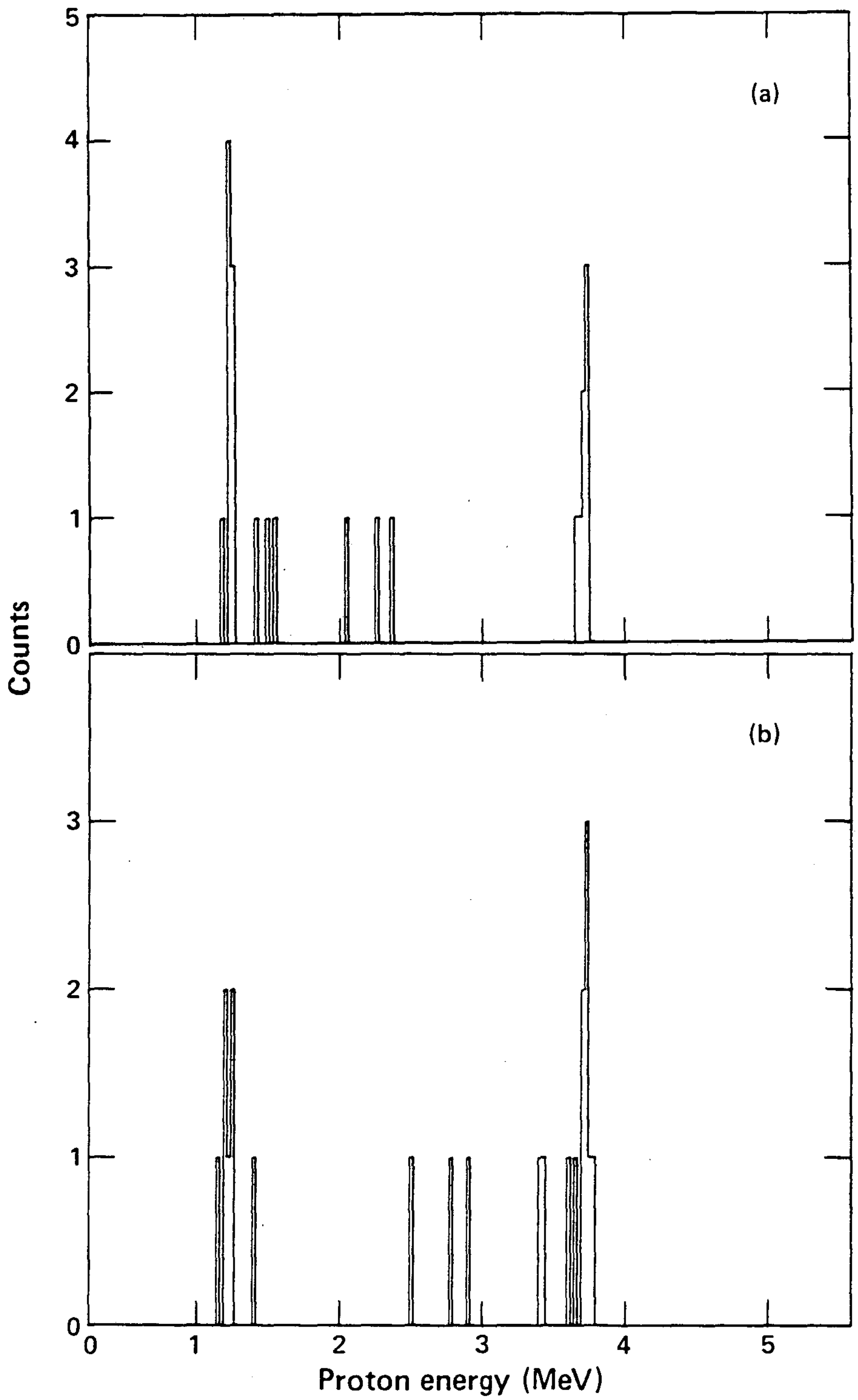
Fig. 2. Individual proton spectra from the two-proton group shown within the gate in Fig. 1. Parts (a) and (b) correspond to events in the "left" and "right" telescopes, respectively.

Fig.3. Proposed decay scheme for the two-proton emission of ^{26}P.



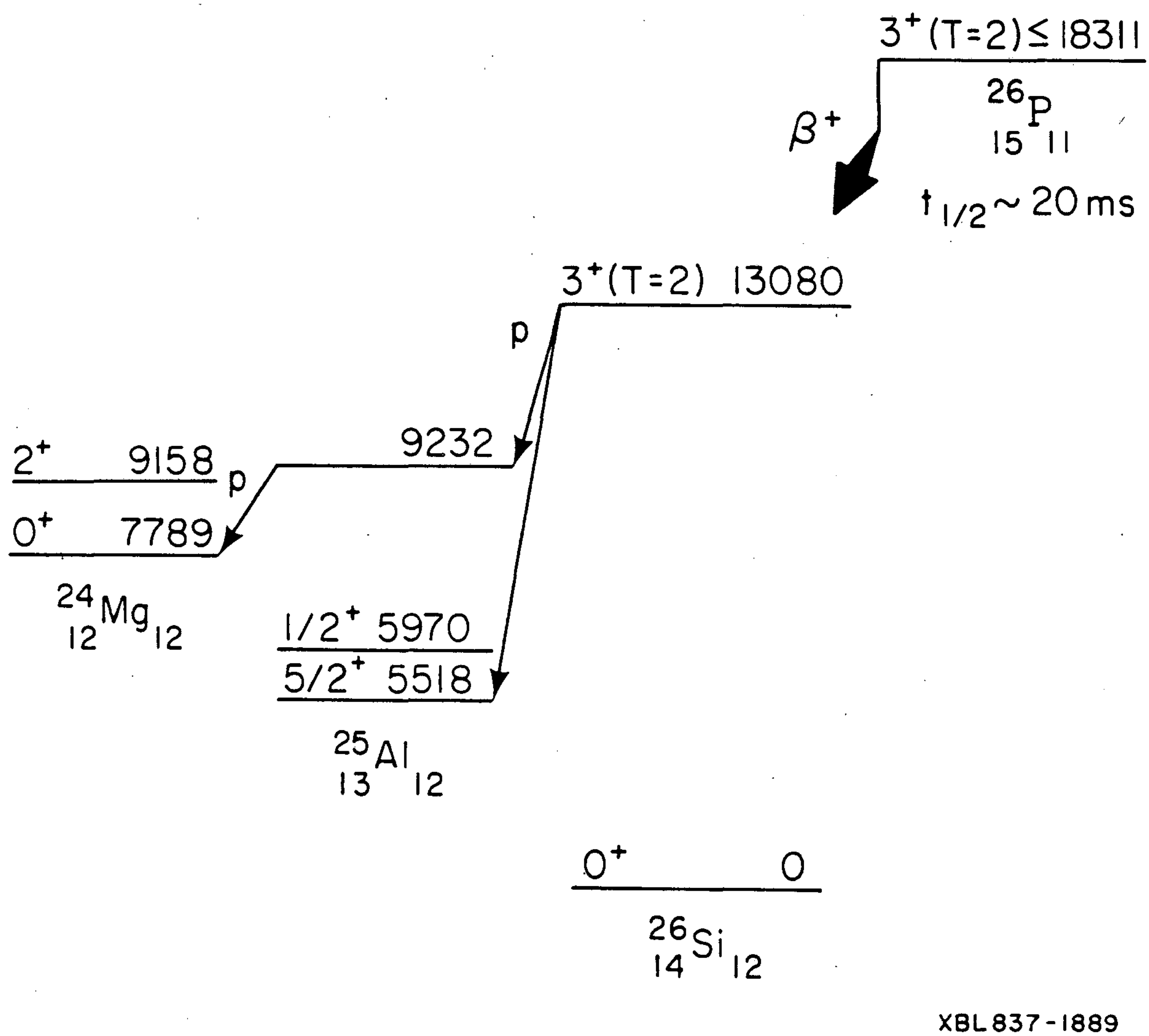
Counts
0
1
2
3
4
5
6
7
8
2
3
4
5
6
7
8
Two proton energy (MeV)
^{22}Al
^{26}P
4.914
^{22}Al
^{26}P
Gate
XBL 831-1062

Fig. 1



XBL 831-1061

Fig. 2



3+ (T=2) ≤ 18311
26 P 15 11
β+
t 1/2 ~ 20 ms
3+(T=2) 13080
p
9232
2+ 9158
p
0+ 7789
24 Mg 12 12
1/2+ 5970
5/2+ 5518
25 Al 13 12
0+ 0
26 Si 14 12
XBL 837-1889

Fig. 3

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720