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DISCLAIMER

Discovery of Beta-Delayed Two-Proton Radioactivity: ^{22}Al*

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Abstract:

A proton-proton coincidence experiment has shown that, following the superallowed beta-decay of the odd-odd, $T_z = -2$ nuclide, ^{22}Al, two protons are emitted with a summed energy spectrum (5.636 MeV, 4.139 MeV) characteristic of decay to the ground and first excited states of ^{20}Ne, respectively.

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Two-proton radioactivity has long been proposed (see the review by Gol'danskii[1]) as a potential mode of radioactive decay for some nuclei far from the valley of beta stability. More recently, Gol'danskii has also discussed beta-delayed two-proton radioactivity[2] and has suggested some potential candidates for this decay mode, among them light mass nuclides in the odd-odd, $T_z = -2$ series. The recent discovery[3] of the first known member of this series, ^{22}Al, and the subsequent observation[4] of an additional member, ^{26}P, made these two nuclei prime candidates for a search for this new mode of decay. We would like to report here the discovery of beta-delayed two-proton emission from ^{22}Al. ^{22}Al is an ideal case for investigation since earlier work on its decay[3] by beta-delayed single-proton emission accurately located the T=2 analog state in its ^{22}Mg daughter (fed by the superallowed branch in ^{22}Al beta-decay), concomitantly showing that this state is unbound to two-proton emission by 6.118 MeV.

^{22}Al ($t_{1/2} \sim 70$ ms) was produced via the ^{24}Mg(^{3}He,p4n)^{22}Al reaction with 110 MeV ^{3}He^{+2} beams of 3-7 μA intensities from the 88-inch Cyclotron at the Lawrence Berkeley Laboratory. Its previously observed cross-section for observation as a beta-delayed proton emitter was 1.2 nb. A helium jet system (see Fig. 1) was used to transport the activity to a counting chamber, much as is discussed in Ref. 3, with the minor modifications that a single target, single capillary (i.d. 1.3 mm, 70 cm long) system was used and the stationary catcher was replaced with a slowly rotating (∿ 1cm/s) catcher wheel to remove long-lived beta activities.

The major difference between this experiment and that described in Ref. 3 was the use of a high geometry, three element particle telescope (with detectors denoted "ΔE1", "ΔE2", "E") capable of identifying and observing two protons simultaneously (see Fig. 1). The "ΔE1" (24μm) and "ΔE2" (155 μm) detectors were fabricated such that the surface contact on one side was divided down the center, effectively producing two detectors on the same silicon wafer. For low energy protons (1.4-4.4 MeV) which stop in the "ΔE2", this construction provides two telescopes (a "left" and a "right") capable of detecting two protons in coincidence even with relatively small angles between the protons. Each two element, low energy telescope subtended 4.5% of 4π sr. Use of the E detector (500 μm), in conjunction with either the "left" or "right" ΔE1 and ΔE2, produces a three element telescope capable of observing, as a monitor of the reaction, the 7.839 MeV proton group arising from the beta-delayed single proton decay of ^{22}Al (with 1.5% of 4π sr subtended in each side). A standard slow coincidence network was used together with fast coincidences measured by time-to-amplitude converters (TAC) giving timing resolution 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[5].

The two-dimensional proton-proton coincidence spectrum obtained following a 690 mC bombardment is shown in Fig. 2(a). This spectrum is the result of identifying and displaying a "left" and a "right" proton in a 20 ns coincidence window; the summed proton energy spectrum appears in Fig. 2(b). Given the 20 ns coincidence window and the observed proton counting rates in each telescope (almost entirely from the $T_z = -3/2$ beta-delayed proton emitters ^{21}Mg and ^{25}Si), only one random coincidence is to be expected in this spectrum.

Laboratory energies of the two-proton total energy peaks shown in Fig. 2(b) are 4.139±0.020 MeV and 5.636±0.020 MeV. Exact corresponding center-of-mass energies depend on the mechanism of two-proton emission, as will be discussed further below; however, these peaks can be shown to correspond to transitions from the ^{22}Mg T = 2 analog state (fed by the superallowed beta decay of ^{22}Al) to the ground state and first excited state of ^{20}Ne (see Fig. 3).

Interpretation of the results, beyond the assignment of the groups observed, requires some consideration of the mechanism(s) for the emission of two protons from the intermediate T = 2 state in ^{22}Mg (this state will be relatively narrow since all open particle-decay channels are isospin-forbidden). Two possibilities are A) single-step ^{2}He emission[1,2] (two protons coupled to a $^{1}S_{0}$ configuration) or B) a sequential two-step process proceeding through an intermediate state (or states) in ^{21}Na.

Focusing on the stronger decay branch, ^{2}He emission to the first excited state of ^{20}Ne should occur predominantly within relative laboratory angles of $\lesssim 40^o$ as evidenced, for example, by the distribution in ^{2}He break-up (BU) energies observed by Congedo et. al.[6], which has the expected maximum at $E_{BU} \sim 0.5$ MeV. Since the telescope pair used in this experiment is capable of detecting protons at angles of 0 - 70^o, it could observe proton coincidences originating from either mechanism. Individual proton energies arising from the former mechanism are expected to show a distribution centered about $E_p^L = E_p^R$, with the observed shape of the distribution determined by the final state interaction and the detector configuration [6]. Sequential emission, while still symmetric about $E_p^L = E_p^R$, would be expected to show distinct proton groups corresponding to transition energies through the intermediate state(s) in ^{21}Na. Given the currently limited statistics, the proton-proton coincidence spectrum shown in Fig. 2(a) cannot conclusively distinguish the mechanism; the observed variation in yields and energies could result from either a ^{2}He type distribution or sequential decay through several states in ^{21}Na or both.

In addition to obtaining higher statistics with this detector configuration, subsequent experiments designed to yield other angular correlation information should clarify the mechanism through the observation of changes in the yield and observed laboratory energies of the emitted coincident protons; however, such experiments are made difficult by the requirement of high geometry to produce usable counting rates.

The calculation of the relative intensity of two-proton to one-proton emission (2p/1p) from $^{22}Mg^*$ (using only the 4.139 MeV two-proton group and the 7.839 MeV single proton group) is dependent on the assumed mechanism since our detector arrangement has an efficiency dependent on the angular correlation of the protons. If an isotropic sequential distribution is assumed, 2p/1p = 1.5 whereas if all events are assumed to be emitted at a laboratory angle of 40° (^2He), 2p/1p = 0.3. (These values are also dependent on the observable individual proton energy range detectable by the telescopes.) For systematic reasons in beta-delayed proton decay, the ratio of 2p/1p = 1.5 for sequential emission appears high and so would perhaps indicate a component of ^2He emission.

In summary, beta-delayed two-proton emission has been established in the decay of ^{22}Al, but the mechanism for this decay is still uncertain. Should these decays proceed by ^2He emission, one could have an exciting new form of radioactivity to explore [1,2]. Work is in progress to determine the two-proton decay mechanism(s) of ^{22}Al and also to determine whether this mode of decay arises in the disintegration of ^{26}P.

We would like to thank C. E. Ellsworth for his valuable assistance on these experiments and J. T. Walton for fabrication of the detectors. We would also like to thank B. Jonson for helpful discussions on this topic.

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Footnotes and References

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Figure Captions:

Fig. 1: A schematic diagram of the experimental set-up.

Fig. 2(a): A proton-proton coincidence spectrum following the beta decay of ^{22}Al (E_p^L vs. E_p^R). Kinematic lines corresponding to decay to the ground state and to the first excited state of ^{20}Ne are shown. Increasing square size corresponds to increasing number of counts.

(b): A summed energy spectrum for the two-proton coincidences in (a):($E_p^L + E_p^R$).

Fig. 3: Proposed partial decay scheme for ^{22}Al.

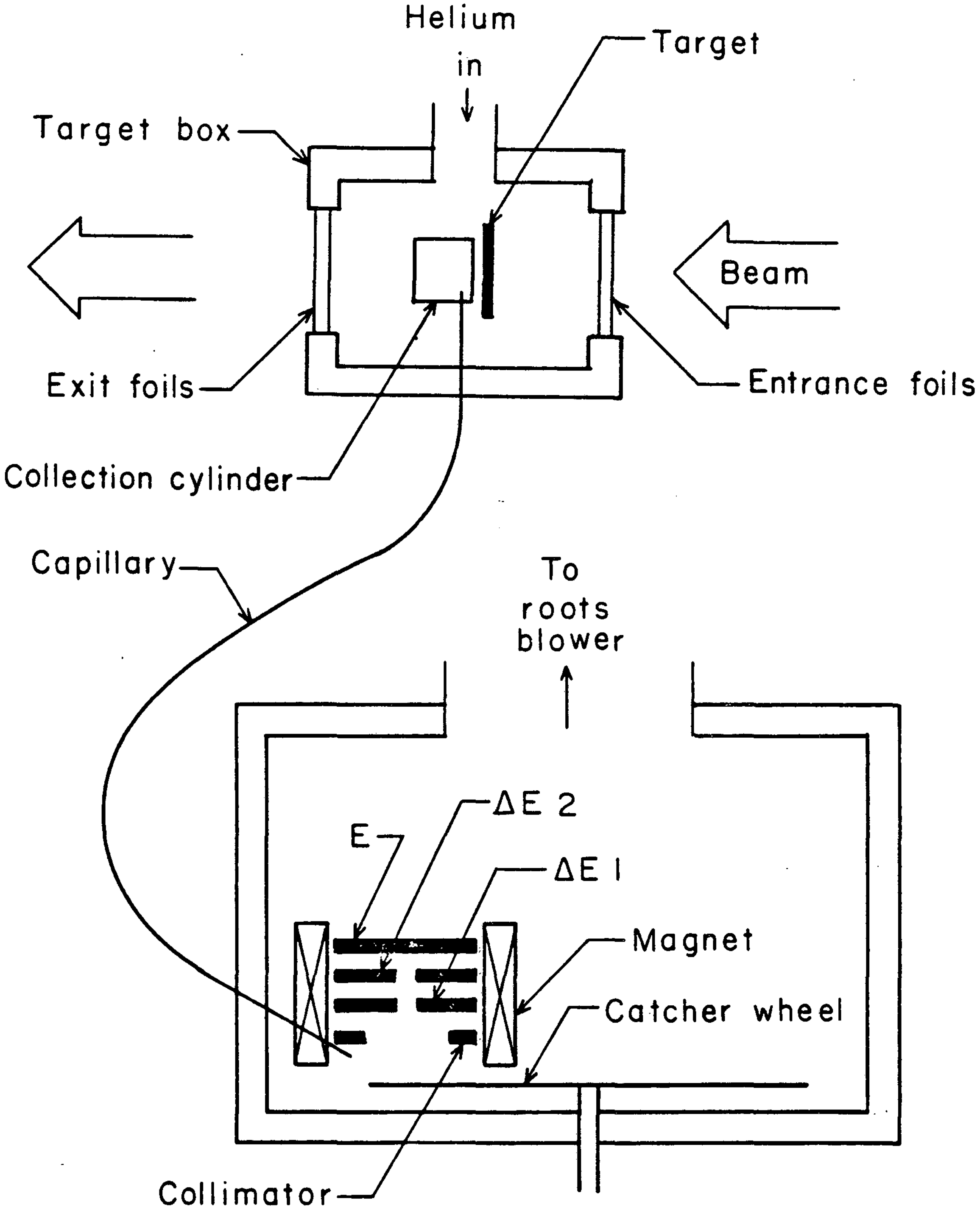

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Fig. 1

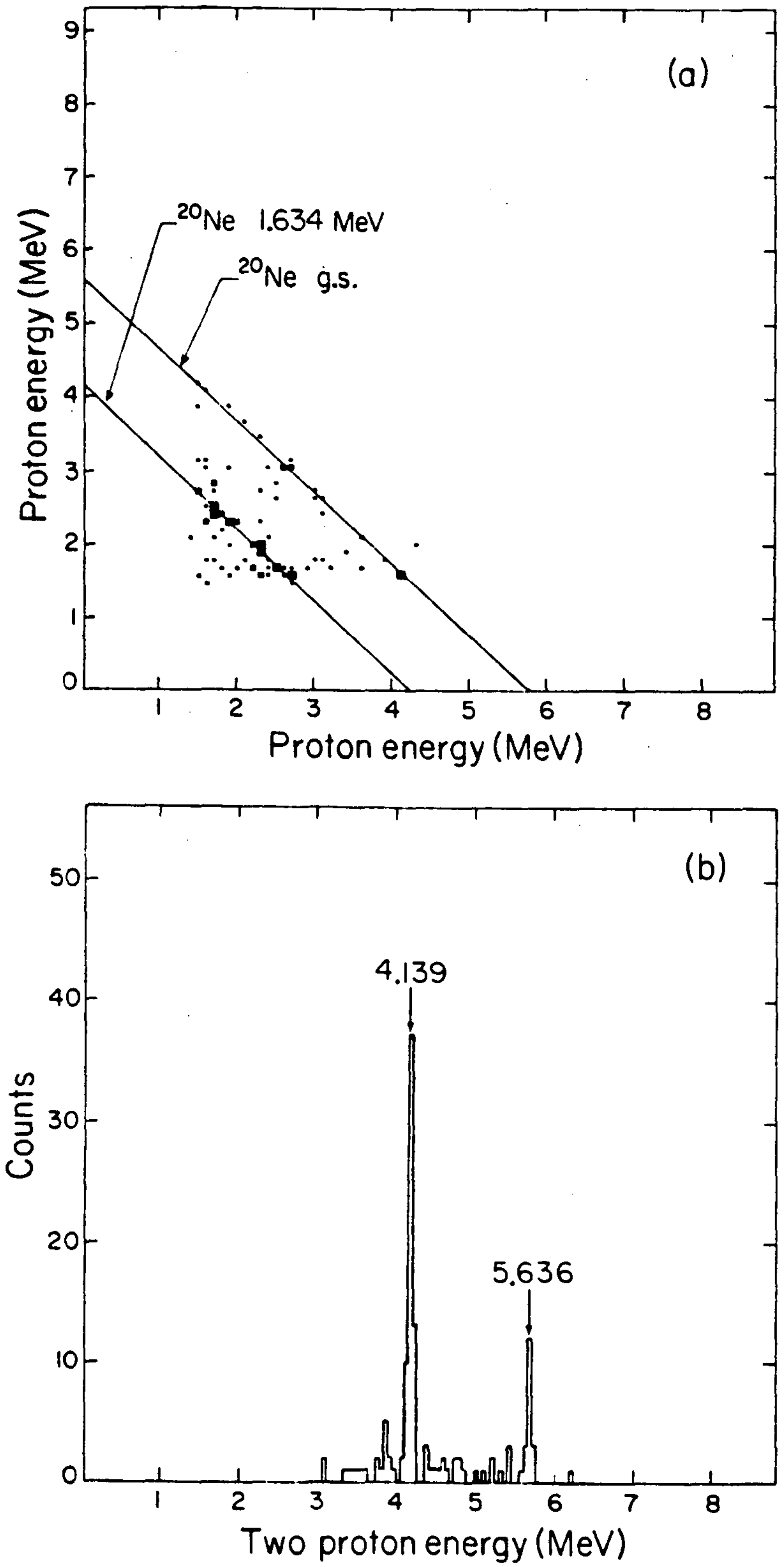

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Fig. 2

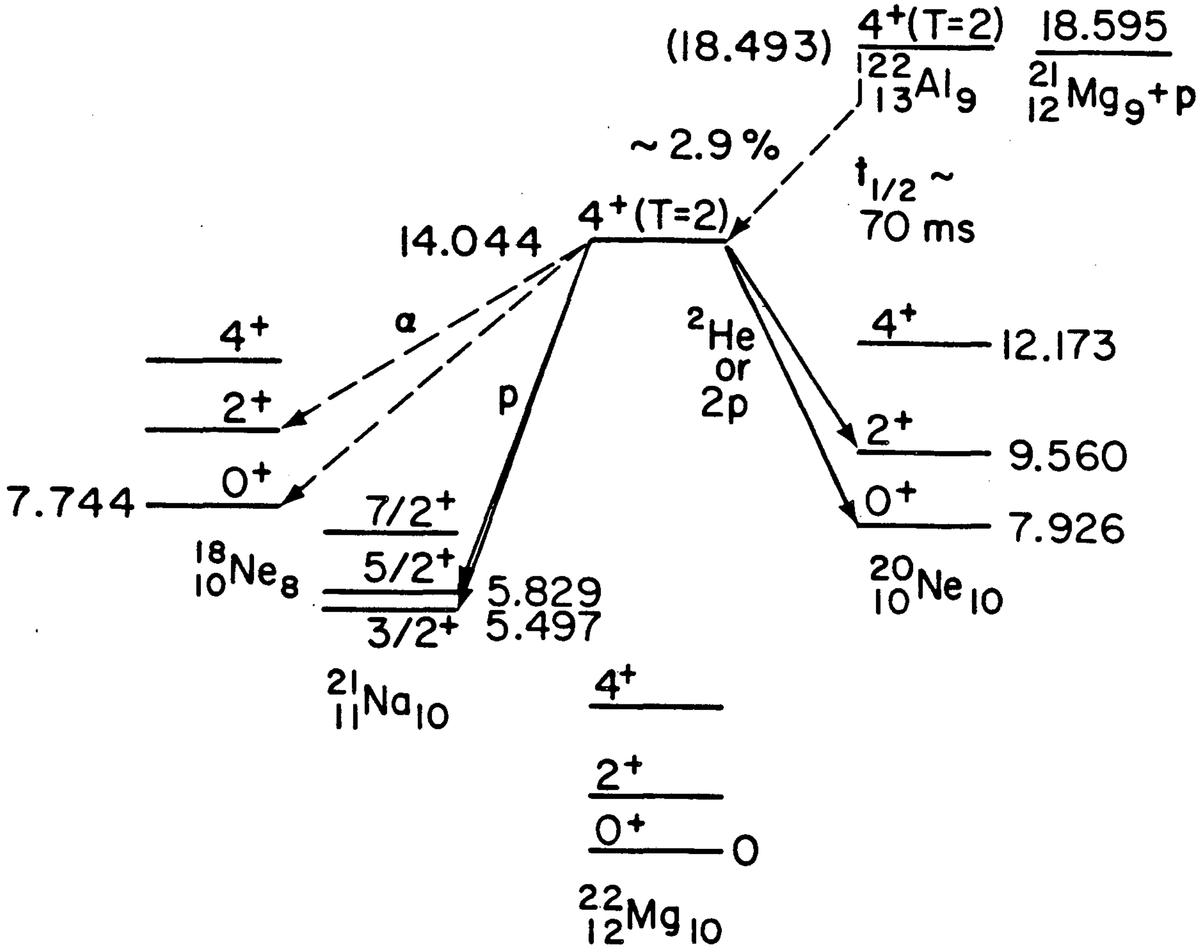

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Fig. 3

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