SEARCH FOR DELAYED-PROTON EMITTER $^{24}Si^{\dagger}$

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Abstract

Preliminary results of a search for ^{24}Si produced via the (^3He,3n) reaction at $\sim$ 60 MeV are reported. The detection apparatus consists of a helium-jet system, a proton detector and a recoil time-of-flight detector for mass identification. Despite some positive indications, it is concluded that the production cross-section for ^{24}Si at this energy is probably less than 2% of the ^{25}Si cross-section.

1. Introduction

The detection of T_z = -2 nuclides (a proton excess of 4) as radioactivities has not been reported despite a number of efforts to produce them. Not only are they of intrinsic interest as the most proton-rich nuclei, but they also may provide a means of precisely locating the T=2 state in the daughter nucleus through Fermi β-decay and delayed proton emission. We wish to report preliminary results of a search for ^{24}Si.

The β^+ decay of ^{24}Si will populate the 0^+, T=2 state in ^{24}Al as well as 1^+, T=1 states. The results of a shell-model calculation[1] combined with information from the β^- decay of ^{24}Ne, and the isobaric multiplet mass equation (IMME), lead to the decay scheme shown in Fig. 1.

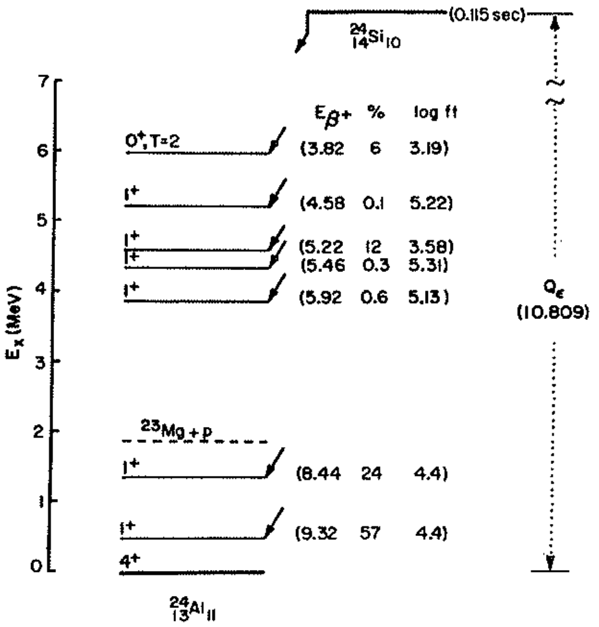

Fig. 1 Proposed decay scheme for ^{24}Si, from ref. 1

The decay of $\sim$ 100 ms - ^{24}Si should populate the 0^+, 2 state of ^{24}Al about 6% of the time. This state, and several 1^+, 1 states, lie above the proton emission threshold. A number of final states in ^{23}Mg are accessible, in particular the ground state ($3/2^+$, 1/2), the first excited state at 451 keV ($5/2^+$, 1/2), and several states above 2 MeV excitation. It is difficult to predict reliably which of these will be populated in the isospin-forbidden proton decay of the 0^+, 2 state, but the ground state transition of (4084 ± 14) keV c.m. lies fortuitously in a region which is clear of proton lines from $^{25}Si(\beta^+)^{25}Al(p)^{24}Mg$.

2. Method

The method adopted to search for ^{24}Si involves coincident measurement of proton energy and recoil fragment time-of-flight. The recoil mass is then proportional to the time-of-flight and the square root of the proton energy. Determination of the recoil mass serves not merely to reduce background and interference from uninteresting species, but more importantly, to identify conclusively the mass of the parent nuclide associated with each proton group.

A schematic diagram of the apparatus is shown in Fig. 2.

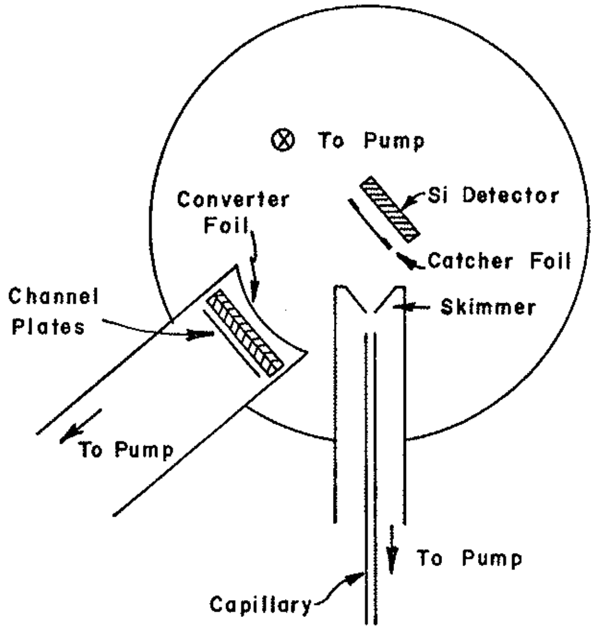

Fig. 2 Schematic diagram of proton-and recoil-mass-detection system

Activities produced in a helium jet system are transported to a thin catcher foil ($\sim$ 30 μg cm^{-2} of Formvar) via a skimmer cone which removes much of the helium gas. Protons pass through the foil to a Si detector and recoils from proton decay pass through a converter foil (also about 30 μg cm^{-2} of Formvar, supported on Ni mesh) about 10 cm away. Secondary electrons from the foil are accelerated to a two-stage microchannel plate assembly which provides the timing information. This procedure has two advantages over direct detection of the recoil ions - it permits compensation of geometrical time dispersion by appropriately curving the foil, and it allows the channel plates to operate in a clean, high vacuum (provided by a turbomolecular pump). The efficiency for detecting recoil ions in the 100-200 keV range under consideration appears to be of order unity, and by recording signals from the interface between the first and second channel plates, some discrimination can be obtained between recoils and β particles, as the latter give much smaller pulses.

The mass resolution is limited entirely by the effects of β-recoil for all transitions of interest in this work. While the electronic time resolution

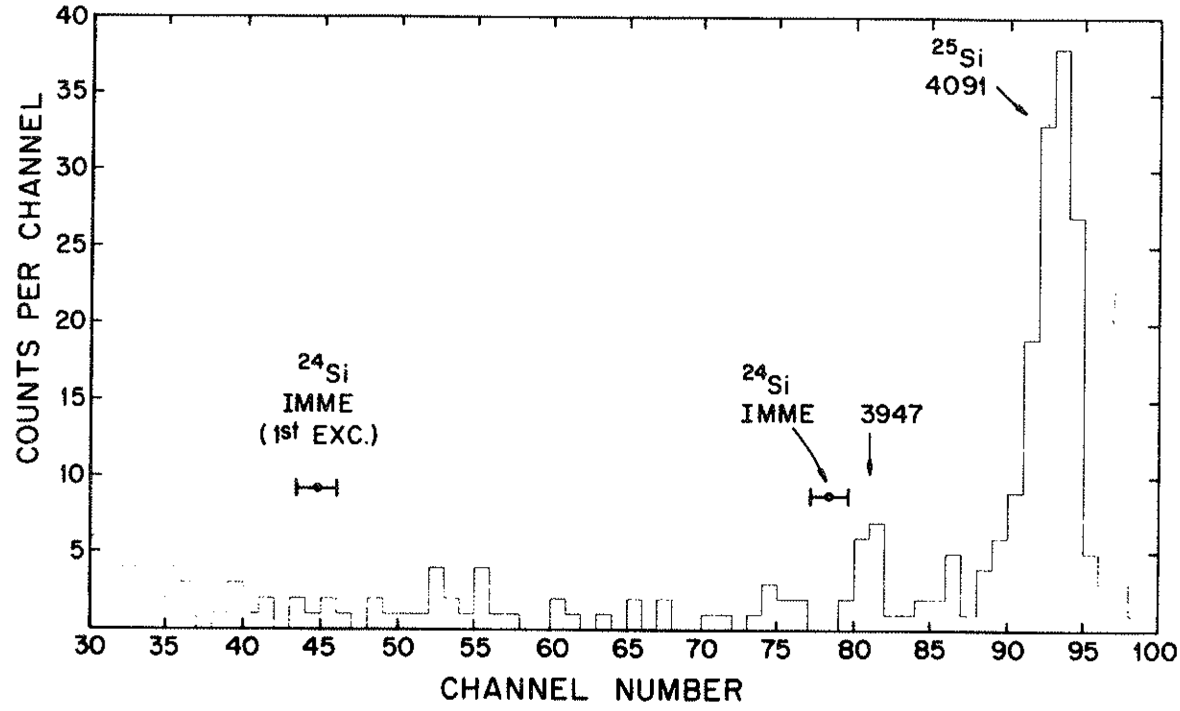

Fig. 3 Portion of the proton energy spectrum gated on recoil mass 23, from the first experiment

is about 1 ns, it is not possible with any flight path to achieve better than about 7% mass resolution, or 2 mass units, for the main transitions in ^{25}Si and ^{24}Si. The transitions of interest are both Fermi decays, for which the electron-neutrino correlation is peaked at zero degrees, and the velocity spread caused by recoil is at a maximum. Nevertheless, this resolution is entirely adequate to remove all activities (such as ^{21}Mg, ^{20}Na) from the ^{24}Si mass band, with the exception of ^{25}Si.

3. Results

An initial experiment was carried out with 57 MeV ^{3}He ions incident on a natural Mg target. About 250 ^{25}Si coincidences at 4091 keV were recorded, and a proton spectrum gated on recoil mass 23 (i.e. appropriate to ^{24}Si decay) is shown in Fig. 3. In addition to the familiar 4091 keV line from ^{25}Si, there is evidence for a weak line at (3946±7) keV. Since no such line is known at that intensity (about 4% of the 4091 keV line) in the ^{25}Si spectrum[2], and since it corresponds quite closely to the energy predicted by the IMME, it seems possible the line could arise from ^{24}Si decay. Support for that belief comes from the mass projection for the line (Fig. 4). However, the centroid of the mass distribution is $A = 23.5\pm0.3$, which may suggest some background contribution with a high mass content. It may also be noted that any transient effect which caused protons from the 4091 keV peak to be registered at 3946 keV would also cause the apparent recoil mass to be 23.5. Nevertheless, the narrowness of the line and its proximity to the IMME prediction are remarkable.

A subsequent experiment at 62 MeV in which some detailed improvements were made in background rejection failed to yield any significant indication of the transition observed previously, although some 400 ^{25}Si coincidences were recorded. A two-dimensional plot of a portion of those data is shown in Fig. 5. The region immediately below

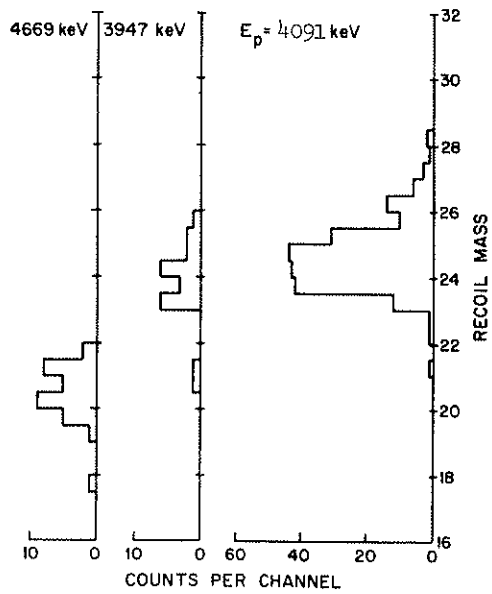

Fig. 4 Mass spectra for three proton groups observed in the first experiment: ^{21}Mg 4669 keV (left), unknown line at 3946 keV (center), and ^{25}Si 4091 keV (right)

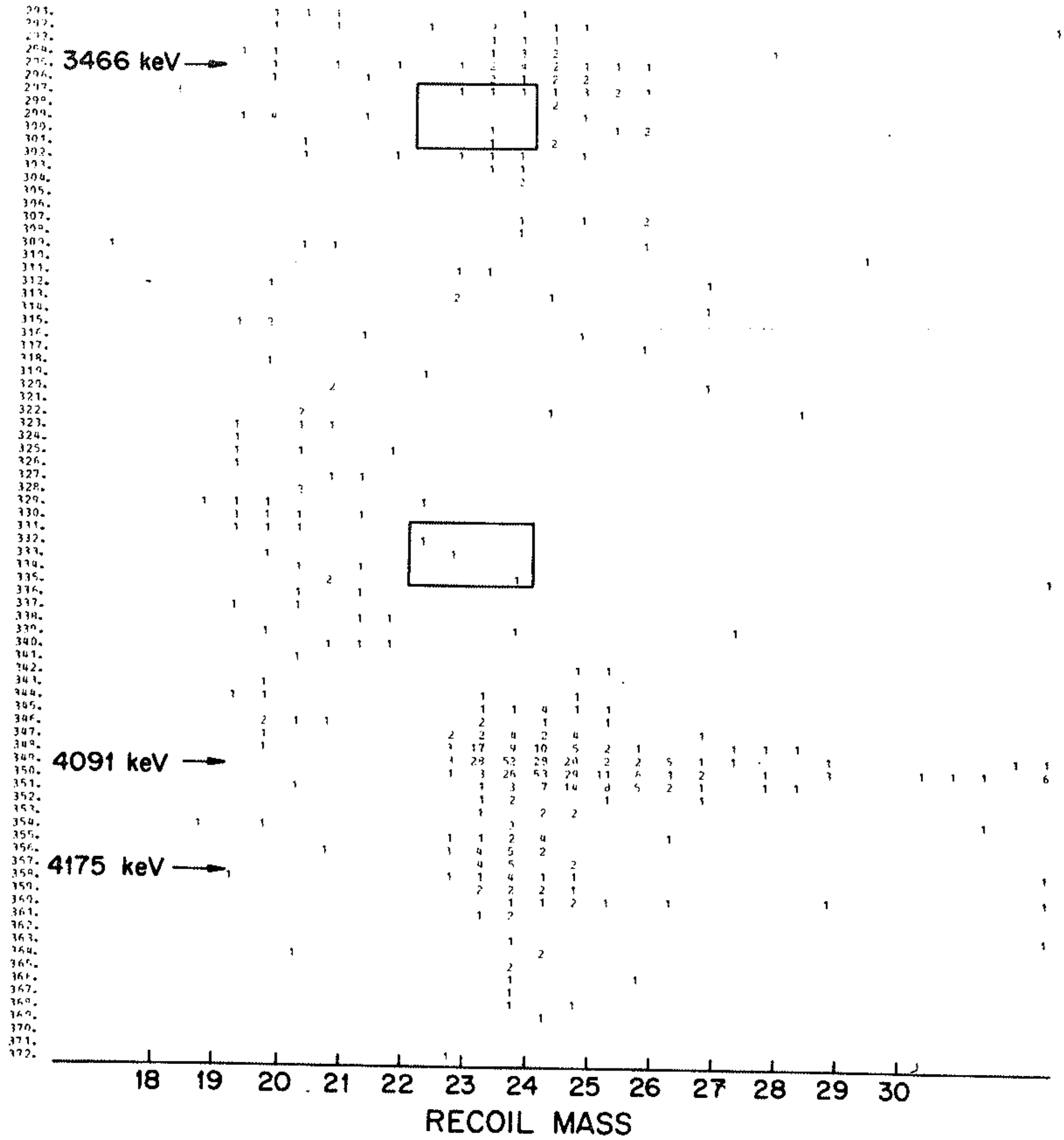

Fig. 5 Two-dimensional plot of proton energy (increasing down the page) against recoil mass. Selected proton groups from ^{25}Si are indicated at left. Weak groups from ^{21}Mg are also visible. The rectangles enclose areas in which proton decays from ^{24}Si are expected

the 4091 keV line in energy is extremely clean, and a single count corresponds to a relative transition strength of 0.3%. Examination of the proton spectrum gated on the recoil-mass-23 band (fig 6) reveals at most 2 or 3 counts at the energy predicted by the IMME for the ground state transition.

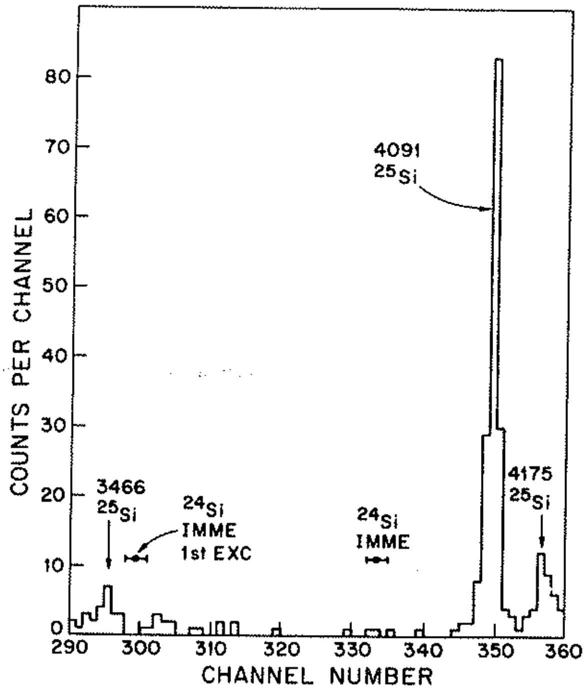

Fig. 6 Plot of proton energy for recoil mass 23, from the data shown in Fig. 5

The present results suggest that at 62 MeV, production of ^{24}Si by the $^{24}Mg(^3He,3n)$ reaction is very weak relative to $^{24}Mg(^3He,2n)^{25}Si$. If the major branch of the proton decay of the 0^+, 2 state in $^{24}A\ell$ leads to the ground state of ^{23}Mg, then the cross-section for the $(^3He,3n)$ process is no greater than 2% of the $(^3He,2n)$ reaction. Nevertheless, by further development of the recoil mass spectrometer described in this paper, a further reduction of at least a factor of 5 in this limit should be achievable.

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1. R.G.H. Robertson and B. H. Wildenthal, Phys. Rev. C8, 241 (1973).

2. R. G. Sextro, Ph.D. Thesis, 1973 (LBL-2360).