β-delayed p-decay of proton-rich nucleus ^{31}Cl

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We have continued our recently started series of measurements of the β-delayed proton decay of proton-rich nuclei using a new technique that was proved very successful [1]. This is part of a larger program motivated by nuclear astrophysics. In the first half of 2007 we have measured the β-p decay of ^{23}Al. We have recently produced and separated ^{31}Cl using MARS (test run in early October 2007) and have done measurements of its β-γ decay and β-p decay in late November 2007. The interest was generated in the first place by the fact that the reaction ^{30}P(p, γ)^{31}S is one of the most important (if not the most!) stepping stones toward heavier elements created in novae and its currently known rate is affected by a factor 100 uncertainty [2]. The dominant contribution is from resonances. Also, very little is known about the decay of ^{31}Cl, because of the difficulties encountered in its production and separation. Its half-life and its decay Q-value are known with large uncertainties ($T_{1/2}$=150(25) ms and Q_{EC}=11980(50) keV, respectively), while the decay scheme can be at best be characterized as poorly known [3]. β-decay of ^{31}Cl can populate and give information about the excited states in ^{31}S above the proton binding energy Sp=6133 keV. These states become resonances in the reaction ^{30}P(p, γ)^{31}S and those within about 1 MeV above threshold are in the Gamow window at novae temperatures and have the largest importance. Precise information about the levels in this region is currently missing or poor [4,5]. The position and the decay widths Γ_p, Γ_γ of these states are needed.

Excited states in ^{31}S above the proton threshold, which are populated in the β-decay of ^{31}Cl can decay by p, γ, or both. To measure protons with the low energies corresponding to these states, the low-energy efficiency of the detectors is always a problem. We avoid them by implanting the source in the detector. This can be done given the large kinetic energy of our sources produced in inverse kinematics with MARS. The same setup [1] as in the ^{23}Al experiment was used: one 65-μm thick Si strip detector (p-detector) and one 1 mm thick Si detector (β-detector). This telescope was at 45° to the beam axis to allow for good gamma-ray detection with a 70% HpGe detector situated at 90° outside the small chamber. A variable energy degrader consisting of two Al foils (sum=0.5 mm thick) on a computer controlled rotating feed-through (redesigned after the previous run to give better accuracy) was used to stop the desired source nuclei in the middle of the thin p-detector.

The ^{31}Cl beam was obtained using a 40 MeV/nucleon ^{32}S beam from the K500 cyclotron bombarding a cryogenic target containing H_2 gas at 2.0 atm. MARS was used to separate ^{31}Cl (at 34 MeV/nucleon) produced through the ^{32}S(p,2n) reaction in inverse kinematics. With the momentum acceptance slits set at +/-1.0 cm we had a maximum beam rate of about 2-3000 pps and a purity of 85% on the target detector. The associated momentum spread (+/-0.65%) and angular spread translates into a too large spread of the implantation depths in the p-detector and we had to close the momentum and angle slits further (to +/-0.27% momentum). We have worked with rates of about 4-500 pps in the p-detector in the actual measurement. This rate proves safe for the detector. Because of the different range in Al (energy degrader)+Si (p-detector) of the accompanying impurities in the beam, the ^{31}Cl sample that stopped in the p-detector during the measurements was almost 100% pure. In cycles, we pulsed the beam from the cyclotron, implanting the source nuclei (for 0.3 sec.), then switched the beam off and, after a very short delay (1 msec), measured β-p and β-γ coincidences simultaneously (also for 0.3 sec.). Si detectors are sensitive to positrons and protons, and the total signal in the implantation detector is the sum of the proton and beta contributions. That produces an asymmetry on the high-energy side of it and a large background at lower energies. To minimize these effects, the p-detector was taken as thin as possible.

The measurements used the telescope in two different modes:

a) The *implantation control mode*, in which the two detectors worked as a ΔE-E HI telescope. It was used to determine that the implantation was restricted to a central region of the p-detector. The signals in each detector were up to 300 MeV.
b) The *decay study mode*, in which the gain was adjusted to accommodate the detection of low energy protons and betas (up to 4 MeV in the p-detector and 8 MeV in the β-detector).

Gamma-rays in the range E_γ=0-8 MeV were measured in coincidence with positrons measured by the β-detector.

We have measured the following:

- implantation control in the HI telescope mode for ^{31}Cl (and later for ^{32}Cl, ^{29}S used for calibrations)
- gamma-ray detector calibration with ^{32}Cl implanted in the p-detector.
- ^{31}Cl β-delayed p-decay with ^{31}Cl implanted in the p-detector. β-p and β-γ coincident spectra were measured here to identify the proton peaks and get the proton branchings.
- p-detector calibration with ^{29}S and ^{32}Cl implanted in the p-detector.
- off-line Ge detector efficiency calibration with sources (^{152}Eu, ^{60}Co, ^{137}Cs).

At this time all data have only been preliminarily analyzed. An excellent gamma spectrum following the decay of ^{31}Cl, far better than existing ones, was obtained and is shown in Fig. 1. A good energy calibration for the whole range up to E_γ=7 MeV could be made. In particular, four decay cascades from the T=3/2 IAS state of ^{31}Cl g.s. are identified and the state's excitation energy is well established at E(IAS)=6279.5±0.3(stat)±1.5(syst) keV. From it, and using the IMME equation, we can deduce a more accurate mass for ^{31}Cl, corresponding to Q_{EC}=11980(8) keV. A preliminary decay scheme has also been established. Proton lines in the proton spectra were measured in the 400-2200 keV range.

We intend to extend our studies to nuclei with similar properties and similar importance in explosive H-burning in stars.

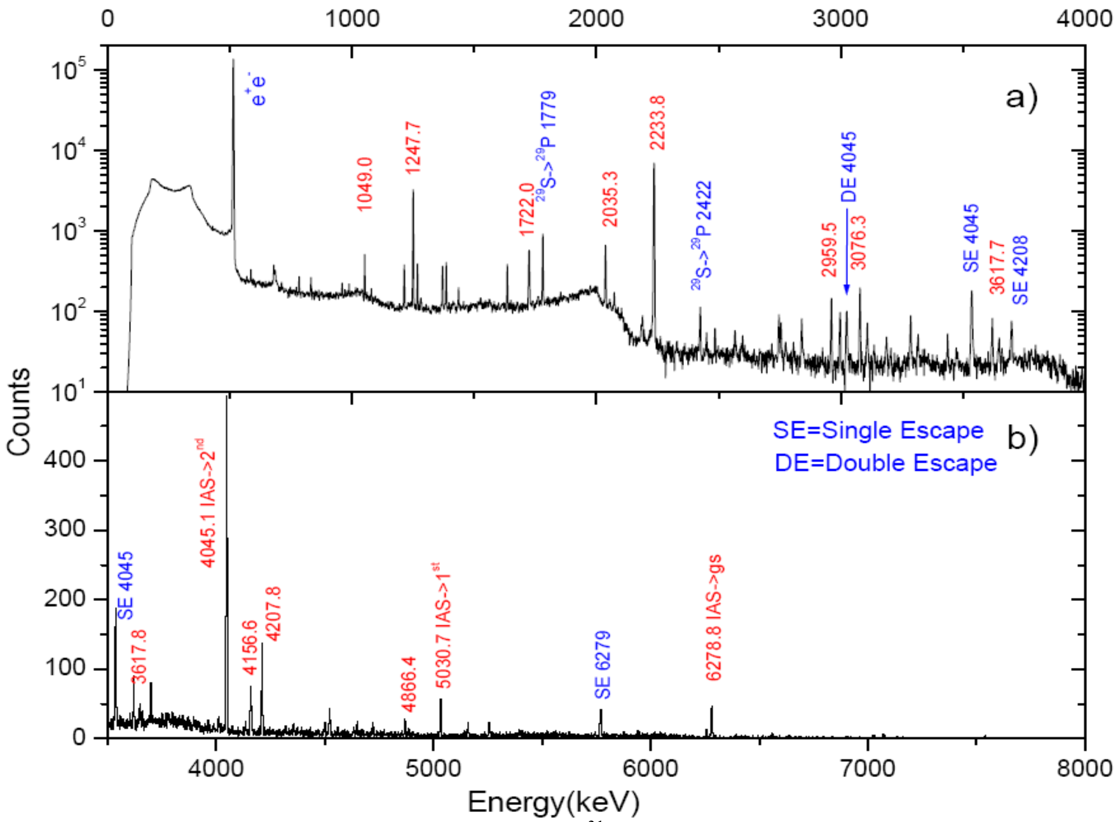

Figure 1. The gamma ray spectrum from the decay of ^{31}Cl implanted in the p-detector.

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