Ground state mass of ^{81}Kr and the solar neutrino problem

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(Received 5 November 1981)

The ^{81}Br(^{3}He,t)^{81}Kr reaction has been used to determine an improved value for the ground state mass of ^{81}Kr. A comparison is made with ^{51}V(^{3}He,t)^{51}Cr and the implications for calibration of the proposed bromine solar neutrino detector are presented.

NUCLEAR REACTIONS ^{81}Br(^{3}He,t)^{81}Kr, ^{51}V(^{3}He,t)^{51}Cr, ^{87}Rb(^{3}He,t)^{87}Sr, ^{85}Rb(^{3}He,t)^{85}Sr, $E(^3$He$)=24.7$ MeV; Q values measured, ground state ^{81}Kr mass inferred.

The theoretical picture for the rates of the nuclear reactions which power the sun is still not reconciled with the single piece of direct experimental information available about the solar interior, namely, the measured flux of neutrinos with energy sufficient to convert ^{37}Cl into ^{37}Ar($Q=-814$ keV) in the Davis experiment.[1,2] The proposed ^{71}Ga based experiment[3] is most sensitive to the much lower energy but far more prolific neutrinos emanating from the presumably primary step of the solar fusion cycle, the $p+p\rightarrow d+e^{+}+\nu+420$ keV reaction. To learn about neutrinos of intermediate energy such as those from the decay of ^{7}Be($Q=862$ keV) requires a different detector. The recently determined[4] logft value of 4.88 ±0.11 for neutrino capture by ^{81}Br leading to the ^{81}Kr 190 keV isomeric $\frac{1}{2}^-$ state makes bromine an attractive candidate.[5]

The yield from such a detector will also have contributions from captures to other excited states. Since the solar neutrino flux tends to diminish with increasing energy, the most important ^{81}Kr states will tend to be those of appropriate spin and parity low in excitation energy. The most worrisome such level is the $\frac{5}{2}^-$ state at 457 keV. Measurement of the inverse process, β decay, is impossible for this level. A large basis shell model calculation[6] finds only 13% of the ^{81}Kr production would proceed via neutrino capture to states other than the isomeric state, but fails to accurately describe the $\frac{5}{2}^-$ state. Thus the only way to calibrate a bromine based detector with complete confidence is to observe a neutrino source of known flux which can excite the $\frac{5}{2}^-$ state.

Several authors have discussed the use of intense terrestrial neutrino sources for the calibration of solar neutrino detectors.[5] ^{51}Cr and ^{65}Zn sources in particular are actively being studied. The high energy branch (90% of all decays) of the ^{51}Cr decay produces neutrinos with an energy above 746 keV. Since the tabulated electron capture Q value for ^{81}Kr is 322 (+31; −14) keV, the ^{81}Kr $\frac{5}{2}^-$ excited state at 457 keV[7,8] appears to lie above the threshold for capture of ^{51}Cr neutrinos by 33 keV.[9,10]

The population of the 457 keV state depends only on the neutrino being above threshold, not how much above threshold it is. This is due to the cancellation of the momentum dependence in the equation for the reaction rate. Since this calibration is crucial to the detector scheme, a more accurate determination of the ^{81}Kr ground state mass is required.

The Princeton cyclotron produced a 24.7 MeV ^{3}He beam and was used in conjunction with the quadrupole-dipole-dipole-dipole (QDDD) spectrograph[11] to perform the two measurements reported here. The targets used consisted of about 147 μg/cm^2 natural RbBr evaporated on 20 μg/cm^2 of carbon and a sandwich target of 49 μg/cm^2 ^{51}V on a 40 μg/cm^2 carbon foil with 130 μg/cm^2 RbBr evaporated on the opposite side.

The RbBr target produced the triton spectrum seen in Fig. 1 at 7°. The ^{87}Rb(^{3}He,t)^{87}Sr [$Q=255(2)$

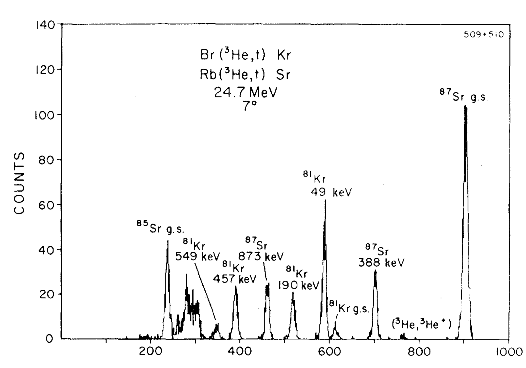

FIG. 1. Spectrum obtained from the (^{3}He,t) reaction preformed on a target of natural RbBr at 7°.

keV][10] reaction provides a calibrant for a precise Q-value determination of the ^{81}Br(^{3}He,t)^{81}Kr reaction. By using a composite target with a similar mass calibrant, errors due to beam energy, scattering angle, and target thickness uncertainties are small, leaving the ^{81}Br and calibrant mass uncertainties as the dominant effect. We determine the ^{81}Br(^{3}He,t)^{81}Kr Q value to be −309(2.0) keV using the tabulated ^{87}Rb − ^{87}Sr mass difference.

This result gives a ^{81}Br(ν,e)^{81}Kr* (457 keV) Q value of 747.4(2.0) keV, larger than the energy of 745.8(0.9) keV for the K capture neutrinos from a ^{51}Cr source.[9] The remaining uncertainties still leave unresolved whether the 457 keV state can contribute to the production of ^{81}Kr by the ^{51}Cr calibrant.

To resolve the issue, a sandwich target was used with ^{51}V and RbBr on opposite sides of a carbon backing. By averaging measurements made with the ^{51}V upstream of the RbBr and with it downstream of the RbBr, target structure effects are eliminated. Figure 2 shows the relevant part of the (^{3}He,t) spectrum for the two target positions. Averaging the results from 7 and 15°, the Q-value difference is found to be Q[^{81}Br(^{3}He,t)^{81}Kr − ^{51}V(^{3}He,t)^{51}Cr] = 13.7(1.8) keV. Including the K binding energy of 5.5 keV for the chromium electron capture decay, the ^{51}Cr neutrinos will populate the ^{81}Kr 457 keV state by 8.2 keV. We also find that the ^{81}Br(^{3}He,t)^{81}Kr Q value is −299.5(1.5) keV assuming the ^{51}V calibrant is correct.

This result shows a conflict between the accepted ^{87}Rb(^{3}He,t)^{87}Sr and ^{51}V(^{3}He,t)^{51}Cr Q values. One or both of the Q values is shown by our results to be in error by a total of 9.5 keV. Wapstra[12] indicates that the ^{51}V − ^{51}Cr mass difference may be more reliable than the ^{87}Rb − ^{87}Sr mass difference. If this is true, our measurements imply that the ^{87}Rb(^{3}He,t)^{87}Sr Q value is 264(2) keV, the ^{85}Rb(^{3}He,t)^{85}Sr Q value is −1083(3) keV, and the ^{81}Br − ^{81}Kr mass difference is − 280.9(1.5) keV. This mass difference places the neutrino capture threshold to the 190 keV state in ^{81}Kr at 471.2 keV, which is less by 42 keV than the previously accepted value. This interpretation places the ^{81}Kr isobaric analog state[13] at 9717(15) keV.

Combining these results with the ^{81}Br mass excess of −77 976(6) keV, gives a ^{81}Kr mass excess of −77 696(6.3) keV. This new value differs by 42 keV from the previously accepted value of −77 654(+32;−15) keV[9] or 11 keV from −77 707(18) keV.[10] Further measurements will be required to eliminate the calibrant uncertainty.

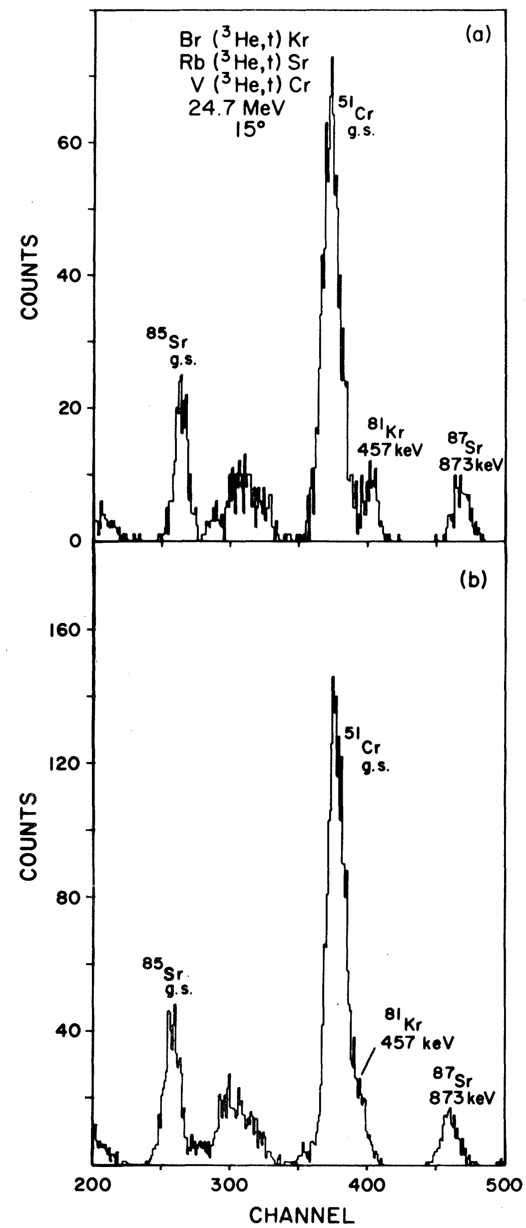

FIG. 2. Spectrum obtained from the (^{3}He,t) at 15° performed on a target of ^{51}V and RbBr, with ^{51}V downstream to the beam (a) and upstream to the beam (b).

We wish to thank J. N. Bahcall for useful discussions about this problem and A. H. Wapstra for communicating very useful data values. This work was supported by a grant from the National Science Foundation.

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