Mass of $^{31}S^{\dagger}$

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A high-resolution study of the $^{32}S(p, d)^{31}S$ reaction shows a discrepancy with the current table of mass values. The $^{32}S(p, d)^{31}S$ reaction Q value is found to be $-12\,817.8 \pm 1.5$ keV, 45.6 keV more positive than the published value, which carried an 11-keV uncertainty. Similar studies of the (p, d) reaction on ^{23}Na, ^{27}Al, ^{33}S, ^{34}S, ^{35}Cl, and ^{37}Cl indicate no discrepancies with the Q values (of 1- to 2-keV accuracy) tabulated for these nuclei. Possible sources for the sulfur discrepancy are discussed.

[NUCLEAR REACTIONS ^{23}Na, ^{27}Al, $^{32,33,34}S$, $^{35,37}Cl(p,d)$, $E = 35$ MeV, measured Q, deduced new value for the mass of ^{31}S.]

In a recent letter,[1] Goss, Browne, and Rollefson reported a new value for the $^{58}Ni(p, \alpha)^{55}Co$ reaction Q value which disagrees with the number calculated from the 1971 Wapstra-Gove Mass Tables[2] by several standard deviations. We report here an error in one of the tabulated mass values for the s-d shell region which is of a comparable magnitude to that found in the iron region. In a high-resolution study of the (p,d) reaction on sulfur we find the $^{32}S(p,d)^{31}S$ Q value to be 45.6 ± 1.5 keV more positive than is indicated by the 1971 Mass Table. The estimated uncertainty of the previous value was 11 keV.

In our experiments, we used a 35-MeV proton beam extracted from the Michigan State University Cyclotron. The beam at the target had a coherent energy spread of about 20 keV. The use of dispersion matching and the other techniques described by Blosser *et al.*[3] enabled us to obtain a resolution of about 8 keV, full width at half maximum, for 25-MeV deuterons at the focal plane. The sulfur target (84.5, 0.5, and 15% of ^{34}S, ^{33}S, and ^{32}S, respectively) was about 10 $\mu g/cm^2$ thick and was sandwiched between thin carbon foils and Formvar films. Spectra of the reaction products were recorded on two abutting nuclear emulsion plates spanning 50 cm of an Enge-type magnetic spectrograph focal plane. Deuteron and proton groups from the (p,d) and (p,p) reaction on the intended target nuclei and on various contaminant nuclei also present in the target were identified on the basis of a first-order spectrograph calibration and/or on differences in particle-track ionization densities. These identifications were then checked by a comparison of final precise excitation-energy assignments at several different angles of observation.

Precise energy values for all observed particle groups were obtained by slightly adjusting about their nominal values the various parameters which affect the calculated values of emergent-particle momenta in our reaction-particle kinematics program,[4] so as to obtain a least-squares fit of the excitation energies (total Q values) of selected reference states to their accurately known values. Parameters which were varied in this procedure were the beam energy, angle of observation, gap between abutting plates, and the linear and quadratic parameters of the $B\rho$ vs focal-plane-position relationship for the spectrograph. For reference peaks in the sulfur spectra, for example, we used deuteron groups from the ground-state transitions of the ^{34}S, ^{28}Si, ^{16}O, ^{14}N, and $^{12}C(p,d)$ reactions, and proton groups from elastic scattering on ^{12}C and ^{16}O and from inelastic scattering to the first excited states in ^{32}S and ^{34}S. The inclusion of both deuteron and proton groups, and reactions on a significant range of target masses, makes an accurate determination of the beam energy and scattering angle possible. The inclusion of (p,d) groups leading to several low-lying excited states of ^{33}S, whose excitation energies are known to ± 1-keV accuracy from Ge(Li) detector studies of their γ-ray decays, leaves the results of the adjustment for these sulfur data essentially unchanged. Finally, the Q value of the reaction in question, $^{32}S(p,d)^{31}S$, was adjusted from its nominal value until the particle groups corresponding to the ground state and the excited states (when accurate values of their excitation energies were available) of the residual nucleus were matched to their observed positions.

The uncertainties which reside in this procedure were estimated from trials with several different target nuclei, from trials for a particular target with several different combinations of input "known-energy" particle groups, and from trials with the same "reference data set" at several different angles of observation, again for a particular target. The standard deviation in the assigned

Q value in analyzing a specific set of scanning results with a specific set of reference peaks is of the order of 0.8 keV. The uncertainty in the reproducibility of the assigned relative positions of peaks on the emulsion plates amounts to approximately 0.6 keV (0.02 mm), leading to an inherent uncertainty in our data of about 1 keV. The remainder of the uncertainty in our results arises from the amount of usable reference-data information, and the various accuracies thereof. In the present case, the amount of reference data was more than adequate. The typical uncertainties in the energies used for the reference peaks were of the order of 1 keV. This leads us to assign a standard deviation of approximately 1.5 keV to our results.

Using the above procedure, the $^{32}S(p,d)^{31}S$ Q value was found to be $-12\,817.8 \pm 1.5$ keV, which differs by 45.6 keV from the $-12\,863.4 \pm 11$-keV value reported in the 1971 Mass Tables.[2] This is in excellent agreement with a preliminary value of 46 ± 3 keV obtained in a recent independent measurement in our laboratory, in which a gas target was used.[5] We have also measured Q values for the (p,d) reaction on ^{23}Na, ^{27}Al, ^{33}S, ^{34}S, ^{35}Cl, and ^{37}Cl with essentially the same technique described above. In all cases our results for these nuclei are consistent with the tabulated values[2] to well within the combination of the various quoted uncertainties and our typical 1.5-keV estimated uncertainty.

An inspection of the sources of the Wapstra-Gove Q-value number, and of the mass of ^{31}S, which is the relevant quantity in the present discrepancy, indicates that three kinds of measurements have been considered in arriving at the quoted value, although the details of the weighting procedure are not transparent. (We will henceforth speak in terms of the mass excess of ^{31}S, given by Wapstra-Gove as $-18\,998 \pm 11$ keV and by our measurement, based on the Wapstra-Gove mass of ^{32}S, as $-19\,043.6 \pm 1.5$ keV.) There are several neutron-pickup Q-value measurements noted in Ref. 2. The only measurement which upon inspection seems to have a genuine measure of precision is that of Moss,[6] whose (^3He, ^4He) Q-value translates to a mass excess of $-19\,046 \pm 6$ keV, in agreement with our value. However, this measurement seems to have been given little, if any, weight in arriving at the averaged Q value listed in Ref. 2. A second measurement[7] quoted is that of the positron end-point energy for the ^{31}S-^{31}P decay. The Q value quoted, $+5410 \pm 30$ keV, is equivalent to a mass excess for ^{31}S of $19\,030 \pm 30$ keV, which is again consistent with our value. Finally, the third type of measurement quoted, the type which seems to have dominated the final composite Wapstra-Gove value and to have been the primary source of the discrepancy, is $^{31}P(p,n)^{31}S$. Both numbers quoted for the Q values of this reaction, -6213 ± 20 keV[8] and -6253 ± 20 keV,[9] come from early measurements on the Chalk River tandem accelerator. These average to an equivalent mass excess for ^{31}S of $-18\,990$ keV.

We conclude that the foregoing implies that there may have been too heavy a reliance placed on low-precision (p,n) threshold mass determinations in the Wapstra-Gove compilation, and that nuclidic masses whose values have been determined largely on the basis of such data may contain errors comparable to those discussed here.

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