# Breakdown of the Z = 8 shell closure in unbound 12O

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# Breakdown of the $Z = 8$ shell closure in unbound $^{12}O$[†]

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[Nuclear structure, unstable nuclei, missing-mass spectroscopy]

We report on the missing-mass spectroscopy of unbound $^{12}$O in the $^{14}$O($p$,$t$) reaction at 51 $A$MeV.

Mirror symmetry is a fundamental feature of atomic nuclei. Recent experimental studies have shown that the conventional magic numbers disappear in neutron-rich regions at $N = 8$, 20, and 28. Theoretical studies point to various underlying mechanisms. The validity of the mirror symmetry of these effects under extreme conditions of isospin and binding energies remains an open question, limiting predictions for very proton-rich nuclei. We experimentally investigated the mirror symmetry in the shell quenching phenomena between $^{12}_{8}O_4$ and its mirror partner $^{12}_{4}Be_8$.

The systematics of the low-lying excited states in even-even nuclei provides a sensitive probe to study the evolution of the shell structure. The anomalously lowered excited states in $^{12}$Be[1–3)] are known to be a manifestation of the breakdown of the $N = 8$ shell closure. However, experimental difficulties have hampered the determination of a level scheme for $^{12}$O. The advantage of the ($p$,$t$) reaction is that the angular distributions are sensitive to the transferred angular momentum. Observations of the characteristic distributions provide a firm confirmation of a new state and enable a reliable determination of its spin-parity.

In missing-mass studies using RI beams, the measurement of the energies and angles of the recoiling particles is essential to identify the excited states of interest and to determine the scattering angles for the reaction. The recoiling ions generally have low energies, and this results in a severe constraint on the possible target thickness. However, in the present reaction, which has a highly negative $Q$ value ($-31.7$ MeV), the momentum of the incoming $^{14}$O that yields $^{12}$O is greatly reduced; this results in a relatively large momentum being imparted to the recoiling triton that is emitted in the forward direction. This enables us to use a 1-mm-thick solid hydrogen target[4)] to increase the experimental yield.

The experiment was performed at the GANIL facility. The secondary $^{14}$O beam at 51 $A$MeV was produced in the SISSI device[5)] and delivered to the hydrogen target located in the scattering chamber of the SPEG spectrometer.[6)] The incident position and incident angle on the target were monitored by two sets of multiwire low pressure chambers, CATS.[7)] The purity (intensity) of $^{14}$O was around 40% ($6 \times 10^4$ pps). The ejectiles were detected by SPEG or a Si $\Delta E$-$E$ telescope provided by RIKEN. The energies and angles of the recoiling tritons were measured by an array of four MUST2 telescopes[8)] located 30 cm downstream of the target. Each telescope, with an active area of $10 \times 10$ cm$^2$, consisted of a 0.3-mm-thick double-sided Si strip detector and a 4-cm-thick 16-fold CsI calorimeter.

The excitation energy ($E_x$) spectrum was made from the total kinetic energy and the laboratory scattering angle of the recoling tritons. We observed a peak at an $E_x$ of 1.8(4) MeV, which indicates a new excited state of $^{12}$O. The spin-parity of the state was determined to be $0^+$ or $2^+$ by comparing the measured differential cross sections with distorted-wave calculations.

The $E_x$ of the $^{12}$O excited state is remarkably smaller compared to the second $0^+$ and first $2^+$ states of $^{14,16}$O ($E_x \sim 6$ MeV) with a firm shell closure at $Z = 8$. On the other hand, it is close to the states of $^{12}$Be ($E_x \sim 2$ MeV) with significant neutron $sd$-shell configurations. Thus, the lowered excited state indicates that the proton shell closure at $Z = 8$ is diminishing in $^{12}$O. This demonstrates the persistence of mirror symmetry in the disappearance of the magic number 8 between $^{12}$O and $^{12}$Be. Implications for the shell quenching mechanism were discussed in terms of the shell model and the cluster model.

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† Condensed from the article in Phys. Rev. Lett. **103**, 152503 (2009)

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