Coulomb and nuclear excitations of narrow resonances in $^{17}\text{Ne}$

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Abstract

New experimental data for dissociation of relativistic $^{17}\text{Ne}$ projectiles incident on targets of lead, carbon, and polyethylene targets at GSI are presented. Special attention is paid to the excitation and decay of narrow resonant states in $^{17}\text{Ne}$. Distributions of internal energy in the $^{15}\text{O}+p+p$ three-body system have been determined together with angular and partial-energy correlations between the decay products in different energy regions. The analysis was done using existing experimental data on $^{17}\text{Ne}$ and its mirror nucleus $^{17}\text{N}$. The isobaric multiplet mass equation is used for assignment of observed resonances and their spins and parities. A combination of data from the heavy and light targets yielded cross sections and transition probabilities for the Coulomb excitations of the narrow resonant states. The resulting transition probabilities provide information relevant for a better understanding of the $^{17}\text{Ne}$ structure.

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The proton dripline nucleus $^{17}\text{Ne}$ is a candidate a two-proton Borromean halo nucleus [1], with a $^{15}\text{O}$ core surrounded by two valence protons. The protons are expected to predominantly possess a mixed $(1s_{1/2})^2$ and $(0d_{5/2})^2$ configuration. There is, however, no real consensus about the relative strength of the $s$ and $d$ configurations, neither experimentally nor theoretically. Estimates based on experimental values for interaction cross-section and momentum distributions of fragments in one-proton knockout [2–5], the magnetic dipole moment [6], first-forbidden $\beta^+$-decay [7,8], Coulomb energy difference between the mirror nuclei $^{17}\text{Ne}$ and $^{17}\text{N}$ [9–13], as well as pure theoretical investigations [14–16], provide widely differing results. Different evaluations of the amount of $(1s_{1/2})^2$ in the $^{17}\text{Ne}$ ground-state wave function, $P(s^2)$, ranges from 15% to 100%. There are also strong contradictions between different theoretical models for Coulomb dissociation of $^{17}\text{Ne}$ [17–20].

A theoretical study [21] points to the importance of the determination of electric transition strengths to elucidate the two-proton halo properties. The authors emphasise in particular the importance of reduced electric transition probabilities from the $^{17}\text{Ne}$ ground state to low-lying states as for example $B(E2,1/2^+\rightarrow3/2^-)$ and $B(E2,1/2^-\rightarrow5/2^-)$, that could be determined through Coulomb excitation.

This paper presents a new comparative study of nuclear and Coulomb excitation of $^{17}\text{Ne}$ at relativistic energies using polyethylene (CH$_2$), carbon, and lead targets.

The experiment was performed at the GSI Helmholtzzentrum für Schwerionenforschung GmbH in Darmstadt, employing the R$^3$B-LAND setup for measurements in inverse and full kinematics. The reaction products, from $^{17}\text{Ne}$ interaction, were first detected in a pair of silicon-strip detectors and then separated in the magnetic field of the large dipole magnet (ALADIN). After the magnet, two branches of detectors were used to measure the position, energy-loss, and time-of-flight, one for heavy ions (two fibre detectors and a ToF-wall) and another for protons (two drift chambers, was calculated in a Monte-Carlo simulation under the assumption of isotopic three-body decay. The acceptance function on $E_{fpp}$ is shown in Fig. 3 of Ref. [22]. The experimental energy resolution was found to be close to a Gaussian shape with a dispersion $\sigma=1.83E_{fpp}^{0.568}$ MeV.

The correlation functions, for the fractional-energy distributions $W(\epsilon_{fp})$ as well as for the angular distributions $W(\theta_{fp})$, normalised to unity $(\int_0^1 W(\epsilon)\,d\epsilon = 1$ and $\int_{-1}^{1} W(\theta)|\cos\theta = 1$) were then constructed and analysed. The experimental excitation energy spectra, $E'=E_{fpp}+S_{2p}(^{17}\text{Ne})$, shown in Fig. 1, are well described as resulting from the contribution of several excited states in $^{17}\text{Ne}$, superimposed on a smooth background, shown as dashed lines. This background corresponds to non-resonant dissociation and may also contain contributions from unresolved resonances. Extrapolation of this smooth background into the region of resonances was done by using information from the $W(\epsilon_{fp})$ distribution. Based on experimental results [25], the widths of the resonance structures were assumed as determined entirely by the experimental resolution. A least-squares fit was performed using the functional minimisation and error analysis code MINUIT [24]. The smooth background, shown as dashed lines in Fig. 1, corresponds to non-resonant dissociation and may also contain contributions from unresolved reso-
Fig. 1. Excitation spectra of $^{17}\text{Ne}$ after breakup of $^{17}\text{Ne}$ 500 MeV/u beam to $^{15}\text{O}+p+p$ in polyethylene, carbon and lead targets. The numbers in parenthesis refer to the resonances presented in Table 1.

Extrapolation of this smooth background into the region of resonances was done by using information from the $W(f_{pp})$ distributions (see Fig. 5).

Table 1
Excitation energies (MeV) and cross sections (mb) with statistical error bars for observed resonance structures in $^{17}\text{Ne}$ excitation spectra. The number N refers to the structures shown in Fig. 1.

<table>
<thead>
<tr>
<th>N</th>
<th>CH$_2$</th>
<th>Carbon</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E^*$</td>
<td>$\sigma$</td>
<td>$E^*$</td>
</tr>
<tr>
<td>(1)</td>
<td>1.790(5)</td>
<td>4.89(15)</td>
<td>1.780(8)</td>
</tr>
<tr>
<td>(2)</td>
<td>2.652(10)</td>
<td>2.39(14)</td>
<td>2.571(37)</td>
</tr>
<tr>
<td>(3)</td>
<td>3.422(44)</td>
<td>1.38(12)</td>
<td>3.393(78)</td>
</tr>
<tr>
<td>(4)</td>
<td>5.79(12)</td>
<td>1.13(22)</td>
<td>5.40(20)</td>
</tr>
<tr>
<td>(5)</td>
<td>10.06(16)</td>
<td>2.10(35)</td>
<td>10.69(59)</td>
</tr>
</tbody>
</table>

Five resonance-like structures corresponding to excitations of narrow resonant states in $^{17}\text{Ne}$ are observed in the data from the CH$_2$ and C targets, while only three are identified in the data from the Pb target (See Fig. 1 and Table 1). The level structure of $^{17}\text{Ne}$ has been studied earlier using the three-neutron transfer reaction $^{20}\text{Ne}(^{3}\text{He},^{6}\text{He})$ [25]. These results were used as a first guidance in our interpretation together with the available experimental information about the structure of excited states in the mirror nucleus $^{17}\text{N}$ [26]. Atomic masses and energy levels of the $A=17$, $T=3/2$ isobaric multiplets taken from Refs. [27,28] were also used together with the isobaric multiplet mass equation (IMME) and the Thomas-Ehrman shifts (TES) for the classification of the states.

1. The first peak in the spectrum is due to an unresolved doublet consisting of two narrow states at 1.764(12) MeV ($I^*=5/2^-$) and at 1.908(15) MeV ($1/2^+$) [25]. The relative contributions of these two states were obtained from an analysis of the three-body correlations in the energy region $0 < E_{f_{pp}} < 1.4$ MeV (see below).

2. The second peak at $E^*=2.652$ MeV (see Table 1) is close in energy to the observed excited state at 2.651(12) MeV [25]. This state was interpreted to be an $I^*=5/2^+$ state. However, a $5/2^+$ state is unlikely to be fed in a Pb target by Coulomb excitation due to the small strength of the required E3 or M2 transitions. Hence, the possibility that the observed peak is due to an unresolved doublet cannot be excluded. Overlapping states with the spin-parity, 5/2$^+$ and 5/2$^-$, were proposed (see Ref. [25] and references therein). However, in this case an unusually large negative cubic-term coefficient is required ($d=-25$ keV) in the isobaric multiplet mass equation (IMME) for the 5/2$^+$ isooquartet and furthermore the Thomas-Ehrman shift for the 5/2$^-$ state is surprisingly large in this case ($\approx 1$ MeV). An alternative hypothesis is an unresolved doublet of 5/2$^+$ and 3/2$^-$ states. The parabolic IMME was used in the analysis (see Table 2). The position of the $T=3/2$, $I^*=3/2^+$ state in $^{17}\text{O}$ is not known, but the assumption of a doublet requires that the positions of the 5/2$^+$ and 3/2$^-$ states in $^{17}\text{Ne}$ are close in energy, which only leaves one possibility for this state – a narrow state at 14.230(2) MeV. The fit using only three states from $^{17}\text{N}$, $^{17}\text{O}$ and $^{17}\text{F}$ allows then to make a prediction for the positions of states: 5/2$^+$ at 2.614(20) MeV and 3/2$^-$ at 2.692(21) MeV, respectively. The resulting TES(3/2$^+_{3/2^-}$)=380(16) keV, is much larger than TES(3/2$^+_{3/2^-}$)=47(14) keV. The structure of the analog states in the mirror nucleus $^{17}\text{N}$ has shown that the 3/2$^-$ and 3/2$^+$ states have wave functions [26] with a 14% configuration with one valence proton in s-shell while the second is in d-shell, for 3/2$^-_{3/2^+}$ and 86% for 3/2$^+_{3/2^-}$ [26]. A similar structure is expected for the analog states in $^{17}\text{Ne}$. Thus a small value for TES(3/2$^+_{3/2^-}$) and a large for TES(3/2$^+_{3/2^-}$) can be explained as a large asymmetry in the weights of the configuration with one valence nucleon in the s-shell and the large spatial extension of the s-wave proton wave function.

1 The Thomas-Ehrman shift, TES($I^*$), was defined as the difference between the distances from 7/2$^-$ to $I^*$ states in the mirror nuclei and $^{17}\text{N}$. The 7/2$^-$ states were chosen as reference since the Coulomb-energy shifts for these states, having three-body structure with two valence nucleons in the d-shell, are expected to be small.

2 Note also a large negative TES for positive-parity states. These states cannot be incorporated in the three-body models generally.
Table 2

<table>
<thead>
<tr>
<th>I*</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>χ²/TES</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/2−</td>
<td>13025(1.2)</td>
<td>-2844.8(1.3)</td>
<td>219.8(3.6)</td>
<td>0.39 -47(14)</td>
</tr>
<tr>
<td>5/2−</td>
<td>1349(2.5)</td>
<td>-2825.0(3.5)</td>
<td>210.10(4.9)</td>
<td>0.61 20(16)</td>
</tr>
<tr>
<td>1/2+</td>
<td>13523(3.8)</td>
<td>-2896.4(4.7)</td>
<td>240.28(5.5)</td>
<td>0.00 -190(19)</td>
</tr>
</tbody>
</table>

Assuming 5/2+ and 3/2− both at E* = 2.651 MeV.

5/2+ | 14219(2.9) | -2906.2(4.7) | 237.8(4.9) | 2.4 |
| 3/2− | 14729(3.2) | -2699.4(4.5) | 169.4(5.0) | 2.4 |

Fit to only 15F, 17O and 17N isotobars.

5/2+ | 14220(3.0) | -2906.2(4.7) | 237.8(4.9) | —- 220(23) |
| 3/2− | 14730(3.2) | -2706.2(6.3) | 179.5(8.4) | —- 380(16) |

(3) The excitation energy of the third peak, at E* = 3.415(38) MeV, is close to the observed position of 9/2− state at E* = 3.548(20) MeV [25] but the energy difference and the fact that there is no sign of a 7/2− state, with should have similar structure as the 9/2− state [26], excludes such an assignment. The 17Ne level scheme is rather intricate, which makes the analysis knotty. The three-neutron transfer reaction has a selectivity to excitation of states with a definite structure and some states may therefore be missed. A comparison with the level scheme of mirror nucleus, 17N, suggests that this state could be the second 5/2− state. The analysis given in Ref. [26] for the 5/2− state in 17N, gave a weight of 72% for a configuration with a single proton in the s-shell, a structure similar to that of the 3/2+ state. The present value TES(5/2−) = 359(40) keV is close to TES(3/2+) = 380(16) keV and is thus in support of the 5/2− assignment for the E* = 3.415(38) MeV state in 17Ne.

(4-5) Two additional resonances at 5.210(79) MeV and 10.06(16) MeV were observed in the present experiment, the latter only for the light targets. A comparison with the levels in the mirror nucleus 17N and the fact that the resonance at 5.210(79) MeV is strongly excited with the lead target, points to an assignment of I* = 3/2+.

The analysis of the narrow resonant states in the low energy region, based on the discussion above, is shown in Fig. 2 and the results are given in Table 3.

Cross sections for excitation of energy levels in the 1H(17Ne(g.s), 17Ne(I*)) reaction were obtained from the relation: σ(CH2) = σ(C) + 2σ(H). The data demonstrate different selectivity for the different targets. Thus, for the hydrogen target, positive-parity states have lower excitation probability compared to those with negative-parity.

Table 3

<table>
<thead>
<tr>
<th>I*</th>
<th>E*</th>
<th>CH2</th>
<th>C</th>
<th>H</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/2− (i)</td>
<td>1.764(12)</td>
<td>4.04(20)</td>
<td>2.44(18)</td>
<td>0.80(14)</td>
<td>11.6(1.5)</td>
</tr>
<tr>
<td>1/2+ (i)</td>
<td>1.908(15)</td>
<td>0.85(15)</td>
<td>0.81(15)</td>
<td>&lt; 0.1</td>
<td>2.5(1.2)</td>
</tr>
<tr>
<td>5/2+</td>
<td>2.614(20)</td>
<td>0.97(51)</td>
<td>1.14(10)</td>
<td>&lt; 0.2</td>
<td>7.68(74)</td>
</tr>
<tr>
<td>(3/2−)</td>
<td>2.692(21)</td>
<td>1.40(53)</td>
<td>&lt; 0.3</td>
<td>0.70(26)</td>
<td></td>
</tr>
<tr>
<td>(5/2−)</td>
<td>3.415(38)</td>
<td>1.37(12)</td>
<td>0.62(10)</td>
<td>0.38(8)</td>
<td>—-</td>
</tr>
<tr>
<td>(3/2+)</td>
<td>5.210(79)</td>
<td>1.13(22)</td>
<td>0.46(19)</td>
<td>0.33(15)</td>
<td>14.4(1.7)</td>
</tr>
</tbody>
</table>

(i) Energies and errors are from Ref. [25].

The partial decay scheme with dominating decay branches is shown in Fig. 6.

In order to extract more information from the data, the low energy part of the Efp spectrum was divided into three separate regions, as shown in Fig. 2, where the fractional energy spectrum W(εfp) and the angular distribution W(θfp) were constructed and analysed. A sequential decay via an intermediate narrow resonance in 19F at εr = Er/Efp appears in the W(Efp) distribution as two peaks at εr and 1 − εr. A 2He decay, or diproton emission, would be characterised by an asymmetric angular W(θfp) distribution, increasing when θfp gets close to 180°. In the present analysis W(θfp) was found to be close to isotropic, within statistical uncertainties, which excludes a significant 2He emission. The shapes of the W(θfp) distributions are well described by assuming sequential decays through the first four excited states in 16F. The parameters for these states were taken from Ref. [23]. The partial W(εfp) shapes are largely determined by the experimental resolution and were calculated in Monte-Carlo simulations. The MINUIT code was used for the least-square fits to the measured W(εfp) spectra.

The fractional energy spectra for the lowest energy bin,
Fig. 3. Fractional energy spectra $W(\epsilon_{fp})$ in the Y-system for the region of $^{15}$O+p+p internal energy $0 \leq E_{fpp} \leq 1.4$ MeV from the CH$_2$ target (a) and Pb target (b). The distributions stem from the unresolved resonances $^{17}$Ne($5/2^-$) and $^{17}$Ne($1/2^+$) decaying to the $^{16}$F ground state. A fit with only one free parameter gives their relative contributions.

$0 \leq E_{fpp} \leq 1.4$ MeV, are shown in Fig. 3. The panels a and b show least-square fits to the $W(\epsilon_{fp})$ distributions assuming sequential decay from states at excitation energies 1.764 MeV ($5/2^-$) and 1.908 MeV ($1/2^+$) [25] through the intermediate $^{16}$F($0^-$) state. The distributions $W(\epsilon_{fp})$ are normalised to unity and in the fit the relative intensity was the only free parameter used. For the CH$_2$ target the fit gives a 17.5(3.2)% contribution from the 1/2$^-$ decay, for C 25.0(4.3)% (not shown), and for Pb 17.6(8.7)%%, with statistical errors.

Fig. 4. Fractional energy spectra $W(\epsilon_{fp})$ in the Y-system for the region of $^{15}$O+p+p internal energy $1.4 \leq E_{fpp} \leq 2.2$ MeV from the CH$_2$ target (a) and Pb target (b). Thin solid and thick dashed lines show decays through the intermediate $^{16}$F($2^-$) and $^{16}$F($3^-$) states, respectively. These states have the structure of $^{15}$O with one proton in the d-shell. The dashed lines represent decays to the $^{16}$F($0^-$) state with the structure $^{15}$O with one proton in the s-shell.

A doublet with 5/2$^+$ and 3/2$^-$ states was identified in the energy region $1.4 \leq E_{fpp} \leq 2.2$ MeV (region II in Fig. 2). The difference in excitation energy of these two states is much smaller than the experimental resolution and the difference in shape of $W(\epsilon_{fp})$ for the decay branches is marginal. The penetrability through the Coulomb and centrifugal barriers for the decay of 5/2$^+$ to 3$^-$ is about 20 times smaller than that for the decay to the 2$^-$ state. Further, this ratio is around 1000 for the decay of 3/2$^-$ state. The main decay branches for both states are therefore expected to proceed via the $^{16}$F($2^-$) state. The analysis of $W(\epsilon_{fp})$ from a carbon target gave a decay branch of 86(2)\% while the rest can be attributed to the feeding of $^{16}$F($3^-$) state. The $W(\epsilon_{fp})$ from CH$_2$ and Pb targets were fitted with an assumption that the $^{17}$Ne($5/2^-$) and $^{17}$Ne($3/2^-$) states decay predominantly through $^{16}$F($2^-$) and $^{16}$F($0^-$) states. Contributions from the $^{16}$F($2^-$) branch were 74(2)\% for CH$_2$ and 41(4)\% for Pb targets, see Fig. 4. The rest can be attributed to the feeding mainly $^{16}$F($0^-$) state with a small contribution from the $^{16}$F($3^-$) branch. In the case of Pb target, the main part of the $^{16}$F($0^-$) branch is coming from a continuous $E_{fpp}$ spectrum.

Fig. 5. Fractional energy spectra in the Y-system $W(\epsilon_{fp})$ for the region of $^{15}$O+p+p internal energy $2.2 \leq E_{fpp} \leq 3.0$ MeV from the CH$_2$ target (a) and Pb target (b). The thin solid lines show decays to $^{16}$F($2^-$) and 3$^-$) states and the dashed lines represent decays to $^{16}$F($0^-$ and 1$^-$) states.

In the energy region $2.2 \leq E_{fpp} \leq 3.0$ MeV a contribution from the $^{17}$Ne($5/2^-$) state is expected. The decay branches from this resonance should proceed mainly by emission of $\ell=0$ protons, feeding dominantly 2$^-$ and 3$^-$ states in $^{16}$F. The population of 0$^-$ and 1$^-$ states in the
resonance decay requires emission of $\ell=2$ protons and is expected to be small due to penetrability factors. Still there are sizeable contributions in the $W(\ell_{fp})$ distribution from feeding to these states, especially pronounced for the Pb target, as shown in Fig. 5. These parts of the distributions were treated as a physical background.

The ratio between the feedings $\sigma(2^-)/\sigma(3^-) \approx 1$ was obtained for both the CH$_2$ and the C target. For the Pb target, keeping this ratio fixed, the $W(\ell_{fp})$ cannot be reproduced, which shows that these events cannot be considered as having their origin in the decay of the $5/2^-$ state. They were therefore also considered as coming from a continuous $E_{fpp}$ spectrum. The distribution was well fitted with only three decay branches to the $0^+$, $1^-$ and $2^-$ states in $^{16}$F.

The cross sections for Coulomb excitation of resonant states, $\sigma_C$, were obtained by subtracting the nuclear contribution from the cross sections measured with the lead target scaled with a factor 1.84(20). The scaling factor was determined experimentally. It was assumed that Coulomb dissociation to $^{14}$O has a very small, if not zero, cross section and the scaling factor was determined as the ratio of ($^{17}$Ne,$^{14}$O) cross sections obtained with Pb and C targets. The scaling factor is close to the ratio between nuclear radii of projectile and target, $(A_{Ne}^{1/3} + A_{Pb}^{1/3})/(A_{Ne}^{1/3} + A_{C}^{1/3})$, reflecting that the nuclear disintegration is of surface character. In this analysis it was assumed that the $5/2^-$ state is not Coulomb excited. Excitation of this state with a large cross section by a M2 or E3 transition or in a multi-step process is unlikely. Cross sections for Coulomb excitation of the identified narrow resonances are given in Table 1. For the state at $E^\pi=5.210(79)$ MeV and a lead target the excitation stems dominantly from Coulomb interaction.

The transition probabilities $B(\pi \lambda)$ from the ground to an excited state in the projectile, where $\pi=E$ or $M$ stands for an electric or magnetic transition with multipolarity $\lambda$, were calculated by the virtual-photon method for intermediate energies [29,30]. The cross section for Coulomb excitation of a narrow resonance at $E^* \pi$ is

$$\sigma_C(\pi \lambda) = \frac{(2\pi)^3}{\lambda^2} \lambda \sum_{\ell=1}^{\lambda} \frac{1}{(2\lambda + 1)} \frac{E^*}{\hbar c} \frac{N(\pi \lambda)}{E^*} B(\pi \lambda),$$

where $N(\pi \lambda)$ is the number of virtual photons at excitation energy $E^\pi$. This expression is used to calculate the transition probability based on the measured cross section $\sigma_C(\pi \lambda)$ (in fm$^2$).

The formalism described in Refs. [29,30] is used to calculate $N(\pi \lambda)$. In Ref. [30] the effect of strong absorption is incorporated from the outset (see Eqs. (13-15)), while a minimal impact parameter $B_{cut}$ has to be used when an analytical semi-classical method from Ref. [29] (Eqs. (2.5.5)) is applied. Calculations using the semi-classical method with $B_{cut}=10.8$ fm give the same result as Eqs. (13-15) in Ref. [30]. The resulting $N(\pi \lambda)$ and $B(\pi \lambda)$ values are given in Table 4.

The Coulomb excitation of the first two excited states in $^{17}$Ne were studied earlier [31] and the transition probability $B(E2, 1/2^- \rightarrow 5/2^-)$ = 24 $e^2$fm$^4$ was deduced. However, in the $B(E2)$ calculations the authors included an extra factor $e^2$ in Eq. (1), which means that the obtained $B(E2)$ values are in units of fm$^4$ and should thus be multiplied with a factor 1.44. The corrected value for $B(E2, 1/2^- \rightarrow 5/2^-)$ is given in the last row in Table 4.

<table>
<thead>
<tr>
<th>$I^\pi$</th>
<th>$E^\pi$</th>
<th>$\sigma_C$</th>
<th>$\sigma_C$</th>
<th>$\pi \lambda$</th>
<th>$N(\pi \lambda)$</th>
<th>$B(\pi \lambda)$</th>
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<tbody>
<tr>
<td>5/2^-</td>
<td>1.764</td>
<td>7.13(1.5)</td>
<td>$E2$</td>
<td>11868</td>
<td>90(18)</td>
<td></td>
</tr>
<tr>
<td>1/2^+</td>
<td>1.908</td>
<td>&lt;2.4</td>
<td>$E1$</td>
<td>121.43</td>
<td>&lt;0.007</td>
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</tr>
<tr>
<td>(3/2^-)</td>
<td>2.692</td>
<td>5.57(76)</td>
<td>$E2$</td>
<td>5180.4</td>
<td>69(10)</td>
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<tr>
<td>(3/2^+)</td>
<td>5.141</td>
<td>13.6(1.7)</td>
<td>$E1$</td>
<td>68.68</td>
<td>0.071(9)</td>
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<td>5/2^-</td>
<td>1.764</td>
<td>29.9(4.4)</td>
<td>$E2$</td>
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<td>179(26)</td>
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</tbody>
</table>

The $B(E2)$ values from Ref. [31] without this correction factor were, however, used in Refs. [21,32] as a confirmation of the proposed $^{17}$Ne wave function. The corrected value $B(E2, 1/2^- \rightarrow 5/2^-)$ is about twice larger than that obtained in the present experiment. This might be connected with the assumption, made in Ref. [31], that the detected events were from pure Coulomb excitation. In the present experiment it is shown that nuclear excitation contributes to the cross section with about 50%, see Tables 3 and 4.

![Fig. 7. Transition probabilities $B(E2, 1/2^- \rightarrow 5/2^-)$ as a function of the s-shell occupation, $P(s^2)$, in $^{17}$Ne(g.s.). The solid line gives experimental $B(E2)$ value and the hatched zone shows the 1$\sigma$ deviation from this value. The dashed line represents calculations from Ref. [21].](image)

A comparison between the $B(E2, 1/2^- \rightarrow 5/2^-)$ values deduced from the present experiment and theoretical calculations from [21] is shown in Fig. 7. The most probable value for the $s^2$ occupancy would be either $P(s^2) = 23\%$ or $P(s^2) = 53\%$. The hatched zones in Fig 7 show the 1$\sigma$ deviations from these values.

In conclusion, new experimental data on dissociation of $^{17}$Ne into $^{15}$O+2p studied at GSI with a relativistic $^{17}$Ne beam impinging on lead, carbon, and polyethylene targets are presented. The main attention is paid to the excitation and decay of narrow resonant states in $^{17}$Ne,
or which cross sections were measured. Three-body correlations were used to determine the relative contributions to unresolved resonances. The data obtained from lead and carbon targets allowed the determination of cross sections and transition probabilities for Coulomb excitation. The reduced electric quadrupole transition probability \( B(\text{E}2, \frac{1}{2}^+ \rightarrow \frac{5}{2}^-) = 90(18) \text{ efm}^4 \) was derived by using the virtual-photon method. The measured \( B(\text{E}2) \) value was compared to the model calculations. Finally, the observation of a resonance at \( E^* = 5.210(79) \text{ MeV} \) tentatively interpreted as \( \frac{3}{2}^+ \) state, mainly Coulomb excited, is of special interest and should be a subject of further investigations. The excitation of positive parity states implies that three-body models without inclusion of the core intrinsic structure are not able to fully describe the reaction mechanism. Theoretical methods are urgently needed to describe excitation spectra and reaction mechanisms, including techniques beyond three-body models.

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