^{6}Be and ^{8}C level widths

F. C. Barker*
Department of Theoretical Physics, Research School of Physical Sciences and Engineering, The Australian National University, Canberra ACT 0200, Australia

(Received 1 May 2002; published 31 October 2002)

R-matrix formulas are used to calculate the two-proton decay widths of the ^{6}Be and ^{8}C ground states and of the ^{6}Be first excited state. The calculated widths for the ^{6}Be states depend strongly on the values taken for the energy and width of the ^{5}Li ground state; agreement for the ^{6}Be ground-state width can be obtained for a reasonable choice of ^{5}Li parameter values, and the same choice gives good agreement for the ^{6}Be excited-state width and branching ratio for ^{2}He decay. For ^{8}C, contributions from two of the possible decay channels give an appreciable fraction of the experimental width.

DOI: 10.1103/PhysRevC.66.047603 PACS number(s): 23.50.+z, 27.20.+n

The latest compilation of "Energy Levels of Light Nuclei, $A=5-7$" [1], gives the width of the 0^{+} ground state of ^{6}Be as 92 ± 6 keV. It mentions two published experimental values of 95 ± 28 keV [2] and 89 ± 6 keV [3]. An earlier published value was 140 ± 40 keV [4], while an unpublished value of 126 ± 15 keV [5] was mentioned in an earlier compilation [6]. The compilation [1] also gives the width of the 2^{+} first excited state of ^{6}Be as 1.16 ± 0.06 MeV, with the branching ratio for decay of this state via the emission of ^{2}He [$T=1$, $S=0$] as 0.60 ± 0.15. The width value comes from the average of many measurements (see Ref. [7]). The branching ratio is from a single measurement [8]; however, this paper actually gives the fraction of diproton emission as about 20% [and of this fraction, (60 ± 15)% has $S=0$].

For ^{8}C , the latest compilation [9] gives the 0^{+} ground-state width as 230 ± 50 keV. This value was obtained by fitting a Gaussian to an observed peak [10]; the same authors also found a width of 183 ± 56 keV by using a Breit–Wigner peak shape [10]. An earlier published value was 220^{+80}_{-140} keV [11].

We here use previously published *R*-matrix formulas [12,13] to calculate the widths of the ^{6}Be and ^{8}C ground states and of the first excited state of ^{6}Be.

The ground state of ^{6}Be decays by two-proton emission to the ground state of ^{4}He, with an available energy of 1.371 MeV [1]. The decay can be by diproton (^{2}He) emission, or it can occur as sequential emission of the two protons through the low-energy tail of the unstable ^{5}Li ground state. *R*-matrix formulas have been given for two-proton sequential decay [12] and for ^{2}He decay [13], where they were used to calculate upper limits on the observed widths for the sequential and ^{2}He decay of the ^{12}O ground state. The partial observed widths as defined in Refs. [12,13] are, however, not additive, as each is based on a one-channel approximation; rather, the corresponding formal widths should be added to give the total formal width and the total observed width obtained from this, with the factor containing contributions from both decay channels. Alternatively, with the original [14] multi-channel definition of the partial observed widths Γ_c^0 (here $c=s$ or d for sequential or diproton decay), but using the notation of Refs. [12,13], we may write the total observed width as

$$\Gamma_{\rm tot}^0=\sum_c \Gamma_c^0, \tag{1}$$

with

$$\Gamma_c^0=\frac{\Gamma_c}{1+\sum_{c'}\gamma_{1c'}^2\overline{S'_{c'}}}, \quad \Gamma_c=2\gamma_{1c}^2\overline{P_c}, \tag{2}$$

where

$$\overline{P_c}=\int_0^{Q_{2p}}P_{1c}(Q_{2p}-U)\rho_c(U)\mathrm{d}U, \tag{3}$$

$$\overline{S'_c}=\int_0^{\infty}\left[\frac{\mathrm{d}S_{1c}(E-U)}{\mathrm{d}E}\right]_{E=Q_{2p}}\rho_c(U)\mathrm{d}U. \tag{4}$$

Here

$$\rho_c(U)=c\frac{\Gamma_{2c}(U)}{[U-Q_{1pc}-\Delta_{2c}(U)]^2+\frac{1}{4}\Gamma_{2c}^2(U)}, \tag{5}$$

which can be written for the ^{2}He channel in the form of Eq. (3) of Ref. [13]. Also

$$\begin{aligned}\Gamma_{2c}(U)&=2\gamma_{2c}^2P_{2c}(U),\\ \Delta_{2c}(U)&=-\gamma_{2c}^2[S_{2c}(U)-S_{2c}(Q_{1pc})].\end{aligned} \tag{6}$$

We note that the suffixes 1 and 2 refer to the first and second decays, although Q_{1pc} and Q_{2p} refer to one-proton and two-proton decay energies. We apply these formulas to the ^{6}Be case. Because the ^{6}Be ground-state width is reasonably small, one would not expect much difference between the observed width and the full width at half maximum (FWHM) as obtained experimentally. One has $Q_{2p}=1.371$ MeV. Un-

*Email address: frederick.barker@anu.edu.au FAX: 61 2 6125 4676.

less otherwise mentioned, we use conventional values of the channel radius $a=\overline{a}(A_1^{1/3}+A_2^{1/3})$, with $\overline{a}=1.45$ fm [15].

We first consider ^{2}He decay. The wave function for the ^{6}Be ground state is taken from the shell-model calculations of Ref. [16]:

$$^6\mathrm{Be}(0^+)=0.934([2]\,^{31}\mathrm{S}_0)-0.358([11]\,^{33}\mathrm{P}_0). \qquad (7)$$

Then the spectroscopic factor for ^{6}Be decay to ^{4}He+ ^{2}He is $\mathcal{S}_{42}=(0.934)^2\times 9/8=0.981$, where 9/8 is the c.m. correction factor [17]. For this decay, the single-particle dimensionless reduced width, calculated from Eq. (16) of Ref. [12] using Woods-Saxon (WS) parameter values $r_0=1.17$ fm, $a_0=0.72$ fm, and $r_\mathrm{C}=1.30$ fm as in Ref. [13], is $\theta^2_\mathrm{sp}=1.13$. Then $\theta^2=1.11$ and $\gamma^2_{1d}=2.03$ MeV. Also $\overline{P}_d=0.0347$ and $\overline{S}'_d=0.320$ MeV^{-1}.

The formulas of Ref. [12] are used to calculate the contribution to the total width of the ^{6}Be ground state due to sequential decay. These formulas assume a one-level R-matrix approximation for the ground state of ^{5}Li, which is described in terms of its resonance energy Q_{1ps} above the ^{4}He$+p$ threshold and reduced width γ^2_{2s} for decay to ^{4}He$+p$. The observed width $\Gamma^0_{2s}(Q_{1ps})$ of the ^{5}Li ground state is given by [14]

$$\Gamma^0_{2s}(Q_{1ps})\ =\Gamma_{2s}(Q_{1ps})/[1+\gamma^2_{2s}(\mathrm{d}S_{2s}(U)/dU)_{U=Q_{1ps}}], \qquad (8)$$

so that values of γ^2_{2s} can be obtained from experimental values of either the formal or observed width. The formulas also depend on the reduced width γ^2_{1s} for the ^{6}Be decay to ^{5}Li(g.s.)$+p$, which depends slightly on Q_{1ps}.

Widely varying experimental values have been given for the energy and width of the ^{5}Li ground state, in part due to the use of different definitions for the energy and width of an unbound level. In the compilation [1], the recommended prescription based on the extended R-matrix method uses the complex energy of a pole of the S matrix, giving the energy as 1.69 MeV above the ^{4}He$+p$ threshold and the width as 1.23 MeV. It is, however, not obvious how Q_{1ps} and γ^2_{2s} can be obtained from these values. From a conventional R-matrix prescription, using definitions as in Lane and Thomas [14], the compilation [1] gives the resonance energy as 2.08 MeV and the observed width as 2.11 MeV, for a channel radius $a_2=2.9$ fm. These values give

$$Q_{1ps}=2.08\ \ \mathrm{MeV},\quad \gamma^2_{2s}=11.9\ \mathrm{MeV}. \qquad (9)$$

The values above all come from a comprehensive multilevel, multichannel R-matrix analysis of reactions in the ^{5}Li system, including all possible reactions for the two-body channels $d+{}^3$He, $p+{}^4$He, and $p+{}^4$He for c.m. energies corresponding to ^{5}Li excitation energies less than 23 MeV. They take no account of reactions in which the ^{5}Li ground state is observed as a particle-unstable product nucleus. The compilation [1] lists 20 such reactions, while in only one of the reactions included in the R-matrix analysis ($p+{}^4$He elastic scattering) is the ^{5}Li ground state expected to contribute significantly.

Values of the ^{5}Li ground-state energy and width obtained from some of these 20 reactions are given in the latest Ajzenberg-Selove compilation [18]; they are essentially values of the peak energy and FWHM of the peak, which are not necessarily the same as the resonance energy and either the formal or observed width, though the FWHM is expected to be closer to the observed width. The compilation [18] gives the energy as 1.97 MeV, based on an atomic mass excess of 11.68 MeV, and the width as ≈1.5 MeV. This value of the mass excess was given originally by Everling *et al.* [19], where it is derived from seven nuclear-reaction results collected by Van Patter and Whaling [20]. These results give ^{5}Li ground-state energy values ranging from 1.53±0.15 MeV from the reaction ^{6}Li$(p,d)^5$Li to 2.06±0.2 MeV from ^{3}He$(d,\gamma)^5$Li, with a weighted mean of 1.74±0.06 MeV, corresponding to a mass excess of 11.45 MeV. It is not clear how Everling *et al.* [19] obtained a mass excess of 11.68 MeV; thus the compilation [18] energy of 1.97 MeV is suspect. It may be noted that the compilations in 1959 and earlier [21–23] took the energy as 1.80 MeV. The width value of ≈1.5 MeV given in the compilation [18] can be traced back to the measurement of Frost and Hanna [24], and appears in all compilations from 1955 [22] to 1988 [18]. Other values of the FWHM have been given [18], ranging from 1.18±0.13 MeV from ^{4}He(^{7}Li,^{6}He)^{5}Li to 2.6±0.4 MeV from ^{3}He$(d,\gamma)^5$Li, while a more recent value of 1±0.2 MeV from ^{1}H$(\alpha,\gamma)^5$Li is given in Ref. [1]. Values of Q_{1ps} and γ^2_{2s} are given directly in a two-level R-matrix fit to data from reactions in which ^{5}Li is formed as an unstable product nucleus [25]:

$$Q_{1ps}=1.861\ \ \mathrm{MeV},$$
$$\gamma^2_{2s}=(0.952\ \ \mathrm{MeV}^{1/2})^2=0.906\ \ \mathrm{MeV}, \qquad (10)$$

for $a_2=5.5$ fm [and $B=S(Q_{1ps})$]. These values give $\Gamma^0_{2s}(Q_{1ps})=1.30$ MeV.

In view of the wide spread of values for the ^{5}Li ground-state energy and width, we initially calculate the sequential contribution to the ^{6}Be ground-state width using one set of values and consider the sensitivity of the results to changes in these values. From the conventional R-matrix prescription [1], we take the values (9). We calculate γ^2_{1s} using the ^{6}Be description (7), giving the spectroscopic factor $\mathcal{S}_{51}=1.88\times 6/5=2.25$. Using conventional WS parameter values $r_0=1.25$ fm and $a_0=0.65$ fm as in Ref. [12], we find $\theta^2_\mathrm{sp}=0.433$, giving $\theta^2=0.975$ and $\gamma^2_{1s}=3.15$ MeV. The formulas of Ref. [12] also give $\overline{P}_s=0.0404$ and $\overline{S}'_s=0.278$ MeV^{-1}. From Eqs. (1) and (2), the total observed width is

$$\Gamma^0_\mathrm{tot}=\frac{2(2.03\times 0.0347+3.15\times 0.0404)}{1+2.03\times 0.320+3.15\times 0.278}\ \mathrm{MeV}=157\ \mathrm{keV}. \qquad (11)$$

This is significantly bigger than the experimental FWHM values, which is not surprising as the value $\gamma^2_{2s}=11.9$ MeV is very large. It leads to $\mathcal{S}_{41}=2.27$, based on $\theta^2_\mathrm{sp}=0.848$ MeV from Eq. (16) of Ref. [12]. Most models for ^{5}Li(g.s.) would give $\mathcal{S}_{41}\leqslant 1.25$ (as 5/4 is the c.m. correction factor). These values use $a_2=2.9$ fm as in Ref. [1]. If we fit the observed width 2.11 MeV given in Ref. [1], using the conventional channel radius $a_2=3.75$ fm, we find $\gamma^2_{2s}=3.98$ MeV and $\Gamma^0_{\rm tot}=93$ keV in good agreement with experiment. In this case, the spectroscopic factor is $\mathcal{S}_{41}=1.46$.

We consider how sensitive this agreement is to changes in the assumed values of parameters and input data, using the results for $a_2=3.75$ fm as standard. Changing the WS parameter values has little effect on the calculated width—10% changes in r_0, a_0, and $r_{\rm C}$ produce at most a few keV change in the width. Decreasing $\overline{a}$ from 1.45 to 1.35 fm increases $\Gamma^0_{\rm tot}$ by 7 keV. If the simplest LS-coupled shell-model description is used for the ^{6}Be ground state (entirely $[2]^{31}{\rm S}_0$, so that $\mathcal{S}_{51}=1.600$), $\Gamma^0_{\rm tot}$ is increased by 4 keV.

For the sequential decay, the calculated values of $\overline{P_s}$ are sensitive to the values assumed for the energy and width of the ^{5}Li ground state. If we retain $Q_{1ps}=2.08$ MeV, as above, but reduce the width from 2.11 MeV to 1.91 MeV, corresponding to $\mathcal{S}_{41}=1.25$, its expected upper limit, then $\Gamma^0_{\rm tot}$ is reduced by 10 keV. From the values (10) (with $a_2=5.5$ fm), which correspond to $\mathcal{S}_{41}=0.97$, we find $\Gamma^0_{\rm tot}=69$ keV. If we use $\Gamma^0_{2s}(Q_{1ps})=1.30$ MeV as derived from Eqs. (10), but then use the conventional channel radius $a_2=3.75$ fm, we find $\gamma^2_{2s}=2.48$ MeV (corresponding to $\mathcal{S}_{41}=0.94$) and $\Gamma^0_{\rm tot}=79$ keV. Keeping $Q_{1ps}=1.861$ MeV and $a_2=3.75$ fm, and taking $\Gamma^0_{2s}(Q_{1ps})=1.57$ MeV corresponding to $\mathcal{S}_{41}=1.25$, we find $\gamma^2_{2s}=3.32$ MeV and $\Gamma^0_{\rm tot}=95$ keV.

With conventional values of all parameters, including $a_2=3.75$ fm, interpolation of the above values shows that the experimental FWHM of 92 keV may be fitted with $\mathcal{S}_{41}=1.25$ and $Q_{1ps}=1.91$ MeV or, alternatively, with $\mathcal{S}_{41}=1.20$ and $Q_{1ps}=1.86$ MeV (or with other combinations with smaller $\mathcal{S}_{41}$ and smaller Q_{1ps}). As an example, we take the values

$$a_2=3.75\ {\rm fm},\quad Q_{1ps}=1.86\ {\rm MeV},\quad \gamma^2_{2s}=3.18\ {\rm MeV}, \tag{12}$$

which give $\mathcal{S}_{41}=1.20$, $\Gamma^0_{2s}(Q_{1ps})=1.53$ MeV, and $\Gamma^0_{\rm tot}=92$ keV. These values seem to be not unreasonable.

From a three-cluster microscopic model of ^{6}Be, Csótó [26] calculated a ground-state width of 160 keV, the large value probably being due to the calculated energy of the state being 150 keV too high (if we use Csótó's energy for the state, we find $\Gamma^0_{\rm tot}=145$ keV). It is of interest that his ground-state wave function contains 87.7%$S=0$, $L=0$, compared with 87.2% from Eq. (7).

The 2^+ excited state of ^{6}Be at an excitation energy of 1.67 MeV decays by two-proton emission to the ground state of ^{4}He, with an available energy of 3.04 MeV [1]. In this case, the sequential decay through $^5{\rm Li}+p$ is energetically allowed, as is the ^{2}He emission. We assume the ^{5}Li parameter values (12), which led above to a good fit to the ^{6}Be ground-state width. Conventional values are assumed for the other parameters.

From Ref. [16], the wave function of the ^{6}Be excited state is

$$^6{\rm Be}(2^+)=0.833([2]^{31}{\rm D}_2)+0.553([11]^{33}{\rm P}_2). \tag{13}$$

For ^{2}He decay, one has $\mathcal{S}_{42}=(0.833)^2\times 9/8=0.780$, and $\theta^2_{\rm sp}=0.520$, giving $\gamma^2_{1d}=0.742$. Also $\overline{P_d}=0.272$ and $\overline{S'_d}=0.260\ {\rm MeV}^{-1}$. For sequential decay, $\mathcal{S}_{51}(s=1)=1.693$ and $\mathcal{S}_{51}(s=2)=0.551$ (where s is here the channel spin) and $\theta^2_{\rm sp}=0.616$, leading to $\gamma^2_{1s}=4.46$ MeV. Also $\overline{P_s}=0.256$ and $\overline{S'_s}=0.200\ {\rm MeV}^{-1}$.

These give $\Gamma^0_{\rm tot}=$ 1.29 MeV, and the branching ratio for ^{2}He emission is 15.0%. An estimate of the corresponding FWHM (using a density-of-states function for sequential decay only) gives a value about 7% less than the observed width—i.e., about 1.20 MeV. There is therefore good agreement with the experimental FWHM of 1.16±0.06 MeV and branching ratio of "about 20%" [of which (60±15)% has $S=0$]—we have assumed that the ^{2}He emission is entirely $S=0$.

With the simplest shell-model description of the ^{6}Be excited state, one finds $\Gamma^0_{\rm tot}=$ 1.16 MeV and a branching ratio of 26.3%. If we use the parameter values (9), with $a_2=2.9$ fm, we obtain $\Gamma^0_{\rm tot}=$ 1.66 MeV with a branching ratio of 12.5%.

Csótó [26] calculated an excited-state width of 0.87 MeV, the small value in this case being associated with a calculated energy that is 230 keV too low (with Csótó's energy, our procedure gives $\Gamma^0_{\rm tot}=1.02$ MeV). His wave function contains 59.9%$S=0$, $L=2$ compared with 69.4% from Eq. (13).

The ^{8}C ground state decays by the emission of four protons to the ground state of ^{4}He, with an available energy of 3.513 MeV [9]. The decay can proceed in various ways—by direct emission of a four-proton cluster (^{4}Be), which seems unlikely, or by sequential decay involving the unstable ground states of ^{5}Li, ^{6}Be, and ^{7}B. We consider only two contributions to the total width of the ^{8}C ground state: ^{2}He emission to the ground state of ^{6}Be and single-proton emission to the low-energy tail of the ^{7}B ground state, which then decays to $^6{\rm Be}+p$. In both contributions, we neglect the width of the ^{6}Be ground state. Then the available energy for decay of ^{8}C to $^6{\rm Be}+2p$ is $Q_{2{\rm p}}=2.142$ MeV [9]. From Ref. [1], we take the energy and width of ^{7}B ground state as $Q_{1ps}=2.21$ MeV and $\Gamma^0_{2s}(Q_{1ps})=1.4$ MeV. The procedure is similar to that for ^{6}Be above.

From Ref. [16], the relevant shell-model wave functions are

$$^8{\rm C}(0^+)=0.934([22]^{51}{\rm S}_0)+0.356([211]^{53}{\rm P}_0) \tag{14}$$

and

$$^7{\rm B}(3/2^-)=0.843([21]^{42}{\rm P}_{3/2})+0.510([21]^{42}{\rm D}_{3/2}) -0.169([111]^{44}{\rm S}_{3/2}). \tag{15}$$

For the ^{2}He decay, $\mathcal{S}_{62}=0.195\times 8/9=0.173$ and $\theta^2_{\rm sp}=1.004$, giving $\theta^2=0.174$ and $\gamma^2_{1d}=0.242$ MeV. Also $\overline{P_d}=0.0478$ and $\overline{S'_d}=0.345\ {\rm MeV}^{-1}$.

For the sequential decay through ^{7}B, we find $\gamma_{2s}^2 = 2.22$ MeV, $\mathcal{S}_{71} = 3.11 \times 8/7 = 3.55$, and $\theta_{sp}^2 = 0.414$, giving $\gamma_{1s}^2 = 3.91$ MeV. Also $\overline{P_s} = 0.0412$ and $\overline{S_s'} = 0.322$ MeV^{-1}.

We then obtain an upper limit on the contribution to the total width coming from these two channels of 148 keV, which is about 70% of the experimental FWHM values.

A rough allowance for the nonzero width of the ^{6}Be ground state increases the calculated width by less than 0.5 keV. Use of the simplest wave functions for the ^{8}C, ^{7}B, and ^{6}Be ground states reduces the calculated width by about 8 keV.

The *R*-matrix formulas [12,13] for two-proton decay give calculated widths of the ground and first-excited states of ^{6}Be in agreement with experimental values, provided the energy and width of the ^{5}Li ground state are suitably and reasonably chosen, and for the excited state the calculated branching ratio for ^{2}He decay agrees with experiment. For the ground state of ^{8}C, which decays eventually to ^{4}He and four protons, contributions from two of the possible decay channels calculated from the *R*-matrix formulas make up an appreciable fraction of the experimental total width.

[1] D. R. Tilley, C. M. Cheves, J. L. Godwin, G. M. Hale, H. M. Hofmann, J. H. Kelley, and H. R. Weller, Nucl. Phys. **A708**, 3 (2002).

[2] J. L. Honsaker, Nucl. Phys. **A90**, 545 (1967).

[3] W. Whaling, Phys. Rev. **150**, 836 (1966).

[4] M. Gulyamov, B. V. Rybakov, and V. A. Sidorov, Sov. Phys. JETP **17**, 1230 (1963).

[5] J. M. Freeman, D. West, and J. H. Montague, AERE Progress Report No. PR/NP 3,4, 1963.

[6] T. Lauritsen and F. Ajzenberg-Selove, Nucl. Phys. **78**, 1 (1966).

[7] F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. **A227**, 1 (1974).

[8] O. V. Bochkarev, A. A. Korsheninnikov, E. A. Kuz'min, I. G. Mukha, A. A. Ogloblin, L. V. Chulkov, and G. B. Yan'kov, Sov. J. Nucl. Phys. **46**, 7 (1987).

[9] J. H. Kelley, J. L. Godwin, X. Hu, J. Purcell, C. G. Sheu, D. R. Tilley, and H. R. Weller, "Energy Levels of Light Nuclei, *A* = 8," report, TUNL, 2002.

[10] R. E. Tribble, R. A. Kenefick, and R. L. Spross, Phys. Rev. C **13**, 50 (1976).

[11] R. G. H. Robertson, S. Martin, W. R. Falk, D. Ingham, and A. Djaloeis, Phys. Rev. Lett. **32**, 1207 (1974).

[12] F. C. Barker, Phys. Rev. C **59**, 535 (1999).

[13] F. C. Barker, Phys. Rev. C **63**, 047303 (2001).

[14] A. M. Lane and R. G. Thomas, Rev. Mod. Phys. **30**, 257 (1958).

[15] A. M. Lane, Rev. Mod. Phys. **32**, 519 (1960).

[16] F. C. Barker, Nucl. Phys. **83**, 418 (1966).

[17] N. Anyas-Weiss, J. C. Cornell, P. S. Fisher, P. N. Hudson, A. Menchaca-Rocha, D. J. Millener, A. D. Panagiotou, D. K. Scott, D. Strottman, D. M. Brink, B. Buck, P. J. Ellis, and T. Engeland, Phys. Rep. **12**, 201 (1974).

[18] F. Ajzenberg-Selove, Nucl. Phys. **A490**, 1 (1988).

[19] F. Everling, L. A. König, J. H. E. Mattauch, and A. H. Wapstra, Nucl. Phys. **15**, 342 (1960).

[20] D. M. Van Patter and W. Whaling, Rev. Mod. Phys. **26**, 402 (1954); **29**, 757 (1957).

[21] F. Ajzenberg and T. Lauritsen, Rev. Mod. Phys. **24**, 321 (1952).

[22] F. Ajzenberg and T. Lauritsen, Rev. Mod. Phys. **27**, 77 (1955).

[23] F. Ajzenberg-Selove, Nucl. Phys. **11**, 1 (1959).

[24] R. T. Frost and S. S. Hanna, Phys. Rev. **91**, 462 (1953).

[25] C. L. Woods, F. C. Barker, W. N. Catford, L. K. Fifield, and N. A. Orr, Aust. J. Phys. **41**, 525 (1988).

[26] A. Csótó, Phys. Rev. C **49**, 3035 (1994).