Negative neutron *p*-resonance of ^{11}B nucleus

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The width of a negative *p*-resonance, $\Gamma_n^1 \approx 4500$ eV, for the –709-keV resonance, which corresponds to the fourth excited state of ^{12}B, has been estimated experimentally for the first time in neutron spectroscopy.

1. Although neutron spectroscopy yields a wealth of information on the states of nuclei excited above the neutron binding energy, it fails to give adequate information on the levels below the binding energy, corresponding to the "negative" neutron resonances. Only the *s*-resonances have been studied. In the present letter we show that the parameters of negative *p*-resonances can be determined under favorable conditions by studying the anisotropy of elastic scattering of neutrons.

2. The scattering cross section far from the resonances depends, as we know, only slightly on the neutron energy and is determined by the potential scattering which is augmented by the nearest-resonance "tails." The "far"-resonance components, on the other hand, are usually represented in the potential-scattering phase shifts, δ_l as a component of the phases in which the scattering occurs from a hard sphere, ϕ_l; for example, they are represented in the form[1] $\delta_l = \phi_l + \arcsin(P_l R_l^{\infty})$, where P_l is the penetration factor, and R_l^{∞} is an experimentally fitted parameter. An important point

is that ϕ_l and δ_l are approximately equal for nuclei with adjacent mass numbers: The first quantities are equal because they depend exclusively on kR (k is the neutron wave number, and R is the nuclear radius) and the second quantities are equal because of the total contribution from many levels. For $l = 0$ this point is confirmed by many data on the scattering radii, $R'_0 = R(1 - R_0^\infty)$ and for p neutrons it is confirmed by experiments in which R_1^∞ or $R'_1 = R(1 - 3R_1^\infty)$ was determined.[1,2]

Analyzing the expression for the differential cross section for scattering near the p-resonance,[3] which depends on the angle θ as

$$\sigma(\theta) = \frac{\sigma_s}{4\pi}\left[1 + \omega_1 \cos\theta + \omega_2 P_2(\cos\theta)\right], \tag{1}$$

we see that the p-resonance has the strongest effect on the second term in (1), which corresponds to the s- and p-wave interference.

3. Figure 1 shows the experimental parameter values of the cross section (1), $\sigma_s(E)$ and $\omega_1(E)$, obtained by the time-of-flight method on the IBR-30 reactor for carbon and boron of a natural isotopic composition (ω_1 is given in the c.m. frame, and E in the laboratory frame). The measurement method is described in Ref. 4. Using these data and parametrizing $\sigma(\theta)$ in accordance with Refs. 3 and 5, we calculated the following values for $R = 1.35A^{1/3}$ fm and $k = 2.197 \times 10^{-4} A\sqrt{E}/(A+1)$ fm^{-1} (E is given in eV):

$$R'_0 = 6.15 \pm 0.02 \text{ fm for } C,\ R'_0 = 5.94 \pm 0.06 \text{ fm for } B, \tag{2}$$

$$R'_1 = 4.29 \pm 0.21 \text{ fm for } C, \tag{3}$$

$$R'_1 = 3.02 \pm 0.17 \text{ fm for } B. \tag{4}$$

These values give the best description of the experiment, which is illustrated in Fig. 1 by the solid lines at zero values of the strength functions which characterize the reso-

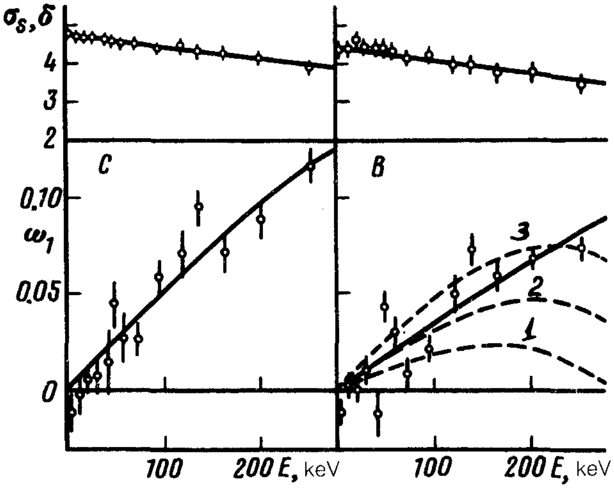

FIG. 1. Parameters of the differential cross section σ_s and ω_1 in (1). Points—Experimental values; curves—various versions of their description (see the text paper).

nance component of the average cross section. This assertion is justifiable because each boron isotope and ^{13}C have just one weak resonance each in the energy region under study, and because the wing of the strong s-resonance of ^{10}B, with $E_0 = 370$ keV, is subtracted, on the basis of the data of Ref. 6, from the cross section σ_s of boron at energies of 95 keV and higher.

4. As expected, the s-scattering radii, (2), are approximately the same for carbon and boron with nearly the same mass number, but (3) and (4) differ appreciably in the case of p scattering. Clearly, the value of R'_1 is more "correct" for carbon with far resonances, while ω_1, and hence R'_1, in boron are "distorted" by the neighboring resonances with $l = 1$ and $E_0 = 430$ keV. The magnitude of this distortion is illustrated by the dashed curve in Fig. 1, which differs from the solid curve only in that the contribution of this resonance, based on its parameters of Ref. 7, is taken into account separately when it is calculated. Clearly, the value of R'_1 must be increased in the experiment. We have accomplished this task by replacing $R_1^\infty = -0.003$, which gives (4), with $R_1^\infty = -0.130$, which corresponds to (3) for carbon and to $R'_1 = 4.16$ fm for boron. The result is represented by curve 2, which is still below most of the data points. Curve 3 goes well through the points. This curve was obtained by choosing the value $R'_1 = 5.38$ fm, which is now a considerably larger value than for carbon.

Another interpretation of curve 3 is, however, better. According to Ref. 8, the negative p-resonance of ^{12}C isotope can produce only the ground state of ^{13}C with spin and parity of $1/2^-$ and one $3/2^-$ excited state at an energy of 3684 keV, which corresponds to the resonance energies in the laboratory frame, $E_0 = -5358$ and -1367 keV. Boron-12 has three suitable states: the 1^+ ground state, the 953-keV 2^+ state, and the 2720-keV 0^+ state—these states correspond to the p-resonance of ^{112}B with $E_0 = -3676$, -2637, and -709 keV. Our hypothesis can be stated as follows: Two negative resonances with $E_0 < -1$ MeV, which were indicated above, along with the remaining positive p-resonance (aside from the ^{11}B resonance with $E_0 = 430$ keV) produce the same values, $R_1^\infty = -0.130$, in each element, and two nearest resonances of ^{11}B, 430-keV and -709-keV resonances, which partially cancel each other, account for the experimentally observable ω_1 of boron.[1)] Taking the isotopic composition into account, we can then easily find the most suitable reduced neutron width of the negative p-resonance:

$$\Gamma_n^1 = 4500\,\text{eV}, \qquad (5)$$

which gives us the function $\omega_1(E)$, which is graphically indistinguishable from curve 3 in Fig. 1. The value (5) is only an estimate, whose error is difficult to determine.

5. Amounting to approximately 3/4 of the Wigner limit, which is based on the single-particle width $\gamma^2 = \hbar^2/M_n R^2$, the quantity (5) is twenty times larger than the average value $\langle \Gamma_n^1 \rangle = 220$ eV, for four positive resonances of ^{11}B (Ref. 7), but the -709-eV resonance is the only resonance with a spin of 0^+ and its $g\Gamma_n^1 = 560$ eV is now only approximately four times larger, $\langle g\Gamma_n^1 \rangle = 130$ eV. Making use of the results obtained by Koehler *et al.*,[10] we find from the width (5) of the 2.72-MeV 0^+ level of ^{12}B that its spectroscopic factor is $S \approx 1$, whereas the shell model yields $S \approx 0.40$ (Ref. 11) and $S \approx 0.21$ (Ref. 10) for this level, and we have $S \approx 0.1$ (Ref. 12) and $S \approx 0.21$ (Ref. 13) from the d, p reaction. Our result, (5), therefore is evidence in favor of a

stronger single-particle nature of the ^{12}B state. To reconcile this discrepancy, more-detailed studies with neutrons and charged particles must be carried out.

[1)] We also ignore in this case the possible contribution from the one-pion-exchange mechanism to R'_1 of boron.[9]

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[1] A. V. Popov and G. S. Samosvat, Nuclear Data for Basic and Applied Science, Proceedings of the International Conference, Santa Fe, 1985, p. 621.

[2] L. V. Mitsyna *et al.*, International Conference on Nuclear Data for Science and Technology, Mito, Japan, 1988 (JINR E3-88-237, Dubna, 1988).

[3] G. S. Samosvat, Fiz. Elem. Chastits At. Yadra **17**, 713, (1986) [Sov. J. Part. Nucl. **17**, 313 (1986)].

[4] V. A. Vagov *et al.*, Preprint P3-82-770, Institute of Nuclear Research, Dubna, 1982.

[5] V. G. Nikolenka, A. V. Popov, and G. S. Samosvat, Nuclear Data for Science and Technology, Proceedings of the International Conference, Antwerp, 1982, p. 781.

[6] D. I. Garber and R. R. Kinsey, BNL-325, **2**, 1976.

[7] S. F. Mughabghab, M. Divadeenam, and N. E. Holden, Neutron Cross Sections, Vol. 1, part A, Academic Press, New York, 1981.

[8] Table of Isotopes ed. by C. M. Lederer and V. C. Shirley, New York, 1978.

[9] L. V. Kuznetsova *et al.*, JINR P3-87-114, Dubna, 1987.

[10] P. E. Koehler *et al.*, Nucl. Phys. **A394**, 221 (1983).

[11] S. Cohen and D. Kurath, Nucl. Phys. **A101**, 1 (1967).

[12] A. Gallman *et al.*, Phys. Rev. **B138**, 560 (1965).

[13] J. E. Monahan *et al.*, Phys. Rev. **C3**, 2191 (1971).

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