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BETA-DELAYED ALPHA PARTICLES AND THE ALPHA STRENGTH FUNCTION BELOW THE COULOMB BARRIER

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ABSTRACT

Beta-delayed alpha emission from neutron-deficient intermediate and heavy nuclei provide a possibility of estimating the alpha strength function in excitation regions below the Coulomb barrier. Recent experimental data are presented and used to obtain the average alpha strength, which in units of the Wigner limit is estimated to be of the order 0.05-0.10 MeV^{-1}. A semiempirical expression for the average alpha width at 5-12 MeV excitation is given and compared with optical model predictions.

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The experimental results on beta-delayed alpha-particle emission from intermediate and heavy nuclei provide the possibility of learning about alpha widths in an energy region where only little is known. The alpha-emitting states are situated typically at 5-12 MeV excitation energy and are thus bridging the gap between, on the one hand, the ground states, which in certain cases show alpha radioactivity, and on the other hand the compound-nuclear states near or above the Coulomb barrier, accessible through reaction processes involving alpha particles. The energy spectra and the emission rates are therefore expected to provide a valuable clue for the understanding of alpha formation probabilities in a relatively cold nucleus.

A summary of our experimental results is given in Table 1. As the details of the experiments have been presented earlier [1,2] and have been further confirmed in the parallel studies by Bogdanov et al. [3], we restrict ourselves here to showing, as an example, the delayed-proton and delayed-alpha spectra from ^{116}Cs (Fig. 1). The alpha strength function, $S_\alpha = \langle\gamma_\alpha^2\rangle \cdot \rho_i$, can be estimated from the experimental data by relating the observed and reduced widths through the expression $\Gamma_\alpha = 2P_\ell\gamma_\alpha^2$. The parameter ρ_i is the density of alpha-emitting levels, and P_ℓ is the barrier penetrability of multipole order ℓ (here calculated with the Igo [4] exponential potential). Although the presence of strong local structure in the alpha strength function is a theoretical possibility [5], it is simpler, as a starting point, to assume a constant strength function in the energy region of interest. This assumption appears not to be in contradiction with experiment. Following the alpha-cluster picture used previously [1] we assume that the reduced width for a cluster level, consisting of the daughter nucleus plus an alpha particle, is equal to the Wigner limit $\gamma_W^2 = 3\hbar^2/2M_r a^2$, where M_r is the reduced mass and a the channel radius (here taken to be 1.55 $A^{1/3}$ fm). It is further assumed that the strength in units of the Wigner limit is the reciprocal of the cluster level spacing $S_\alpha = (2\hbar\omega)^{-1}$, where $\hbar\omega = 41/A^{1/3}$ is the harmonic oscillator level spacing. From this an estimate of the average alpha width is derived:

$$\langle\Gamma_\alpha\rangle = \frac{\gamma_W^2\,P_\ell}{\hbar\omega\cdot\rho_i}\ . \qquad (1)$$

With this estimate a calculation similar to previous delayed-particle calculations [2,6] has been performed under the assumption of a constant beta-strength function, standard level density parameters [7] and, for the proton widths, optical model calculations [8]. In Table 1 the calculated alpha branching ratios and delayed-proton to delayed-alpha intensity ratios are compared with the experimental results. The agreement is excellent; the largest deviation in P_α amounts to a factor of 6, while the ratio P_p/P_α, which is insensitive to assumptions about the beta-strength function and the level density, agrees even better. In units of γ_W^2 our results thus give an alpha strength of 0.05-0.1 MeV^{-1}, which is in close agreement with results from (n,α) experiments [9].

The above estimate may appear overly primitive and we have therefore compared it with optical model calculations. The average alpha width is obtained from the calculated transmission coefficients T_α^ℓ with the expression:

$$\langle\Gamma_\alpha\rangle = \frac{T_\alpha^\ell}{2\pi\rho_i} . \qquad (2)$$

The choice of parameters was guided by the results given by the analysis of alpha scattering data [10-12]. As an example, Fig. 2 illustrates the calculated ratio $T_\alpha^{\ell=0}/P_0$ for (Z,A) = (52,114). The curves correspond to different values of the imaginary part of the potential, and they are seen to agree almost quantitatively with our estimate above 8-9 MeV. This agreement is hardly in itself surprising as the two estimates both represent single α-cluster models treated with different degrees of refinement. The essential conclusion is then that the experiments are in agreement with this picture and that the alpha-strength function at 5-12 MeV excitation energy can be understood in a simple way.

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REFERENCES

[1] P. Hornshøj, K. Wilsky, P.G. Hansen and B. Jonson, Phys. Letters 55B (1975) 53.

[2] B. Jonson, E. Hagberg, P.G. Hansen, P. Hornshøj and P. Tidemand-Petersson, Proc. 3rd Internat. Conf. on Nuclei far from Stability, Cargèse, 1976 (CERN 76-13, 1976), p. 277.

[3] D.D. Bogdanov, J. Vobořil, A.V. Demyanov and L.A. Petrov, Phys. Letters 71B (1977) 67.

[4] G. Igo, Phys. Rev. 115 (1959) 1665.

[5] Yu.P. Popov, in Nuclear Structure Study with Neutrons, Budapest, 1972 (eds. J. Erö and J. Szücs) (Plenum Press, London, 1974), p. 65.

[6] P. Hornshøj, K. Wilsky, P.G. Hansen, B. Jonson and O.B. Nielsen, Nuclear Phys. A187 (1972) 609.

[7] A. Gilbert, A.G.W. Cameron, Canad. J. Phys. 43 (1965) 1446.

J.W. Truran, A.G.W. Cameron and E. Hilf, Proc. Internat. Conf. on Properties of Nuclei far from the Region of Beta Stability, Leysin, 1970 (CERN 70-30, 1970), p. 275.

[8] F.D. Becchetti Jr. and G.W. Greenless, Phys. Rev. 182 (1969) 1190.

[9] V.I. Furman, S.H. Kademensky and S. Kholan, Dubna report P4-8734 (1975).

[10] L. McFadden and G.R. Satchler, Nuclear Phys. 84 (1966) 177.

[11] A.R. Barnett and J.S. Lilley, Phys. Rev. C 9 (1974) 2010.

[12] R.M. DeVries, J.S. Lilley and M.A. Franey, Phys. Rev. Letters 37 (1976) 481.

Table 1

Experimental and calculated delayed-alpha branching ratios and proton to alpha ratios

Nuclide	$Q_{EC}-B_{\alpha}$ a) (MeV)	Delayed-alpha branching ratio P_{α}		Delayed-proton to delayed-alpha ratio P_p/P_{α}	
		Experimental	Calculated	Experimental	Calculated
^{76}Rb b)	5.7	$(3.8 \pm 1.0) \times 10^{-9}$	7.6×10^{-9}	e	144
^{114}Cs b)	14.8	e	1.0×10^{-3}	33 ± 12	40
^{116}Cs b,c)	12.5	$(8 \pm 2) \times 10^{-5}$	4.6×10^{-5}	47 ± 2	50
^{118}Cs b)	11.1	$(2.4 \pm 0.4) \times 10^{-5}$	3.9×10^{-6}	17.2 ± 0.3	18.9
^{120}Cs b)	9.3	$(2.0 \pm 0.4) \times 10^{-7}$	1.4×10^{-7}	0.36 ± 0.10	0.26
^{181}Hg d)	13.2	$(1.2 \pm 0.4) \times 10^{-7}$	6.0×10^{-8}	$(1.5 \pm 0.6) \times 10^{3}$	0.6×10^{3}

a) Mass parameters determined from measured end-point energies and systematics [2].

b) Ref. 2.

c) The values given here are for the 3.5 sec isomer of ^{116}Cs. In the present experiments there is no indication of particle emission from the 0.7 sec isomer [2], in disagreement with the results given in Ref. 3.

d) Ref. 1.

e) Not determined.

Figure captions

Fig. 1 : Delayed-proton and delayed-alpha spectra from ^{116}Cs measured with a ΔE-E detector telescope equipped with surface barrier detectors (ΔE: 25 μm, 100 mm^2; E: 500 μm, 450 mm^2). The measurement was performed at the ISOLDE facility at CERN, the caesium activity being produced in a target of molten lanthanum metal bombarded with a 1 μA beam of 600 MeV protons. The ratio of delayed-protons to delayed-alphas was measured to be 47 ± 2 and the alpha branching ratio to be $(8 \pm 2) \times 10^{-5}$ [2].

Fig. 2 : Ratios of transmission coefficients $T_\alpha^{\ell=0}/P_0$. The parameters given in the figure were taken from Ref. 12, and the three curves show the results of optical-model calculations with different choice of the surface absorption (W_s) and volume absorption (W_v) potentials. The horizontal line shows the value 0.21 which is obtained by combining Eq. (1) and Eq. (2). It is clear that this "ansatz" in the region of interest ($E_\alpha > 8$ MeV) is in nearly quantitative agreement with the optical model. The behaviour of T_α at low energies must in all cases depend critically on the radius parameter.

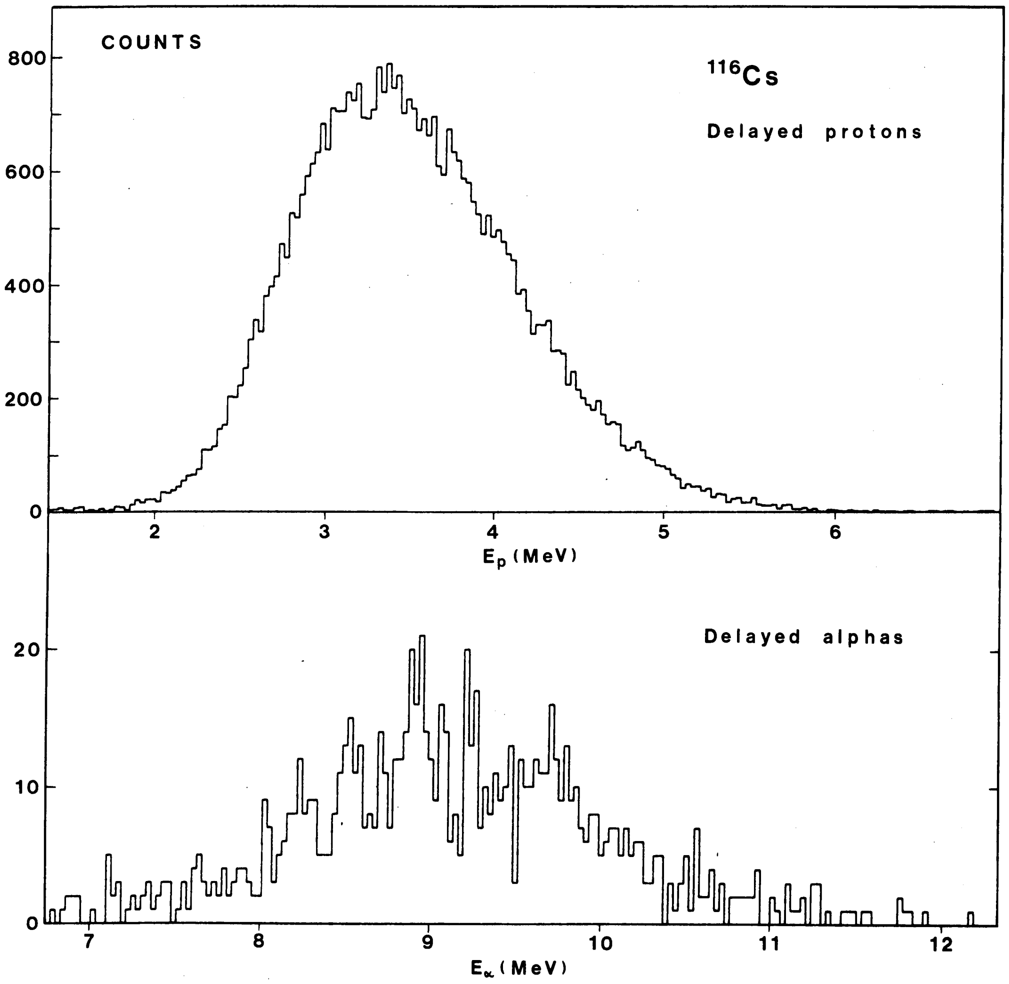
COUNTS
800
600
400
200
0
^{116}Cs
Delayed protons
2
3
4
5
6
E_p (MeV)
Delayed alphas
20
10
0
7
8
9
10
11
12
E_α (MeV)

Fig. 1

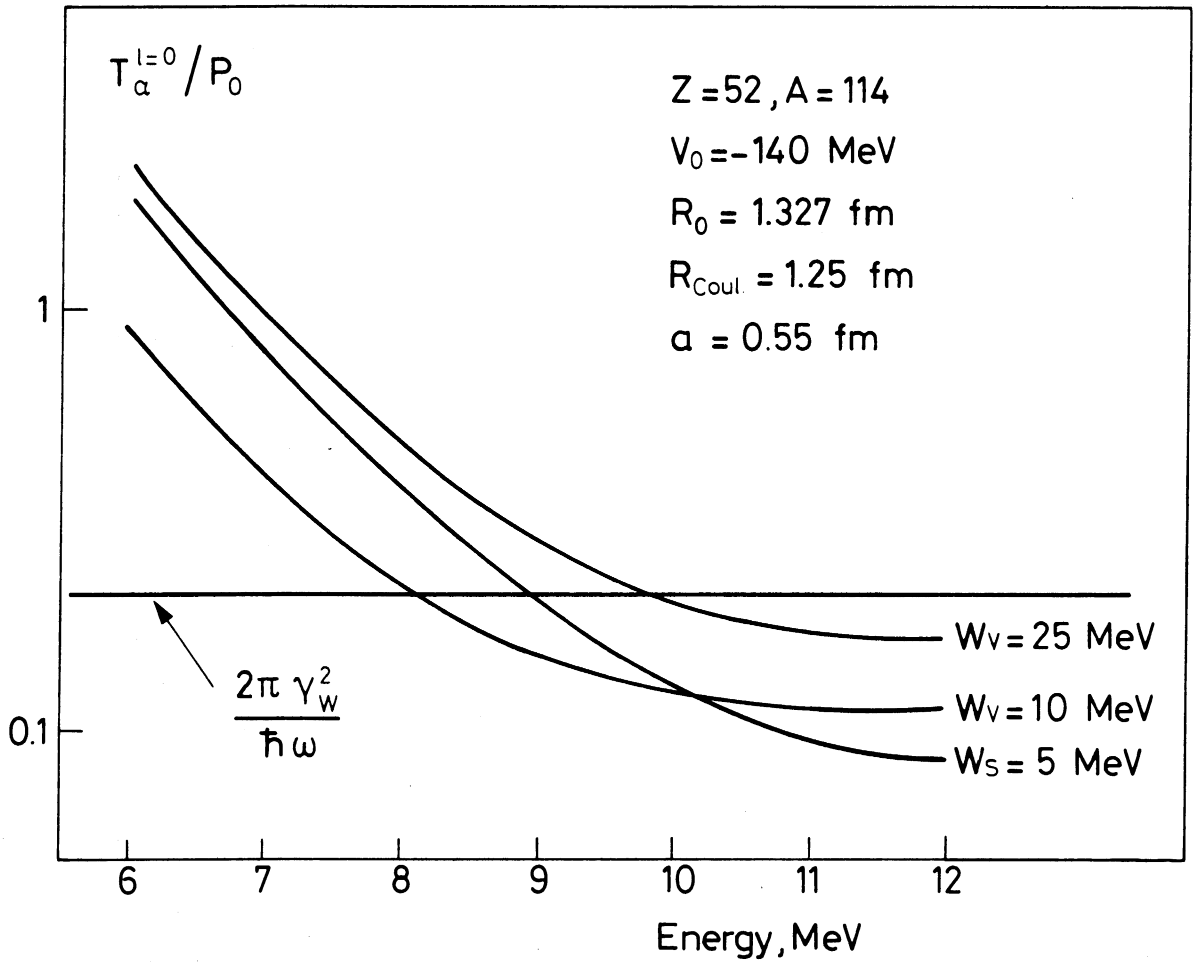
$T_{\alpha}^{l=0}/P_0$
Z = 52, A = 114
V_0 = -140 MeV
R_0 = 1.327 fm
$R_{Coul.}$ = 1.25 fm
a = 0.55 fm
1
0.1
$\frac{2\pi\gamma_W^2}{\hbar\omega}$
W_V = 25 MeV
W_V = 10 MeV
W_S = 5 MeV
6
7
8
9
10
11
12
Energy, MeV

Fig. 2