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ON

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STATIC POLARIZATION EFFECTS ON THE NUCLEUS-NUCLEUS POTENTIAL

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We calculate the nucleus-nucleus potential as a function of two variables : the distance between the centres of the nuclei R or equivalently the distance s_o between the surfaces $s_o = R - R_1 - R_2$ where R_i $(i = 1,2)$ are the nuclear radii and a surface thickness parameter a . The second variable was introduced in order to investigate the possibility of the polarization of the nuclei seen as a change in the thickness of the surface layer.

We define the nucleus-nucleus potential $\tilde{V}(s_o,a)$ as the difference between the binding energy of the composite system at a separation distance s_o and the binding energy of the nuclei separated at infinity. The Skyrme interaction energy density formalism [1] is used to calculate the binding energies. The sudden approximation for the total density together with the Thomas-Fermi approximation for the kinetic energy density reduce the Skyrme interaction energy density H to a function of ρ only. If we call a_o the equilibrium surface thickness the potential can be written as the volume integral

$$\tilde{V}(s_o,a) = \int [H(\rho_1^a + \rho_2^a) - H(\rho_1^{a_o}) - H(\rho_2^{a_o})]dv \quad . \tag{1}$$

By adding and subtracting the term $H_1(\rho_1^a) + H_2(\rho_2^a)$ the interaction potential can be splitted into two parts

$$\tilde{V}(s_o,a) = V(s_o,a) + \Delta V(a,a_o) \tag{2}$$

where

$$V(s_o,a) = \int [H(\rho_1^a + \rho_2^a) - H(\rho_1^a) - H(\rho_2^a)] \tag{3}$$

is the definition of the potential with the same value for a at all separation distances s_o [2] and

$$\Delta V(a,a_o) = \int [H(\rho_1^a) - H(\rho_1^{a_o}) + H(\rho_2^a) - H(\rho_2^{a_o})]dv \qquad (4)$$

is the variation in the surface energy of both nuclei when a changes.

To investigate if a polarization effect can appear we use some approximations to calculate the quantities (3) and (4). For the potential $V(s_o,a)$ we use the proximity formula [3]

$$V(s_o,a) = 2\pi \frac{R_1 R_2}{R_1 + R_2} \int_{s_o}^{\infty} [e_t(s,a) - e_t(\infty,a)]ds \qquad (5)$$

where $e_t(s,a)$ is the total surface energy per unit area of two parallel surfaces separated by a distance s_o and having a surface thickness a. The difference $e_t(s,a) - e_t(\infty,a) = e(s,a)$ is the interaction energy per unit area.

The quantity $\Delta V(a,a_o)$ is a surface energy and can be approximated by

$$\Delta V(a,a_o) = \pi(R_1^2 + R_2^2)\ [e_t(\infty,a) - e_t(\infty,a_o)] \qquad (6)$$

if we admit that roughly only the halfs of the nuclei facing each other suffer a change in a with the same maximum amount over the whole half of each nucleus. The expression (6) is then an upper limit of $\Delta V(a,a_o)$.

To evaluate (5) and (6) one needs a nucleon-nucleon interaction which gives reasonable values for the surface energy E_{surf} and the equilibrium thickness parameter a_o. For a semi-infinite slab of the form

$$\rho/\rho_0 = \frac{1}{1 + e^{z/a}} \qquad (7)$$

and the Thomas-Fermi approximation for the kinetic energy density we found that the set of parameters SII [1] of the Skyrme interaction are the most satisfactory giving $a_o = .48$ fm and $E_{surf} = 22.38\ \mathrm{MeV/fm^2}$.

As an example we show in Fig. 1 the result for $^{208}Pb + ^{208}Pb$ for which (5) is a very good approximation. We have drawn equi-potential energy curves as a function of s_o and a. The bottom of the valley is indicated by points on each curve. One can see that the valley goes towards larger a as s_o decreases. There is therefore an indication of a polarization effect which is diminished because of the estimate (6). To have a better measure of this effect we have calculated $\tilde{V}(s_o,a)$, eq.(1), with a model where a varies continuously from one side to the other of the nucleus.

This model was applied to the pair $^{40}Ca + ^{40}Ca$ and the result is shown in Fig. 2 : V_P is the proximity approximation, eq. (5), (dashed line) to V (full line) calculated from eq. (3) with $a = a_o$ over the whole surface of each nucleus. The polarized potential, represented by crosses, is the minimum value with respect to a of $\tilde{V}(s_o,a)$ at fixed s_o. For instance at $s_o = 0$ the minimum is reached for $a \simeq .72$ fm. The potential $\tilde{V}$ is deeper than V by about 20 % at $s_o = 0$, 40 % at $s_o = 1$, and 60 % at $s_o = 2$ (barrier region). This is interesting in view of the fact that the potential V, calculated even with a better expression of the kinetic energy density than the Thomas-Fermi approximation, is not deep enough at the barrier [2]. A systematic study over several pairs of nuclei seems to be necessary.

References

[1] D. Vautherin and D.M. Brink, Phys. Rev. C5 (1972) 626

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[3] J. Błocki, J. Randrup, W.J. Swiatecki and C.F. Tsang, Ann. Phys. 105 (1977) 427.

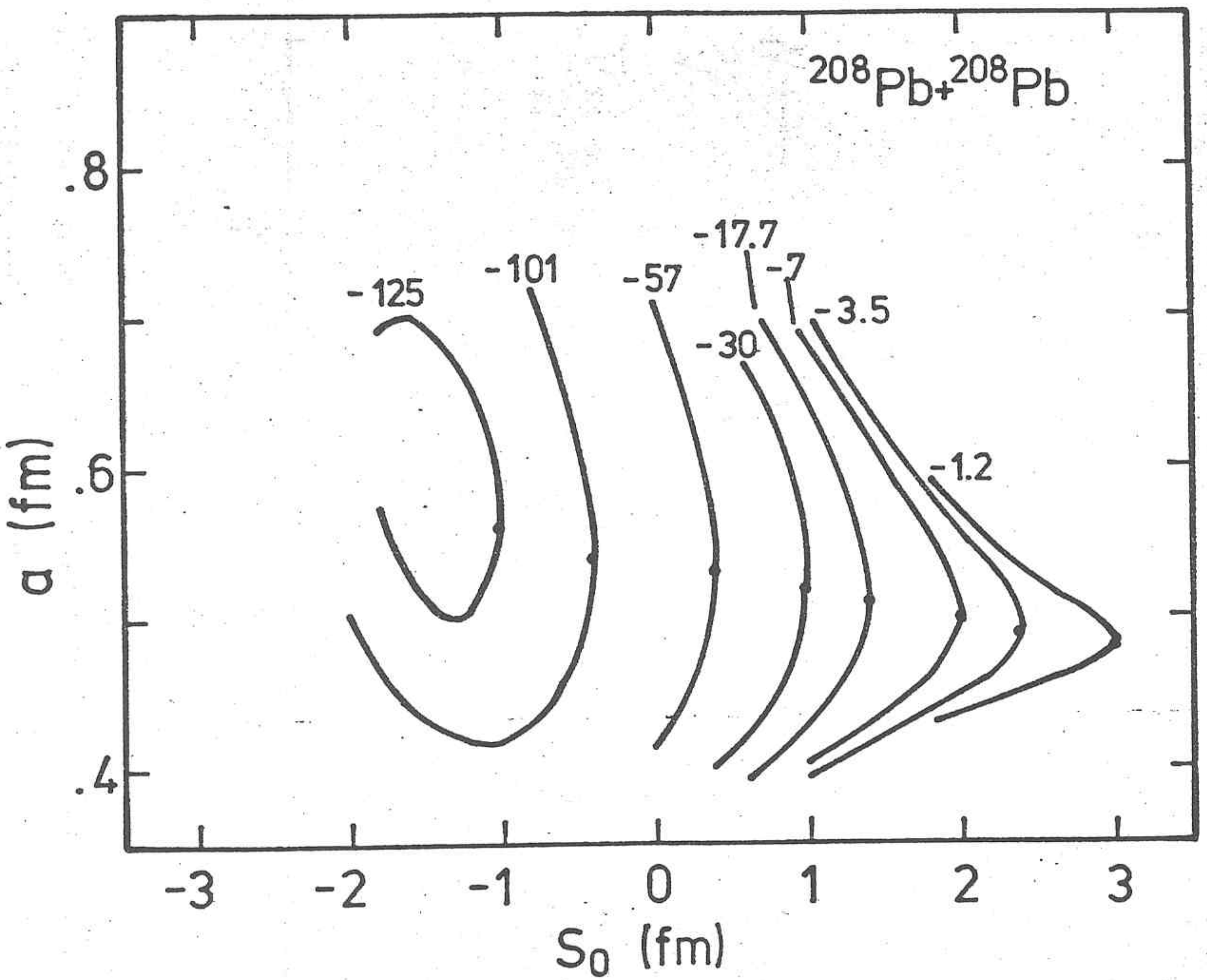

Fig. 1. Equipotential energy curves for $\tilde{V}(s_o,a)$ in MeV calculated with approximations (5) and (6).

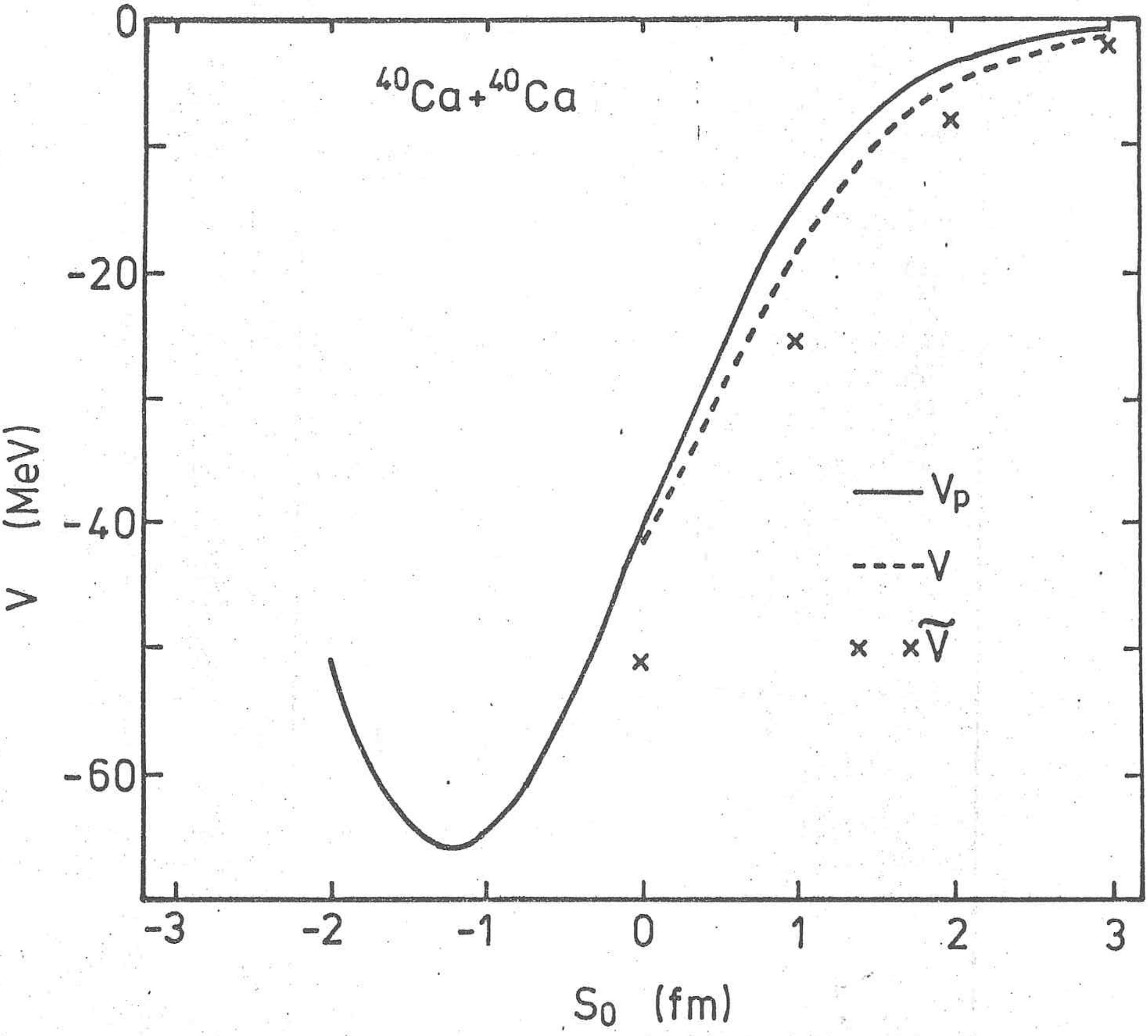

Fig. 2. Interaction potential $\tilde{V}$ of polarized nuclei as compared to potential V for non-polarized nuclei and proximity approximation V_p .