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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 \( s_o = R - R_i - R_j \) 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 \( \mathcal{V}(s_o, a) \) 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 \( \rho \) only. If we call \( a_0 \) the equilibrium surface thickness the potential can be written as the volume integral

\[
\mathcal{V}(s_o, a) = \int \left[ H(\rho_1^a + \rho_2^a) - H(\rho_1^{a_0}) - H(\rho_2^{a_0}) \right] dv \quad .
\] (1)

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

\[
\mathcal{V}(s_o, a) = \mathcal{V}(s_o, a) + \Delta \mathcal{V}(a, a_0)
\] (2)

where

\[
\mathcal{V}(s_o, a) = \int \left[ H(\rho_1^a + \rho_2^a) - H(\rho_1^a) - H(\rho_2^a) \right] dv \quad .
\] (3)
is the definition of the potential with the same value for \( a \) at all separation distances \( s_0 \) [2] and

\[
\Delta V(a, s_0) = \int \left[ H(a^1) - H(a^1^0) + H(a^2) - H(a^2_0) \right] dv \tag{4}
\]

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 \( V(s_0, a) \) we use the proximity formula [3]

\[
V(s_0, a) = 2\pi \frac{R_1 R_2}{R_1 + R_2} \int_{s_0}^{\infty} [e_t(s, a) - e_t(\infty, a)] ds \tag{5}
\]

where \( e_t(s, a) \) is the total surface energy per unit area of two parallel surfaces separated by a distance \( s_0 \) 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 \( \Delta V(a, s_0) \) is a surface energy and can be approximated by

\[
\Delta V(a, s_0) = \pi(R_1^2 + R_2^2) [e_t(\infty, a) - e_t(\infty, a_0)] \tag{6}
\]

if we admit that roughly only the halves 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 \( \Delta V(a, s_0) \).

To evaluate (5) and (6) one needs a nucleon-nucleon interaction which gives reasonable values for the surface energy \( E_{\text{surf}} \) and the equilibrium thickness parameter \( a_0 \). For a semi-infinite slab of the form

\[
\rho / \rho_0 = \frac{1}{1 + e^{s/a}} \tag{7}
\]

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 \( a_0 = .48 \text{ fm} \) and \( E_{\text{surf}} = 22.38 \text{ MeV/fm}^2 \).
As an example we show in Fig. 1 the result for $^{208}\text{Pb} + ^{208}\text{Pb}$ for which (5) is a very good approximation. We have drawn equipotential energy curves as a function of $s_0$ 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 $s_0$ 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 $\hat{V}(s_0,a)$, 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 $^{40}\text{Ca} + ^{40}\text{Ca}$ 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 $a = a_0$ over the whole surface of each nucleus. The polarized potential, represented by crosses, is the minimum value with respect to $a$ of $\hat{V}(s_0,a)$ at fixed $s_0$. For instance at $s_0 = 0$ the minimum is reached for $a = 0.72$ fm. The potential $\hat{V}$ is deeper than $V$ by about 20% at $s_0 = 0$, 40% at $s_0 = 1$, and 60% at $s_0 = 2$ (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

Fig. 1. Equipotential energy curves for $\Psi(s_0, a)$ in MeV calculated with approximations (5) and (6).
Fig. 2. Interaction potential $\hat{V}$ of polarized nuclei as compared to potential $V$ for non-polarized nuclei and proximity approximation $V_p$. 