Nucleus-nucleus potential in the range $-2 < S < 2.5$ fm

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The nucleus-nucleus potentials (V_N) over a range of interaction distances ($-2 < S < 2.5$ fm) have been obtained from the analyses of the fusion excitation function data spanning a large range of energies. A three-parameter Fermi function adequately represents the observed variation of $V_N/\bar{R}[R=R_1R_2/(R_1+R_2)$, with R_1 and R_2 the radii of the interacting nuclei] with S in the above-mentioned range.

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A number of methods [1–5] have been employed for the deduction of nucleus-nucleus potentials (V_N) from analyses of fusion excitation function data. Bass [2] has followed a graphical method to obtain the potential from fusion data. Gupta and Kailas [5] have proposed a method similar to that of Bass [2] but using an empirical expression for fusion excitation functions. The common procedure of using the expression

$$\sigma_F = \pi R_B^2(1 - V_B/E) \tag{1}$$

("slope and intercept method") (V_B is the potential barrier, R_B is the barrier radius) to get the potential yields only one set of V_N and R values over a given energy range for the interacting system. However, following the methods of Refs. [2] and [5] it is possible to deduce the V_N values for a range of R values, over a given energy range.

A large number of earlier work have reported determination of V_N mainly from analyses of fusion data available at lower energies. With the recent availability of fusion data at higher energies, Gomez del Campo and Satchler [4], Doukellis [6], and others have deduced V_N at smaller distances for a number of systems following the "slope and intercept method." The purpose of the present work is not only to enhance the database with the inclusion of more recent data for some other systems but also to use the method of Ref. [5] to determine V_N at several R values for each interacting system.

The procedure for the determination of the nucleus-nucleus potential from fusion data has been discussed in detail in Ref. [5] and hence will not be repeated here except for pointing out some of the important steps involved. The fusion cross section for the interacting nuclei (Z_1, A_1) and (Z_2, A_2) at the collision energy E (MeV; c.m. system) is defined as [5]

$$\sigma_F = 10\pi\rho(\rho - D) \text{ mb} , \tag{2}$$

where

$$\rho = mE + b \text{ fm}$$

and

$$D = 1.44 Z_1 Z_2 / E \text{ fm} .$$

In the above expression m and b are adjustable parameters used so that the best fit with the fusion excitation function can be obtained. Starting from the above expression it is possible to obtain [5] analytical expressions for the total potential (V_T) and the interaction distance R as

$$V_T(R) = E - \frac{\rho^2 E - \rho z}{R^2}, \quad R^2 = 3\rho^2 - 2\rho b - mz , \quad z = 1.44 Z_1 Z_2 . \tag{3}$$

The nuclear potential V_N may be obtained after subtracting from V_T the Coulomb potential. In the present work, the Coulomb potential acting between the heavy ions has been calculated using the expressions given in Ref. [7] for sphere-sphere distribution of charges. The fusion excitation functions for the systems ^{12}C, ^{16}O, ^{20}Ne, ^{32}S+^{27}Al, ^{16}O, ^{19}F+^{40}Ca, ^{32}S+^{24}Mg, ^{20}Ne+^{26}Mg, available up to fairly high energies [8], have been considered for the present analysis. Most of these systems have been analyzed earlier using the "slope and intercept method" to get the potentials. As mentioned before, in the present work, the procedure of Ref. [5] has been followed for all systems to determine the potentials at different values of R. The fusion cross section data for each system have been fitted with the expression (2). Starting with the m and b values deduced, the nucleus-nucleus potentials have been obtained at several values of R using (3). The radii R_1 and R_2 of the interacting ions have been calculated using the expressions [9]

$$r_i = 1.28 A_i^{1/3} - 0.76 + 0.8 A_i^{-1/3}, \quad R_i = r_i(1 - 1/r_i^2) \quad i = 1,2 . \tag{4}$$

The variable S is defined in the usual manner as

$$S = R - (R_1 + R_2) . \tag{5}$$

The mean radius $\bar{R}$ is expressed as

$$\bar{R} = R_1 R_2 / (R_1 + R_2) . \tag{6}$$

The V_N values obtained as discussed above for several values of R have been transformed to a universal $V_N/\bar{R}$ versus S plot. In Fig. 1 the $V_N/\bar{R}$ values are plotted as a function of S. For each S, we have several $V_N/\bar{R}$ values, depending on the system concerned. The spread in the $V_N/\bar{R}$ values represent the uncertainty in the determination of this quantity. The values of $|V_N/\bar{R}|$ range between 100 and 3 MeV as the S values are changed from -2 to 2.5 fm. Gomez del Campo and Satchler [4] have represented the variation of $V_N/\bar{R}$ with S with a form

$$V_N/\bar{R} = -V_0 \exp(-S/a_0) \tag{7}$$

with $V_0 \sim 24$ MeV fm^{-1} and $a_0 \sim 1.4$ fm. As the S range over which the variation of potential being considered is rather large, i.e., -2 to 2.5 fm, we have fitted the data of $V_N/\bar{R}$ versus S with the more appropriate form—Fermi or Woods-Saxon—

$$V_N/\bar{R} = -V_0\{1+\exp[(S+S_0)/a_0]\} \ . \tag{8}$$

The best-fit values of the parameters were $V_0 = 113 \pm 16$ MeV fm^{-1}, $S_0 = 1.0 \pm 0.2$ fm, and $a_0 = 0.97 \pm 0.03$ fm.

We have also used the expression (7) to fit the potential data. The values of V_0 and a_0 have been determined to be 24.5 MeV fm^{-1} and 1.21 fm, respectively. As can be seen from Fig. 1 and also from fitting criteria, the three-parameter form (8) gives a better representation of the data than the two-parameter form (7). The value of χ^2 per degree of freedom obtained using expression (8) was about 1.5 and 2 times better than the one obtained using expression (7) with the new parameters and that of Ref. [4], respectively. For completeness we have also shown in Fig. 1 the modified proximity potential calculated using Ref. [10].

Following the present method we have determined $V_N/\bar{R}$ values for each system over the same S range. Hence by combining these values we are able to determine more precisely the $V_N/\bar{R}$ values over the entire S range. Further it may be pointed out that using the present procedure we are able to deduce $V_N/\bar{R}$ at S values smaller than possible by the slope-intercept method. For example, using the latter method for the system $^{32}S+^{27}Al$, only the $V_N/\bar{R}$ values at $S = 0.6$ is obtained (region II of Ref. [6]). However, using the present method we are able to get $V_N/\bar{R}$ values up to $S = -2$ fm.

To conclude, we have determined nucleus-nucleus potentials at several values of R (S) from analyses of recent fusion data available up to high energies. A three-parameter Fermi functional form, as discussed above, gives a better reproduction of the observed variation of $V_N/\bar{R}$ with S than the simple two-parameter form suggested in Ref. [4].

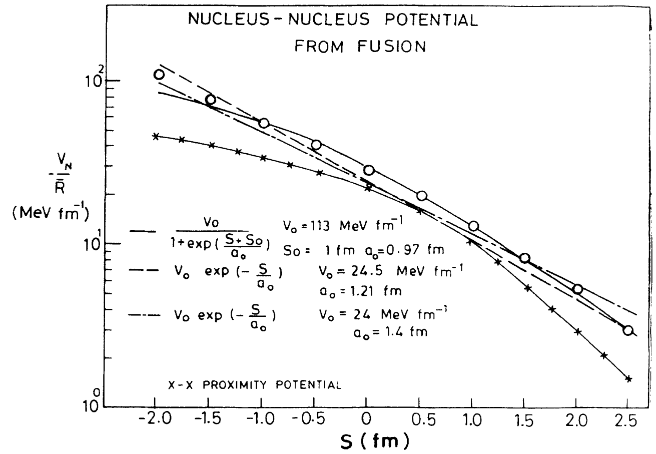

FIG. 1. Plot of $V_N/\bar{R}$ versus S in the range from -2 to 2.5 fm. The continuous line is the prediction as per the three-parameter form given by expression (8). The dashed lines are calculations as per expression (7) (see text for details).

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