The binding energies of $^4$He, $^{16}$O, and $^{40}$Ca are computed applying the Brueckner theory of the reaction matrix for the Tabakin and the Mongan nonlocal separable potentials. Binding energies ($\sim$ 10 MeV/nucleon) obtained are substantially greater than similar values for the local Hamada-Johnston potential (approx. $4 \div 5$ MeV/nucleon). Detailed comparison of reference and exact reaction matrices for both types of potentials (local and nonlocal) in the coupled $^3S - ^3D$ channel confirms the existence of a strong correlation between the magnitude of the matrix elements of the reaction matrix and the intensity of a tensor force. A similar correlation also exists in the $^1S_0$ channel between the magnitude of matrix elements of the reaction matrix and the singlet scattering length. A different off-shell behaviour of individual potentials plays also a certain role.

INTRODUCTION

Two-nucleon scattering data and certain properties of the bound state are the only direct experimental criteria which may be applied when constructing two-nucleon interaction. A relatively good knowledge of these data has made it possible to suggest several realistic N--N potentials which fit the phase shifts in the energy region $0 \div 400$ MeV and clarify the well-known properties of the deuteron in a satisfactory way as well. In addition to local static potentials [1--3], a number of nonlocal separable potentials has appeared [4--8]. Both groups of potentials describe the scattering data with reasonable accuracy; they, however, give differing values for the deuteron D-state probability ($P_D$). For local static potentials $P_D = 6 \div 7\%$ [1--2] while for nonlocal potentials $P_D \leq 3\%$ [9]. Moreover, scattering data determine only the matrix elements of transition matrix $T$ on the energy shell while its behaviour off the energy shell may differ for different potentials essentially. The question therefore arises how sensitive are certain properties of many-nucleon systems to the differences in the behaviour of individual N--N potentials.

All the potentials mentioned [1--8] contain a strongly repulsive hard-core or soft-core. The resulting strong two-particle correlations may be included in the Brueckner reaction matrix theory [10]. For local potentials [1--2] a number of computations of binding energy were made according to this theory for the nuclear matter and for finite nuclei, e.g. [11--15]. (Of extensive literature we only list those works to which we refer). Some of the realistic nonlocal potentials were applied by Clement, Serduke and Afnan [9] in computations of nuclear matter. They compared the results thus attained with similar results for the Reid potential. Kahana, Lee and Scott [7] applied their own nonlocal potential when computing the effective interaction of valence nucleons on the $^{18}$O and $^{18}$F nuclei while Gmitro and Sotona [16] carried out a computation of the $^4$He and the $^{16}$O binding energy in the case of the Tabakin potential. Computations using the nonlocal potentials are by far not as complete as those using local potentials. Part I of this series will therefore be devoted to the computation of binding energies of magic nuclei ($^4$He, $^{16}$O, $^{40}$Ca) while Part II deals with a computation of the effective interaction of valence nucleons.

*) 250 68 Řež, Czechoslovakia.
in the $^{16}$O and $^{18}$F nuclei with nonlocal separable potentials. In both cases we apply the second set of the Mongan potentials [6] (potentials M 1, M 2, and M 4) and the Tabakin potential (T) frequently used in nuclear physics [4].

In Sect. 2 we briefly describe the method applied in the computation of the reaction matrix and we investigate the accuracy of some applied numerical approximations. Sect. 3 contains the results for the $^4$He, $^{16}$O, and the $^{40}$Ca nuclei. In Sect. 4 we compare in detail the reaction matrices for local and nonlocal potentials. The results are briefly summarized in the conclusion.

2. CALCULATION OF REACTION MATRIX

The reaction matrix is defined by the operator equation [10]

$$ t(W) = v - v \frac{Q}{H_{12} - W} t(W) $$

where the Pauli operator $Q$ prevents scattering into occupied states and $W$ is the starting energy. For matrix elements of $t$ in two-particle state $|h_1, h_2\rangle$ it holds $W = \varepsilon_{h_1} + \varepsilon_{h_2}$.

In solving equation (1), the frequently used approximations [10, 16] are employed in the following:

(i) The equation is solved in the basis of single-particle harmonic oscillator functions.

(ii) An averaged Pauli operator is used, which is diagonal in quantum numbers of the centre-of-mass motion (equations (23–24) of Ref. [16]).

(iii) Single-particle energies of occupied states $\varepsilon_h$ are determined self-consistently from Bruckner-Hartree-Fock (BHF) condition:

$$ \varepsilon_h = \langle h | T | h \rangle + \sum_{h'} \langle hh' | t(\varepsilon_h + \varepsilon_{h'}) | hh' \rangle . $$

(iv) All unoccupied harmonic oscillator states are shifted by the constant amount $C = (2n_p + l_p + \frac{3}{2}) \hbar \omega / 2$, where $n_p$ and $l_p$ are the quantum numbers of the lowest unoccupied state (i.e. 0p in the case of the $^4$He nucleus, etc.). Such a choice of spectrum guarantees that the contribution of the simplest diagram of Fig. 1 (f) with $U$-insertion in the particle line will be cancelled.