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STRUCTURE EFFECTS IN ^{20}Ne + ^{208}Pb QUASI-ELASTIC SCATTERING*

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Preliminary results of an analysis of experiments devoted to a study of the sensitivity of the ^{20}Ne + ^{208}Pb quasi-elastic angular distributions at two near-barrier energies and the previously measured corresponding barrier distribution to the value of the nuclear quadrupole deformation length of ^{20}Ne are reported.

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1. Introduction

Quasi-elastic scattering barrier distributions provide valuable information on the influence of nuclear structure properties on the interaction between two heavy ions. Angular distributions of the quasi-elastic scattering are also sensitive to the structure of the interacting nuclei. In a combined

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analysis of new angular distribution data and the previously measured barrier distribution [1] for the ^{20}Ne + ^{208}Pb system we investigate the relative sensitivity of these experimental quantities to the nuclear quadrupole deformation length $\beta_2 R$ of ^{20}Ne.

2. Experimental set-up

Angular distributions for the quasi-elastic scattering, defined as the sum of the elastic scattering plus inelastic scattering to the first (2^+) and second (4^+) excited states of ^{20}Ne, were measured using the multipurpose scattering chamber ICARE. Low-lying excited states of ^{208}Pb are also included in the quasi-elastic peak but are not expected to be strongly excited — with the possible exception of the first (3^-) state — and may be safely neglected for most purposes.

The experiment was performed at the Heavy Ion Laboratory of the University of Warsaw with a ^{20}Ne beam of intensity approximately 6×10^8 ions per second delivered by the $K = 160$ cyclotron. Beam energy resolution was approximately 1.5%. The beam impinged on a ^{208}Pb target of a real density 100 μg/cm^2 and gas-silicon telescopes were used to detect and identify the charged particles. The gas ΔE stages were filled with isobutane at 25 mbar pressure and the silicon E stages were 500 μm thick. Data were collected at two beam energies, 108.6 and 115 MeV. A sample two-dimensional spectrum is presented in Fig. 1. The angular distributions were normalised to the Rutherford cross section at the most forward angles measured.

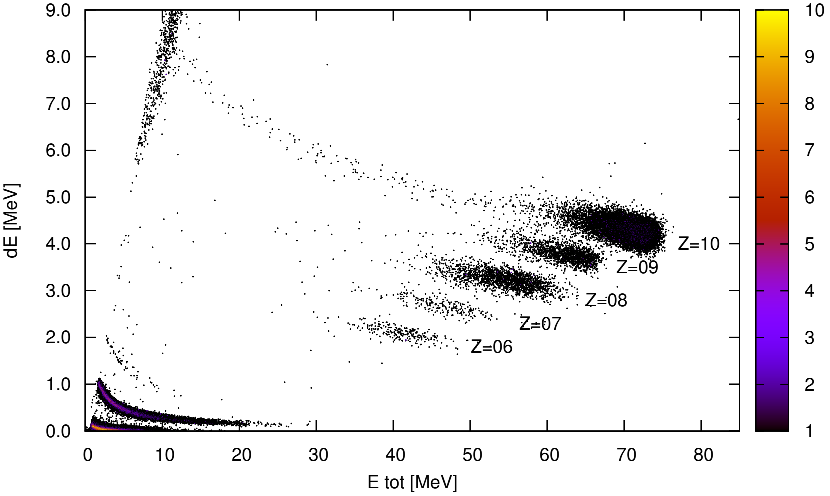

Fig. 1. Typical two-dimensional ΔE vs. E spectrum at $E_{\mathrm{Lab}} = 108.6$ MeV.

3. Angular distribution analysis

Angular distributions for the ^{20}Ne + ^{208}Pb quasi-elastic scattering at 108.6 MeV and 115 MeV are plotted in Figs. 2 and 3 respectively. The data were analysed using the coupled-channels (CC) method including couplings to the first 2^+ and 4^+ states of ^{20}Ne, assumed to be members of the ground-state rotational band. Any residual effect due to couplings to the excited states of ^{208}Pb, not included in the coupling scheme, is subsumed into the optical potential. All calculations were performed with the code FRESCO [2]. The optical potential was of the following form

$$V(r) = (N_r + iN_i)\, V_{\rm DF}(r)\,, \tag{1}$$

where $V_{\rm DF}(r)$ is a double-folded potential calculated using the code DFPOT [3] with the energy-independent form of the M3Y interaction [4] and ^{208}Pb and ^{20}Ne matter densities taken from Ref. [5] and derived from the charge density of Ref. [6] respectively: N_r and N_i denote normalisation parameters.

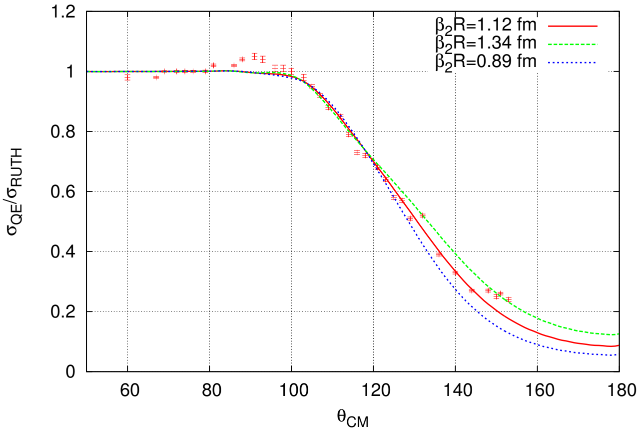

Fig. 2. ^{20}Ne + ^{208}Pb quasi-elastic scattering angular distribution at 108.6 MeV.

As a first step, existing elastic and inelastic (to the first 2^+ state of ^{20}Ne) scattering data at 131 MeV [7] were analysed. An automatic search routine was used to minimise simultaneously χ^2 for the elastic and inelastic scattering angular distributions while searching on the normalisation parameters N_r and N_i and the deformation length $\beta_2 R$. The best fit values were as follows: $N_r = 1.12$, $N_i = 0.66$ and $\beta_2 R = 1.12$ fm. The hexadecapole deformation length, $\beta_4 R$, was kept fixed at a value of 0.6875 fm (the average of the values quoted in Ref. [8]) throughout, as there are no data for inelastic scattering to this state and its influence on the available data is not sufficient to enable it to be unambiguously determined.

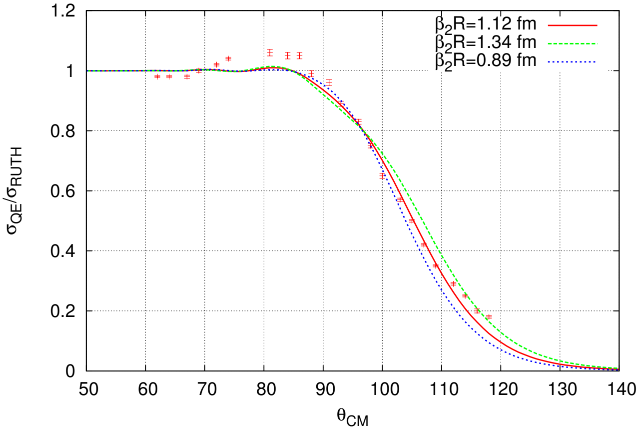

Fig. 3. ^{20}Ne + ^{208}Pb quasi-elastic scattering angular distribution at 115 MeV.

In the next step, the new quasi-elastic data at 115 and 108.6 MeV were fitted by a two-parameter grid search (the automatic search routine could not be used as the data are quasi-elastic), adjusting N_r and N_i to give the best overall description of the data while keeping $\beta_2 R$ fixed. The resulting best-fit values were: $N_r = 0.65$, $N_i = 0.16$ at $E = 108.6$ MeV and $N_r = 0.72$, $N_i = 0.25$ at $E = 115$ MeV. The results of these calculations are denoted by the solid (red) curves on Figs. 2 and 3. The dashed (green) and dotted (blue) curves on Figs. 2 and 3 correspond to calculations with $\beta_2 R$ values increased and decreased by 20% respectively in order to show the sensitivity of the calculated quasi-elastic scattering angular distributions to this parameter.

The relatively poor description of the experimental angular distributions around the Coulomb-nuclear interference peak may be ascribed to employing the same geometry for both the real and imaginary parts of the optical potential. Using a Woods–Saxon form imaginary part for the residual optical potential would improve the fit but at the expense of increasing the number of parameters to be searched on. However, this region is essentially insensitive to $\beta_2 R$, at least within the limits of ±20% of the best-fit value.

4. Barrier distribution analysis

To test the sensitivity of the quasi-elastic barrier distribution to the value of the ^{20}Ne quadrupole deformation length we extended our calculations to lower energies. In these calculations N_r and N_i were kept fixed at their best-fit values for $E = 108.6$ MeV. This is something of a compromise since the residual optical model potential is energy-dependent due to the influence of channels not explicitly included in our channel-coupling scheme. A quasi-elastic scattering excitation function was calculated and the corresponding barrier distribution derived from it according to the following formula

$$D_{\mathrm{QE}}(E_{\mathrm{eff}}) = -\frac{d(\sigma_{\mathrm{QE}}/\sigma_{\mathrm{R}})}{dE_{\mathrm{eff}}}\,, \tag{2}$$

where σ_{QE} is the quasi-elastic cross section, σ_{R} the Rutherford cross section and E_{eff} the effective energy, defined as

$$E_{\mathrm{eff}} = \frac{2E_{\mathrm{c.m.}}}{1+\mathrm{cosec}(\theta/2)}\,, \tag{3}$$

where θ is the centre-of-mass frame scattering angle at which the quasi-elastic excitation function is measured and $E_{\mathrm{c.m.}}$ the centre-of-mass frame energy. The calculated barrier distribution is compared with the previously obtained experimental one [1] in Fig. 4. The different curves on the figure correspond to sets of coupled-channels calculations with the three ^{20}Ne $\beta_2 R$ values, as in Figs. 2 and 3. Note that the barrier height distribution is much more sensitive to the value of $\beta_2 R$ than the angular distributions.

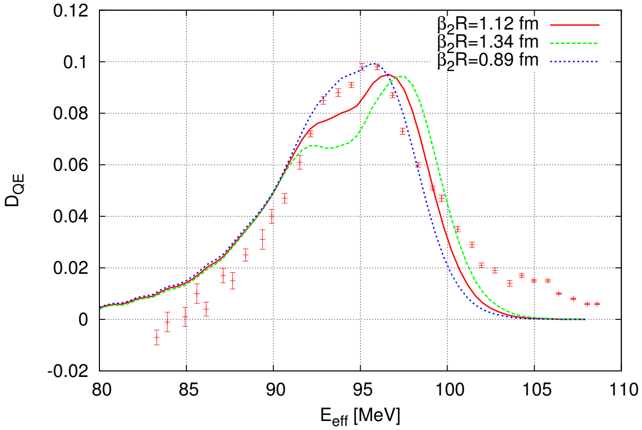

Fig. 4. ^{20}Ne + ^{208}Pb quasi-elastic barrier height distribution.

5. Conclusions

It has been shown that the ^{20}Ne + ^{208}Pb quasi-elastic barrier distribution is much more sensitive to the ^{20}Ne $\beta_2 R$ value than the corresponding angular distributions. Thus, measurements of D_{QE} can form valuable additional information when trying to fix nuclear deformation lengths. It should be noted, however, that based on the level of agreement with D_{QE} alone a value of $\beta_2 R = 0.894$ fm would be deduced as the best-fit value, whereas the angular distribution data favour $\beta_2 R = 1.12\,\text{fm}$. This most likely indicates the need to include further channels in the coupled-channels analysis. The sensitivity of D_{QE} and the angular distributions to other reaction channels (*i.e.* nucleon and cluster transfers) will be investigated in future work.

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