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ENERGY STORING IN COMPRESSED NUCLEAR MATTER

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Résumé - On rappelle que les analogies avec la dynamique des fluides conduisent à une équation de Schrödinger non-linéaire (NOSE), qui modélise des collisions élastiques d'ions lourds. On montre que l'énergie élastique de compression stockée dans les régions superficielles des ions en contact produit une force de répulsion. Des résultats numériques obtenus en résolvant la "NOSE" confirment cette méthode. On attire l'attention sur le fait que la même physique est apparemment encore valable à des énergies relativistes.

Abstract - It is recalled that fluid dynamical analogies lead to a nonlinear Schrödinger equation (NOSE) modelling elastic collisions of heavy ions. The elastic compressional energy stored in the surface regions of the touching ions is shown to give rise to a repulsive force. Numerical results obtained upon solving the NOSE support the approach. Attention is drawn to the point that the same physics do apparently also work at relativistic energies.

The angular distributions of the differential cross-sections of elastically scattered heavy ions, \( \frac{d\sigma}{d\Omega} \), are "anomalous" in so far as one observes a distinct rise of \( \frac{d\sigma}{d\Omega} \) for backward angles (in contrast to the "normal" almost exponential fall off). It has been noted that this anomalous large angle scattering (ALAS) may be accounted for by supplementing the usual optical model potential by a repulsive term, \( V_r \):

\[
V_{\text{ESP}} = V_{\text{om}} + V_r
\]

(ESP - effective surface potential).

The effect of \( V_r \) in liaison with \( V_{\text{om}} \) is to produce a potential pocket in the surface region which facilitates the description of \( \frac{d\sigma}{d\Omega} \) for backward angles (see e.g. /1/ and references).

The of the simple potential model /1/ lead on one side to calculations within the microscopic resonating group method (see /2/ and references) and on the other side to an attempt to model such collisions in terms of liquid drops with diffuse surfaces /3,4/. The physical picture invoked in this semi-classical model is that of two drops compressing each other elastically in their respective surface regions as they approach each other. The elastic energy stored in the compressed nuclear matter gives then rise to a repulsive spring-type force providing the wanted repulsive potential \( V_r \). Putting this picture into practice and using the fluid dynamical interpretation of the wavefunction /5/ we ended up with a nonlinear Schrödinger equation (NOSE) /3/. Approximating the nonlinearity in the spirit of (1) by phenomenological expressions lead to very nice results /6/. However, in the meantime we reduced the NOSE to its counterpart for the wavefunction of relative motion, \( \chi \),
Fig. 1: Experimental and theoretical differential cross-sections for elastically scattered $^9$Be ions ($E=27$ MeV) incident on $^{16}$O are displayed. Top: $K$ is varied from 0 MeV to 350 MeV. Bottom: Experimental data (points) are compared with computations based on $K=0$ MeV (broken curve; i.e. optical model) and on $K=270$ MeV (full curve).

Fig. 2: As bottom of Fig. 1 but $E=20$ MeV and $K=270$ MeV.

Fig. 3: As bottom of Fig. 1 but $E=30.6$ MeV and $K=270$ MeV.
\[ \frac{x^2}{2m} \nabla^2 x + V_{\text{om}} x + C |x|^2 \chi = E \chi \quad \text{with} \quad C = K/9 > 0 \]

(2)

and solved it numerically. The notation is standard with \( K = 9C \) denoting the compressibility of nuclear matter. For \( C = 0 \) (2) is just the usual optical model equation with \( V_r = 0 \). \( C \neq 0 \) implies that \( V_r \) will also be different from zero. In the case of nucleon-nucleus scattering, the compression of nuclear matter will be negligible, a point correctly reflected by (2); We apply (2) in such a way that we take the parameters of the optical model from the literature, hence, \( C \) is the only adjustable parameter available to improve the correspondende between theory and experiment. In the "normal" case, say, of nucleon-nucleus scattering the \( V_{\text{om}} \) yields adequate \( \frac{d\sigma}{d\Omega} \) implying \( C = 0 \). However, in the case of colliding heavy ions \( V_{\text{om}} \) leads only for forward angles to an adequate description; the anomalous rise for backward angles requires \( C \neq 0 \). It turned out that an increase in \( C \) leads also to an increase in \( \frac{d\sigma}{d\Omega} \) for backward angles giving also rise to some changes in its structure. An unexpected feature is that from a critical value of about \( K = 9C = 260 \text{ MeV} \) onwards \( \frac{d\sigma}{d\Omega} \) does no longer rise but it just fluctuates around this critical value. We did not yet find a satisfactory interpretation for this behaviour. But it is interesting that this critical value is very close the one required for the description of the experimental \( \frac{d\sigma}{d\Omega} \). From our analysis of more than ten cases we obtain the (average) value \( K = 250 \text{ MeV} (\pm 10\%, -15\%) \) for the compressibility modulus of (finite) nuclear matter -- a result which is not just in line with literature results but also with the numbers due to older calculations of ours, see e.g. /6/.

Turning towards relativistic heavy ions, let us recall that it has recently been shown /7/ that systematic discrepancies between experimental data and cascade model calculations may be explained invoking the picture that part of the available kinetic energy of the projectile goes into the elastic compression of nuclear matter. At a later stage of the reaction process this energy is to be released. -- The amount of compressional energy required is compatibel with compressions involving only the surface regions of the participating ions. This is readily verified by taking Eq.(6) of /4/ and by inserting into it reasonable numbers for mass numbers, radii and separations between the two ions; the resulting numbers compare nicely with the equation of state given in Fig.2b of /7/. A more detailed discussion is to be given elsewhere.

REFERENCES


