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INGOING WAVE BOUNDARY CONDITION ANALYSIS OF α-Ni^{62} ELASTIC SCATTERING CROSS SECTIONS

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Ingoing Wave Boundary Condition Analysis of α-Ni^{62} Elastic Scattering Cross Sections.

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An investigation of the elastic scattering cross section of α-particles on Ni^{62} at laboratory energies of 25, 33, 50 and 85 MeV[1] is presented utilizing an ingoing wave boundary condition (IWB).

The IWB method[2][3] is an elaboration of the old scheme of Feshbach and Weisskopf[4] and compared to optical model descriptions has several simplifying features. It is a surface description which represents diffraction from a potential surface surrounding a black[5] nucleus, while in the optical model description additional diffraction may come from the waves which re-emerge from the interior of the nucleus. In the present IWB model a nuclear potential is added to the Coulomb potential. The resulting wave functions in the region "outside" of the potential well are very isensitive to the assumed value of the nuclear potential in the "inside" region because of the absence of interference between the outgoing and ingoing branches of the waves in the interior of the well[6,3]. The position of the boundary condition radius also does not affect the wave functions as long as it lies in the region of validity of the JWKB approximation inside the well[3].

Fig. 1 shows IWB results for α-Ni^{62} scattering cross sections at four energies.[1] The nuclear potential adopted is of the form

$$V = V_0 (1 + i\xi) \exp(-r/a) \qquad (1)$$

l.c. greek

and the values obtained for the three parameters are listed in Table I. The goodness of the fits was judged "by eye" and the values of the parameters should be taken only as indications of the general trend. However, the non-applicability of the 85 MeV parameters to the 33 MeV case, and vice-versa, has been ascertained. The four potentials listed in Table I have the property that at about 8 fermis their values are all equal to -2.2 MeV ($8 = 1.7 \times (62)^{1/3} + 1.3$). The position of the Coulomb barrier, where the sum of nuclear and Coulomb potentials goes through a maximum, lies at approximately 8 fermis in the α-Ni case. Furthermore, any one of the potentials in Table I gives rise to interference maxima and minima in the cross section which lies at the appropriate approximate experimental positions at all four energies. In other words, it is the position of the barrier rather than the slope of the potential or the value of ξ which determines the position of the diffraction minima. Since these diffraction minima change with energy in a non-trivial manner, the IWS procedure appears to provide a useful description. When plotted as a function of momentum transfer q, the position of the maxima and minima in the cross section shift to smaller values of q for increasing values of the energy. The shift is presumably due to the Coulomb repulsion which is relatively more important at the lower energies, and it is for this reason that the shift was called "non-trivial" in the sentence above.

Once the position of the minima is fitted, the remaining two parameters a and ξ are determined from the overall slope of the cross section with angle and the peak to valley ratio. The visible discrepancy of the position of the 50 MeV experimental and theoretical minima can be remedied by a 20% increase in the value of V_o. Since after this change the agreement with theory at all energies is better than the agreement shown at 50 MeV, it is felt that the accuracy in the determination of the real part of V at $\sim$8 fermis is better than 20%.[7] The increase of a with energy is curious. The increase of ξ with energy indicates larger participation of the surface in the excitation of inelastic processes,[8] and may be quite reasonable.

In view of the interest in the determination of deuteron-nucleus potentials and distorted waves, an attempt was made to examine the 11.8 MeV deuteron copper elastic scattering cross section[9] by means of the IWB procedure. It was not possible to find an acceptable fit. Not only was it impossible to reproduce the position of the minima and maxima, but also the experimental overall slope of the cross section with angle and the peak to valley ratios were mutually incompatible in the IWB description. Of course the model has very few parameters, spin zero is assumed for the deuteron and additional effects such as the possible presence of Coulomb distortion and excitation at large distances are not allowed for. If inclusion of such effects still would lead to no

agreement with experiment, then the discrepancy would be very interesting. It might then indicate the need of deuterons "returning" from the interior of the nucleus, much in agreement with present optical model descriptions.[10,11] There the low angular momentum optical model partial waves have the character of standing waves inside the potential well,[12] and these appear to be required to fit the data.[11]

The author wishes to thank Dr. John Meriwether for discussions which stimulated the α-Ni analysis. It is a pleasure to thank Professors John O. Rasmussen and I. Perlman for their kind hospitality at the Lawrence Radiation Laboratory during the summer months as well as the hospitality of Professor W. Gentner at the Max-Planck-Institut für Kernphysik.

Footnotes

1. J.R.Meriwether et al, UCRL-11484 (June 1964) unpublished
2. N.Oda and K.Harada, Theo.Phys. 15, 545 (1956) appear to be the first to use an IWB method to calculate α-particle scattering.
3. G.Rawitscher, Phys. Rev. 135, B 605 (1964). Other than imposing a boundary condition on the wave function at a radius away from the origin, the IWB procedure is numerically similar to optical model calculations.
4. H.Feshbach and V.F.Weisskopf, Phys. Rev. 71, 145 (1947) and 76, 1550 (1949).
5. When the wave number is complex the meaning of an ingoing current becomes difficult to define, even if the JWKB approximation is applicable. Therefore the word "black" should strictly be applied only to those cases for which the boundary condition radius lies in a region where the potential is real. Helpful conversations with Professor Jensen concerning this point are gratefully acknowledged.
6. By "inside" is meant that portion of the potential well where for each significant partial wave the JWKB approximation is valid. It can be shown by means of the JWKB approximation that changes in the inside potential do not affect the outside IWB wavefunction.
7. In the optical model fits of G.Igo, Phys. Rev. 115, 1665 (1959) to the 40 MeV elastic α-copper scattering cross sections; the tail of the real potential appears to be determined to an accuracy of about 20%. Igo's exponential potential is approximately 1.7 times larger than the 33 MeV potential listed in Table I. The difference may be due to the presence of an imaginary potential in Igo's calculation, but it may also be that for projectiles as light as the α-particle, optical model and IWB potentials are different.

8. For $\xi = 0$ all absorption occurs in the "inside" region.
9. G.Igo, W.Lorenz and U.Schmidt-Rohr, Phys. Rev. 124, 832 (1961).
10. C.Perey and F. Perey, Phys. Rev. 132, 755 (1963)
11. R.H. Bassel et al, "Elastic Scattering of Deuterons by Ca^{40}", to be published.
12. As can be seen from the presence of zeros in the plots of the absolute value of the wave function versus distance, as shown for instance in Fig. 4 of Ref. 10.

Table I

l.c. greek letter xi

Energy[a]	Vo[a]	a[b]	ξ[c]
85	$-.51 \times 10^6$	.650	.50
50	$-.51 \times 10^6$	.650	.37
33	$-.25 \times 10^7$	.574	.10
25	$-.195 \times 10^8$	.500	.00

a in units of MeV

b " " " F

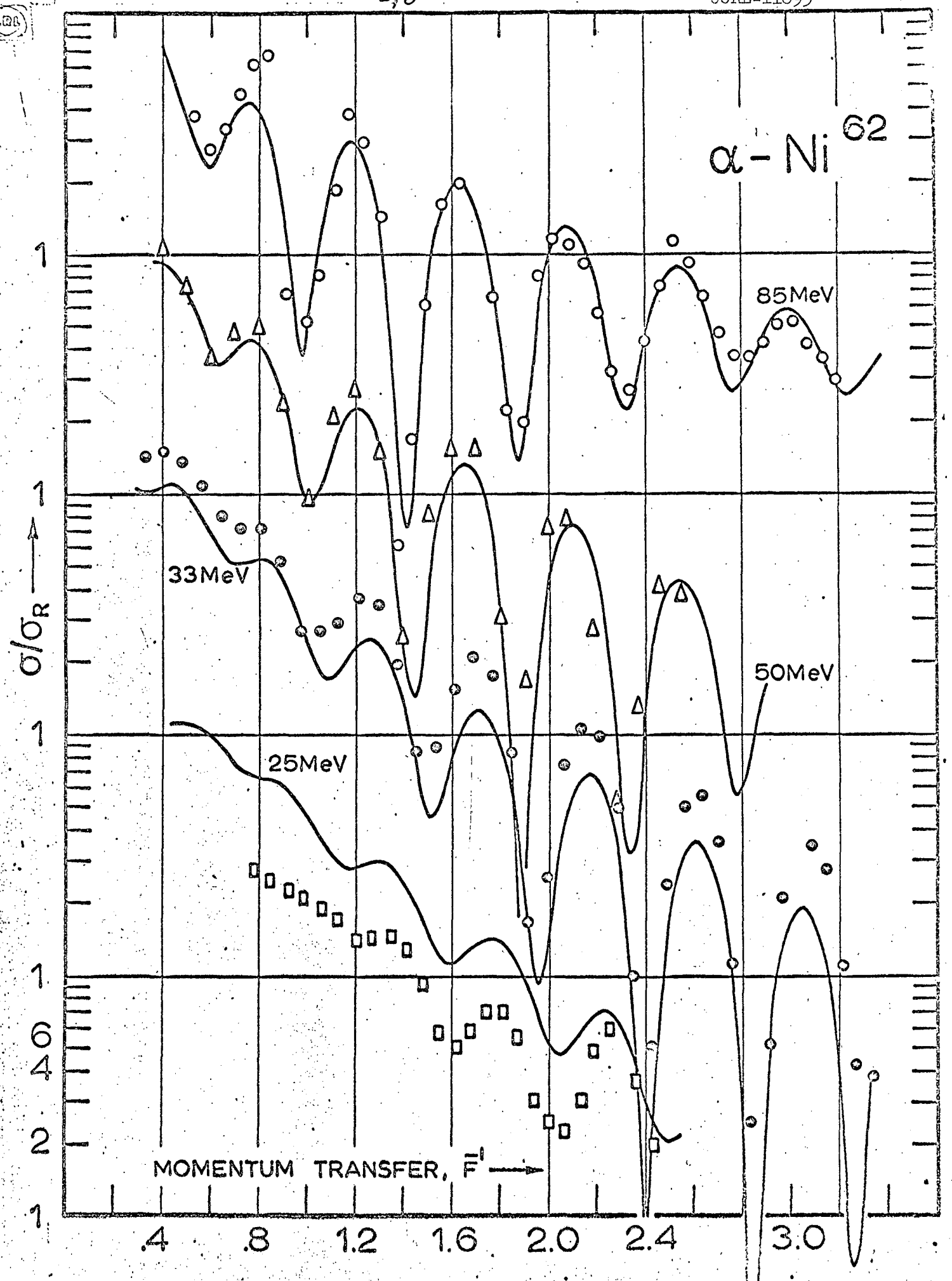
c dimensionless

CAPTION TO TABLE I:

Parameters used in Eq. (1) to obtain the fits shown in Fig. 1.

Figure Caption

Fig. 1 Scattering of α-particles by Ni^{62}. The ordinate represents ratio of cross section to Rutherford cross section. The abscyssa represents momentum transfer $Q = 2\lambda(p/\hbar) \times \sin(\theta/2)$ in units of F^{-1}. The C.M. scattering angle is θ, the momentum is p. The experimental points are those of Ref. (1) and the solid curves are the theoretical results corresponding to the parameters listed in Table I.


α - Ni 62
85MeV
33MeV
50MeV
25MeV
σ/σR
1
1
1
1
6
4
2
1
MOMENTUM TRANSFER, F' →
.4
.8
1.2
1.6
2.0
2.4
3.0

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