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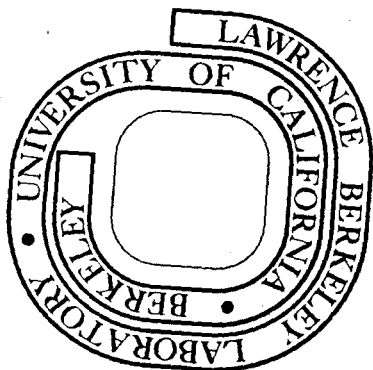
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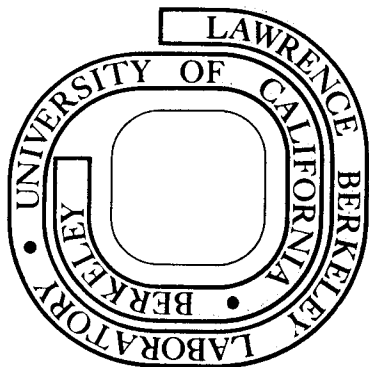
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SYSTEMATIC STUDY OF COULOMB ABSORPTION IN HEAVY ION SCATTERING*

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March 1978

ABSTRACT

Sub-Coulomb heavy ion scattering of ^{20}Ne on $^{148}, ^{150}, ^{152}\text{Sm}$ at 70 MeV has revealed a strong depletion of the elastic scattering flux at backward angles, systematically increasing with the collectivity of low-lying target states. A comparison with a semiclassical Coulomb absorption model and coupled channel calculations is given.

Recent investigations of elastic scattering of heavy ions, with sufficient resolution to separate the ground state from low-lying target and projectile states, reported a strong damping of the elastic scattering cross-section below the Rutherford value even at angles smaller than the grazing angle [1,2]. The effect can be reproduced by coupled channel calculations, which include Coulomb and nuclear coupling to low-lying target and projectile states excited during the scattering process.

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However, less time consuming calculations have become possible with the development of an effective potential simulating this effect [3,4]. Baltz and co-workers [4] derived a long range, imaginary potential arising from quadrupole Coulomb excitation. Inserting this potential into a semi-classical weak absorption model, the resulting analytical closed form obtained for the elastic scattering amplitude greatly simplifies below the Coulomb barrier. We present a systematic investigation of ^{20}Ne scattering on $^{148}, ^{150}, ^{152}\text{Sm}$ at 70 MeV (20 MeV below the Coulomb barrier) to test this model by studying deviations from pure Rutherford scattering as a function of the deformation of the target nucleus.

The measurements were performed with a 70 MeV $^{20}\text{Ne}^{4+}$ beam from the 88-inch cyclotron; scattered ^{20}Ne particles were detected in the focal plane of the QSD magnet spectrometer by Borkowski-Kopp type position detectors and an ionization chamber measuring the residual energy loss [5].

The beam position on the target was monitored by two additional proportional counters placed above and below the internal Faraday cup. Targets were $32 \mu\text{g}/\text{cm}^2$ of ^{148}Sm , $7 \mu\text{g}/\text{cm}^2$ of ^{150}Sm and approximately $5 \mu\text{g}/\text{cm}^2$ of ^{152}Sm enriched to $> 95\%$, all evaporated onto $5\text{-}10 \mu\text{g}/\text{cm}^2$ carbon backing foils. The spectrometer was operated with a solid angle of 1 msr typically. Under these conditions the energy resolution was sufficient to resolve the 551 keV, 2^+ state in ^{148}Sm , the 334 keV, 2^+ level in ^{150}Sm , and at a few angles the 122 keV, 2^+ level in ^{152}Sm (see fig. 1). A peak fitting procedure was applied to all spectra and errors in the cross-sections represent uncertainties in this procedure. Systematic effects due to

energy dependent charge state distributions were measured up to 80° in the laboratory system and extrapolated [6] to be 5% for backward angles.

Position spectra from the focal-plane detector taken at 90° and 140° in the laboratory system are shown for the different target nuclei in fig. 1. A comparison with energy spectra taken at the most forward angles shows an increasing enhancement of the inelastic yields when approaching the backward angles, which become larger than the elastic yield for the ^{152}Sm target.

In fig. 2 we compare the measured angular distributions for elastic scattering with the predictions of the analytical closed form for the cross-section ratio $\sigma_{el}/\sigma_R = \exp(-a \cdot f(\theta))$, based on a long range imaginary potential [4]. All reaction parameters are contained in the sum

$$a = 0.223 \frac{k^4}{\eta^2} \left[\frac{B_T(E2, 0^+ \rightarrow 2^+)}{Z_T^2 e^2} g_T(\xi) + \frac{B_P(E2, 0^+ \rightarrow 2^+)}{Z_P^2 e^2} g_P(\xi) \right]$$

and $f(\theta)$ is a function only of the scattering angle θ in the center of mass system. The $B_T(E2, 0^+ \rightarrow 2^+)$, $B_P(E2, 0^+ \rightarrow 2^+)$ values for the target and projectile respectively, were taken from the compilation of Christy and Häusser [7]. The Sommerfeld parameter is $\eta = 52$ in the present experiment. The semi-classical model applies a correction factor $g(\xi)$ to the potential in order to take some account of the energy loss during the 2^+ excitation process.

The model (dashed curves in fig. 2) gives a satisfactory description of the measured angular distributions up to 100° in the c.m. system. Some discrepancies occur at more backward angles, especially for ^{148}Sm and ^{150}Sm . For comparison coupled channel calculations were performed using the code CHORK [8] with the same $B(E2, 0^+ \rightarrow 2^+)$ transition probabilities as in the semi-classical model, and with quadrupole moments derived in the rotational limit [7] from these values. Coupling to both low-lying 2^+ states in target and projectile and including reorientation effects in both channels result in distributions given by the solid curves in fig. 2.

The lower solid curve for ^{152}Sm shows the calculation, without reorientation coupling. For ^{148}Sm and ^{150}Sm , non-reorientation coupling calculations (not given in fig. 2) are only 6% and 16% lower at extreme backward angles, respectively, indicating the decreasing importance of this coupling mode for the lighter Sm nuclei. While direct coupling to additional target states at incident energies above the Coulomb barrier is known [9] to reduce further the elastic scattering flux, their influence is assumed to be small in the present experiment.

Figure 3 shows the angular distributions obtained for the 2^+ target states. They are well described by the coupled channel calculation including reorientation effects. No attempt has been made to improve the fit to the backward angle data.

We have demonstrated that the elastic scattering flux is depleted by 30 to 80% at backward angles in sub-Coulomb heavy ion scattering, systematically increasing with the collectivity of low-lying target states. From a comparison with the semi-classical Coulomb absorption model and coupled channel calculations it becomes clear that the present model does not account for (i) reorientation effects and (ii) trajectory dependent energy loss corrections, which seem to be required for ^{148}Sm and ^{150}Sm by the remaining difference between non-reorientation calculations and the model calculations at backward angles. Nevertheless the development of this analytical approach is useful for giving physical insight into the process, and for surveys of much heavier systems, such as $^{84}\text{Kr} + ^{209}\text{Bi}$ [3,10], for which the exact calculations are difficult to perform.

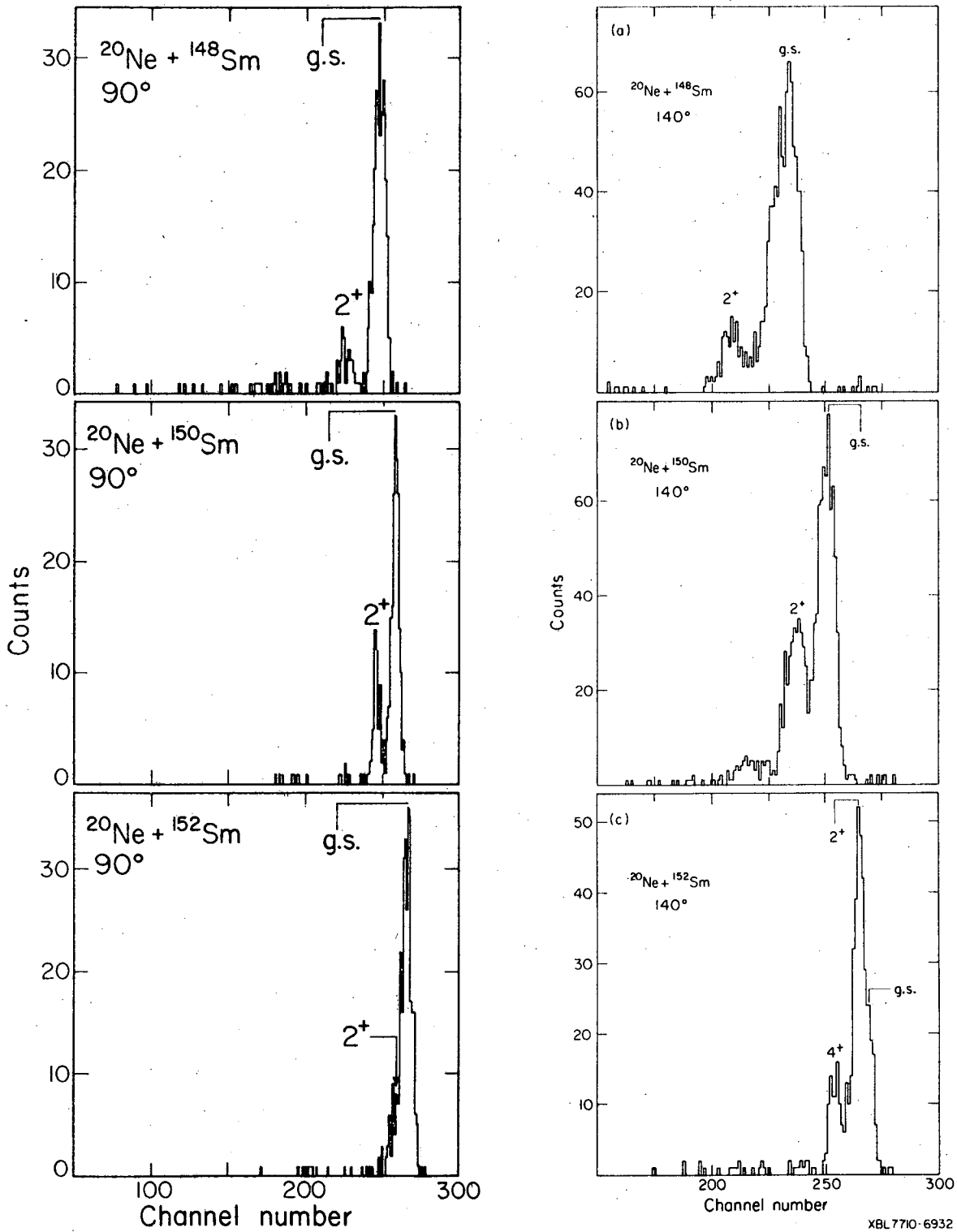
We would like to thank P. D. Bond for clarifying discussions.

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 $B(E2, 0^+ \rightarrow 2^+) [e^2 b^2]$ used: 0.048, 0.73, 1.44, 3.40 for ^{20}Ne , ^{148}Sm , ^{150}Sm , ^{152}Sm , respectively and $Q_{\text{rot}}^{2+} [eb] = -0.9059 \sqrt{B(E2, 0^+ \rightarrow 2^+)}$.
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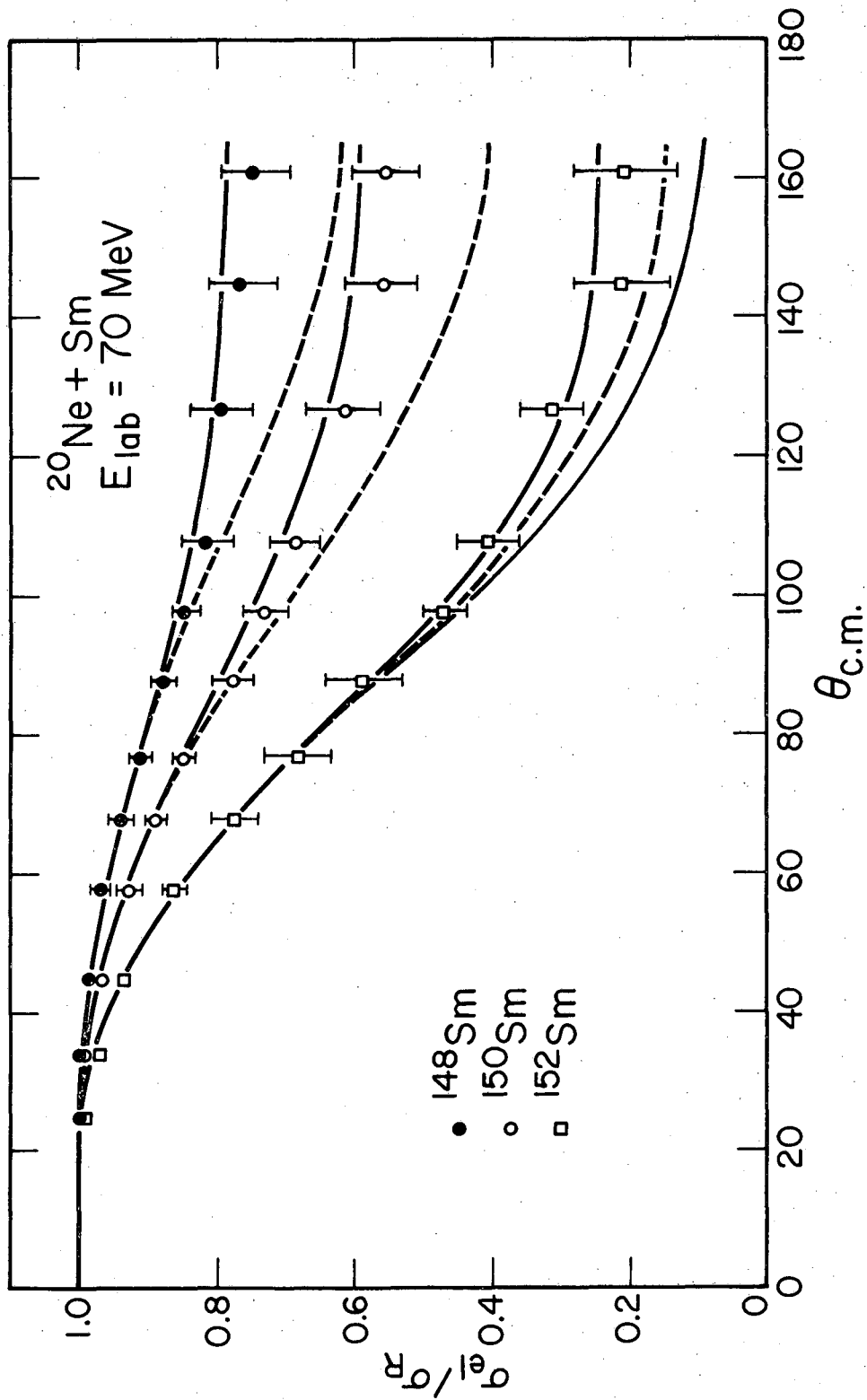
FIGURE CAPTIONS

- Fig. 1. Energy spectra of $^{20}\text{Ne}^{9+}$ after scattering from $^{148, 150, 152}\text{Sm}$ at $\theta_{\text{lab}} = 90^\circ$ and $\theta_{\text{lab}} = 140^\circ$.
- Fig. 2. Angular distributions from elastic scattering of ^{20}Ne on samarium nuclei. Dashed curves show calculations in a Coulomb absorption model, solid curves represent coupled channel calculations (see text).
- Fig. 3. Angular distributions from inelastic scattering of ^{20}Ne on 2^+ target states. Solid curves represent coupled channel calculations.



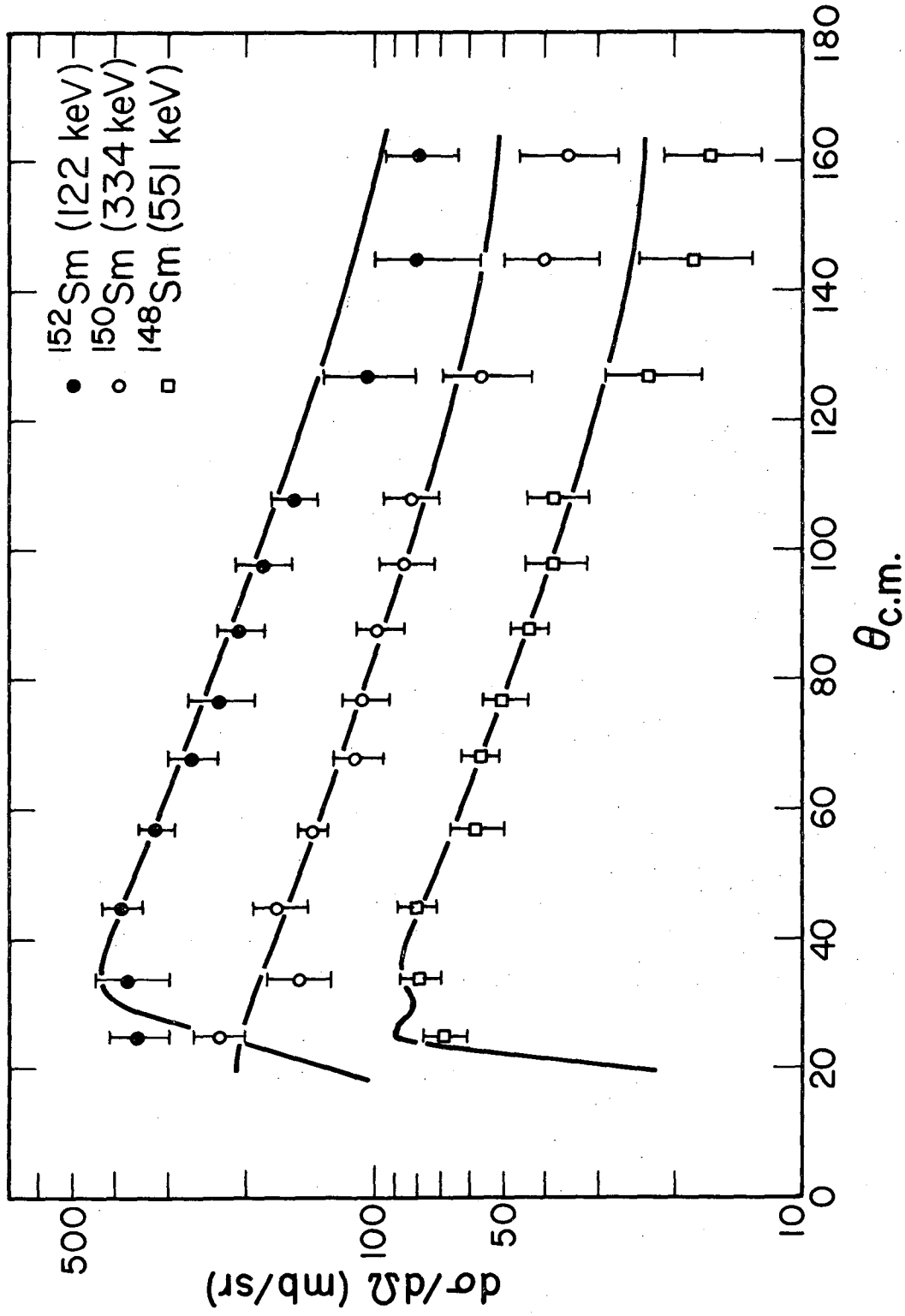
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Fig. 1



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Fig. 2



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Fig. 3

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