the dislocation distribution, leads to an additional thermodynamic force that tends to homogenize the superconductor, to rarefy the dislocation clusters, etc. Conversion of this force into the effective mechanical stress σ_{eff} acting on the dislocation yields

$$\sigma_{eff} = \delta F/\delta\varepsilon. \quad (2)$$

Here $\delta\varepsilon$ is the deformation produced when the dislocation density is equalized over the crystal. When typical superconductor parameters and data on the dislocation structure are used (see, e. g., [18]), the estimate (2) shows that the stresses σ_{eff} can reach values on the order of 10^5 dyn/cm^2. Such stresses, being small in comparison with the applied stress, are nevertheless significant under special deformation conditions (for example, when the number of mobile dislocations is depleted under creep conditions).

To assess the relative roles of the quasistatic and dynamic effects, it is highly desirable to perform experiments on samples with different dislocation structures and to analyze the change occurring in the dislocation structure as a result of the N-S transition. Great interest attaches to experiments on the mobility of individual dislocations in the N and S states, which make it possible to exclude the quasistationary effects.

[1] V. B. Pustovalov, V. I. Startsev, and V. S. Fomenko, Preprint, Phys. Tech. Inst. of Low Temp. Ukr. Acad. Sci., Khar'kov, 1968; Fiz. Tverd. Tela 11, 1382 (1969) [Sov. Phys.-Solid State 11, 1119 (1969).
[2] H. Kojima and T. Suzuki, Phys. Rev. Lett. 21, 896 (1968).
[3] I. A. Gindin, B. G. Lazarev, Ya. D. Starodubov, and V. P. Lebedev, Dokl. Akad. Nauk SSSR 188, 803 (1969) [Sov. Phys.-Dokl. 14, 1011 (1970)].
[4] M. I. Kaganov, V. D. Natsik, ZhETF Pis. Red. 11, 550 (1970) [JETP Lett. 11, 379 (1970)]; Zh. Eksp. Teor. Fiz. 60, 326 (1971) [Sov. Phys.-JETP 33, 177 (1971)].
[5] V. L. Indenbom and Yu. Z. Estrin, Phys. Stat. Sol. (a) 4, K37 (1971).
[6] V. D. Natsik, Zh. Eksp. Teor. Fiz. 61, 2540 (1971) [Sov. Phys.-JETP 34, 1359 (1972)].
[7] V. S. Bobrov and E. Yu. Gutmanas, ZhETF Pis. Red. 17, 137 (1973) [JETP Lett. 17, 95(1973)]
[8] V. P. Soldatov, V. I. Startsev, and T. I. Vainblat, Phys. Stat. Sol. 37, 47 (1970).
[9] H. Kramers, Physica 7, 284 (1940).
[10] V. P. Soldatov, V. I. Startsev, T. I. Vainblat, and Yu. G. Kazarov, J. Low Temp. Phys. 11, 321 (1973).
[11] A. V. Granato, Phys. Rev. B4, 2196 (1971).
[12] Yu. Z. Estrin and V. L. Indenbom, Paper at Conf. on Physical Mechanisms of Plastic Deformation at Low Temperatures, Khar'kov, October, 1971. In: Fizicheskie mekhanizmy plasticheskoi deformatsii pri nizkikh temperaturakh (Physical Mechanisms of Plastic Deformation at Low Temperatures), Kiev, Naukova Dumka, 1973, in press.
[13] G. Kostorz, J. Low Temp. Phys. 10, 169 (1973).
[14] T. Suzuki, Tech. Report of ISSP, Ser. A, No. 544, 1972, Inst. for Solid State Physics, The University of Tokyo, Japan.
[15] J. H. Davis, M. J. Skove, and E. P. Stillwell, Solid State Comm. 4, 597 (1966).
[16] K. Luders, Z. Physik 193, 73 (1966).
[17] P. G. de Gennes, Superconductivity of Metals and Alloys, Benjamin, 1965 (Russ. transl., Mir, 1968, p. 174).
[18] T. V. Kopetskii, M. M. Myshlyaev, N. I. Novochatskaya, N. A. Tulina, and V. A. Yukhanov, Phys. Stat. Sol. 16, 307 (1973).

SCATTERING OF HIGH ENERGY PROTONS BY ^{58}Ni AND ^{208}Pb NUCLEI

V. E. Starodubskii
B. P. Konstantinov Institute of Nuclear Physics, USSR Academy of Sciences

Submitted 7 May 1973
ZhETF Pis. Red. 17, No. 12, 678 - 682 (20 June 1973)

New measurement data on the differential scattering cross sections of high-energy protons by nuclei were recently reported [1, 2]. The present article is devoted to a comparison of the theoretical calculations with the data on elastic and inelastic scattering of 1-GeV protons by ^{58}Ni and ^{208}Pb nuclei, obtained at Saclay [2]. The excited states 2^+ (1.45 MeV) in ^{58}Ni and 3^- (2.62 MeV in ^{208}Pb are interpreted as collective. The excitation of these levels is described within the framework of Glauber's theory [3] on the basis of a generalization of the method

proposed in [4]. This generalization includes an analysis of collective levels with different multipolarities (one- and two-phonon) and high rotational states. The method is based on the adiabatic approximation and makes use of perturbation theory in the nonsphericity parameter $\beta_L = (2L + 1)\hbar\omega_L/2C_L$, where $\hbar\omega_L$ is the energy of a phonon with angular momentum L, and C_L is the surface tension. The resultant expansion for the scattering amplitude can be intepreted as a Born series in terms of a potential $\sim\beta_L R f \rho' Y_{LM}$, where f is the paired amplitude of the nucleon-nucleon scattering and $\rho(r)$ is the nuclear density, which we chose in the form of a Fermi distribution, $\rho \sim \{1 + \exp[(r - R)/a]\}^{-1}$. The distorted waves in the input and output channels are described by an optical potential $\sim f\rho(r)$. The amplitude was chosen in the form $f = ik\sigma'/4\pi$, $\sigma' = \sigma(1 - i\varepsilon)$, $\varepsilon = -0.33$, and $\sigma = 4.4\ F^2$ for Ni and $\sigma = 4.32\ F^3$ for Pb (average over the protons and neutrons in Pb). The angular dependence of the paired amplitude was not taken into account explicitly, since $\rho(r)$ was regarded not as the distribution of the particle centers, but as the distribution of the density of the medium with allowance for the finite dimensions of the nucleons. As noted in [5], allowance for the finite dimensions is numerically equivalent to allowance for the angular dependence of the paired amplitude at 1 GeV energy. Therefore $\rho(r)$ for protons yields the experimental charge form factor of the nucleus directly, without a correction for the proton form factor.

We present the basic formulas. The excitation cross section of the one-phonon state with angular momentum L (first order in β_L) is of the form

$$\left(\frac{d\sigma}{d\Omega}\right)_L = \frac{\beta_L^2}{2L+1}\sum_{M=-L}^{L}\left|\frac{k\sigma' R}{4\pi}\int d^2b\, e^{iqb} E \int dz\, \rho' Y_{LM}(\tilde{z}, \phi)\right|^2,$$

$$\tilde{z} = \frac{z}{\sqrt{z^2 + b^2}}, \qquad E = \exp\left(-\frac{\sigma'}{2}\int dz\, \rho\right).$$

The elastic cross section, with allowance for the contribution of the oscillations, in second order in β_L, is given by

$$\frac{d\sigma}{d\Omega} = \left|F_0 + \Sigma_L \frac{\beta_L^2}{2(2L+1)}\sum_M (-1)^M F_{LM}\right|^2,$$

$$F_0 = ik\int_0^\infty b\, db\, J_0(qb)(1 - E),$$

$$F_{LM} = \frac{ik\sigma' R^2}{4\pi}\int d^2b\, e^{iqb} E\left[\frac{\sigma'}{2}\int dz_1 \rho' Y_{LM}(\tilde{z}_1, \phi)\int dz_2 \rho' Y_{L-M}(z_2, \phi) - \right.$$
$$\left. - \int dz\, \rho'' Y_{LM}(\tilde{z}, \phi) Y_{L-M}(\tilde{z}, \phi)\right].$$

We now proceed to discuss the calculation results. The magic nucleus $^{58}_{28}$Ni has almost as many protons as neutrons; the charge and neutral distributions ρ_p and ρ_n were therefore chosen equal. The dashed curve in Fig. 1 describes elastic scattering with a spherical Fermi distribution with parameters R = 4.28 F and a = 0.566 F obtained from electron scattering [6]. The corresponding elastic charge form factor is shown in Fig. 2 (dashed curve). It is compared with the data of [6] (circles) and [7] (squares). Allowance for the vibrational oscillations of the nuclear surface leads to an effective change of the distribution parameters. The quantities R, a, and β_L where therefore determined from a comparison of the cross sections and of the form factors with experiment. The elastic and inelastic (2^+, 1.45 MeV) cross sections and form factors are shown in Figs. 1 and 2 by solid lines, for R = 4.4 F, a = 0.56 F, and $\beta_2 = 0.2$. The obtained value of β_2 agrees very well with the data on inelastic scattering of protons and electrons of low energy and on Coulomb excitation ($\beta_2 \simeq 0.2$). The necessary references can be found in [8].

In the case of Pb we have $\rho_p \neq \rho_n$, owing to the large neutron excess. We have therefore introduced an average density $\bar{\rho}$, the parameters of which were obtained by comparison with data on the elastic and inelastic cross sections (Fig. 3). We obtained R = 6.85 F, a = 0.57 F, and $\beta_3 = 0.1$. For the sake of completeness, we mention the charge density parameters [9] R = 6.47 F and a = 0.52 F. The obtained values of R and a can be interpreted by assuming that the

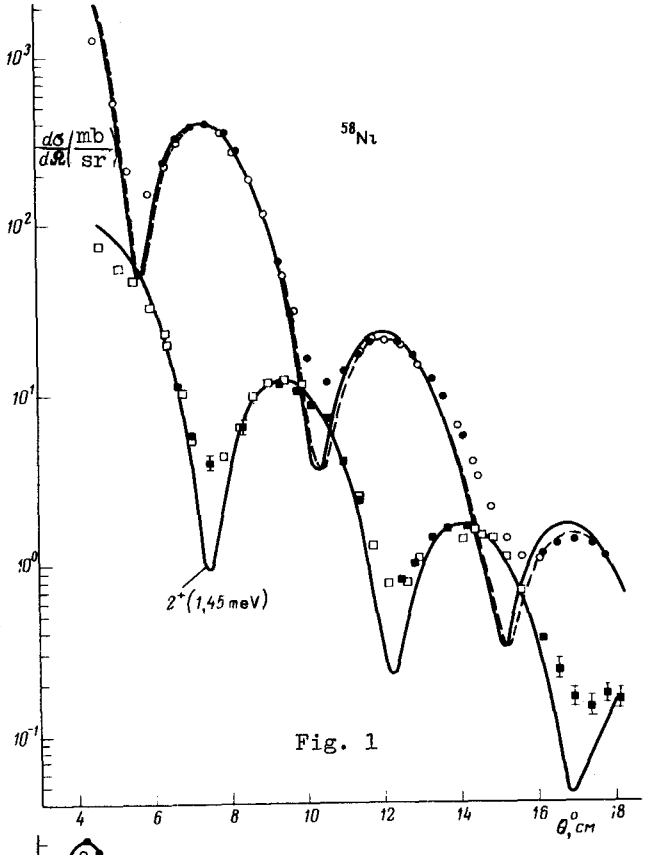

Fig. 1

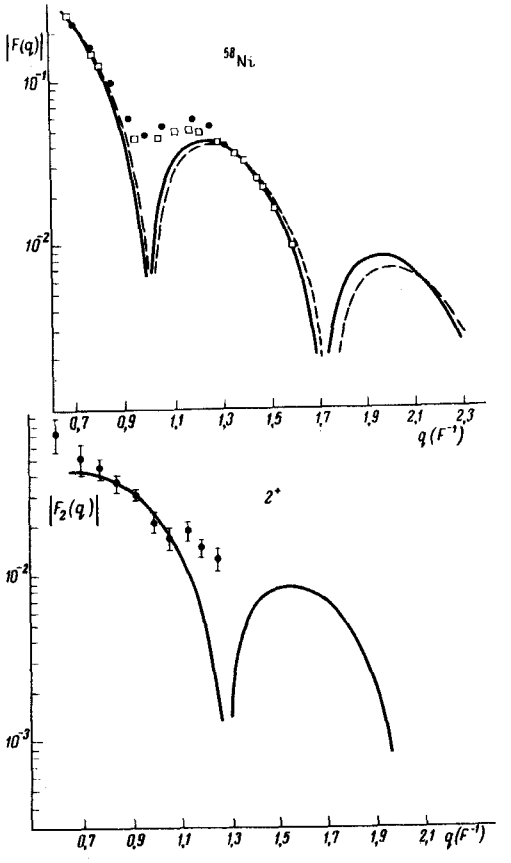

Fig. 2

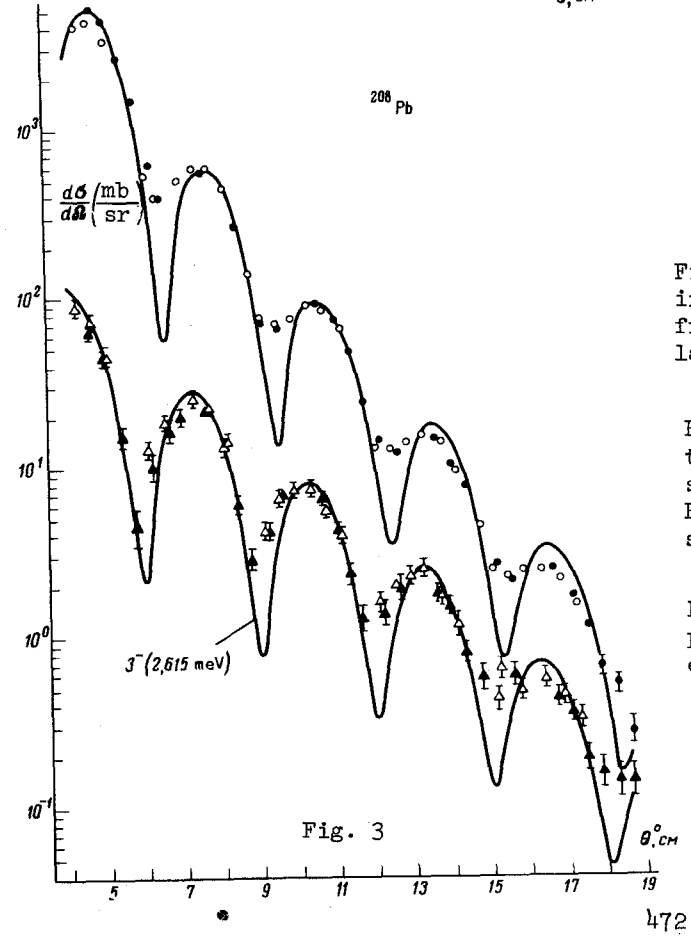

Fig. 3

Fig. 1. Elastic and inelastic proton scattering by ^{58}Ni; dashed - with electron parameters from [6], solid - with allowance for the oscillations (R = 4.4 F, a = 0.56 F, β_2 = 0.2).

Fig. 2. Elastic and inelastic charge form factors for ^{58}Ni; dashed - with parameters of [6], solid with allowance for oscillations (R = 4.4 F, a = 0.56 F, β_2 = 0.2). Circles - from [6], squares - from [7].

Fig. 3. Elastic and inelsastic scattering of protons by ^{208}pb; density distribution parameters: R = 6.85 F, a = 0.57 F, β_3 = 0.1.

excess neutrons fill the states above the doubly-magic "82-82" core, without essentially perturbing it, and lead to an increase of R. The obtained value of β_3 agrees with the data on inelastic proton and electron scattering at low energies: β_3 = 0.11 [10], 0.14 [8], 0.107 [6], and 0.12 [11]. It is interesting to note that the course of the cross sections of Ni and Nb agrees with the Blair's phase rule [12], namely, the elastic and inelastic cross sections vary in phase for transitions with change of parity (3^- in Pb), and in counterphase for transitions without change of parity (2^+ in Ni).

We note in conclusion that the oberved good agreement between theory and experiments proves that the employed approach is adequate. Although the collective states are described phenomenologically, the parameters that enter in the theory are compared simultaneously with data on elastic and and inelas tic scattering of protons, and also of electrons where possible (Ni). This comparison increases the reliability not only of the parameters themselves, but also of the method.

The author thanks L. A. Sliv, V. Efimov, and A. A. Vorob'ev for valuable discussions.

[1] G. D. Alkhazov et al. Phys.Lett. 42B, 121 (1972).
[2] J. Thirion et al., Preprint, Centre d'Etudes Nucleaires, Saclay, France, 1973.
[3] R. J. Glauber, Lectures in Theoretical Physics, Vol. 1, p. 315, N.Y., 1959.
[4] V. E. Starodubsky and O. A. Domchenkov, Phys. Lett. 42B, 319 (1972).
[5] H. Feshbach, A. Gal, and J. Hufner, Ann. Phys. 66, 20 (1971).
[6] R. H. Crannell et al., Phys. Rev. 123, 923 (1961).
[7] V. M. Khvastunov et al., Nucl. Phys. 146A, 15 (1970).
[8] T. Stovall and N. M. Mintz, Phys. Rev. 135, B330 (1964).
[9] J. B. Bellicard and K. J. Van Oostrum, Phys. Rev. Lett. 19, 242 (1967).
[10] A. Scott and M. P. Fricke, Phys. Lett. 20, 654 (1966).
[11] J. F. Ziegler and G. A. Peterson, Phys. Rev. 165, 1337 (1968).
[12] J. S. Blair, Phys. Rev. 115, 928 (1959).

SHELL EFFECTS IN ELASTIC SCATTERING OF NUCLEONS BY NUCLEI, AND NEUTRON STRENGTH FUNCTIONS

Yu. V. Adamchuk, D. F. Zaretskii, V. K. Sirotkin, and M. G. Urin
Moscow Engineering Physics Institute
Submitted 8 May 1973
ZhETF Pis. Red. 17, No. 12, 683 - 687 (20 June 1973)

The shell approach to the description of nucleon scattering by nuclei is used to parametrize the scattering matrix averaged over the resonances of the compound nucleus. Concrete calculations are performed for the s-neutron strength functions. It is shown that, in contradiction to the predictions of the optical model, the magnitude and the isotopic dependence of the strength function at the minimum ($A \sim 100 - 140$) are determined, in the main, by the spectroscopic factor of the 3s state.

The phenomenological description of the scattering of nucleons by nuclei is based on the use of the optical model. In this model, the excitation of the compound-nucleus levels during the scattering process is taken into account by introducing an imaginary part in the optical potential. The parameters of this part are chosen to fit best the experimental data. A more consistent approach to the description of the excitation of the compound-nucleus levels is based on the use of the shell model [1, 2]. Within the framework of the shell approach to the theory of nuclear reactions it is also possible to calculate the average S matrix ($\bar{S}$) and to trace its dependence on the shell-model parameters and on the quantities that determine the binding force of the single-particle states with the compound-nucleus levels. Since, unlike the optical model, the shell approach takes into account effects connected with the existence of Fermi filling of the single-particle states, the average S matrix can depend also on the structure of the Fermi boundary.

In the shell model, the wave functions of the excited states of the nuclei (systems of A + 1 nucleons) can be classified in accordance with the number of particles and holes. In addition to the single-particle states of the continuous and discrete spectra $|1p\rangle \equiv |E\rangle$, there exist also multiparticle configurations of the type 2p - 1h, 3p - 2h, etc. As a rule, at excitation energies on the order of or larger than the binding energies of the nucleon, the multi-