higher energy states. Meanwhile, it is not difficult to consider the absorption of infrared light by the same method. Vonsovskii[3] has reviewed the effect of oscillating electric field of low frequency on a system of coupled electrons in a crystal by the method of the density operator. However, since he did not take damping into account, he obtained only the expression for the polarization current, while the conduction current turned out to be zero.

We can include the damping of the electron motion by replacing in the calculations the energy of the excited state E by the complex quantity $E - i\hbar\Gamma$, where Γ is the damping factor. Using the wavefunction of a system of N interacting electrons in the form given by Sokolov[1], it is not difficult to generalize the calculations to this case. We obtain the following expression for the dielectric constant ϵ and the conductivity σ:

$$\varepsilon = 1 - 4\pi e^2 S^* / m(\omega^2 + \Gamma^2), \qquad (1)$$

$$\sigma = e^2 \Gamma S^* / m(\omega^2 + \Gamma^2),$$

where e is the electron charge, m is the electron mass, ω the frequency of light and S^* a tensor representing the effective number of conduction electrons whose components are

$$(S^*)_{\alpha\beta} = \frac{1}{\hbar V} \qquad (2)$$

$$\times \sum_{j=1}^{N} \int (k \mid \hat{\rho}(0) \mid k) \frac{\partial}{\partial k_{j\alpha}} \left(k \left| \sum_{i=1}^{N} \hat{P}_{i\beta} \right| k \right) dk (\alpha, \beta = x, y, z).$$

In this expression V is the volume of the unit crystal cell, $\hat{\rho}(0)$ is the density matrix at the initial moment, ΣP_i is an operator of the total momentum, and the index k represents all of the quantum numbers $k_1, \ldots, k_N$ that determine the state of the system.

If we discard in Eq. (1) the damping terms by setting $\Gamma = 0$, we obtain the formula derived by Vonskovii[3] for the dielectric constant. In the case of noninteracting electrons, Eq. (2) becomes a corresponding expression of the one electron band theory.

Thus, the dispersion formulas for the infrared spectral range have the same form in the many electron theory as in the one electron band theory of metals. The concept of an effective number of conduction electrons retains the same meaning in the many electron theory. However, the effective number of conduction electrons is determined by a density matrix of the entire system of the metal, and also by the matrix elements of the total momentum of the system. Therefore, a correct description of the optical properties of metals in the infrared spectral range should include the interactions between electrons.

We note that Eq. (1) cannot be obtained by a simple substitution $\omega \to \omega - i\Gamma$ in the expression for ϵ given by Vonskovii[3], because such a substitution has a meaning only for the natural frequency of the system and not for the light frequencies.

To determine the numerical values of S^* it is necessary to apply the described scheme in any particular many electron model of a metal. That allows us then to solve the problem of the effect of the coupling of electrons among themselves on the value of the effective number of conduction electrons.

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Elastic Scattering of 18.7 MEV Protons by Nickel and Copper Nuclei

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A COMPARISON of experimental data for elastic scattering of nucleons with energies from a few mev to a few tens of mev by nuclei [1-10] with the existing theoretical calculations[11,12] shows that the differential cross section for elastic scattering qualitatively corresponds with the "black body" model, but there is no quantitative agreement. Calculations based on the optical model with sharp boundaries for the potential well[13] give too large a value for the differential cross section for large angles as compared with the experimental data. Only the consideration of the diffuse boundary of the nucleus[14] gave results closer to the experimental data of the calculations for heavy nuclei.

In the present work the elastic scattering of 18.7 mev protons from the neighboring nuclei —

Ni and Cu was studied. Nickel and Cu differ very little in size, but they have different spins, magnetic moments and quadrupole moments. For Ni, $I=0$, $\mu=0$, $q=0$; for Cu, $I=3/2$, $\mu=2.22$ and 2.38, $q=-0.1$.

The source of protons was a linear accelerator, which yielded (after magnetic analysis and collimation) an intensity of incident beam on the target of the order of 10^8 protons/sec. The beam current was measured with the help of a Faraday cylinder attached to an electrometer. The half width of the energy spectrum of the proton beam, incident on the target, was about 400 kev. The target was in the form of a foil of thickness 10-15 μ.*

Detectors of scattered protons were scintillation counters with CsI (Tl) crystal. The total energy resolution of the registering scheme was 3%. Such energy resolution permitted the separation of elastic scattering from inelastic, while the Ni nucleus is excited to 1.33 mev energy, and the Cu nucleus to 0.96 mev.

The differential cross section for elastic scattering was measured at 5° intervals in the range of angles from 20 to 170°. The systematic error for each point was not more than 2.5%.

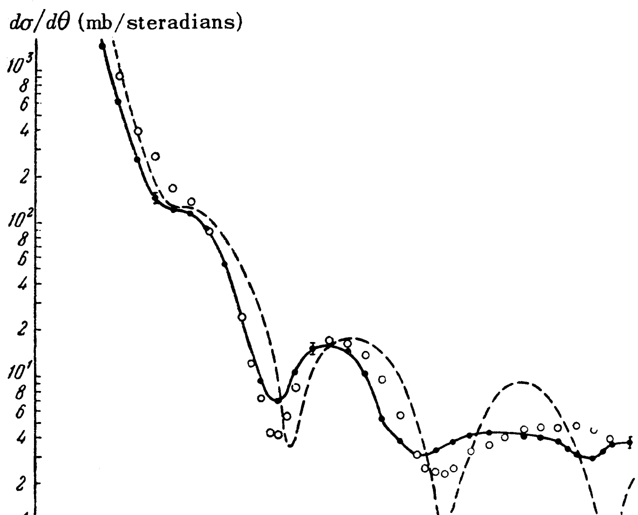

FIG. 1. Differential cross section for the elastic scattering of protons from Ni. Solid curve-cross section obtained in the present work for $E_p = 18.7$ mev. Circles-data obtained by Dayton for $E_p = 18.1$ mev. Dotted line-theoretical curve due to Wood and Saxon, whose calculation was based on the following parameters: $V=40$ mev, $W=10$ mev, $R=5.3\times10^{13}$ cm, $a=0.35\times10^{-13}$ cm and $E_p=18.1$ mev

Figure 1 shows the differential cross section of elastic scattering obtained for Ni, and Fig. 2 that

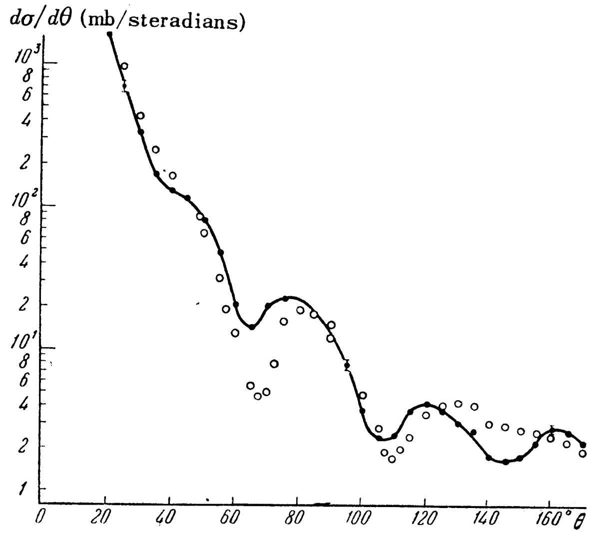

FIG. 2. Differential cross section for the elastic scattering of protons from Cu. Solid curve-cross section obtained in the present work for $E=18.7$ mev. Circles-data obtained by Dayton for $E_p = 18.7$ mev.

for Cu. For comparison, experimental data are shown on the same figures obtained by Dayton.[10] In Fig. 1 the dotted line represents the theoretical

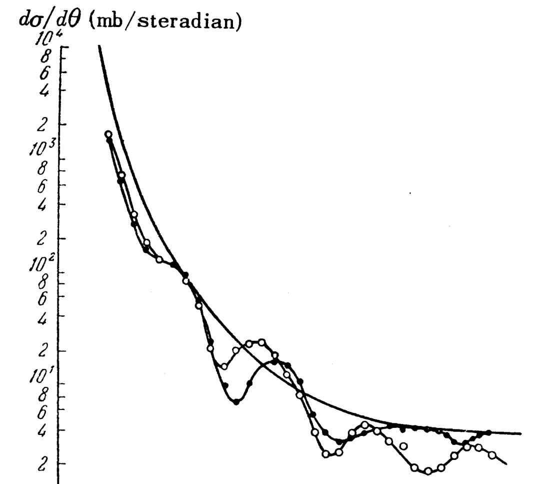

FIG. 3. Differential cross sections for the elastic scattering from Ni (closed circles) and Cu (open circles) for $E_p=18.7$ mev obtained in the present work. Upper solid curve-cross section for Coulomb scattering for $Z=29$ and $E_p = 18.7$ mev.

curve by Saxon[14]; this curve is calculated for protons with energy 18.1 mev and is based on the optical model with a diffuse boundary of the nucleus.

It is seen from the comparison, that we observed a fourth minimum at large angles, which qualitatively corresponds to the theoretical calculations[14] (the fourth minimum is in the region of 160° for Nickel). Deeper first minima, obtained in Ref. 10, can probably be explained by better energy resolution of the apparatus due to the use of the many-channel analyzer.

Figure 3 shows data for nickel and copper. It is seen from these curves that, in the range of angles up to 110°, the cross section for elastic scattering qualitatively corresponds to the "black body" model; for larger angles, the cross section for these two neighboring elements differs considerably. Since the size of the nickel and copper nuclei are very nearly the same, the observed difference in the cross section could characterize the influence of such factors as spin, magnetic or quadrupole moment, and also the shape of the diffuse boundary. For a final check of this supposition it is proposed that a study of the elastic scattering from various isotopes be undertaken.

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Concerning the Electric Charge of the Neutron

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ACCORDING to the present point of view, the neutron does not have an electric charge. This conviction was originally based on experimental data concerning the ionization caused by neutrons during their passage through gases[1]. An estimate of the upper bound for the neutron charge , based on these data, gives a value less than 1/700 of the electron charge e.[2] However, a considerably more precise estimate of the upper bound for the neutron charge can be obtained if it is based on the neutrality of atoms and molecules. Recently, Rabi (see Ref. 3), experimenting with a molecular beam of CsI, came to the conclusion that the charge of this molecule, if not equal to zero, is less than 10^{-10} e. Considering this, and assuming that the proton charge is equal to the charge of an electron, or differs from it by a small quantity equal in magnitude and opposite in sign to the charge of the neutron, it can be obtained that the charge of the neutron is less than 2×10^{-12} e. An analysis of this type assumes that the law of conservation of charge is absolutely accurate. At the present time one cannot exclude the possibility of constructing theories (many dimensional type) with more general conservation laws, in which strict conservation of electric charge, taken separately, does not necessarily hold. It should be also noted that, for instance in a 5-dimensional theory by Ramer[4] , any particle of a finite mass, including a neutron, is given an electric charge. In view of the above considerations, it is interesting to consider the question of the possibility of the direct determination of an upper boundary for the charge of a free neutron.

From the experiments on the observation of the neutron-electron interaction[5] it is difficult to make any conclusions about the magnitude of an upper boundary for the neutron charge in view of the uncertainty of the data concerning the meson cloud of the nucleon.[1] A direct estimate of the magnitude of the upper bound of the neutron charge can be obtained from the fact that the interaction cross section of a thermal neutron with the nucleus does not depend on the charge of the nucleus. This gives evidence for the smallness of the Born parameter: