CALORIMETRIC METHOD OF DETERMINING THE OPTICAL CONSTANTS OF METALS IN THE INFRARED REGION AT LOW TEMPERATURES

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MEASUREMENTS of the optical constants of metals, as has already been noted,[1] are extremely important since these measurements, under certain conditions, afford the possibility of determining conduction-electron density.*

In the low temperature region it is convenient to determine the optical constants by calorimetric methods because these methods are simple and because the small heat capacities of metals make it possible to achieve high sensitivity. The calorimetric method has already been used by a number of authors;[2,3] in these experiments, however, only the absorption was measured i.e., $A = 1 - r$, where r is the reflection coefficient for normal incidence on the surface of the sample.

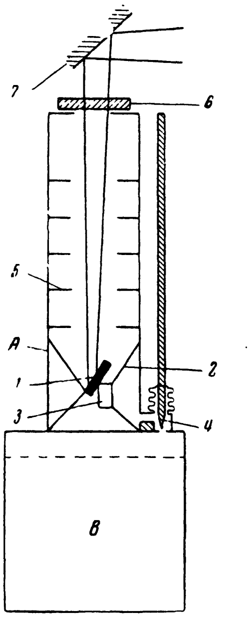

FIG. 1. (A) vacuum calorimeter, (B) carbon "pump," (1) sample, (2) caprone rods, (3) bronze thermometer, (4) valve for carbon "pump," (5) diaphragms, (6) window of KRS—5, (7) mirror.

Measurements of this kind cannot be used to calculate both optical constants of a metal. Two independent measurements are required. For this reason we have used an instrument with which both quantities can be measured. A schematic diagram of the apparatus is shown in Fig. 1.

A plane-polarized beam of infrared radiation is incident on the surface of the sample 1 at an angle φ close to the principle incident angle of incidence. The sample is located inside a vacuum calorimeter A on thin caprone rods 2. The calorimeter is suspended in a liquid-helium Dewar. The sample is cooled by heat exchange with helium with which the calorimeter is filled. During the measuremets the helium coolant is removed by the carbon pump B (Ref. 4) located in a separate chamber under the calorimeter and the sample is slowly heated by the absorbed radiation.

The temperature of the sample is measured by the thermometer 3 of phosphor bronze which is in good thermal contact with the sample. A thin-walled copper coil, which acts as a black body, is soldered to one side of the sample and is used to determine the intensity of the incident radiation.

By carrying out measurements of simple heating in a given time for two orientations of the polarized radiation (in the plane of incidence and perpendicular to the plane of incidence) it is possible fo find $A_{par} = 1 - r_{par}$ and $A_{perp} = 1 - r_{perp}$. Then, the quantities η and κ can be computed graphically using Eqs. (5) and (1) of Ref. 1.

This method was used to determine the optical constants of bismuth for wavelengths from 1 to 7μ at an angle of incidence $\varphi = 70°$. In this case, at 7μ the values of η and κ were found to be respectively 2 and 2.5, whence $|\epsilon| = 2.2$. An estimate based on the assumption that in this region $|\epsilon| \sim 1/\omega^2$ gives for bismuth $N \approx 3 \times 10^{20}$. This assumption can be verified at longer wavelengths; however, because of the low intensity it is extremely difficult to make the measurements. The intensity of the radiation incident on the sample can be increased by using a wider beam and by introducing the radiation into the calorimeter through an optical window in the side wall of the Dewar. It is convenient to use a metal Dewar with one side window for this purpose and to place the samples in the general vac-

*As has been pointed out by Ginzburg and Motulevich, if the dielectric constant of a metal $\epsilon = \eta^2 - \kappa^2 \sim 1/\omega^2$, then

$$N = (n^2 - \varkappa^2)\, m\omega^2 / 4\pi e^2,$$

where N is the number of conduction electrons per unit volume, n is the index of the refraction, κ is the absorption index, m is the mass of the free electron, e is the charge of the electron, and ω is the frequency of the incident radiation.

uum space of the Dewar on a fixed heat conductor. A detailed report on work being carried out will be published in the near future.

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CONVERGENCE OF THE PERTURBATION-THEORY SERIES FOR A NON-RELATIVISTIC NUCLEON

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In the quantum theory of interacting fields the perturbation-theory series is an asymptotic series.[1] On the other hand, the problem of a non-relativistic nucleon interacting with a neutral scalar-meson field (n.s. theory) has an exact solution.[2] In this case the exact Green's function of the nucleon is an analytic function of the coupling constant with an infinite radius of convergence (in the coordinate representation; in the momentum representation the radius of convergence is finite[3]).

The problem of a non-relativistic nucleon which interacts with a symmetric pseudoscalar meson field (s.p.s. theory) does not as yet have an exact analytical solution. In spite of this fact an analysis of the convergence of the perturbation-theory series can be carried out.

For the interaction

$$(g_0/2\mu)\,\psi^*[(\sigma\nabla)(\tau_i\varphi_i)]\,\psi \tag{1}$$

there is a definite rule for writing the Feynman diagrams. The rule can be completely stated if we write only one matrix element, corresponding to the self-energy diagram in the first approximation

$$M(E) = -i\left(\frac{g_0}{2\mu}\right)^2\frac{1}{8\pi^2}\int\frac{(\sigma\,\mathbf{k})\,\tau_j\,(\sigma\,\mathbf{k})\,\tau_j\,d^3k\,d\,k_4}{(E-k_4-i\eta)\,(k_4^2-\mathbf{k}^2-\mu^2+i\varepsilon)}, \tag{2}$$

where E is the nucleon energy (we neglect the kinetic energy of the nucleon), and the integration extends to some upper limit. We go around the poles in the complex plane K_4 by infinitesimal increments $\epsilon > 0$ and $\eta > 0$. The symbol η corresponds to the appropriate Green's function in the non-relativistic case.[4] In the upper half plane of k_4 there is only one pole $k_4 = -\sqrt{\mathbf{k}^2+\mu^2}$. Closing the integration path in the k_4 plane in an upward direction, it is easy to calculate the integral over k_4 in (2). After integrating over the angles we have

$$M(E) = \frac{1}{6}\left(\frac{g_0}{2\mu}\right)^2\sigma_i\tau_j\sigma_i\tau_j\int_0^\Lambda k^4dk/\left(E+\sqrt{k^2+\mu^2}\right)\sqrt{k^2+\mu^2}, \tag{3}$$

where Λ is the cut-off momentum. In what follows we neglect the meson mass; going over to dimensionless variables of integration we have

$$M(z) = \frac{1}{6}\left(\frac{g_0\,\Lambda}{2\,\mu}\right)^2\Lambda\sigma_i\tau_j\sigma_i\tau_j\int_0^1\frac{x^3dx}{z+x}, \tag{4}$$

($z = E/\Lambda$). The rules for forming more complicated diagrams can be obtained easily by generalizing this example.

Similarly, in n.s. theory with the interaction $g_1\psi\varphi\psi$, we obtain in place of (4)