scattering in some "damage region" produced during the irradiation of the crystal. Such "damage regions" were observed by NMR methods in alkali-halide crystals around impurity atoms [2]. We are presently carrying out experiments on neutron scattering in crystals containing impurities (impurity atom concentration varies from 0.1 to 5 mol.%).

These results should be compared with the already discussed data obtained for irradiated crystals that contain no impurity atoms. This can establish the nature of the defects responsible for the observed neutron scattering.

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USE OF SUBSTANCES CONTAINING RARE-EARTH IONS WITH EVEN NUMBER OF ELECTRONS TO OBTAIN INFRALOW TEMPERATURES

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Only rare-earth ions with an odd number of electrons have been used so far to obtain low temperatures by magnetic cooling. Ions with an even number of electrons are assumed to be unsuitable, since their energy levels are completely split in the crystalline field, owing to the lack of Kramers degeneracy. We wish to call attention to a possibility of advantageously using rare-earth ions with an even number of electrons.

1. The splitting in the crystalline field of the ground level of a rare-earth ion with an even number of electrons is frequently such that the lowest level is a singlet separated from the nearest level by an interval $\Delta \simeq 10 - 100$ cm^{-1}. Consequently, at sufficiently low temperatures, the electronic magnetic moment of the ion vanishes. It must be borne in mind, however, that practically all isotopes of rare-earth triply charged ions with an even number of electrons (Pr^{3+}, Tb^{3+}, Ho^{3+}, Tm^{3+}) have a nuclear spin $I \neq 0$. Furthermore, the magnetic hyperfine interaction of rare earths is relatively large; the hfs constant is $A \simeq 0.1 - 0.4$ cm^{-1}. Owing to this interaction, some moment of the order of $(A/\Delta)\beta$, where β is the Bohr magneton, is added to the nuclear magnetic moment. The magnetic moment of the ion in the ground state is thus increased 10 - 100 times. The resultant consequences for the magnetic-resonance phenomenon were first considered theoretically [1], and then observed experimentally on V^{3+} in corundum [2]. Owing to the weaker hyperfine interaction, the increase in the magnetic moment of the iron-group ions is less pronounced.

2. The substances considered by us, in which the paramagnetism carriers have a magnetic moment of magnitude intermediate between the electronic and nuclear moments, can be used to obtain lower temperatures than reached with the aid of ordinary parametric salts. It is estimated that the sample temperature can be readily reduced thus to 10^{-4} - 10^{-5}°K.

If compounds of elements with $I \gg 1/2$ are used, say salts of Pr ($I = 5/2$) or Ho ($I = 7/2$), then the total splitting in magnetic fields of the order of several dozen kOe will be so large that initial cooling with the aid of He^3 will be sufficient. If a cascade cooling method is used, and an ordinary paramagnetic salt first lowers the temperature to ~0.01°K, then the most suitable for reaching the lowest temperatures will be salts of Tm (e.g. thulium ethyl sulfate), which has $I = 1/2$, so that the spin levels are not split in the absence of an external magnetic field.

3. Unlike nuclei in diamagnetic substances, whose gyromagnetic factors can be assumed, with high accuracy, to be scalar quantities, the gyromagnetic factors of rare-earth ions at singlet electronic levels are tensors with greatly differing principal values. Calculations show, for example, that for thulium ethyl sulfate $\gamma_{\parallel} = \gamma$ and $\gamma_{\perp} \simeq 70\gamma$, where γ pertains to the free atoms, and $\gamma_{\parallel}$ and $\gamma_{\perp}$ are the gyromagnetic factors parallel and perpendicular to the crystal trigonal axis. Such an appreciable dependence of the spin-level splitting on the crystal orientation relative to the magnetic field makes it possible to effect magnetic cooling by rotating the magnetic field so as to change the angle with the crystal axis from $\pi/2$ to 0.

4. Substances with "intermediate electron-nuclear paramagnetism" can be conveniently used to measure infralow temperatures. First, the limiting temperature to which the Curie law holds for these substances is approximately two orders of magnitude lower than for ordinary paramagnetic salts. Second, these substances have a magnetic susceptibility two orders of magnitude lower than nuclear paramagnets and are thus measurable by ordinary methods.

5. An important problem is the rapid establishment of thermal equilibrium between the spin system and the lattice vibrations. In the substances considered by us, the magnetic moments μ of the paramagnetic centers are small and therefore the spin-lattice relaxation time τ will be very high, since $\tau \sim \mu^2$ if $I > 1/2$ and $\tau \sim \mu^4$ if $I = 1/2$. However, following Casimir [3], we can readily establish that the equalization of the spin-system and lattice temperatures will be rapid, within a time of the order of seconds. We note that the time to establish equilibrium can be greatly shortened by introducing a negligible amount of rare-earth ions with an even number of electrons, whose lower level is a doublet (for example Pr^{3+} in ethyl sulfate). It is well known that the relaxation time of such ions is very short, $\tau \sim 10^{-3}$ - 10^{-4} sec at ~1°K. Recognizing that the initial splittings of the spin levels of these ions are of the order of 0.1 cm^{-1} and that the spin-lattice relaxation at infralow temperatures is determined primarily by the spontaneous transitions whose probabilities do not depend on the temperature, we can readily estimate that the relaxation time will be lengthened by two orders of magnitude.

We note in conclusion that introduction of a trace of ions with even number of electrons to reduce the relaxation time may be advantageous also in the salts customarily used for magnetic cooling.

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MAGNETORESISTANCE OF BISMUTH IN STRONG MAGNETIC FIELDS

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By virtue of the specific features of the energy spectrum of the carriers - small effective masses and low degeneracy temperature [1,2] - the quantization of the energy levels in Bi becomes appreciable in relatively weak magnetic fields. The condition $\hbar\omega \sim \epsilon_F$ ($\omega = eH/m^*c$ = cyclotron frequency, ϵ_F = Fermi energy) is satisfied for certain electrons in fields of approximately 20 kOe. At magnetic-field directions in which several essentially different extremal sections of the electronic part of the Fermi surface of bismuth are realized, satisfaction of this condition will lead to "spilling" of electrons from certain ellipsoids into others [3]. This assumption has been confirmed by observations of the periodic growth of the magnetic-susceptibility oscillation frequency with increasing magnetic field [4].

We shall use the data of [2], which contain, besides the value of the limiting Fermi energy in bismuth ($\epsilon_F^{(1)} = 0.031$ eV) also the energy distance to the "openness" closest to the Fermi level ($E_0^{(1)} = 0.048$ eV, "openness" - value of the energy at which the conditions for the closure of the Fermi surface are violated). By virtue of the foregoing, a change of $\Delta = E_0^{(1)} - \epsilon_F^{(1)}$ due to "spilling" of the electrons in a magnetic field should give rise to an open trajectory. We shall attempt to estimate roughly the possible change in the Fermi level, assuming "total spilling" of the electrons from one sphere to another. In this case [5], $n \sim \epsilon^{3/2}$ (n = number of electrons, ϵ = energy). After the "spilling" the number of electrons in one of the sphere doubles, i.e., equals $2n \sim \epsilon_1^{3/2}$. Consequently $\Delta_1 = \epsilon_1 - \epsilon = 0.589\epsilon$. Assuming $\epsilon = \epsilon_F^{(1)}$, we obtain $\Delta_1 = 0.018$ eV, which agrees well with Δ.

The foregoing qualitative treatment shows that in principle open trajectories can be produced in bismuth by means of a unique magnetic breakdown.

The occurrence of open trajectories greatly influences the behavior of the magnetoresistance [6]. In this connection, we investigated the electric resistivity of single-crystal Bi samples of varying purity and orientation in transverse pulsed magnetic fields ($\vec{H} \perp \vec{I}$, $\vec{H}$ = magnetic field, $\vec{I}$ = current through sample) up to 80 kOe at temperatures 4.2 and 20.4°K.