$\eta_+ = 129 \pm 10$ and $\eta_- = 118 \pm 10$, corresponding in a field H = 3500 Oe to a proton polarization P $= \eta P_0 = (8 \pm 0.5)\%$. The distance between η_+ and η_- is $\Delta H = H_+ - H_- = 21 \pm 2$ Oe, compared with a width $\Delta_{pp} = 16 \pm 1$ Oe of the EPR signal between the extremal points of the absorption derivative.

Measurements of the amplification coefficient for different EPR saturation microwave power levels have shown that to obtain the maximum amplification coefficient 1 mW is sufficient (resonator Q approximately 1000).

The measurement of the proton spin-lattice relaxation time $T_{1\,nuc}$ yielded a temperature dependence in the form $T_{1\,nuc}^{-1} \sim T^{1.65\pm0.15}$, with $T_{1\,nuc}$ = 920 ± 80 sec at T = 0.32 ± 0.03°K. An experiment carried out with an analogous crystal at 1.6°K yielded $\eta = 124 \pm 12$ [3].

Thus, experiments at temperatures below 1°K show that the amplification coefficient does not decrease when the specimen temperature is sharply reduced. The use of higher magnetic fields and frequencies will yield nearly 100% proton polarization. An analogous experiment is now being set up with an EPR frequency of 37 Gc.

We have also carried out DPP experiments with low-pressure polyethylene irradiated by fast neutrons under the conditions described in [5]. The amplification of the NMR signal obtained at 0.5°K was 20 times the value $\eta = 30$ obtained at T = 1.6°K. [5]

In conclusion, the authors take this opportunity to thank Professor F. L. Shapiro for great interest and attention to the work.

Note added in proof (July 18, 1963). A similar amplification coefficient, $\eta = 120 \pm 10$, was obtained at 0.38 ± 0.1°K.

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Translated by J. G. Adashko
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LOW TEMPERATURES OBTAINED WITH THE AID OF THE DE HAAS-VAN ALPHEN EFFECT

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Submitted to JETP editor June 12, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **45**, 396-397 (August, 1963)

THE method of obtaining low temperatures by adiabatic demagnetization of paramagnetic salts is well known. The shortcomings of this method are connected, in particular, with the low heat conductivity of the salts. We shall show that adiabatic variation of the magnetic field in metals also leads to a lowering of the temperature.

It is easy to verify that

$$\left(\frac{\partial T}{\partial H}\right)_S = \frac{\partial(T, S)}{\partial(H, T)}\frac{\partial(H, T)}{\partial(H, S)} = \frac{T}{C}\frac{\partial M}{\partial T}, \qquad (1)$$

where C is the specific heat, M the magnetic moment, T the temperature, H the magnetic field intensity, and S the entropy.

Both the Pauli paramagnetism and the Landau diamagnetism depend quite weakly on the temperature, and the associated cooling of the metal can only be extremely small. The use of ferro- and antiferromagnetism is likewise hardly promising, for in the most interesting region, that of the lowest temperatures, the heat capacity decreases like T (electron specific heat) or T^3 (phonon specific heat), whereas the magnetic moment decreases exponentially (see, for example, [1]).

There exists, however, an essentially temperature dependent oscillating part of the moment, calculated for an arbitrary conduction-electron dispersion law by I. M. Lifshitz and Kosevich [2].

Merely for the sake of simplicity, we assume the initial temperature to be sufficiently low and the metal sufficiently pure for the principal role to be played by the electron specific heat C_e and for the following conditions to be satisfied

$$kT < \mu H/2\pi^2,\ \mu_0 H/2\pi; \qquad l > r\pi m_0/m \qquad (2)$$

(μ, l, r, and m are the Bohr magneton, mean free path, the Larmor radius and the effective mass of the conduction electron; μ_0 and m_0 are the Bohr magneton and the mass of the free electron).

Using the formula of Lifshitz and Kosevich [2] for the oscillating part ΔM of the moment M under conditions (2) (which allow us, in particular, to disregard the finite nature of l, see [3]), we can show

that a change in the magnetic field from a value at which ΔM is minimal to a value at which ΔM is maximal (i.e., by half of the de Haas–van Alphen oscillation period) is equal to

$$\Delta(1/H) = \pi e\hbar / cS_{ext}, \tag{3}$$

($S_{ext} = S(p_0)$ is the extremal area of the intersection between the limiting Fermi surface and the plane $p_z = \text{const}$, $\mathbf{p}$ is the quasimomentum of the electron, $z \parallel \mathbf{H}$, and c is the velocity of light) leads in the main approximation to the following value of ΔT:

$$\frac{\Delta T}{T} = -\frac{8}{\pi\sqrt{2\pi}h^3 v_0} \frac{m^{3/2}\sqrt{\mu H}}{|S''_{p_z}|^{1/2}_{p_z=p_0,\ \varepsilon=\varepsilon_0}} \sum_{l=0}^{\infty} \frac{\cos(2l+1)\pi m/m_0}{\sqrt{2l+1}}$$

$$\sim -\left(1+\frac{m_0}{\pi m}\right)^{1/2}\left(\frac{e\hbar H}{cS_{ext}}\right)^{1/2},$$

$$C \approx \tfrac{1}{6}\pi^2 k^2 \nu_0 T. \tag{4}$$

The most suitable are the directions of the magnetic field for which S_{ext} is minimal [i.e., the de Haas–van Alphen oscillation period is maximal in accordance with (3)], and the metals have a minimum number of conduction electrons per atom, i.e., are of the bismuth type.

Other "convenient" cases are those when $m = 2sm_0$ with s an integer, for then $\Delta T/T$ increases appreciably: $(1 + m_0/\pi m)^{1/2}$ is replaced by

$$\{\pi^2 kT/\mu H + 2\pi kT/\mu_0 H + ml/\pi m_0 r\}^{1/2}$$

(of course, formula (4) cannot be used to prove this; it is necessary to employ the exact formula for ΔM[2,3]).

In a real experiment we can obtain $\Delta T/T \sim 1$–10%. By repeating many times an adiabatic magnetization and an isothermal demagnetization (or vice versa, depending on the initial value of the magnetic field), we can attain in principle as low an energy as desired (since $\Delta T/T$ does not depend on the temperature, i.e., on the number of the cycle). A favorable fact is that $\Delta(1/H)$ is also the same in all cycles.

When condition (2) is not satisfied the effect decreases exponentially; when the condition $T < T_0$, $C_e(T_0) \sim C(T_0)$ is not satisfied it decreases by a factor $(T/T_0)^3$.

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Translated by J. G. Adashko
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