scanned with an aim of observing antinuclei [1]. The scanning was with an MBI-2 microscope with overall magnification of 105. In the course of scanning we identified the multiply charged nuclei stopped in the emulsion and the stars produced by multiply-charged nuclei. Since the scanning was at low magnification, the primary alpha-particles were barely registered, and only particles with $Z > 2$ were selected.

The scanning of the stack for antinuclei is now complete. We investigated 1079 stopped ordinary nuclei and 748 stars. None of the stars can be regarded as resulting from annihilation of a stopped antinucleus. We therefore conclude that the number of antinuclei with $Z > 2$ (at any rate, low-energy antinuclei) in primary cosmic radiation does not exceed 0.1%.

[1] Grigorov, Zhuravlev, Kondrat'eva, Rapoport, and Savenko, Iskusstvennye sputniki Zemli (Artificial Earth Satellites), No. 10, 1961, p. 96.

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DYNAMIC PROTON POLARIZATION AT 0.5°K

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SEVERAL successful experiments were recently carried out on dynamic proton polarization (DPP) in $La_2Mg_3(NO_3)_{12} \cdot 24H_2O$ crystals with impurities of paramagnetic cerium [1-3] and neodymium [4] at temperatures 1.4—1.7°K. The greatest proton polarization (51%) was obtained by Schmugge and Jeffries [4] through the use of a strong magnetic field (~ 20 kOe) and a high electron paramagnetic resonance (EPR) saturation frequency (~ 50 Gc). Further increase of the magnetic field and of the EPR frequency involves serious technical difficulty, particularly in the polarization of large targets (~10 cm³). At the same time, an increase in polarization could be obtained by using the progress made in obtaining stationary temperatures of 0.3—0.5°K if, of course, the coefficient of dynamic amplification does not drop sharply in this case.

We report here the results of preliminary DPP experiments in a double-nitrate crystal with a cerium concentration 0.8% (relative to lanthanum) at ~ 0.5°K. The investigated specimen with dimensions $6 \times 6 \times 2$ mm was placed in a quartz ampoule and inserted in a resonator kept at 1°K through a hole in the plunger. The ampoule was filled with liquid He^4, which produced the thermal contact between the specimen and a liquid He^3 bath, the temperature of which was regulated by the pumping rate of its vapor.

The specimen was placed in the resonator in such a way that the crystal hexagonal axis was perpendicular to the external magnetic field H_0.

In this case the g-factor of the Ce^{3+} ion is equal to $g_\perp = 1.83$. The resonator was excited in the H_{102} mode with frequency $\nu_e = 9000$ Mc.

The increase in the proton polarization in the crystal with EPR saturation of the "forbidden" transitions of the Ce^{3+} ions was determined from the amplification of the nuclear magnetic resonance (NMR) signal of the protons. The NMR signal was detected by an autodyne circuit with automatic control of the oscillation level. Special measures were employed to eliminate the influence of the NMR saturation on the measurement results. At the minimum autodyne oscillation level attained in our installation, the NMR saturation effect was practically nonexistent. The measurements were made at several values of the autodyne oscillation levels. The true result was obtained by extrapolating the experimental data to the zero oscillation energy level.

We observed in the temperature region 0.5—1.7°K a noticeable increase in the proton polarization and investigated the following:

1) The dependence of the proton polarization amplification coefficient on the value of the external magnetic field at a fixed EPR frequency.

2) The dependence of the amplification coefficient on the microwave EPR saturation power.

3) The dependence of the proton spin-lattice relaxation time $T_{1\,nuc}$ on the temperature.

The experimental dependence of the amplification coefficient η on the field H for a fixed klystron frequency is a typical plot observed in dynamic polarization: the amplification has a maximum negative value η_- at $H_- = H_0 - \frac{1}{2}\Delta H$ (corresponding to a "forbidden" transition with frequency $\nu_e + \nu_{nuc}$) equal to zero when $H = H_0$ (ν_e transition), and has a maximum positive value η_+ at $H_+ = H_0 + \frac{1}{2}\Delta H$ ($\nu_e - \nu_{nuc}$ transition). At 0.55 ± 0.05°K the amplification coefficients were

$\eta_+ = 129 \pm 10$ 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 $T_{1\,nuc} = 920 \pm 80$ sec at $T = 0.32 \pm 0.03$°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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LOW TEMPERATURES OBTAINED WITH THE AID OF THE DE HAAS-VAN ALPHEN EFFECT

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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

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

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