where $A = 5.4 \times 10^{-5}$ $cm^{-2}sec^{-1}sr^{-1}$, $E_{cr} = 116$ GeV, and $\gamma_\mu = 2.6 \pm 0.1$, a spectrum characteristic of the pion mechanism of muon production (Fig. 2). Comparison of the energy spectra of all the registered cascades and of the cascades with $\theta \leq 50°$ confirms the conclusion that the angular distributions of the muons with $E_\mu \gtrsim 10^{12}$ eV are practically independent of their energy. The larger isotropy of all the angular distributions can be reconciled with the assumed pion origin of the muons, provided the theoretical calculations are made with a steeper generation spectrum and with a larger muon energy loss than those used in [2]. These refinements are fully justified in light of the results obtained in recent years [3,4].

At energies $E \gtrsim 6 \times 10^{12}$ eV an excess of cascades is observed in comparison with that expected from the spectrum (1) and the usual cross sections for their interaction with matter. This excess can be related to the change in the energy spectrum of the muons or to an increase in the effective cross section for the transfer to the muon of a larger fraction of the energy in the electron-photon component at muon energies $E_\mu \gtrsim 2 \times 10^{13}$ eV.

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SUPERCONDUCTIVITY OF PHOSPHORUS AT HIGH PRESSURES

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Following the recent discovery of the superconducting modifications of Ge, Si [1], Sb [2], Te [3], and Se [4], which arise at high pressures in the fifth group of the periodic system, we are left with two elements, P and As, which can also be expected to exhibit superconductivity upon compression. We report here observation of superconductivity of P in the pressure region 170 - 260 kbar.

The procedure used to obtain the pressures was similar to that used in [5]. The pressure was produced between the planes of Bridgman anvils (Fig. 1, 1) made of VK-3 alloy and placed in a booster. The high-pressure chamber was made up of two discs, 2, approximately 10 - 15 μ thick, and pressed from finely dispersed powder of iron oxide Fe_2O_3, two blocking rings, 3, ~20 μ thick, with inside diameter ~0.5 mm and outside diameter ~1.5 mm, pressed in a special device from a mixture of Fe_2O_3 powder and powdered steatite, and two steatite

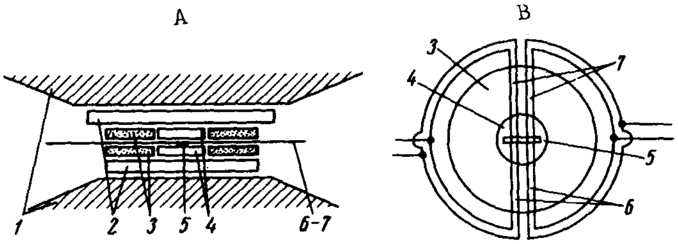

Fig. 1. A. Construction of high-pressure chamber. B. Arrangement of the sample and of the current and potential electrodes.

washers, 4, ~20 μ thick and of ~0.5 mm diameter. To exclude the influence of the possible non-coaxiality, one of the anvils had a somewhat larger working-area diameter. The high-pressure chamber was mounted on the anvil having the smaller diameter. The pressure was determined from the force compressing the anvil, which was measured directly with a superconducting manometer at the temperatures of the experiment and using a calibration curve which was plotted at room temperature and had reference points with absolute accuracy ±20 kbar (the accuracy of the relative determination of the pressure in various experiments is much higher).

Phosphorus samples, 5, in the form of rectangular strips ~10 μ thick were placed between steatite washers 4. We investigated the central part of the sample, with dimensions 0.2 x 0.1 mm. The transition of the sample into the superconducting state was revealed by the change of the electric resistance. The current and potential electrodes were four platinum strips 6, 7, approximately 10 μ thick, interconnected for better reliability as shown in Fig. 1.

The field for the destruction of the superconductivity was produced by an electromagnet. The magnetic field at the location of the sample, which differed from the external magnetic field as a result of the additional magnetic moment introduced by the anvils, was determined by means of a special bismuth measuring device.

The measurements were made in an instrument of the desorption type. Temperatures lower than 4.2°K were obtained by pumping off helium vapor, and temperatures above 4.2°K were obtained by slow heating of a block of activated charcoal, inside of which the booster and the measuring coils were located. Temperatures above 4.2°K were measured with an Allen-Bradley

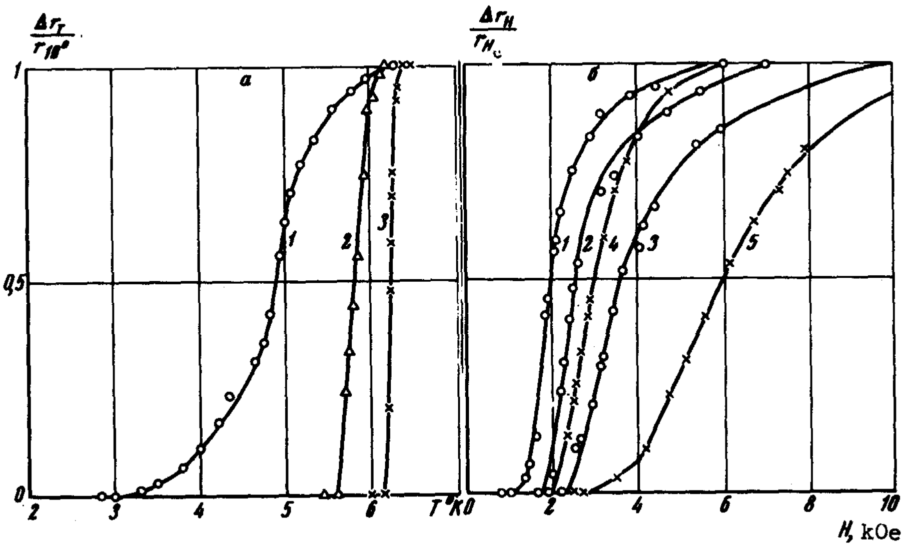

Fig. 2. Relative change of resistance in the superconducting transitions: a) H = 0. 1) P = 260 kbar; 2) P = 170 kbar; 3) P = 220 kbar. b) In magnetic field: o) P = 170 kbar. 1) T = 4.2°K; 2) T = 3.427°K; 3) T = 2.223°K; ×) P = 230 kbar; 4) T = 4.2°K; 5) T = 3.053°K.

semiconductor thermometer.

We investigated samples of black phosphorus, synthesized by S. S. Boksha [*], and of red phosphorus. In both cases, the samples revealed a metallic temperature dependence of the resistance at pressures 170 - 260 kbar. Cooling from 240 to 10°K decreased the resistance by a factor ~40. Further lowering of the temperature revealed clearly-pronounced transitions into the superconducting state; the widths of the transitions were strongly dependent on the applied pressure (Fig. 2a).

The destruction of superconductivity by the magnetic field is illustrated by the curves of Fig. 2b. A characteristic feature of these curves is the increased diffuseness on going to lower temperatures, resulting in an uncertainty in the value of the critical field. In addition, regardless of the method of determining H_c (by using the midpoints of the curves or the ends of the transitions), extrapolation of the $H_c(T)$ curves (Fig. 3, values of H_c were determined from the midpoints of the curves showing the destruction of the superconductivity by the magnetic field) yields, in experiments at pressures exceeding 170 kbar, smaller values of T_c than those determined from the curves of the superconducting transitions at H = 0 (Fig. 2a). (At 170 kbar, the extrapolated value of T_c coincides with the value determined from the transition curves at H = 0.)

These singularities can be explained by assuming that phosphorus has two or more superconducting modifications with $T_c = 5.8$°K (at P = 170 kbar) and $(\partial H_c/\partial T)_{T_c} = 1.2$ kOe/deg.

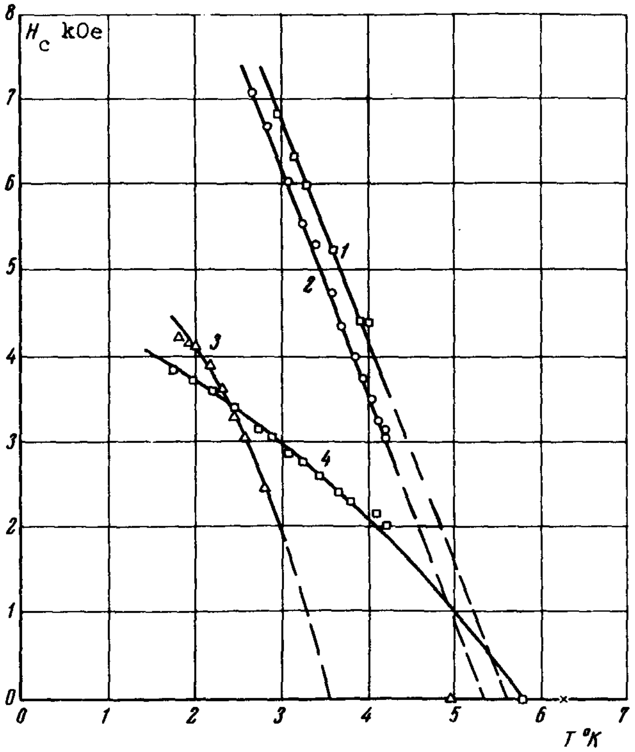

Fig. 3. Plots of the critical fields of phosphorus: 1) P = 220 kbar; 2) P = 230 kbar; 3) P = 260 kbar; 4) P = 170 kbar.

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[*] We take the opportunity to express sincere gratitude to S. S. Boksha for supplying the high grade samples of black phosphorus.

At higher pressures, the sample consists apparently of a mixture of two or three superconducting modifications with larger values of $\partial H_c/\partial T$. The presumed existence of several superconducting modifications of P agrees with the notion that among the crystalline modifications that are stable at high pressures there should also be modifications with a structure analogous to the structure of the superconducting modifications of Bi and Sb [6] *.

Additional detailed investigations are necessary to clarify this question.

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LONG-WAVE INFRARED ABSORPTION IN ANTIFERROMAGNETIC $CoWO_4$

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Cobalt tungstate $CoWO_4$ has a rhombic structure. Below $T_N = 55°K$ it goes over into an antiferromagnetic state [1]. Since the exchange energy ($\gamma H_E \sim kT_N$) is large, and apparently the magnetic-anisotropy energy is large (this is usual for antiferromagnetic compounds containing the ion Co^{2+}), we can expect both antiferromagnetic resonance and two-magnon absorption to lie in the far infrared [2-4,7,8]. If this is the case, then it becomes possible to determine in a single experiment the extremal frequencies of the spin-wave spectrum, both at the center of the Brillouin zone ($|\vec{k}| = 0$) and on its boundary ($|\vec{k}| = \pi/\alpha$).

In this paper we report the results of an investigation of the absorption spectrum of $CoWO_4$ in the frequency region 20 - 200 cm^{-1} and in the temperature range from 10 to 100°K. The experiment was performed with a previously described setup [5] that makes it possible to carry out low-temperature investigations in polarized radiation in stationary magnetic fields up to 25 kOe.

Figure 1 shows the absorption bands observed only for the magnetically ordered $CoWO_4$.

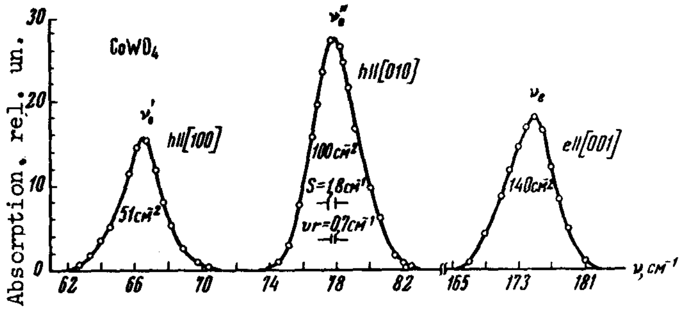

Fig. 1. Absorption spectra of antiferromagnetic $CoWO_4$ in the far infrared region. T = 22 ± 3°K, $T_N = 55°K$. The frequencies of the absorption peaks are corrected for $\nu\tau$.

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[*] Unfortunately, the phase diagram of phosphorus was investigated only up to a pressure of 150 kbar.