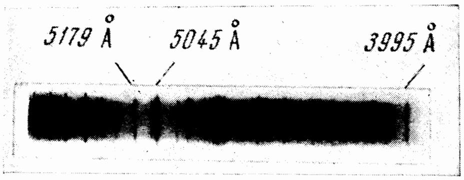

FIG. 3. Spectrum of a laser spark in air in the visible region (4000–6600 Å).

We photographed the spectrum of the laser spark, integrated over time. Figure 3 shows a spectrogram of such a spark in air in the visible region ($\Delta\lambda \sim 3900-6500$ Å). Interpretation of this spectrum showed that the observed lines belong mainly to singly ionized nitrogen and oxygen atoms N II and O II. We have also observed a line of atomic nitrogen N I and the H_α line of hydrogen. These lines are observed also in the spectrum of the ordinary spark discharge. However, in comparison with the spectrum of the ordinary spark, in the spectrum of the laser spark our attention is drawn to the very strong continuous background and the very large width of the observed lines—in fact, the majority of the lines are unresolved multiplets in which the distance between the individual lines is several Angstroms. Both of these facts—the strong background and the large line width—indicate a high electron concentration in the laser spark.

We made an evaluation of the quantity N_e by measuring the line widths in the laser spark spectrum and in the spectrum of a spark from a standard source (a type IG-2 generator operated at $V = 14$ kV, $C = 0.02$ μF, $L = 0.01$ μH). According to Mazing[5] the average value of N_e in such a source is 1.5×10^{17} cm^{-3}. The measured half-widths of the N II line $\lambda = 3995$ Å in the laser spark spectrum and in the IG-2 spectrum are 10 and 0.8 Å, respectively, which gives a value of 2×10^{18} cm^{-3} for the electron concentration in the laser spark. A direct evaluation of N_e carried out using the formulas of Vaĭnshteĭn and Sobel'man[6] for the N II lines $\lambda = 3995$ and 5045 Å ($\gamma \sim 8-10$ Å) gives a value $N_e \sim 2-3 \times 10^{18}$ cm^{-3}.

We also evaluated the temperature of the laser spark from the relative intensity of the N II lines $\lambda = 5179$ and 5045 Å. The line $\lambda = 5179$ Å is a superposition of two multiplets, some of whose components are unresolved. The transition probability for the entire group of unresolved components was calculated from the formulas of Bates and Damgaard.[7] Experimentally we measured the total area under the line. In view of the large errors in photometric measurements and in calculation of the transition probabilities by an approximate method, the accuracy of the temperature determination in this case is quite poor. The value of T_e obtained by this method is 30,000–60,000°K. It should be emphasized again that the spectra obtained are integrated over time. The values of N_e and T_e obtained by us must apply to the already developed stage of the discharge in which the main part of the light is produced. By this time, as can be seen from Fig. 2, the spark already occupies a considerable volume ($\sim 10^{-1}$ cm^3). In the initial moments when the volume occupied by the spark is much smaller, we can anticipate that the electron concentrations and temperatures existing in the discharge must be substantially greater. Therefore the study of the initial stage of a laser-induced spark in a gas presents considerable interest, and research in this direction will be continued.

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289

ON THE SUPERFLUIDITY OF NEUTRON STARS

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THE problem of neutron stars has recently provoked very considerable attention. The reasons for this are, first, current research into gravitational collapse, which for a star with sufficiently small mass $M \lesssim M_\odot$ should lead to the onset of the "neutron state," and secondly, the realization that it should be possible in principle to detect neutron stars by their x-radiation[1,2] (cf. also[3]).1)

The x-radiation of a neutron star is sufficiently strong only if the temperature is high enough ($T \approx 10^9$ °K at the center of the star), and even quite a small decrease in temperature leads to a sharp reduction in luminosity. Because of this calculations are very sensitive to the equation of state of the star. The latter is usually taken to be that of an ideal Fermi gas[1,2,6]. However, a neutron star may well exhibit the phenomenon of superfluidity; if so, this would lead to an exponential temperature dependence of the specific heat for $T < T_c$, if we neglect the phonon branch of the spectrum.2)

Indeed, the interaction between neutrons with antiparallel spins is attractive for the relevant region of momentum (i.e., for p of the order of the momentum on the Fermi surface $p_F = \hbar k_F$, $k_F \lesssim 10^{13}$ cm^{-1})[7]. Although this attraction does not lead to a stable bi-neutron, nevertheless if we consider a degenerate Fermi gas, the energy spectrum of one-particle excitations will display a gap. Thus, under the assumption that the interaction between two neutrons in the medium is of the same general nature as between two nucleons, a medium of neutrons will actually go into a superfluid state below some critical temperature T_c. According to the BCS theory[8] of superconductivity, the gap width $\Delta \sim kT_c \sim \epsilon_0 \exp - 1/NV$, where $\epsilon_0 \sim p_F \hbar/ma$ is the width of the effective region of interaction ($a \sim 10^{-13}$ cm is the range of the nuclear force, m is the nucleon mass and $\hbar/a$ a characteristic momentum transfer). For densities of order 10^{13}–10^{15} g/cm^3 we have $\epsilon_0 \sim 5$–20 MeV. The density of states at the Fermi surface $N = mp_F/2\pi^2\hbar^3 \sim (0.5-2) \times 10^{42}$. The quantity most difficult to estimate reliably is the interaction matrix element V. If we describe the singlet-state interaction by a potential well of depth 15 MeV and width 2.5×10^{-13} cm[7], we find $V = \int V(x) d^3x \sim 2 \times 10^{-42}$; from these data $\Delta \sim 1$–20 MeV. (If we take $\rho = 10^{14}$ we get the value $\Delta \sim 5$ MeV which agrees with the data for atomic nuclei.)

Thus at the center of a neutron star (where $\rho \sim 10^{14}$–10^{15}), $T_c \sim 10^{10}$–10^{11} °K. T_c decreases with decreasing density, but calculations in this region are particularly unreliable in view of the resonance character of the nucleon-nucleon interaction. If we apply the same estimation technique as used above, we find that on the boundaries of the neutron phase (where $\rho \sim 10^{11}$; cf [1]), $T_c \sim 10^7$ °K.

Rough as the above estimates are, they are strongly indicative that under conditions usually assumed to obtain[1,2,3,6], neutron stars or at least their central regions may be superfluid.

As already mentioned, this fact is important when we come to calculate the thermal capacity. Moreover, the superfluid state will display a large specific thermal conductivity of a convective nature. (However, for Chiu and Salpeter's[1] isothermal model of a neutron star this fact is of course irrelevant.) At first glance it also seems that superfluidity in a neutron star would lead to a large change in its moment of inertia. Actually, however, the moment of inertia will return to its normal value for a negligibly small value of the angular velocity $\omega_c \sim \hbar/mR^2 \ln(k_F R)$ (where R is the radius of the star) as a result of the formation of vortex lines[11]. On the other hand, the presence of a large number of vortex lines may affect the equation of state and possibly other characteristics of a rotating neutron star.

To sum up, we restate the aim of this note: to point out that any analysis of the problem of neutron stars must take account of the possibility of their being superfluid. Obviously in this case their rate of cooling would be much increased and their active phase (from the point of view of x-radiation) shortened.

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1)It is true that, as far as we have been able to ascertain, the observations of the Crab nebula carried out by the Firedman group during the lunar eclipse indicate the existence of an x-ray source of fairly large dimensions. Thus in this case we are not dealing with a hot neutron star; the source is in fact probably charges accelerated by a magnetic field[4,5]. However, the idea of observing neutron stars by their x-ray radiation is still of interest.

2)The T^3 term in the specific heat due to sound waves is relatively small; the ratio of the phonon specific heat to the term linear in T is of order $(p_F/mk\Theta)^2(T/\Theta)^2$ where $\Theta \sim up_F/k \sim 10^{11}$ °K is the Debye temperature of a neutron medium ($u \sim 10^9$ cm/sec is the speed of sound in this medium for $\rho \sim 10^{14}$ g/cm^3).

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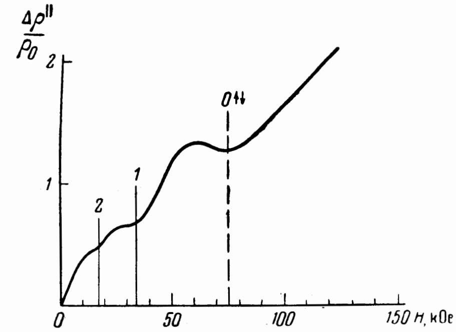
290



Curve showing the dependence of the longitudinal magnetoresistance of n-type InSb on the magnetic field intensity at T = 90 °K. The electron density was $n = 6 \times 10^{13}$ cm^{-3}, and the mobility was $u = 6 \times 10^5$ $cm^2 \cdot V^{-1} \cdot sec^{-1}$. The vertical lines identified by indices (M = 1, 2) indicate the resonance values of the field.

NEW DATA ON THE MAGNETOPHONON OSCILLATION OF THE LONGITUDINAL MAGNETORESISTANCE OF n-TYPE InSb

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PARFEN'EV, Shalyt, and Muzhdaba[1] have shown that the oscillatory nature of the transverse and longitudinal magnetoresistance curves for nondegenerate samples of n-type InSb may be explained by the phenomenon of magnetophonon resonance predicted theoretically by V. L. Gurevich and Yu. A. Firsov.[2]

Further experimental investigation of this phenomenon in pulsed magnetic fields has made it possible to establish that the longitudinal magnetoresistance curve of n-type InSb has continued to oscillate in stronger fields beyond the upper limit of the interval established earlier, which extended only to 35 kOe (cf. the figure). It has been shown in [1] that the identification of the magnetic field values corresponding to the magnetophonon resonance condition ($\omega_0 = MeH/m^*c$, where M is an integer) is simple only for the transverse effect when, according to the theory, the resonance values of the field always correspond to the resistance maxima. It has been shown since [3] that the situation is much more complex for the longitudinal effect both in experiment (because a temperature shift of the phase of the oscillating curves was observed) and in theory (because of the need to allow for the fact that, characteristically, the various scattering mechanisms are competing against one another[4]). Therefore, reliable identification of the resonance values of the magnetic field for the longitudinal effect has to be made by comparing the experimental oscillatory curves of the longitudinal and transverse magnetoresistance, using the transverse effect maxima as the calibration points.

In the study up to 38 kOe, described in [1,3], both experimental curves were available and it was possible to establish that at sufficiently low temperatures the longitudinal effect curve had minima at the resonance values of the field. It was established, in particular, that the minimum at $H \approx 33$ kOe should correspond to electron transitions between the two lowest unsplit Landau levels with quantum numbers zero and unity. Therefore, from the most general considerations, it follows that the oscillation of the magnetoresistance in stronger fields ($H > 40$ kOe), discovered in the present work, should be associated with the spin splitting of the Landau levels. However, a reliable determination of the resonance field values in this range of fields is difficult because the experimental curve of the transverse effect does not show oscillations in strong fields and the theory of transitions between split Landau levels with spin reversal under conditions of competition between various scattering mechanisms has not yet been developed. If we assume, on the basis of the results of the earlier work, that also in the region of strong fields ($H > 40$ kOe) at $T = 90$°K the resonance condition is satisfied by a minimum of the longitudinal magnetoresistance curve, the corresponding type of