hydromagnetic velocity-space instability of the "mirror" type. In our experiments, using high-energy electrons, it has been observed to cause an enhanced rate of transport of particles across field lines. It may also cause other effects, such as more rapid thermalization of the plasma, or the emission of plasma radiation. These effects, or those which might arise when the instability is associated with anisotropies in the ionic component of the plasma rather than the electronic component, we have not investigated. Although it is possible to avoid the instability by controlling the plasma parameters, we have shown that it may occur in plasma compression experiments. It also seems likely that any method of creating a hot plasma which results in anomalously large anisotropies (such as the method of injecting highly directed high-energy particles), may stimulate this instability during buildup, even if the final plasma state aimed for is stable. Finally, since this instability feeds on perturbation in energy density, and is not of electrostatic origin, it should persist in the limit of very low particle densities, provided the anisotropy becomes correspondingly large. For this reason, it (or related instabilities) might occur in some astrophysical situations or in particle accelerators, even though the conditions are such that cooperative effects would normally be considered unimportant.

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SUPERCONDUCTIVITY IN Nb_3Sn AT HIGH CURRENT DENSITY IN A MAGNETIC FIELD OF 88 kgauss

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We have observed superconductivity in Nb_3Sn at average current densities exceeding 100 000 amperes/cm^2 in magnetic fields as large as 88 kgauss. The nature of the variation of the critical current (the maximum current at a given field for which there is no energy dissipation) with magnetic field shows that superconductivity extends to still higher fields. Existing theory does not account for these observations. In addition to some remarkable implications concerning superconductivity, these observations suggest the feasibility of constructing superconducting solenoid magnets capable of fields approaching 100 kgauss, such as are desired as laboratory facilities and for containing plasmas for nuclear fusion reactions.[1,2]

The highest values of critical magnetic fields previously reported for high current densities have been less than 18 kgauss.[3,4] However, values as large as 30 kgauss have been reported[5] for low current densities.

The discovery of the existence of Nb_3Sn with its high critical temperature of 18.0°K by Matthias, Geballe, Geller, and Corenzwit[6] immediately suggested that the critical field might be high. The existence of superconductivity in Nb_3Sn at high fields is also indicated by the recent susceptibility observations of Bozorth, Williams, and Davis.[7]

Nb_3Sn is very brittle and is thus not readily fabricated into specified configurations. However, a method of minimizing this difficulty was developed during the current investigation. Two distinctly different types of samples were studied. The first type consisted of rectangular rods cut from an ingot which was prepared by first sintering a stoichiometric mixture of Sn and Nb powders at 1800°C and then melting the compact in a zirconia crucible in an argon atmosphere at about 2400°C. X-ray diffraction data confirmed the existence of essentially a single homogeneous phase of the β-wolfram structure. The rods were about 2 cm long and had thicknesses varying from 0.025 cm to 0.063 cm. The second type consisted of small niobium tubes which contained thin cores of Nb_3Sn. These were prepared by packing 0.6 cm o.d. − 0.3 cm i.d. niobium tubes with either a mechanical mixture of powdered Nb_3Sn + a 10 weight percent excess of powdered Sn or similar mixtures of unreacted Sn and Nb powders. The ends of the tubes were closed with Nb plugs and the sealed tubes were mechanically reduced in size to 0.038 cm o.d. Each tubular sample was heated to a prescribed temperature between 970°C and 1400°C for a predetermined period of time, as long as 24 hours.

Current and potential leads were attached to each of the samples using an ultrasonic soldering iron and indium solder. The potential leads were about 1 cm apart. The samples were mounted transverse to the axis of a solenoid magnet capable of a maximum steady-state field of 88 kgauss. Observations were made by selecting a fixed value for the magnetic field and slowly increasing the current through the sample until a potential drop across the sample of a few hundredths of one microvolt was observed. The results for three sizes of parallelepiped samples cut from the Nb_3Sn ingot are shown in Fig. 1.

In addition to the high magnetic fields and current densities for which superconductivity exists in Nb_3Sn, there are two other interesting fea-

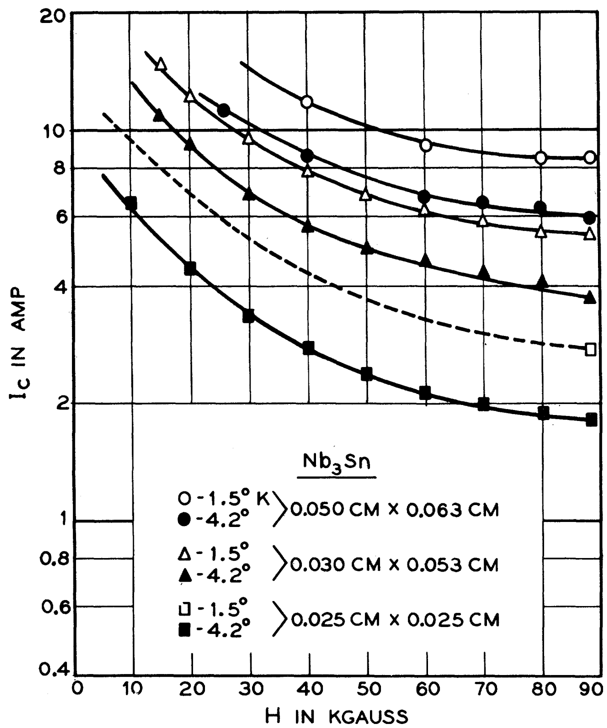

FIG. 1. Critical current vs applied magnetic field for three sample sizes at 1.5°K and 4.2°K. The magnetic field was perpendicular to the current direction. Each experimental point represents the maximum current, at the value of magnetic field indicated, for which no voltage drop along the sample was observed, the smallest detectable voltage being a few hundreths of one microvolt.

tures of the data of Fig. 1. First, the average current density does not scale as the perimeter of the cross-sectional area as is expected for a "soft" superconductor, nor as the cross-sectional area as is observed for "hard" superconductors, such as mechanically deformed Mo_3Re,[4] but is about midway between the two types of behavior. This variation with sample size suggests that appreciable current is being carried both by the surface and by "filaments." Secondly, the variation of the maximum permissible applied magnetic field with temperature, at constant current, is far from parabolic. Although T_C is about 18°K for Nb_3Sn,[6] the magnetic field increases more than 50% between 4.2°K and 1.5°K. We have not been able to account for these observations in terms of existing theory.

Critical current vs applied magnetic field curves for several characteristic samples of "Nb_3Sn" cores clad with Nb are shown in Fig. 2. It is of considerable interest that all of the curves

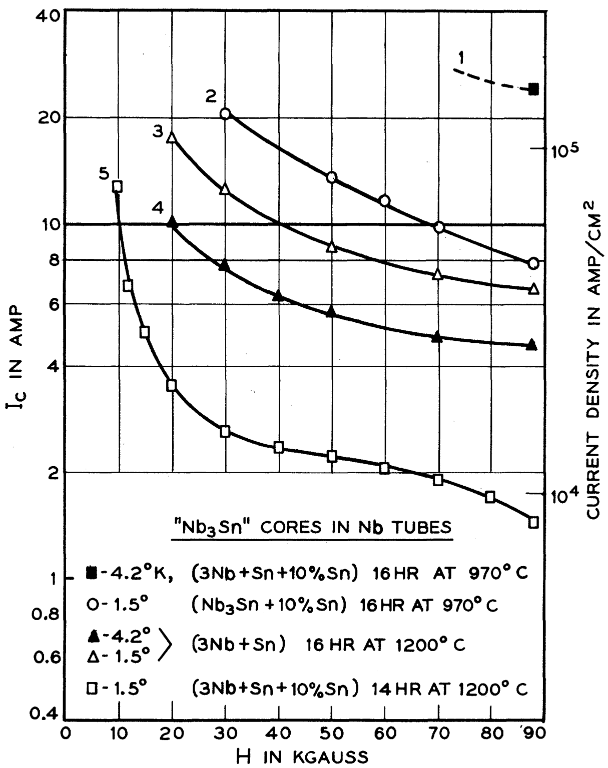

FIG. 2. Critical current vs applied magnetic field for Nb-clad cores of "Nb_3Sn." The o.d. of the cores was about 0.015 cm and the o.d. of the Nb jackets was about 0.038 cm. "+ 10% Sn" in the table legend means 10 wt. % more Sn than is required to form Nb_3Sn assuming no reaction with the Nb tube. The magnetic field was perpendicular to the current direction. Each experimental point represents the maximum current, at the value of magnetic field indicated, for which no voltage drop along the sample was observed, the smallest detectable voltage being a few hundreths of one microvolt.

represent significantly higher average current densities at the highest fields than the samples cut from the Nb_3Sn ingot. The single point shown on Curve 1 in Fig. 2 represents an average current density nearly 50 times higher than the data of Fig. 1. The average current density of this "Nb_3Sn" core exceeds 100 000 amperes/cm^2. The Nb tubes do not contribute since it is found that annealed niobium becomes normal in fields well below 20 kgauss. A comparison of Curve 3 of Fig. 2 with Curve 5 suggests that a stoichiometric mixture of Nb and Sn powders is preferable to an excess of Sn. A comparison of these curves with Curves 1 and 2 indicates that it is preferable to start with the elemental powders, with or without an excess of Sn, rather than with powdered Nb_3Sn + excess Sn powder. Also, the curves of Fig. 2 and similar data for heat treatment at temperatures as high as 1400°C show that a lower temperature of heat treatment consistently yields material capable of higher critical current density. This rapid trend with temperature suggests that still higher current densities might be obtained at still lower reaction temperatures.

The data of Fig 2 and data from related samples suggest that the difference in properties between pure dense Nb_3Sn and the Nb-clad samples is not principally one of chemistry but rather is in some manner associated with the physical state of the "Nb_3Sn" in the core. However, the critical temperature of the fused dense Nb_3Sn was found to be 17.8°K (when extrapolated to the limit of zero current through the sample) while that of the clad sample having the highest critical current density (Curve 1 of Fig. 2) was found to be 17.9°K. Although the pertinent physics of the situation is not yet clear, it is tentatively concluded that the conditions of preparation of the clad samples are such as to lead to a structure containing large numbers of "filaments." It is fortunate that these conditions are compatible with those which are expected to permit fabrication of the material into high-field superconducting electromagnets.

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