Persistent Currents in Frozen Metal-Ammonia Solutions

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R. A. Ogg[1,2] has cited the persistence of currents in frozen rings of sodium solutions in liquid ammonia as support for the hypothesis of the Bose-Einstein condensation of trapped electron pairs.

However, Boorse *et al.*,[3] and Daunt and co-workers[4] have reported that under the conditions of their experiments there was no evidence of superconductivity. In this note, I wish to report a series of experiments in which corroboration was found for Dr. Ogg's observations.

The ring of metal-ammonia solution was formed in the trap C illustrated in Fig. 1. The bottom portion of the trap was constructed of especially thin glass to allow for rapid cooling. Freshly distilled sodium was cut under pure pentane, and transferred to a weighing tube which was immediately evacuated. The sodium was weighed by difference and transferred under pentane into trap *C*. The pentane was distilled from the sodium under reduced pressure and the trap pumped down to about 10^{-4} mm pressure, and then closed off from the system. Anhydrous ammonia was condensed into trap *B* which was surrounded by dry ice-acetone (−78°C). The volume of liquid ammonia necessary to give the required solution was measured in the graduated tube on the trap, and then distilled into trap *C*, now refrigerated in liquid air. With *C* immersed in liquid air, pumping was carried out for about an hour, to remove traces of permanent gases. The tap on *C* was then closed, and the trap was removed from the system, and allowed to warm up to either −34°C (boiling ammonia) or −78°C (dry ice). The familiar blue solution formed a ring in the trap which always contained 7.5–8.5 ml of solution.

As a source of magnetic flux, a solenoid coil was employed, containing a central hole large enough to accommodate a flask of liquid air. The flux density through the operating coil was found by calibration to be 1600 gauss.

The 3200-turn search coil had almost the same geometry as the ring of solution. A ballistic galvanometer was used in conjunction with the search coil, and the assembly was calibrated in terms of the current detectable in a 2-inch loop moved adjacent to the search coil. The sensitivity was found to be 0.1 ampere per scale division, corresponding to a field of strength 0.01 gauss for the ring concerned.

To make a test for persistent current, the ring of liquid solution was suspended in the center of the coil at the desired starting temperature, with the flux (1600 gauss) threading the coil. Liquid air was then allowed to just make contact with the ring of solution, care being taken not to allow the trap to dip into the liquid air more than ½ inch. This precaution was important in order to avoid "flashing" of the sodium solution from the ring to the sides of the trap. After two minutes' immersion in the liquid air, the frozen ring was withdrawn through the field, immediately placed above the search coil, and the galvanometer reading observed.

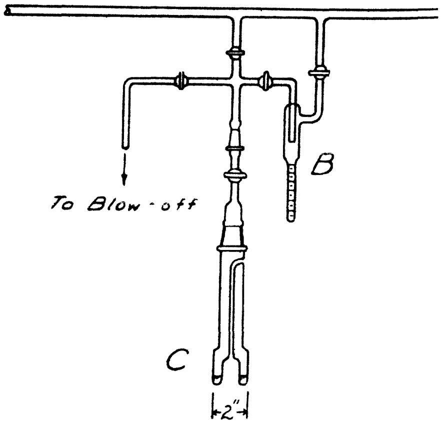

Fig. 1. Diagram of apparatus.

Some 115 experiments were carried out with solutions ranging in concentration from saturation to 0.90 molar. Four instances of persistent currents were observed in one series of 36 experiments on a solution where the mole ratio NH_3:Na was 43:1. It will be noted that this solution is in the concentration range where it exhibits liquid-liquid phase separation, and has an upper consolute temperature of −50°C.[5] This series was the only one yielding positive results. The first persistent current was observed on freezing from −70°C, at which temperature the two phases had already formed, while the other three results were obtained at a starting temperature of −34°C, where the solution was homogeneous. The galvanometer deflection indicated the expected polarity each time, and reversal of the direction of the solenoid field reversed the direction of the deflections caused by persistent currents in the frozen ring. This latter observation would seem to vitiate the possibility of the deflection being caused by paramagnetic regions in the solution. The largest of the persistent currents was 0.1 ampere, and its duration about one-half minute.

Twenty-four observations were also made by rapidly freezing lithium solutions in liquid air (mole-ratio NH_3:Li = 30:1) from above the consolute temperature. No persistent currents were observed, although liquid-liquid phase separation normally occurs at that concentration.

The resistance of the ring is indicated to be in the order of 10^{-12} ohm. It is suggested that the rapidity of freezing is not critical, for it is estimated that these solutions were not completely solid before a period of immersion of 15 seconds in the liquid air. The low incidence of successful experiments is attributed to the severe cracking of the samples on freezing. Lithium solutions were particularly bad in this respect.

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[1] R. A. Ogg, Jr., Phys. Rev. **69**, 243 and 544 (1946).

[2] R. A. Ogg, Jr., Phys. Rev. **70**, 93 (1946).

[3] H. A. Boorse, D. B. Cook, R. B. Pontius, and M. W. Zemansky, Phys. Rev. **70**, 92–93 (1946).

[4] J. G. Daunt, M. Désirant, K. Mendelssohn, and A. J. Birch, Phys. Rev. **70**, 219 (1946).

[5] C. A. Kraus and W. W. Lucasse, J. Am. Chem. Soc. **44**, 1951 (1922).