the anomaly on warming, are found to correlate directly with the proportion of h.c.p. phase present. As expected thermodynamically the h.c.p. phase has a higher Debye temperature than the b.c.c. phase.

Recent experiments by other workers in this laboratory have shown that the martensitic transformation also affects the electrical[6] and mechanical[7] properties of lithium.

A full account of this work will be published later.

[1]C. S. Barrett, J. Inst. Metals 84, 43 (1955).
[2]C. S. Barrett, Acta Cryst. 9, 671 (1956).
[3]D. L. Martin, Phys. Rev. Lett. 1, 4 (1958).
[4]C. S. Barrett, Phys. Rev. 72, 245 (1947).
[5]C. S. Barrett and O. R. Trautz, Trans. Am. Inst. Mining Met. Engrs. 175, 579 (1948).
[6]J. S. Dugdale and D. Gugan (private communication).
[7]L. Verdini (private communication).

MASER ACTION IN THE REGION OF 60°K

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A three-level solid-state maser of the type suggested by Bloembergen[1] has been operated successfully by several investigators.[2-6] In these experiments, the cavity containing the active material was cooled to temperatures of a few degrees Kelvin by the use of liquid helium. In the course of our investigations, we have operated such a maser using a cavity cooled by other refrigerants, notably oxygen and nitrogen, to temperatures in the region of 60°K.

The cavity, in the form of a right circular cylinder split midway along its axis, was designed to support the TE_{013} mode at pump frequencies in the neighborhood of 24 kMc/sec and the TE_{111} mode at signal frequencies near 9.3 kMc/sec. It was 1.167 inches long and 0.802 inches in diameter. The pump power was coupled to the cavity from a wave guide through an iris, and the signal-frequency coupling was effected by means of a loop terminating a coaxial line. The paramagnetic material was in the form of a sphere of ruby,[7] 0.625 inches in diameter, which had a nominal concentration of 0.1% chromium. The presence of such a large sample resulted in an increase in the number of cavity resonances which allowed operation at various frequencies in the region of interest.

At the polar angle $\theta = 54° \, 44'$ the four energy levels of the Cr^{+++} ion are split so that the levels (3) and (4) are the mirror images in energy of the levels (2) and (1). The transitions between the levels (1) and (3) and between (2) and (4) are thus degenerate for all values of the external magnetic field. Hence by using a single pump frequency it is possible to modify the population difference between levels (2) and (3) by a "push-pull" action.[6] It is easy to set up this condition experimentally by observing at room temperature the onset of degeneracy between the above pump transitions, or of the absorption lines arising from the transitions at the signal frequency between levels (2) and (1) and between (3) and (4).

The cavity assembly was enclosed in a conventional double Dewar system. The outer Dewar contained liquid nitrogen at atmospheric pressure and the inner Dewar contained the refrigerant pumped to a low pressure. Below 63.2°K nitrogen at reduced pressures is a solid and some trouble was experienced due to insufficient thermal contact between the refrigerant and the wave guide assembly. Oxygen has been used in preference in later experiments as the triple point is appreciably lower, 54.4°K. The rate of evaporation of the liquid oxygen was about 40 ml per hour so that a run of about 40 hours is possible for one filling of the Dewar.

At 78°K, variation of the pump power level produced a strong interaction on the signal frequency absorption. It was possible, in fact, to remove the center of the absorption line, rendering the sample transparent at this signal frequency, but, to date, no appreciable stimulated emission has been observed at this temperature with the available pump power. However, at temperatures below about 60°K, amplification and oscillation have been observed over the frequency range from 9280 Mc/sec to 9520 Mc/sec, the predicted pump frequencies in the region of 23.5 kMc/sec to 24 kMc/sec being in good agreement with theoretical calculations of D. J. Howarth of this laboratory. At these temperatures "push-pull" pumping should theoretically be about six times more efficient than single pumping in producing a negative spin temperature. Indeed, although single pumping produces a strong interaction with the signal frequency absorption, it has not been found possible to produce any stimulated emission at 56°K when the crystal was misorientated by more than a degree from the "push-pull" condition.

The results quoted below were obtained by an experiment using liquid oxygen pumped to a pressure of about 2 mm of mercury, which indicated a temperature near to 56°K. The cavity Q was in the region of 20 000. The pump power available was limited, our source being a war surplus 2K33 klystron whose power output was measured to be 50 milliwatts at the frequency of interest. It was apparent that the power entering the cavity was not sufficient to saturate the pump transitions completely. With the cavity undercoupled at the signal frequency, oscillations were observed, the power output being 50 microwatts at a frequency of 9518 Mc/sec. By using increased penetration of the coupling loop, the cavity could be overcoupled at the signal frequency and stable gain was achieved up to 30 db. The product $B\sqrt{G}$ was measured to be 3.8 Mc/sec. This figure was constant for signal levels in the range 10^{-12} to 10^{-7} watts.

The successful operation of a maser at these comparatively high temperatures has both theoretical interest, indicating that the relaxation processes are not so temperature dependent as was at one time envisaged, and also practical importance, as freedom from the use of liquid helium will simplify considerably the operation of maser equipment in the field. In conclusion, we would emphasize that our results are preliminary only, being obtained with restricted pump power, a cavity designed for experiments with another material at helium temperatures, and using an active sample whose size and shape were determined for us by chance. Thus we hope to see better performance data as a result of further development.

[1]N. Bloembergen, Phys. Rev. 104, 324 (1956).

[2]Scovil, Feher, and Seidel, Phys. Rev. 105, 762 (1957).

[3]A. L. McWhorter and J. W. Meyer, Phys. Rev. 109, 312 (1958).

[4]Strandberg, Davis, Faughan, Kyhl, and Wolga, Phys. Rev. 109, 1988 (1958).

[5]Artman, Bloembergen, and Shapiro, Phys. Rev. 109, 1392 (1958).

[6]Makhov, Kikuchi, Lambe, and Terhune, Phys. Rev. 109, 1399 (1958).

[7]This sample was obtained through the courtesy of Dr. A. E. Siegman of Stanford University.

FERROMAGNETIC SUPERCONDUCTORS

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Studies previously reported,[1] particularly on lanthanum-gadolinium solutions, have raised the possibility that the phenomena of superconductivity and ferromagnetism might overlap, resulting in a ferromagnetic superconductor. An interesting case where this occurs is found in the solid solutions between $CeRu_2$ (superconducting at about 5.1°K) and $PrRu_2$ or $GdRu_2$ (respectively, ferromagnetic at 40° and above 70°K).

The first system, $(Ce,Pr)Ru_2$, is shown in Fig. 1 and the region at which superconductivity and ferromagnetism might overlap is at temperatures below 1°K, not conveniently accessible with our apparatus.

The second system, $(Ce,Gd)Ru_2$, however, gave a temperature region a good deal above 1°K for the simultaneous occurrence of superconductivity and ferromagnetism in the same sample though perhaps not in the same volume element. This is shown in Fig. 2. For a composition of $Ce_{0.94}Gd_{0.06}Ru_2$, Curie point (Cpt) and superconducting transition temperature (T_C) coincide, provided the measuring field is below 10 gauss. With larger fields T_C can be lowered and so be more separated from the corresponding Cpt. For compositions with much higher T_C than Cpt the measurements require the destruction of superconductivity by a magnetic field before ferromagnetism can be detected. The inverse case in which the Cpt is higher than T_C is a much

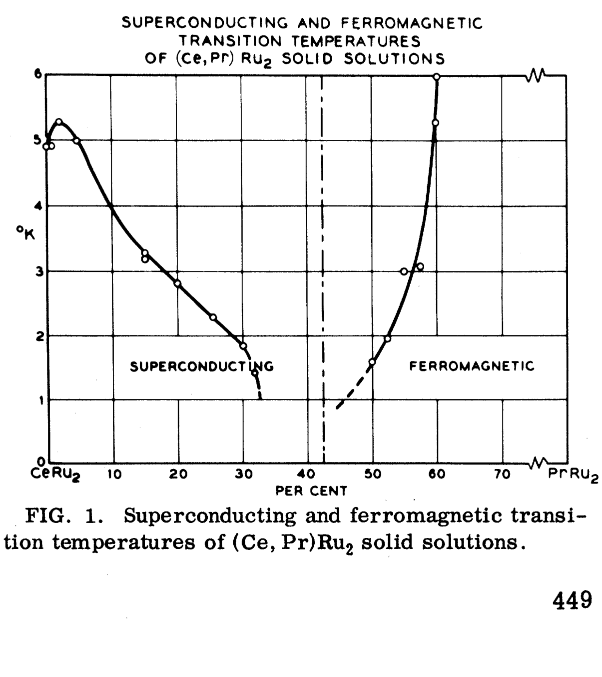

FIG. 1. Superconducting and ferromagnetic transition temperatures of $(Ce, Pr)Ru_2$ solid solutions.