EXPERIMENTAL EXAMPLES

We demonstrated operation in regions A, B, and C of Fig. 1 with various cores of bismuth. No experiment was attempted in region D, which is the indeterminate case.

Case 1. Region A on the impedance curve, $a/s \rightarrow 0$. The resistivity of bismuth is $120 \times 10^{-6}\ \Omega \cdot \text{cm}$ at 25°C. For our standard sample size, 0.63 cm in diameter$\times$1.25 cm long, a frequency of 1000 cycles yields $a/s = 0.2$, which is suitable for the test. The measured inductance and resistance of the coil as a function of pressure are shown in Fig. 6. The inductance curve shows clearly the I $\rightarrow$ II and II $\rightarrow$ III transitions. The total change in inductance is 2.7%. From relation (6), it follows that the volume change is 8.4%. This agrees well with the accepted value.[11]

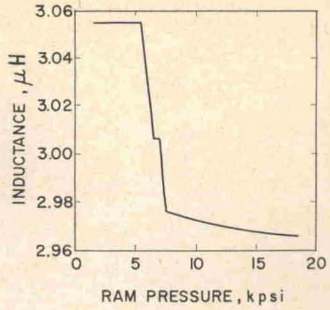

FIG. 6. Inductance of a standard sample coil on a bismuth core at 1000 cps. The skin depth in this case is much larger than the core dimensions.

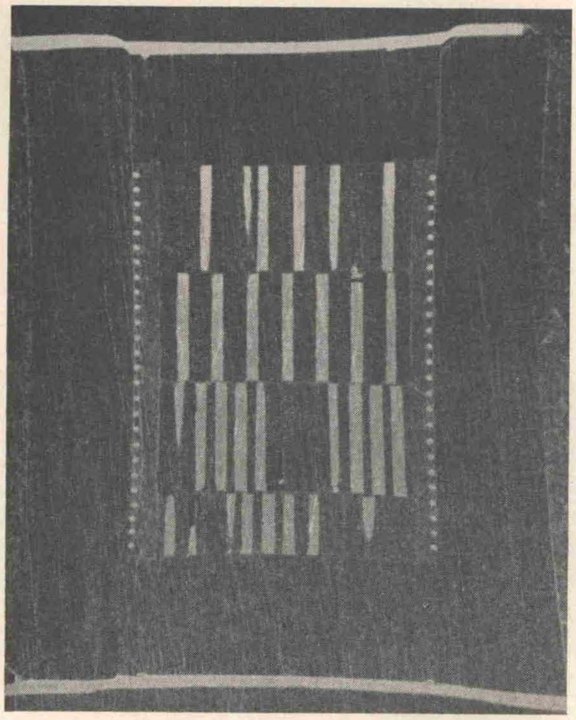

FIG. 5. Cross section of the filamentary sample core for which the skin depth equals the radius of the bismuth needles.

The filling factor and the exact nature of inductance-volume relation are neglected here. Apparently, these nearly offset each other for the sample geometry employed. When comparing cores with different rheological properties, one should consider details of the coil collapse.

The total change and the fractional changes through each transition have been repeated several times and are reproducible to about $\pm 7\%$.

The resistance curve has no simple interpretation and is not shown. At this frequency, it represents chiefly the dc resistance of the copper wire and leads. In some experiments, however, the resistance curve was qualitatively similar to the volume curve. It might well be useful in specific circumstances.

The operation of the coil in region A was further demonstrated for thallium and barium. These metals have well-known polymorphic transitions at 37 and 59 kbar, respectively. The volume decrement at the transition is about 1% for Tl and 1.9% for Ba.[11] Standard size coils and cores were used in both cases, and the measurements were made at 1 kc. These conditions give a suitable ratio of a/s. Figure 7 shows the measured inductances as functions of pressure. The two transitions are clearly exhibited. The inductance change at the transition is 0.35% for Tl and 0.74% for Ba. These yield computed volume changes of 1.0 and 2.2%, in good agreement with the published data.

The ordinary compressibility of the sample core may also be determined with good accuracy from the inductance curve. As a specific example, our data yield a volume change of 13.0% for barium between 20 and 50 kbar. Bridgman[12] reports 12.9% for the same range.

Case 2. Region B on the impedance curve, $a/s \rightarrow \infty$. A frequency of 2.1 Mc was used in this region, which yields $a/s = 8$. The measured data are the parallel capacitance C_p required to tune the coil, and the equivalent resistance R_p of the tuned circuit at resonance. The directly observed data are plotted in Fig. 8. We note first of all that

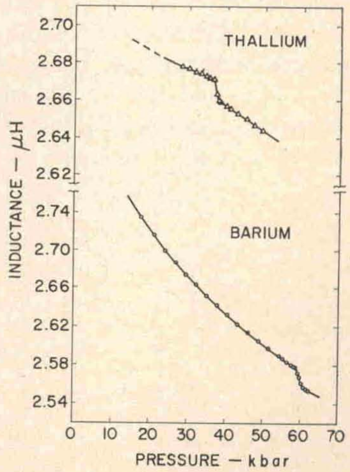

FIG. 7. Inductance of coil on barium and thallium cores at 1000 cps.

[11] P. W. Bridgman, Proc. Am. Acad. Arts. Sci. 74, 425 (1942).

[12] P. W. Bridgman, Proc. Am. Acad. Arts. Sci. 81, 165 (1952).

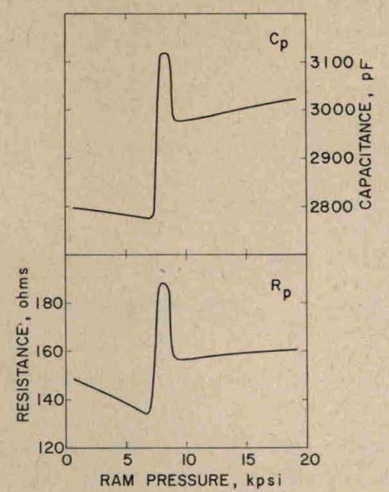

FIG. 8. Directly observed parallel impedance of coil on a bismuth core at 2.1 Mc. The skin depth here is much less than the dimensions of the core.

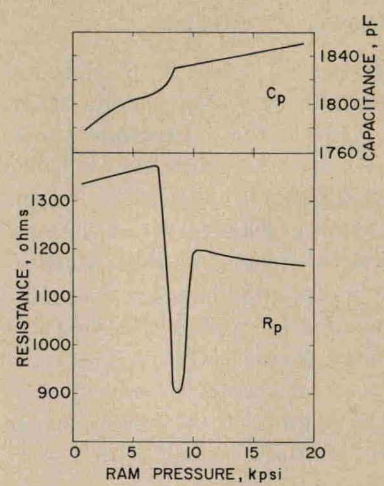

FIG. 10. Directly observed parallel tuning capacitance and equivalent parallel resistance of coil on filamentary bismuth core. In this case the skin depth is equal to the effective sample radius.

the two curves are quite similar, as would be predicted from the equations. There is a slight difference in the relative "recovery" level of the curves after the II → III transition, which represents the volumetric information.

The data in Fig. 8 were corrected by use of a Smith chart, and reduced by means of relations (12) and (13). The reduced results are shown in Fig. 9. The curve agrees closely with accepted data on bismuth.[12] The reduced volumetric curve is not shown, since volume information in region B is very inconsistent in the face of mixing with such large resistivity effects.

The reversal of the observed parallel resistance curve with respect to the actual resistivity curve of bismuth has an interesting qualitative explanation. For the phase designated Bi-II, the resistivity is about one-sixth the value at the peak just before the I → II transition. As the pressure is increased to bring about the I → II transition, the observed parallel resistance of the coil increases. This indicates that the series resistance of the coil has decreased, i.e., the Q of the coil is higher. Physically, the skin depth has become much less, and the rf field from the coil is prevented from intercepting so much dissipative core material. Quite literally, the rf field has been "squeezed out" of the specimen core, in a manner somewhat analogous to the "freezing out" of magnetic fields from a superconductor.

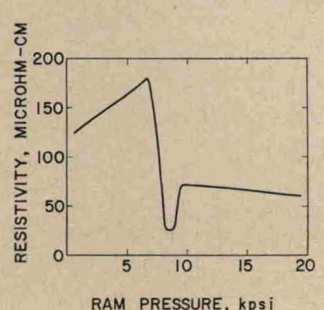

FIG. 9. The resistivity of bismuth as a function of ram pressure. This curve was derived from the observed data of Fig. 8.

Case 3. Intermediate case, region C on the impedance curve, $a/s \approx 1$. Here, we used the filamentary coil discussed earlier, and a frequency of 1.73 Mc, which yields $a/s = 1$. The data are shown in Fig. 10. Both the volumetric and resistivity information are clearly displayed as predicted. We did not attempt to reduce the data, since the lack of an AgCl medium and the low filling factor preclude high accuracy in this particular experiment.

Sensitivity

The chief interest in developing the inductive coil technique lies in the practicability of remote measurement of volume changes. As an indicator of the sensitivity of the method, a compound sample core was prepared of concentric cylinders of bismuth, thallium, and barium. The fractional volumes of Bi, Tl, and Ba were 80, 10, and 10%, respectively. The inherent volume changes at the principal transitions in these materials are 8.5, 1, and about 1.9%. Thus the volume curve from the compound sample should show changes of 7, 0.1, and 0.2%. The experiment was

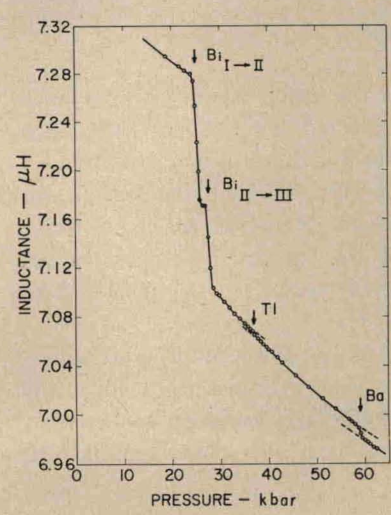

FIG. 11. The inductance of the coil on a compound core of concentric cylinders of bismuth (80%), thallium (10%), and barium (10%).