higher bursting strength, even at 600°. It is also possible that higher pressures may be reached with tubing drawn from other varieties of steel, or made by drilling. Values given by the manufacturer for the creep strength of this stainless steel suggest that if mechanical imperfections can be eliminated, considerably higher pressures than caused rupture in the present experiments can be used for the short periods required for most experimental work.

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Thermal Conductance of Metallic Contacts*

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INTRODUCTION

THE problem of a good make-and-break heat contact between different parts of cryogenic apparatus, is a common one. The usual technique involves the use of a contact gas (usually helium or hydrogen) as a conducting medium. After temperature equilibrium has been obtained between the different parts by means of this contact gas, they may be thermally isolated from each other by pumping off the gas to a hard vacuum. This process of "thermal switching" is analogous to the common electrical switching process, the contact gas corresponding to the electrical switch arm. For temperatures less than 1° Kelvin, the vapor pressure of the only available gas, helium, is too small to provide adequate heat conduction. The use of liquid helium involves many complications. At higher temperatures the use of the contact gas is sometimes awkward. It is possible that under these circumstances a mechanical switch consisting of two metallic surfaces brought into contact may be satisfactory.

The thermal conductance between two clean metallic surfaces, in contact in a vacuum, is of importance for the design of such apparatus. No experimental work along this line has been published as far as the authors are aware. The electrical conductance of metallic contacts has been the subject of much research,[1] for the obvious reason that electrical switching devices are widely used. An important requirement of a mechanical thermal switch is that such a switch be capable of operation without the use of grease on the contacting surface, inasmuch as grease hardens at low temperatures. A further requirement is that the thermal switches operate in vacuum as this is used for effective heat insulation at low temperatures. Accordingly, the following investigation of the thermal conductances between various surfaces was undertaken with clean metallic contacts in a high vacuum. The conductances were studied as a function of pressure, and the investigation was limited to good heat conductors.

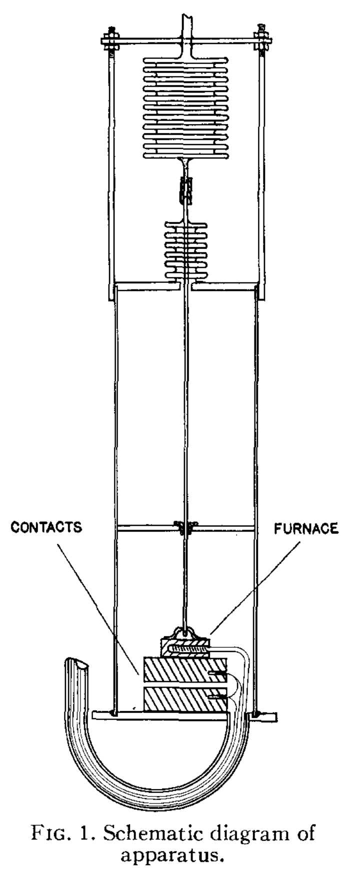

FIG. 1. Schematic diagram of apparatus.

APPARATUS

Figure 1 shows the vacuum chamber enclosing the two metallic contacts. The upper contact block is heated by a small

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[1] F. Kesselring, *Elements of Switchgear Design* (Pitman, 1932).

furnace and is then brought into contact with the lower block, which remains at the constant temperature of the vacuum case. A copper-constantan thermocouple differentially connected between the two blocks allows the measurement of the rate of fall of temperature of the upper block. The thermal conductance (per unit area) of the contact gap is given theoretically by the equation:

$$K=\frac{C}{At}\cdot\log\frac{\Delta T_1}{\Delta T_2},$$

where C is the thermal capacity of the upper contact block, A is the area of the contact, and t is the time required for the temperature difference to fall from ΔT_1 to ΔT_2. This logarithmic decrease of the temperature was confirmed experimentally. The contact pressure is controlled by suitably adjusting the gas pressure in the bellows arrangement shown in the figure.

RESULTS

Figure 2 shows the results for gold, silver and copper as a function of contact pressure at room temperature and at the temperature of boiling nitrogen. As the quality and flatness of the surfaces considerably affected the results, each surface was polished to approximately optical flatness. Complete repolishing of the surfaces gave results reproducible to within 5 percent. Very clean surfaces were necessary as the slightest trace of grease resulted in an increased conductance at room temperature, and a seriously decreased conductance at low temperatures, where the grease became hard.

It can be seen from Fig. 2 that only in the case of copper does the conductance vary linearly with contact pressure.* In all cases one would expect only heat transfer by radiation at zero pressure. This was corroborated experimentally as it was found that the thermal conductance was approximately the same when the surfaces were "just touching" or separated by a few millimeters. This radiation conduction is less than 10^{-3} watt/cm/°C.

In all cases the thermal conductances are much smaller at the lower temperatures.† This is probably due to adsorbed surface films. Thermal distortion of the surfaces seems an

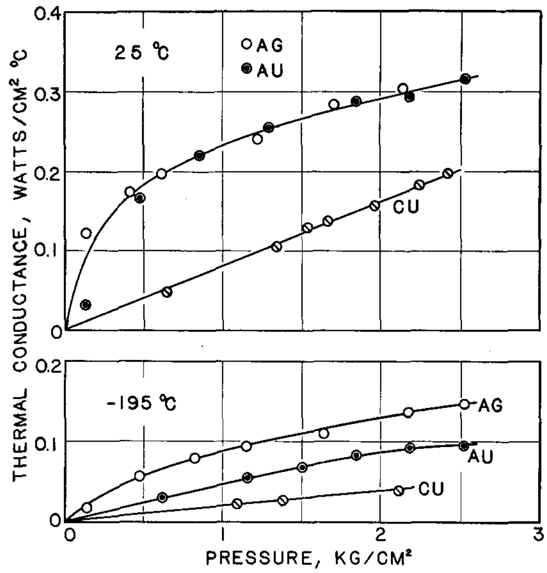

FIG. 2. Thermal conductance as a function of contact pressure for Cu, Ag and Au.

unlikely cause since annealed and unannealed blocks give identical results. For the gold and copper contacts a progressive decrease of conductance with time after cooling was observed. This behavior would also indicate the formation of surface films at low temperatures. Silver did not exhibit this phenomenon. Furthermore, its conductance was least affected by temperature, making it the logical choice as a contact material for low temperature work.

In attempting to cool metallic samples by contact with paramagnetic salts which have been cooled by demagnetization, one is confronted with a problem quite similar to that which we have investigated. It is interesting to notice that where thermal contact was attained in such experiments,[2,3] it was found necessary to apply considerable pressure between the salts and metals involved; in general, there was agreement with the results of our experiments.

* This has been found to be the case for electrical contacts operated through a considerable pressure range. See reference 1.

† This is also true for electrical contacts.

[2] N. Kenti and F. Simon, Proc. Roy. Soc. **151**, 610 (1935).

[3] E. S. Shire and J. F. Allen, Proc. Camb. Phil. Soc. **34**-**2**, 301 (1938).