A METHOD OF DRAWING METALLIC FILAMENTS AND A DISCUSSION OF THEIR PROPERTIES AND USES

By G. F. Taylor

Abstract

If a glass tube filled with a molten metal is placed in a tubular furnace or in a transverse hole through a heated copper rod and drawn out at the proper rate, metal filaments of almost any degree of fineness may be obtained down to a diameter of 10^{-5} cm, or even less. The glass or quartz used must soften at a temperature between the melting and the boiling point of the particular metal. Filaments of Pb, Sb, Bi, Au, Ag, Cu, Fe, Sn, Tl, Cd, Co, Ga, and In have been made by this method. The glass envelop may serve as insulation or may be removed, if desired, with HF. The filaments are very pliable and have greater *tensile strength* than wires of ordinary size. The *temperature coefficients of resistance* were not found to differ markedly from those of the metals in bulk, and to be more constant. Metallic filaments made in this way have been *used for resistance thermometers, thermocouples, galvanometer suspensions, and hair lines for the eye pieces of telescopes. Their use in micropiles, bolometers and the moving coil of both direct and alternating current galvanometers is suggested. Conducting quartz threads* were made by drawing down a tube with a silver core.

CERTAIN experiments conducted by the Bureau of Plant Industry which required thermocouples and resistance thermometers of exceptionally small dimensions have lead to the development of a process of drawing wire of extreme fineness, the description of which may be of interest in other fields.

The metals Pb, Sb, Bi, Sn, Cd, Ga, Tl, Cu, Ag, Au, Fe, In, Al and numerous alloys of these metals with each other were drawn into wire by the process described below, which applies in general to all these metals and alloys, though special comment must be made in most cases.

The process consists essentially of filling a glass tube with the metal from which the wire is to be drawn, placing this in a heated cylinder or flame and drawing it out as fine as desired. The glass selected must soften at a temperature between the melting and the boiling point of the metal used and must not react chemically with the metal at high temperatures.

A freshly drawn glass tube about 2 mm inside diameter is closed at one end. A bit of the metal to be drawn is dropped into the tube and lodges at the closed end. This end is heated in a flame until the metal melts and the glass softens. Most of the metals form an oxide at this temperature but the oxygen near the metal is soon exhausted. The metal is freed from its coat of oxide by pressing the walls of the tube together with small forceps, causing the bright liquid metal to flow back to a clean portion of the tube and leave the slag behind. The original end of the tube, now containing only the slag, is drawn off and discarded. It may be necessary to repeat this operation a number of times for unless the metal appears as a flawless mirror against the inner surface of the glass, it cannot be drawn into a perfect wire. The new end, now containing the bright metal, is strongly heated and drawn out to a diameter of .5 to 1 mm and a foot or more in length. These metal filled glass tubes are now ready to be drawn through a heated cylinder to almost any degree of fineness.

The cylinder, or muffle, is made from a copper rod, 1 cm in diameter and 7 cm long (Fig. 1, a). Toward one end is a row of holes *f*, 2 mm in diameter, parallel to each other and perpendicular to the axis of the rod. These holes are each lined with a spiral of nichrome wire to prevent the semiliquid glass from adhering to the red hot copper. This rod is supported in a horizontal position by a smaller steel rod *c*, attached at one end to the copper rod, and at the other end to any kind of support.

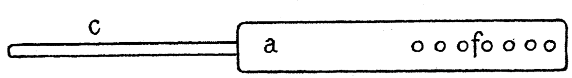

Fig. 1

By means of a flame the rod is heated to a bright red on the end nearest the support, the temperature diminishing toward the other end. The hole having a suitable temperature is selected and one end of the glass-covered wire, already prepared, is passed through the hole, grasped with small forceps and drawn out as fine as desired.

The size of the wire is determined by the wall thickness of the glass and the rate at which it is fed into and drawn out from the heated cylinder. When a constant rate is maintained, a wire of uniform thickness is drawn. By varying the ratio of the feeding in to the drawing out, a wire of any degree of taper within the limits of the original diameter may be produced.

When heated in a flame and drawn in air, those metals which contract on solidifying will form breaks at short intervals, while those which expand will rupture the glass capillary. When drawn slowly from a heated cylinder, however, a perfect cast is formed, because solidification takes place at a point adjacent to the liquid metal.

Special glasses must be used for most of the metals and the manipulation varies more or less with each case. Pb, Sn and Bi can be drawn in almost any kind of glass by the process described above. Tl may be drawn in the same way, but only in a certain borosilicate glass No. G-80 manufactured by the Corning Glass Works. Cd and Ga were drawn in a very soft glass No. G-1. Sb works best in a Jena glass No. 59^{III} and the walls should be made as thin as possible. Au, Ag, Fe, and Co were drawn in quartz. In this case the muffle was made of a carborundum cylinder and heated by three oxy-acetylene flames focused upon it. An arm's length of Ag and shorter lengths of Au and Cu may be drawn directly from a flame in a very hard Corning glass No. G-707-CR.[1] In the case of Ag a borax bead should be dropped into the tube and fused with the metal. These metals and also Mn and Cr could probably be drawn to indefinite lengths in a glass which softened between 1200° and 1400°C. At present no glass is obtainable between quartz (about 1800°) and G-707-CR, (about 900°). Al combines with silicate glasses at the temperature of its melting point but was drawn in a tube made of its own borate. Fine threads of In were drawn in a very soft glass of unknown origin.

The glass may be removed from the metallic filament with hydrofluoric acid, which does not readily attack any of the metals which were drawn in silicate glasses except Ga.

Temporary electrical connections were made to filaments of the order .0001 cm and smaller by pressing the ends between bits of tin amalgam. Permanent connections were made to larger filaments by embedding them in alloys of suitable properties. One end of the filament was soldered to the body of the alloy and the other end to a wire which was insulated from the alloy by a glass tube.

Properties

Wires drawn in glass have brilliant reflecting surfaces. Owing to this and the principle of irradiation, wires as small as .0001 cm diam. are visible under the proper light conditions. Wires of this degree of fineness float in air as a single line of silk or spider's web and no means have been found for weighing them directly. However, the weight and diameter may be calculated from the resistance of a known length if we assume that the specific resistance of the filament is the same as that of the metal in bulk. One filament of Sb had a resistance of 125,000 ohms

[1] This special glass was obtained from the General Electric Company through the kindness of Mr. D. A. Mullaney.

per cm. Since the specific resistance of this metal has been determined[2] a simple calculation gives for this filament a mass of .000002 mg per cm and a diam. of .00002 cm (No. 92 B and S gauge).

On account of the importance of Bi and Sb in thermo-electric measurements, the physical properties of the very fine wire made from these metals deserve special attention. Though very brittle in bulk, Bi and Sb are pliable in the form of fine wire. Antimony wire as large as .003 cm diam. may be bent repeatedly without breaking. It is highly elastic and has a tensile strength of 1800 to 2200 kg per cm^2. In diameters .001 cm and smaller it will stand an indefinite amount of bending and twisting. Bi wire as large as .035 cm diam. when freshly made is very soft, less elastic than Pb and has a tensile strength of about 50 kg per cm^2. It rapidly hardens with bending and breaks after being bent into a right angle twenty times or so. The smaller sizes have greater tensile strength and the extremely small sizes, .002 cm and less, will stand indefinite bending.

No limit has been found to the smallness of filaments which can be produced. Even when they become invisible under the microscope their existence can be detected by making electrical contact to a source of current and a sensitive galvanometer. Boys[3] in his classical experiment with quartz fibers, estimated that a bit of quartz the size of a grain of sand, that is 1/60 mm^3 if drawn into the finest thread would be 2000 miles long. As this fiber can be drawn with a gold core having a diameter only a small fraction of the total, it is clear that we can not assign any limit to the smallness of the gold fiber.

Uses and Suggested Uses

The most important application of these filaments has been in resistance thermometers made by embedding glass-insulated filaments in metals or alloys having suitable properties. Type metal was the alloy found to be most suitable for Pb filaments. More than one hundred of these thermometers were made, some of Pb and some of Tl. They were made in resistances covering a range from 10 to 5000 ohms and many of them have been kept under almost daily observation for several months. The lengths of the measuring elements were .5 to 1.5 cm and the diameter of the embedding alloy was about 2 mm. Those having the highest resistance showed a constancy of about 1 part in 15000 while those having resistances less than 100 ohms changed about 1/5000 of their total resistance in the same time. A better constancy may be

[2] Bureau of Standards, Circular 74, 1918

[3] C. V. Boys, Smithsonian Report 1890, p. 315

expected after a longer period of seasoning. Twenty-five of these Pb thermometers with resistances of 443.3 ohms are now in regular use by the Bureau of Plant Industry. With this resistance a change of 1 ohm is equal to 1°F within 1° over the range 22° to 38°. These thermometers will be more fully described in another article.

A convenient means of preparing wire in the laboratory for determining the temperature coefficient of resistance and hence the purity of a particular sample of metal, is afforded by this method of drawing wire in glass. It is especially convenient in cases where the quantity of metal is too small to be extruded into wire or analyzed chemically. Only a few mg are necessary to produce a satisfactory conductor. The method might be used to advantage in determining the electrical constants of the very rare metals provided their properties are suitable for drawing in glass.

Quartz fibers were made conducting by drawing them with a silver core instead of employing the former method of platinizing, silvering or gilding them on the outside. In fact it would be possible to make them doubly conducting by using both methods on the same filament.

Wire drawn in glass obviously is not contaminated by magnetic impurities as is wire drawn through steel dies. It seems possible, therefore, to eliminate zero shift[4] in moving coil galvanometers by winding the coil with wire drawn in glass and using a quartz suspension.

Hair lines for the eye pieces of telescopes may readily be prepared in the laboratory by drawing a fine thread of one of the metals or alloys and dissolving away the glass. Being opaque they make better defined lines than quartz or spider's web.

Thermocouples were made of extremely fine Bi and Sb wire. On account of the high resistance of these metals, the thermocouples must either be made very short or built up of cables of the filaments. Though this type of thermocouple is not practicable for ordinary use, except in special cases, it appears that it may be used to advantage in very sensitive micropiles and in instruments such as the Boys radiomicrometer and the Dudell alternating current galvanometer in which an infinitesmal heat capacity and lag are essential.

The nearest approach to this method of drawing fine wire, so far as the writer has been able to find, was that of W. H. Wollaston who, a century ago, drew Pt to a diameter of .000075 cm by using a silver wire with a Pt core, drawing both down and dissolving away the silver with nitric acid.

[4] W. P. White, Phys. Rev. **30,** 782 (1910)

Theoretical

If the large changes in resistance which are observed in the same pure metal after different kinds of heat treatment, strain etc. are due to variations in the size of the crystals, as has been suggested[5] we would expect filaments of minute diameter to show a greater constancy than the same metal in bulk, since, in case of the filament, a limit is set to the size of the crystals which can form. This is suggested as a possible explanation of the greater constancy of the higher resistance thermometers.

Bureau of Plant Industry,
U. S. Department of Agriculture,
Washington, D. C.
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[5] P. W. Bridgman, Proc. Amer. Acad. vol. 52.