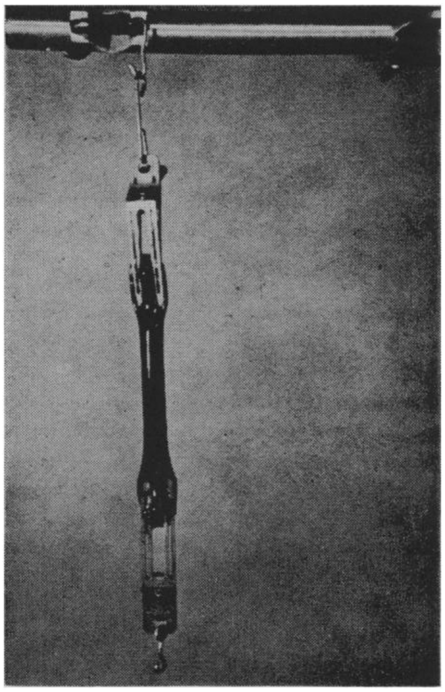

Fig. 1. The clamps and suspended clot prior to immersion in bath.

force is sufficient to effect significant deformation of the tissues to which the clot adheres, and therefore to allow retraction to occur. Previous work has been done on the mechanical properties of purified fibrin clots (*5*). However, these studies were carried out on platelet-free systems, and they are therefore not applicable to the problem of clot retraction induced by platelets.

Venous blood was collected from the forearm of normal adults in syringes of siliconized glass, nonsiliconized glass, and plastic. So long as the blood was drawn slowly and carefully there was no evident effect of the syringe wall. Nonsiliconized disposable needles were used one time. The blood was promptly transferred to nonsiliconized glass test tubes of two sizes, 13 by 125 mm or 11 by 75 mm. The blood was incubated for approximately 20 minutes at 37°C, at which time the clotting process appeared to be virtually complete. The clots were then carefully removed by rimming with a stainless steel wire, 0.5 mm in diameter. This procedure produced cylindrical clots of standard dimensions. The clots were then secured at each end by two-prong spring clamps, the tension of which was adjusted so that neither slipping nor tearing occurred (Fig. 1). The clots were suspended from above and various weights were attached to the lower clamp. The clots and the weighted clamps were then immersed in a 37°C bath of Ringer solution containing 0.08*M* glucose. At the beginning of clot suspension and 30 minutes later the intraclamp distance and the clot diameter were measured with calipers. The cross section of those clots which assumed an elliptical shape was estimated by measuring the largest and smallest diameters and by using the formula for the area of an ellipse, area $= \pi ab$, where a and b are the semimajor and semiminor axes. The force of clot retraction per unit area was calculated by dividing the sum of the half-clot weight and the weight of the lower clamp and its attachments (less a correction for the buoyancy of the entire assembly as determined by displacement) by the cross sectional area in square centimeters.

Table 1. The force of in vitro clot retraction in 14 tests.

Applied weight (dyne)	Clot: Shortening change in length/original	Clot: (cm^2)	Force of retraction (10^3 dyne/cm^2)
1390	0.11	0.53	2.7
1390	0.09	0.52	2.7
1410	0.08	0.52	2.8
2750	0.06	0.47	6.0
2780	0.08	0.47	6.0
4030	0.04	0.47	8.7
4050	0.03	0.47	8.7
2900	0.07	0.33	8.7
2900	0.04	0.33	9.0
3030	0.03	0.33	9.1
4250	0.02	0.47	9.4
4260	0.03	0.47	9.4
3050	0.04	0.33	9.5
4220	0.04	0.28	12.0

The results, summarized in Table 1, show that under the conditions of the experiment the maximum force of clot retraction induced by platelets was about 1.2×10^4 dyne/cm², which is equal to the pressure of about 9 mm Hg. The shortening of the clot was inversely related to the applied stretching stress. With stresses in excess of about 10^4 dyne/cm² clot retraction did not occur consistently.

The force of clot retraction, although small in proportion to the elastic modulus of isolated segments of such tissue as artery or vein wall, is nevertheless sufficient to effect significant distending or collapsing displacements of intact hollow structures such as stomach, bladder, lungs, and veins (*6*). It is reasonable to conclude therefore that clot retraction can occur in vivo (*7*).

EDWARD RUBENSTEIN

Department of Medicine, Stanford University School of Medicine, and San Mateo County General Hospital, San Mateo, California

References and Notes

1. A. A. Sharp, in *Blood Platelets*, Henry Ford Hospital International Symposium (Little, Brown, Boston, 1961), p. 67.
2. E. F. Luscher, *ibid.*, p. 445.
3. C. L. Conley, *ibid.*, p. 437.
4. O. E. Budtz-Olsen, *Clot Retraction* (Thomas, Springfield, Ill., 1951).
5. J. D. Ferry and P. R. Morrison, *J. Am. Chem. Soc.* **69**, 388 (1947).
6. A. L. King and R. W. Lawton, in *Medical Physics* (Year Book Publishers, Chicago, 1950), vol. 2, p. 310; L. H. Peterson. *Mod. Concepts Cardiovas. Disease* **31**, 725 (1962).
7. Supported by research grant H-4544, National Institutes of Health. The technical assistance of Paul R. Johnson is acknowledged.

19 October 1962

Four-Lead Electrical Resistance Measurements in Bridgman Anvils

Abstract. A geometry is described which permits four-lead electrical determinations of the pressure coefficient of resistance of metals in Bridgman anvils. It is also possible in this geometry to mount more than one sample and to make independent measurements on each sample simultaneously.

When Bridgman developed anvils for the determination of electrical resistance, he found it essential to run all of the necessary leads through the anvil faces (*1*). This introduced an unknown contact resistance for which no exact correction could be made. In most systems, however, the contact resistance was negligibly small compared with the total resistance. Bridgman made several attempts to run leads through the sides of the pyrophylite ring directly into the sample, but the leads were pinched off at such a low pressure that this technique was discarded.

The apparent reason for the pinching was the very large pressure gradient that exists in the gasket. In an earlier paper we, along with two associates, showed that in the 1/32-inch-wide pyrophylite ring the pressure gradient in the gasket went from a few kilobars at the outside edge to a pressure roughly 20 percent higher than the average applied load in 0.025 inch (*2*). This pressure gradient is above the shear strength of any wire, and consequently breakage by shear occurred. We have found that by inceasing the width of the ring to 3/32 inch and its thickness from 0.010 to 0.020 inch it is possible to insert electrical leads through the ring, without introducing sufficient shear to cut the wire, to an applied average load of about 200 kbar. The ring design has also been found to change the pressure-load relationships owing to the increased gasket width. Also, because of the increased thickness of the silver chloride, it is possible to mount more than one sample in the same cavity, and make independent measurements on each.

Figure 1 shows in a schematic manner the method of mounting a single sample. The two silver chloride disks, *A*, are punched from pre-rolled sheet of carefully controlled thickness to a diameter 0.010 inch less than the internal diameter of the pyrophylite ring. Gold electrical contacts, *B*, are inserted in 0.020 inch holes drilled near the edge of the rings. These plugs are of such a thickness that contact is made between the anvils and the wire, *M*, when the assembly is under load. The wire, *M*, is usually 0.003 inch in diameter and is bent in a circular arc, flattened at the ends to about 0.002 inch and mounted concentric to the center of the anvil face; such mounting insures a minimum pressure gradient in the sample. The ends of the lead wires, *L*, are also flattened at the ends where contact is made with the sample wire in order to reduce the tendency to pinch at the contact point. In order to facilitate mounting of the lead wires the containing pyrophlite gasket is made in two sections, 0.010 inch thick and 3/32 inch wide. On final assembly one gasket is placed on the anvil face, next the silver chloride assembly containing the sample and the lead wires is placed within this ring, and then the second ring is placed over the leads. The top and side views of a completed setup are shown in Fig. 2. The dimensions given are for ½ inch diameter anvil faces. For smaller anvil diameters the same gasket thickness and sample clearances are used.

It is relatively easy to mount two separate samples in the same capsule by using three thinner silver chloride disks with an appropriate gold plug in the center disk to connect the two sample wires in series. To obtain more accurate voltage-drop data across each sample, separate leads are used. This requires that four leads pass through the gasket for a double sample test. Several times we have attempted to mount three separate samples in the same capsule, but we have not as yet been able to make a successful run because of the complexity of the assembly. An electrical short or breaking of the circuit occurred each time within the silver chloride cell.

It was found that metals with a high modulus of elasticity such as tungsten, molybdenum, and platinum make the most successful lead-through wires. Wires of 0.005 inch diameter did not undergo shear failure. Platinum is the most desirable since it can be easily soldered; however, it has the disadvantage of lower shear strength than either tungsten or molybdenum and it fails about 125 kbar. Tungsten has the disadvantage of end fraying during the flattening process. Mechanically molybdenum is superior and has been used for most of our tests despite its poor soldering qualities. A crimping procedure has been developed for connecting external lead wires to molybdenum and tungsten, which introduces relatively small contact errors. Both of these metals will successfully resist shear breakage to pressures of 200 kbar.

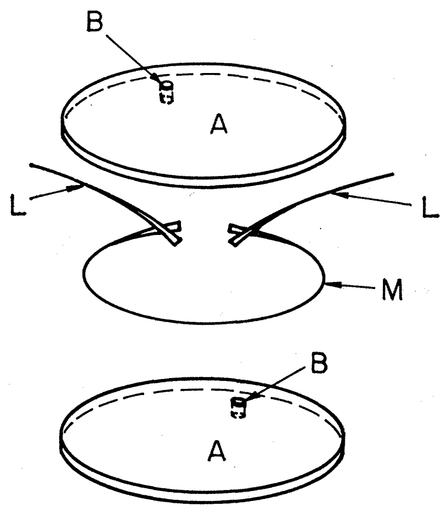

Fig. 1. Schematic sketch of setup with leads through gasket.

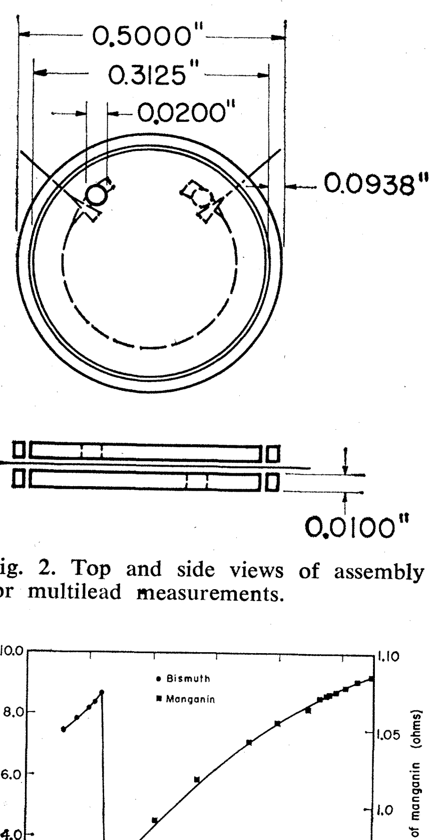

Fig. 2. Top and side views of assembly for multilead measurements.

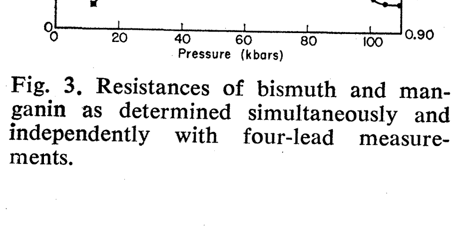

Fig. 3. Resistances of bismuth and manganin as determined simultaneously and independently with four-lead measurements.

The electrical resistance of the samples is measured by passing a constant current through the entire sample stack connected in series. Current connections are made through the anvil faces. The potential drop is measured across the individual samples with separate leads that pass through the split pyrophylite rings. Ohm's Law is then used to compute the resistance of the sample. Pressures are determined with a strain gage instrumented steel load cell in conjunction with an SR 4 bridge manufactured by Baldwin Lima Hamilton Corporation.

Figure 3 shows a typical determination by means of this technique. This was a two-sample assembly, one bismuth, the other manganin. The bismuth 1-2 and 6-8 transitions are used as an internal pressure calibration. The SR 4 readings have been converted to pressures on the assumption that the 1-2 transition occurs at 25.5 kbar and that the pressure is proportional to the load. There is some evidence that this latter assumption is not valid until pressures of about 30 to 35 kbar are reached.

Because the use of a wider gasket gives a higher ratio of gasket to silver chloride area, the effective area of the anvil over which the load is distributed is greatly decreased. With the standard rings as used by Bridgman, the load required to attain the same pressures in ½-inch faces is about 30 percent greater than that required with this technique. In the anvils with ¼-inch faces, the load required to attain a given pressure is roughly one-fourth of the calculated required load. In this case the bismuth 1-2 transition occurs at an indicated load of between 6 and 7 kbar.

Harold Stromberg
George Jura

Department of Chemistry and Lawrence Radiation Laboratory, University of California, Berkeley 4

References

1. P. W. Bridgman, *Proc. Am. Acad. Arts Sci.* **81**, 165 (1952).
2. P. W. Montgomery, H. Stromberg, G. H. Jura, G. Jura, in preparation.

15 November 1962