with C_0 determined to an accuracy of one part in 10^7 for diameter ratios of 0.1 to 0.95. (Note that numerical errors in Smythe's earlier paper are corrected in a later paper.[4])

In Fig. 1 we compare the various expressions for F by plotting $(F-1)$ as a function of $(d/D)^3$ on logarithmic coordinates. Also shown is the semiempirical equation presented by DeBlois and Bean as the best fit[6] (at small diameter ratios) of their experimental results,

$$F_6=1+0.73(d/D)^3. \qquad (6)$$

This figure shows that (1) Smythe's numerical results F_5 agree well with the experimental data F_6 at small $(d/D)^3$; (2) DeBlois and Bean's limiting theory F_4 does not coincide with F_5, as $(d/D)^3\to 0$; and (3) F_3 converges with the numerical results as $(d/D)^3\to 1$, the error being less than -8% in F at $(d/D)^3=0.86$. Table I compares representative F values obtained from Eqs. (4)–(6).

Smythe also presents calculations for spheroids of eccentricity $\frac{1}{2}$ (prolate) and 2 (oblate), the axis of revolution coinciding with the pore axis. His results are unreliable for the prolate spheroid as $(d/D)^3\to 1$ because of convergence problems; however, in this region one can use the results obtained from an area integration [the basis of Eq. (3)] to obtain

$$F_7=\frac{1}{\epsilon}(D/d)^3\left\{\frac{\sin^{-1}(d/D)}{[1-(d/D)^2]^{\frac{1}{2}}}-\frac{d}{D}\right\}, \qquad (7)$$

where d is the diameter of revolution. One can show[7] that any potential function Ψ that is continuous in $\nabla\Psi$ and equal to the exact solution Φ far from the particle will give rise to a current distribution which has an energy dissipation greater than or equal to that of the true solution. Thus, the exact solution Φ will give the maximum resistance (i.e., F), and hence, Eq. (7) will always be smaller than the true solution, converging to the true value as $(d/D)^3\to 1$. [For an oblate spheroid of $\epsilon=2$, Eq. (7) yields a value of F only 5.3% below Smythe's numerical result for $d/D=0.95$.]

Finally, mention should be made of the assumption that the particle (spheroid) travels on the center line. Happel and Brenner[8] state that there is no preferred path for a particle traveling through a pore, and because of Brownian motion, the exact result for F must include all orientations and radial positions for the particle. However, Fig. 1 indicates that the analytical model (F_5) describes the system reasonably well, at least for spheres, for which there are no orientation effects.

TABLE I. A numerical comparison of the theory of DeBlois and Bean F_4 with Symthe's analysis F_5, and DeBlois and Bean's fit of their experimental results F_6.

$(d/D)^3$	F_4	F_5	F_6
0.001	1.001269	1.000797	...
0.005	1.006369	1.004008	1.0036
0.010	1.012797	1.008055	1.0073
0.050	1.066325	1.041728	1.036
0.100	1.14	1.087354	1.073
0.500	2.31	1.686712	1.36

This work was supported in part by a grant from the Office of Saline Water, U. S. Department of the Interior. J. L. Anderson was the recipient of a National Institutes of Health Research Fellowship. We would like to acknowledge the very beneficial discussions we have had with Dr. C. P. Bean on various aspects of membrane transport.

[1] R. W. DeBlois and C. P. Bean, Rev. Sci. Instrum. 41, 909 (1970).
[2] H. E. Kubitschek, Research (London) 13, 128 (1960).
[3] W. R. Smythe, Phys. Fluids 4, 756 (1961).
[4] W. R. Smythe, Phys. Fluids 7, 633 (1964).
[5] E. C. Gregg and K. D. Steidley, Biophys. J. 5, 393 (1965).
[6] Note that the pore diameter in DeBlois and Bean's membrane was determined by matching their theoretical equation (F_4) to their measured resistive pulses for a range of particle diameters. If F_5 were used to fit the experimental results the coefficient in F_6 would probably show a slight change, and, hence, the agreement between F_5 and F_6 in Fig. 1 would reflect this change.
[7] J. C. Maxwell, *A Treatise on Electricity and Magnetism* (Academic Reprints, Stanford, California, 1953), 3rd ed., Vol. 1, pp. 424, 429.
[8] J. Happel and H. Brenner, *Low Reynolds Number Hydrodynamics* (Prentice-Hall, Englewood Cliffs, N. J., 1965), pp. 205–207.

Subnanosecond Switch for Use in Shock Wave Experiments*

T. T. COLE AND J. W. LYLE

Lawrence Radiation Laboratory, University of California, Livermore, California 94550

(Received 25 January 1971; and in final form, 26 March 1971)

A SUBNANOSECOND selenium switch has been developed for use in shock wave experiments (see Fig. 1). Bulk selenium makes a transition to the metallic state at a pressure of 128 kilobars, with a resistivity decreasing by a factor of about 10^{11} from the value at atmospheric pressure.[1,2] A shock wave traversing the selenium film in a direction normal to the film induces the transition.

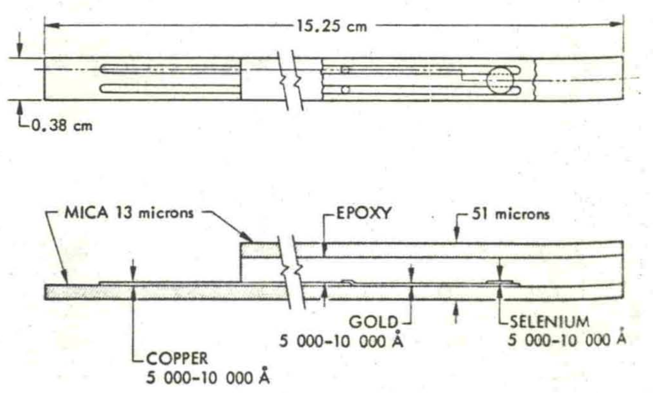

FIG. 1. Construction of the selenium switch.

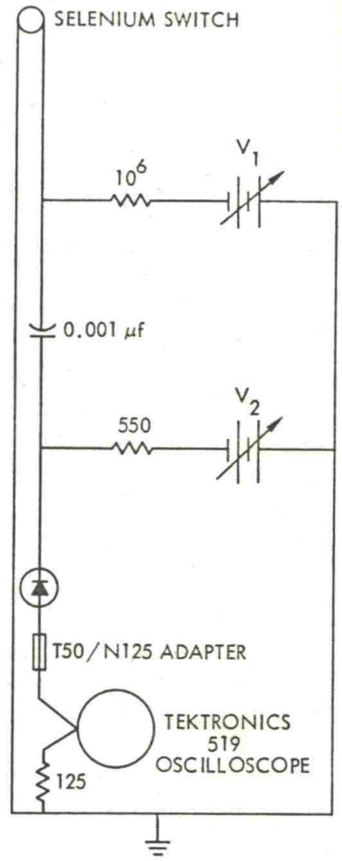

FIG. 2. An electrical circuit used to test the selenium switch.

We used vacuum evaporation to deposit the selenium and metallic leads onto mica. Connection to the selenium was made with gold to avoid unwanted chemical reactions. The switches were tested to 20 kV under oil, and when failure occurred it was in the region where the leads were soldered. The switch, used successfully in high explosive experiments, will withstand several kilovolts in air at atmospheric pressure.

The electrical circuit used to test the switch is shown in Fig. 2. Most components were enclosed in coaxial configurations to minimize circuit risetime. Coaxial cables with 50 Ω impedance were used. This circuit is similar to circuits commonly used with shorting pins and switches, but has a higher voltage source V_1 and the additions of the source V_2 and a rectifier. Since the circuit risetime is insensitive to the peak voltage, a given signal level will be attained more rapidly with greater voltage. The signal applied to the oscilloscope was limited by diode action. The diode provides clipping of the high voltage pulse generated by switch closure and determines the signal decay time. The diode used was a Semtech silicon rectifier rated for 45 kV peak inverse voltage. Voltage source V_2 provides a variable forward bias for the diode. The peak signal voltage is adjustable to values greater than a few volts.

An oscilloscope record (Fig. 3) was obtained in an impact experiment using a 0.90 caliber gun. In this case, V_1 was 1 kV and V_2 was 36 V. With suitable calibration, the

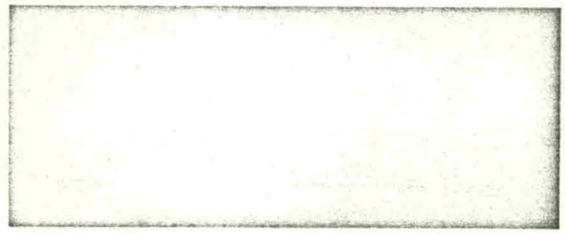

FIG. 3. Tektronix 519 oscilloscope record. Deflection factor, 9 V/div; sweep rate, 5 nsec/div.

arrival time of the signal can be determined to within a fraction of a nanosecond. Time intervals can be determined with subnanosecond accuracy by displaying two signals on a single oscilloscope.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] *Solids Under Pressure*, edited by W. Paul and D. Warschauer (McGraw-Hill, New York, 1963), p. 378.

[2] A. S. Balchan and H. B. Drickamer, J. Chem. Phys. **34**, 1948 (1961).

uhv Evaporation Source for Aluminum and Other Metals*

JAMES L. BREUNIG

Department of Physics, University of California, Berkeley, California 94720

(Received 12 February 1971; and in final form, 2 April 1971)

THE object of the research project here reported upon was the vapor deposition of aluminum films in the best vacuum obtainable, given reasonable limitations on the modification of an existing vacuum system and on total processing time required to obtain the final vacuum.

The oldest and probably most common technique of vacuum evaporation of aluminum is the evaporation of the metal directly from resistance heated coils or wire baskets. But molten aluminum, unfortunately, alloys with the refractory metal and also flows over its surface erratically so as to produce filament thinning, hot spots, and resultant gassing. Only a vacuum on the fringe of the ultrahigh vacuum was obtained with this technique.

A new approach, emphasized by the presence of a number of commercially available systems, is to heat the aluminum or other metal directly by a well focused electron beam of several kilowatts power. Although attractive, these systems were too bulky and also too expensive for present purposes and budget. Moreover, it seemed possible that a better vacuum could be obtained by designing for a lower power requirement to produce less gassing.

The design eventually settled upon is a hybrid configuration with special provision for insertion of charge subsequent to outgassing of the heaters.