TEL-RP2111

COMPUTERIZED CAVENDISH BALANCE

TEL-Atomic, Incorporated
P.O. Box 924
Jackson, MI 49204
1-800-622-2866 – FAX 1-517-783-3213
email: telatomic@mindspring.com
website: www.telatomic.com

COMPUTERIZED CAVENDISH BALANCE

The Computerized Cavendish Balance is designed to allow data to be taken with a microcomputer, analog meter or (for the masochistic) an optical lever arrangement. The period of the unit depends on the length of the tungsten wire and will vary from approximately 3½ to 4½ minutes. The electronics used to collect data are on the PCBV located inside the unit. They are designed such that the pendulous mode (at least to a first order approximation) can be ignored. Thus the TEL-RP2111 Computerized Cavendish Balance is fairly immune to environmental vibrations. (This does not mean however, that you can bump the table when taking data or be reckless when moving the perturbing masses!)

The experiment can be completed in one (long) laboratory period. (This does not include replacing the tungsten wire if that is necessary). Most of this time will be spent setting up and calibrating the unit. Setting up includes forcing the swinging masses to swing near the center line of the Cavendish apparatus. Dampening the swing is required. By letting the boom bounce about the calibration pin, the time to dampen the swing will be much reduced. If the tungsten wire needs to be replaced, we recommend that this tedious task be performed before the laboratory begins. See *Appendix A* for attaching the wire to the boom.

The actual taking of data can be accomplished in a fairly short time.

SET UP AND CALIBRATION

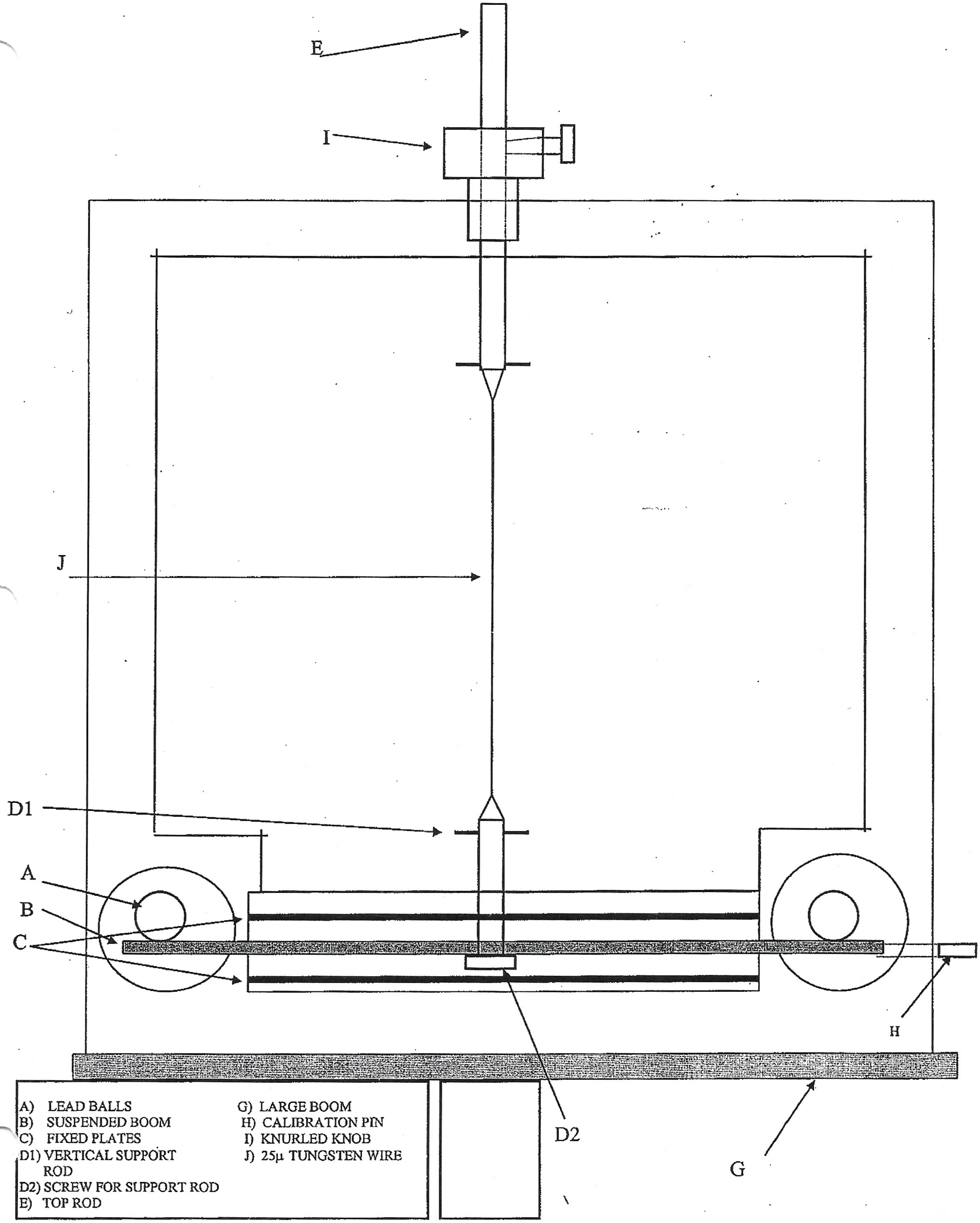
See figure 1.
With the small lead balls (A) in place on the suspended boom (K) assure that the boom is, as nearly as possible, horizontal and centered between the fixed plates (C This can be accomplished by sliding the small vertical support rod (D1) until the boom is level. Raise or lower the boom with the top support rod (E) to center it between the fixed plates. Also assure that neither the wire support rod nor the boom comes into contact with any part of the unit. If this happens, it is impossible to cause the boom to rotate since the gravitational attraction between the small (≈15gm) and large (≈1kg, not shown) lead balls is a much smaller force than the friction caused by any part of the boom being in contact with any part of the unit.

Insert the glass and place the large lead balls on the large boom. Position the large boom (G) so that the large balls are perpendicular to the face of the unit.

NOTE: When placing or removing the large lead balls, it is good practice to be sure that both balls are placed on or removed from the boom at the same time. If you don't, the unit could tip over and the wire will probably break resulting in very unhappy campers.

Zero Adjust Knob
There is a single knob on top of the small box, which connects to the 6 conductor wire from the Cavendish Unit. This box has few electronics inside and serves simply as a way to connect power to the Cavendish Unit and get the signal from inside the Cavendish Unit to the outside world. The ten turn pot simply serves as an offset to make the signal read at a convenient level. The Cavendish has an output of ≈-5 to +5 volts as the boom swings from "glass to glass". The 10-turn pot provides an approximate 2.5V offset. In a perfect world, if the boom could be stopped at exactly the center of the sensor inside the Cavendish Unit, one would obtain a zero reading. Due to the very small diameter wire the likelihood of the boom coming to rest in the center is exceedingly small. Therefore, the fine adjust pot simply "offsets" the signal so that when the boom is moving in the "operating area", the output signal can be offset so that one sees a signal of ≈600-1000mV.

Figure 1. Computerized Cavendish Balance



CALIBRATION

Now is a good time to calibrate the unit. Connect a voltmeter or computer interface to the connector box (which is connected to the Cavendish balance) to monitor the movement of the boom. You will need to obtain a voltage reading as each side of the slot in the end of the boom comes in contact with the calibration pin (H). See figure 3.

An easy way to determine the calibration constant is to do so dynamically. With the Computerized Cavendish Unit connected to a Kis or other computer interface. Set the sample rate to at least 10/20 samples/sec. You should get a voltage swing of ≈ 650 mV for the small gap and ≈ 1000 mV for the large gap as the boom swings about the calibration pin. Take data long enough so that you obtain at least 5 - 10 complete boom cycles. Do this for both the large and small gaps.

One can be sure the boom is hitting the slot if the graph has sharp turning points as shown below in figure 2.

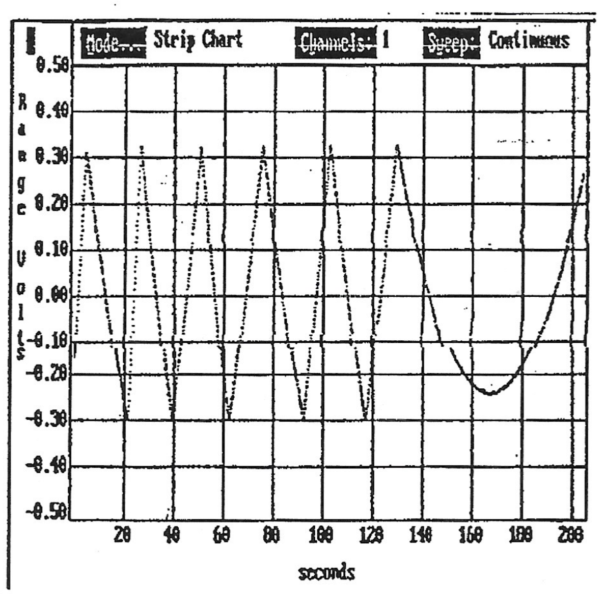
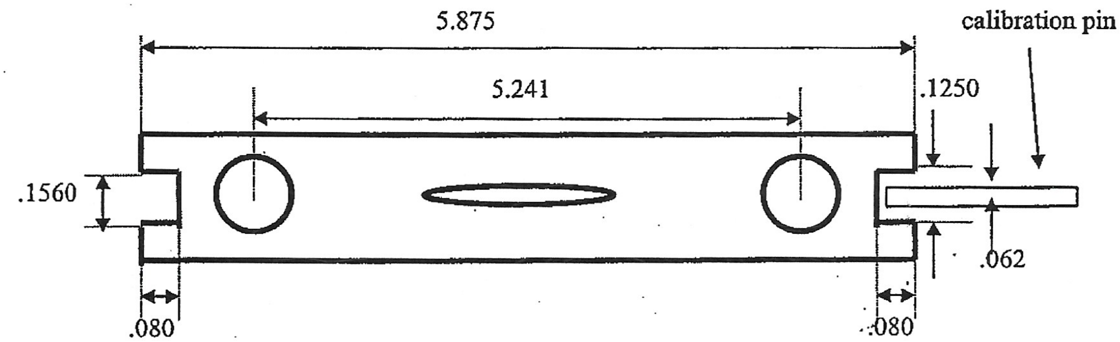


figure 2. Large gap of boom swinging about the calibration pin.

If the boom does not hit the pin, the curve will be sinusoidal without the sharp turning points. Since the boom is balanced, one can assume that the support is (mostly) centered, although there will be small differences in the turning radius of each gap.

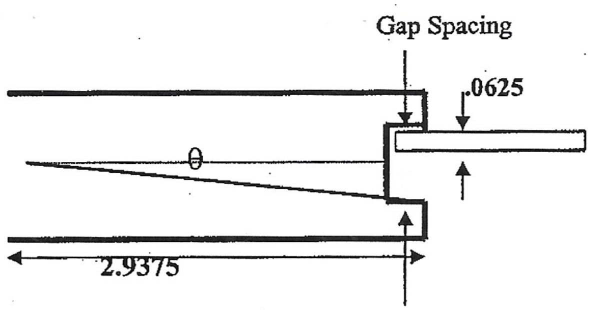
The total angle through which the boom rotates is very small (1 - 2°) therefore the tangent of the angle through which the boom swings is approximately that angle in radians. The distance the boom can move is the gap spacing less the calibration pin diameter. Figure 3A.

Figure 3. Suspended Boom (B)



dimensions are in inches.
all measurements are ± .0005

figure 3A



As you can see in figure 3A, the boom can move a distance of .125 - .062 for the small gap or .156 - .062 for the large gap.

If the support is in the center then tan θ = θ

and for the small gap $\tan\theta = \dfrac{.125 - .062}{2.938} = .0214\ Radians.$

For the large gap $\tan\theta = \dfrac{.156 - .062}{2.938} = .032\ Radians.$

The fact that the boom support may not be exactly centered is minimized by determining a calibration constant for each side and averaging the values obtained.

One needs to obtain the calibration constant dynamically as described above, rather than by letting the boom come to rest against the pin. This could cause the point about which the boom is turning to move so that the calibration constant obtained would be in error.

(This calibration is a gross method and not recommended for accurate G measurements. A more accurate calibration method is described at the end of this section.)

After calibration, remove the pin. The boom will start to swing. Rotate the top knurled knob (I) to cause the boom to swing near the geometric center of the unit. This is very important. The unit is designed to work near the null position. If the boom tends to stop off center, then rotate the wire so that the boom will move towards the other side.

It is possible (but not likely) that the tungsten wire is completely twisted, perhaps more than one turn, therefore you may have to turn the knob more than 360° to get the boom to swing in the appropriate range. A voltmeter or computer interface connected to the Symmetric Differential Capacitive Control Unit will help determine when the boom is centered.

After the motion of the boom has been appropriately damped, you are ready to begin taking data.

Swing the large perturbing masses so that they just touch the outside glass. Observe the output from the connector box so that when the boom reaches the limit of its rotation, you can swing the large masses so that they will again attract the small mass. Be sure to swing the large masses **at the turning points** in order to build up the amplitude of the rotation.

You will need to determine the amplitude of the boom on at least three successive swings (more is better) i.e.: θ_1, θ_2, θ_3. (See *appendix B* for the calculation of G)

After gathering data place the perturbing masses in the neutral position perpendicular to the face of the cavendish balance. Let the small boom rotate in free decay in order to determine $\beta\tau$. You will need the amplitude of at least three successive swings of the small boom (more is better).

BEST (MOST ACCURATE) CALIBRATION METHOD

A more accurate way to determine the calibration constant is to use an optical lever arrangement.

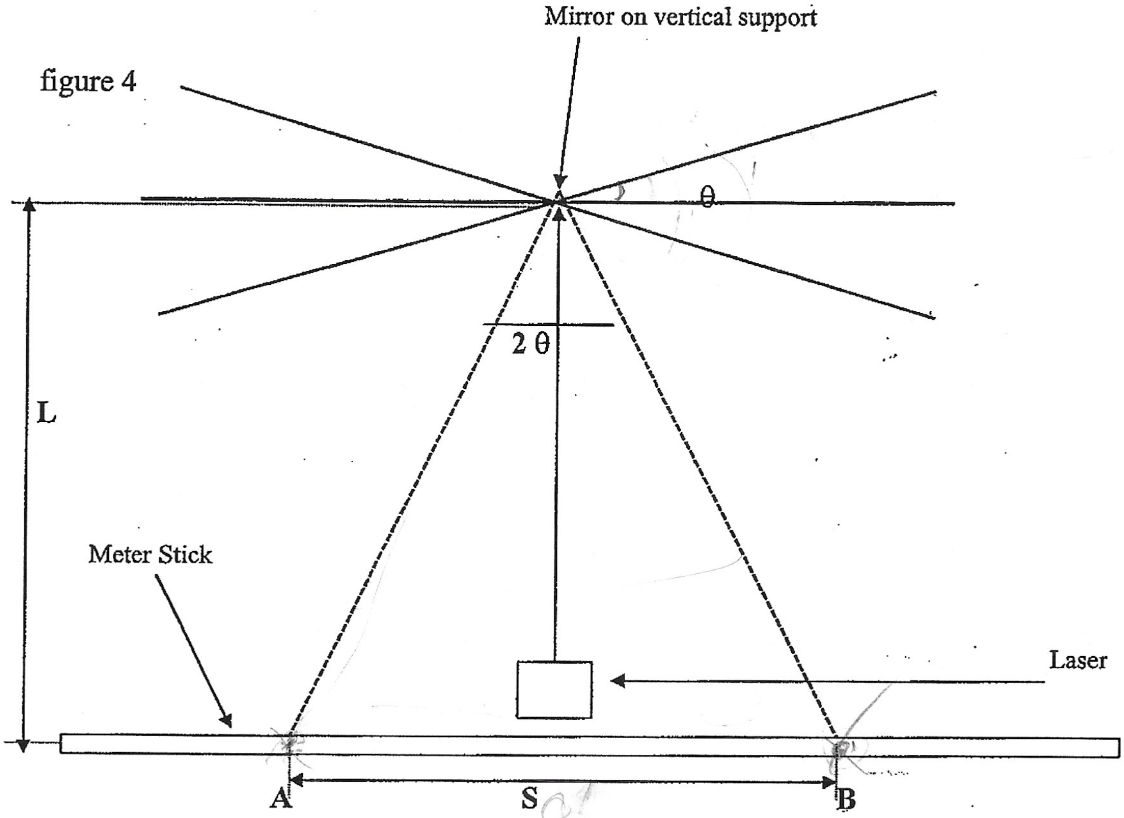
Place a laser at a distance **L** from the mirror. Place a meter stick so that the reflected laser beam moves back and forth along this meter stick.

Set up the Cavendish balance so that the small boom is moving through a small angle. The angle should not be significantly greater than the angle through which the small boom will move during the experiment, (1 - 2°).

Measure the distance **S** (figure 4, not to scale) that the reflected laser beam spot travels while noting the voltage reading (obtained from the output of the connector box) at the successive turning points A & B. The calibration constant is then **ΔV/angle** in radians.

$\frac{\Delta V}{\text{angle}}$ 2.7 mV

figure 4



S - distance laser spot moves between turning points
L - distance of meter stick to mirror
θ - angle through which small boom moves
2 θ - angle through which the reflected beam moves, (angle is 2 θ because of angle doubling due to reflection)

EXPERIMENT

RESONANCE
You now have all of the data necessary to calculate G. (See appendix B)

APPENDIX A

The tungsten wire is only 25 microns in diameter and fairly fragile, therefore extreme care needs to be taken when tying this wire to the support rods. Carefully unroll and cut off 1 1/2 - 2 feet of wire. Although you only need a few inches it is easier to work with a larger piece of wire. Work in a well lighted area. Thread one end of the wire through the "eye" of one of the support rods. Carefully pull it through. Take two or three turns through the "eye". Be sure the wire is against the surface of the rod. You do not want a "loop" at this point because you want the wire to twist about its axis. Now make a "reverse loop around the cross pieces. There will be enough friction to prevent the wire from slipping. (See figure below)

It is imperative that you do not have any kinks in the wire.

We have empirically determined that those of us who are "old" and who have less than desirable eye/hand coordination are best served if we beg, grovel, plead or do whatever it takes to have a young highly eye/hand coordinated person perform this task. It can be done by such a person in 10-15 minutes. Otherwise be prepared for a patience testing and potentially frustrating experience!