



**LaCoste & Romberg** LLC

*The first name in gravity since 1939*



**INSTRUCTION MANUAL**

**MODEL G & D GRAVITY METERS**

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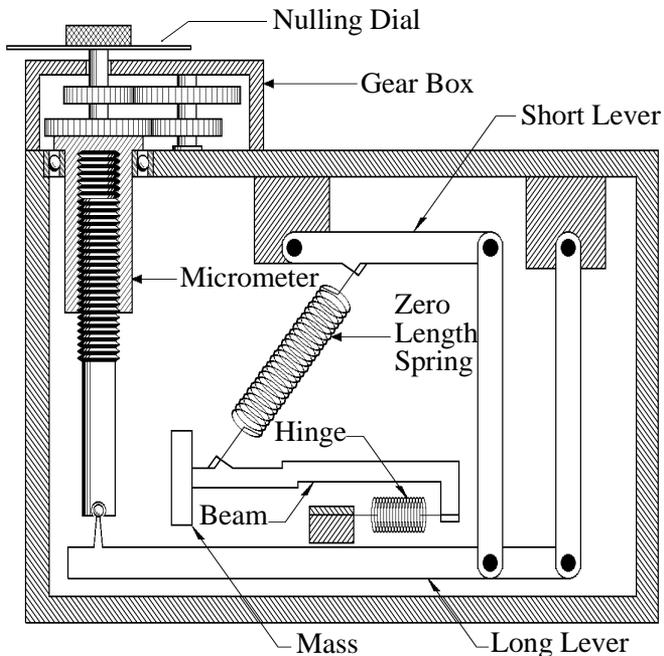
# PRIMARY INFORMATION

## INTRODUCTION

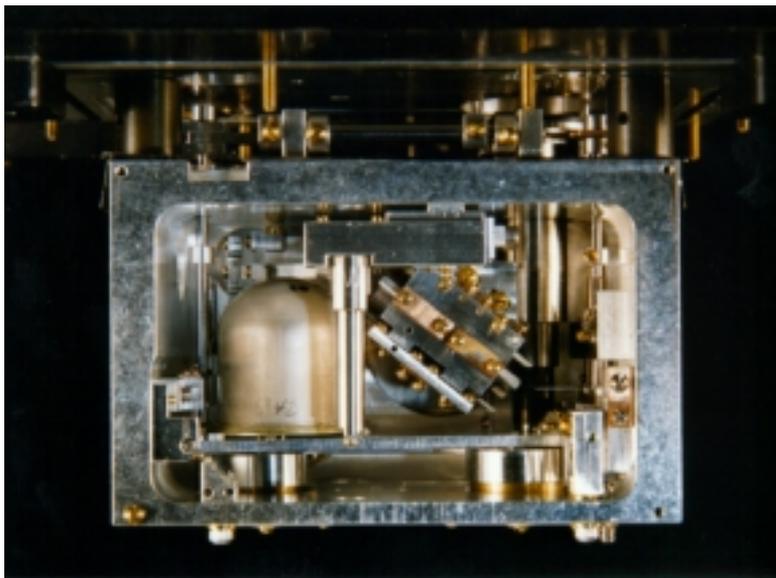
### DESIGN

The *LaCoste and Romberg* gravity meter is made of metal parts. It is far more rugged than meters made of fused quartz glass. Because the thermal expansion and contraction of metals are generally greater than quartz, the *L and R* meters must be accurately thermostated. Since metals creep when thermally expanded or contracted, it is best to maintain the *L and R* meters at their constant thermostated temperature whenever practical.

The Model G meters have a worldwide range without resetting. The Model D meters normally have a range of 200 milligals and a reset that allows them to operate any place on earth.



The design of the meter allows it to be very sensitive to small changes in gravity. The simplified diagram of the meter shows a mass at one end of a horizontal beam. At the other end of the beam are a pair of fine wires and springs that act as a frictionless hinge for the beam. One purpose of the hinge springs is to help eliminate damage to the meter from all but the most severe impact.



The beam is supported from a point just behind the mass by a “zero length” spring. The spring is at an angle of approximately 45 degrees from horizontal. The meter is read by nulling the mass position, that is, adding or subtracting a small amount of force to the mass to restore it to the same “reading” position. This is accomplished by lifting up on the top end of the zero length spring. This must be done with great accuracy and is accomplished with a series of levers. In turn, the levers are moved by a high-precision screw which in turn is rotated by a gear box with considerable reduction.

The lever system and screw are accurately calibrated over their entire range. Calibration factors depend only on the quality of the lever system and measuring screw, not upon a weak auxiliary nulling spring as are used in other meters. For this reason the calibration factors of the *L* and *R* meters do not change perceptibly with time. This eliminates any need for frequent checks of the calibration.

The moving elements of the meter are restricted from movement of more than a few thousandths of an inch (less than a tenth of a millimeter). Thus, if the meter sustains a severe impact it would be difficult for the movable parts to attain enough momentum to damage themselves. For further security and to minimize irregular instrumental drift, the beam can be clamped when not in use.

When the beam is clamped, it is pushed down against the bottom movement limiters or “stops”. This would elongate the main spring and induce creep in the springs metal. To eliminate this creep, the beam also is pushed backwards upon clamping. Thus the length of the main spring in the clamped position is exactly the same length as it is when unclamped and at the reading line.

Few ferrous metal parts are used in the meter. The meter is demagnetized or compensated, then installed in a double  $\mu$ -metal shielding to isolate it from magnetic fields.

Changes in air pressure could cause a small apparent change in gravity because of the buoyancy of the mass and beam. This is prevented by sealing the interior of the meter from the outside air. As an additional precaution, should the seals fail, there is a buoyancy compensator on the beam.

When the meters are new, their average drift is less than one milligal per month. With a few years of aging, their average drift is usually less than half a milligal per month. This small drift is true drift, not a large drift compensated to a small value by a clock and microprocessor.

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## BASIC OPERATING INSTRUCTIONS

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### STARTING

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**B**efore unpacking the meter and its accessories, inspect the shipping carton for signs of damage during transit. Promptly report any damage to the transporting company.

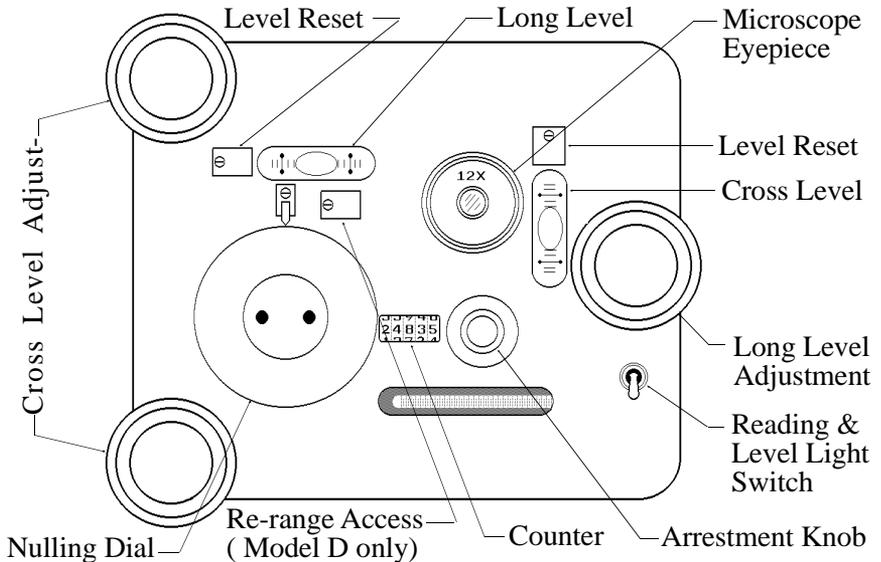
The meter is shipped cold. At all other times the meter should be maintained at its thermostated temperature. The charger/eliminator is a charger for the meter batteries and a regulated 12-volt power supply for the meter when it is not on battery power. It can operate from 50 or 60 Hertz power without any adjustment. Also, it can operate from 115 or 230 volts AC power. There is a small slide switch in the charger for selecting the voltage. AFTER setting the voltage switch, the charger should be connected to the AC power source. A power indicator lamp on the charger face should now be on. There are more details about the charger in the sections on accessories and meter details.

Now connect the meter to the charger at the fitting on the charger's face. The small red light by this fitting should now come on indicating 12-volt DC power is flowing to the meter. This light will remain on until the meter reaches its thermostated temperature. (When used in the field, the gravity meter is connected directly to a charged battery.) From about two to five hours will be required to reach operating temperature, depending upon how cold the meter is. Then, the power will cycle on and off as needed to maintain the constant temperature.

When the meter is at operating temperature, a series of tests may be performed to be certain the meter is in good condition. Each meter has its own operating temperature. It is recorded in the manual or on the meters' calibration table.

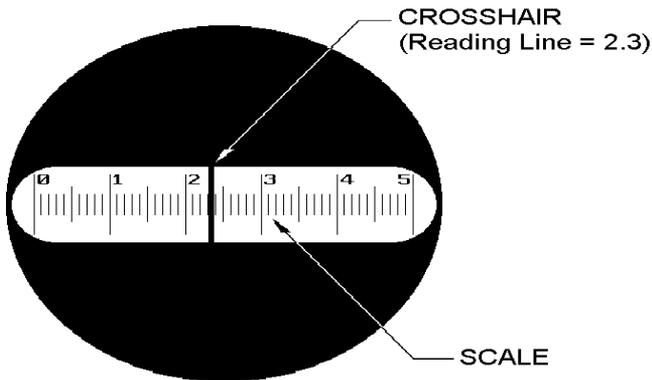
## TAKING THE FIRST READING

- Place the meter on the aluminum base plate.
- Turn on the reading light and the spirit level lights. The switch is located on the near right side of the black lid. Do not leave the light turned on for a prolonged time, especially in hot weather, if accurate readings are desired. If the meter is equipped with electronic levels, the lights may not be necessary.



- Gently slide the meter in the concave base plate until the meter levels indicate the meter is approximately level. Finish the leveling with the three leveling screws of the meter. For efficiency, you may wish to level the cross level first then the long level. On the meter in the standard white box, there are three knobs atop the meter that turn the leveling screws. On some early meters in the miniature white box, these screws and their knurled turning flanges are under the white box.
- Release the internal beam of the gravity meter by turning the knurled arrestment knob counterclockwise to its limit. The knob is located on the near side of the microscope eyepiece.

- The position of the beam is determined by the image of the crosshair in the microscope. The crosshair is a very fine wire attached to the beam. A reticle or scale is placed in the optical path for a reading reference. The total motion of the beam is 14 small scale divisions. The downscale or left side of the crosshair is used as the reading edge.



- Each meter has its characteristic reading line. There is a small placard on the meter lid indicating the reading line for the meter. In the example above, the reading line is 2.3.
- Bring the left side of the crosshair to the reading line by turning the nulling dial. If the crosshair needs to move to the right, turn clockwise. If it needs to move to the left, turn counterclockwise.
- Always approach the reading line from the same direction. For uniformity, we suggest approaching from left to right, (turning clockwise). If coming from the right side (counterclockwise), turn the dial about a quarter turn past the null and approach clockwise. The play or slack in the gears and universal joint would cause an error if the null is not approached always from the same direction.
- The number of turns of the nulling dial is limited by the counter. The counter is located under a window in the middle of the black lid and just to the right of the nulling dial. The maximum reading of the model G is 7000, on the model D it is 2000 and on the extended range model D it is 3000. If there is

a large difference between the gravity at your location and the location where the meter was last read, it will require many turns of the nulling dial to balance the meter's beam. Because of the limited range of the model D, it may be necessary to re-range the meter.

**Model G:** If the meter was last read at a much different latitude, a rough estimate of the counter reading necessary to null a Model G may be obtained from this table:

<b>Latitude</b>	<b>Approx. Gravity</b>	<b>Approx. Reading</b>
0 . . . . .	978.046 . . . . .	1430
10 . . . . .	978.203 . . . . .	1600
20 . . . . .	978.652 . . . . .	2050
30 . . . . .	979.337 . . . . .	2750
40 . . . . .	980.178 . . . . .	3600
50 . . . . .	981.078 . . . . .	4530
60 . . . . .	981.930 . . . . .	5400
70 . . . . .	982.623 . . . . .	6100
80 . . . . .	983.073 . . . . .	6560
90 . . . . .	983.223 . . . . .	6700

**Model D:** To re-range a Model D meter, set the counter to mid-range, 1000.0, and range the meter until it is roughly balanced. This is done by turning the coarse or re-ranging screw located beneath a small cover plate near the center of the black lid (see diagram pg. 1-7). Each turn of the ranging screw is about 74 milligals. If the crosshair is on the left side of the scale, turn clockwise. If it is on the right side, turn counter-clockwise. If the meter is tapped with the finger, the crosshair will bounce at the end of its range of travel. The closer the meter is to balance, the slower the crosshair will return to the end of travel. When the meter is in approximate balance, close the cover plate and finish balancing with the nulling dial. For more details on re-ranging the Model D, see the Field Procedures section ( pg. 3-8).

- Obtain the reading from the counter and nulling dial. The last digit on the counter should correspond with the number on the nulling dial. This number is considered tenths of units. The dial is further divided so that hundredths of units can be read.
- It is good practice to double check the levels, the reading and the field notes after each reading.
- Clamp the meter by turning the arrestment knob clockwise to the end of travel (about 3 full turns).

After the meter has been shipped or received a hard impact, it is good practice to check the setting of the levels and sensitivity. See the paragraphs in this section for more details.

# CONVERTING THE COUNTER READING TO MILLIGALS

Let us illustrate conversion of meter readings to milliGals with some examples.

## MODEL G

If the counter reading is **2654.32**, look at the calibration table for your meter. Remember that each meter has its own unique table.

Portion of calibration table

Counter Reading	Interval Factor	Cumulative Value
2500 . . . . .	1.00794 . . . . .	2519.42
2600 . . . . .	1.00799 . . . . .	2620.21
2700 . . . . .	1.00805 . . . . .	2721.01
2800 . . . . .	1.00811 . . . . .	2821.82

Divide the reading into two parts.

$$\begin{array}{r}
 2600.00 \\
 + 54.32 \\
 \hline
 2654.32
 \end{array}$$

$$\begin{array}{r}
 2620.21 \\
 + 54.75 \\
 \hline
 2674.96
 \end{array}$$

Interval factor x reading within interval

$$1.00799 \times 54.32 = 54.75$$

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## MODEL G SURVEY OVER SMALL CHANGE IN GRAVITY

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If all the readings are within an interval, you may use a single calibration factor, the interval factor.

Reading x Interval Factor = milligals

$$2654.32 \times 1.00799 = 2675.53$$

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## MODEL D WITH SINGLE CALIBRATION FACTOR

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Many model D meters have a calibration curve that is adequately straight so that a single calibration factor can be used for the meter. The calculation is almost like the example above except for an important difference: one turn of the D meter's nulling dial is equal to about 0.1 milligal (100 microgals) instead of 1 milligal (1000 microgals) on the G meter's nulling dial. Thus, the decimal must be moved one place to the left in the reading or one place to the left in the calibration factor. If the meter counter reading is 0943.21 and the calibration factor is 0.10123, then the converted reading is  $0943.21 \times 0.101234 = 95.485$ . The same setting could be read 094.321 and the calibration factor 1.01234. The converted reading would then be  $094.321 \times 1.01234 = 95.485$ .

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## MODEL D WITH CALIBRATED WORLDWIDE RANGE

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The standard Model D meter has two micrometer screws and lever systems for balancing the force of gravity. The “coarse” side has a worldwide range of at least 7,000 milligals. Normally this is not calibrated and is only used to place the meter into the operating range of the “fine side”. The "coarse" side (re-range) micrometer screw is normally turned by placing a small screwdriver through the re-range access port in the middle of the black lid (see diagram pg. 1-5).

If the coarse side is calibrated, a gearbox, counter and nulling dial are mounted above the "coarse" micrometer screw. There are 100 turns of the coarse nulling dial for each turn of the micrometer screw. Each turn of the screw is about 70 milligals. Thus, each turn of the of the nulling dial is about 0.7 milligals.

During surveys over a gravity span of less than the range of the fine screw, the coarse side would be locked and unused. The meter would be used in the same manner as the regular Model D meter. Be sure to use the fine side calibration table.

Where the range of the gravity observations is greater than the range of the of the fine side screw, the fine side can be locked and the meter used in the same way as a Model G geodetic meter. Be sure to use the coarse side calibration table.

A better method of reading the meter over a large range of gravity is to turn the coarse screw integral numbers of turns and complete the balancing of gravity with the fine side. If there is periodic or circular error on the coarse side, full turns of the screw should minimize this possible source of error. Because of the design of the Model D meter, periodic error of the fine side should be insignificant.

Here is an example of calculating the gravity difference between two sets of readings.

	<b>Coarse Side</b>	<b>Fine Side</b>
First Reading . . . . .	4565.00 . . . . .	1234.56
Second Reading . . . . .	4865.00 . . . . .	1567.89

From the coarse side calibration table:

From the fine side calibration table:

First Reading

Coarse Side  $3351.446 + 65.00 \times 0.74682 = 3399.989$

Fine Side  $84.633 + 34.56 \times 0.07021 = \underline{87.059}$   
 $\underline{3487.048}$

Counter Reading	Factor	Counter Reading	Factor
4500 ... 3351.446....	0.74682	1200 .... 84.633.....	0.070210
4600 ... 3426.128....	0.74691	1300 .... 91.654.....	0.070175
4700 ... 3500.819....	0.74699	1400 .... 98.672.....	0.070134
4800 ... 3575.518....	0.74706	1500 .. 105.685.....	0.070120

Second Reading

Coarse Side  $3575.518 + 65.00 \times 0.74706 = 3624.077$

Fine Side  $105.685 + 67.89 \times 0.07012 = \underline{110.445}$   
 $\underline{3734.522}$

Gravity is 247.474 milligals greater at the second reading than at the first.  $3734.522 - 3487.048 = 247.474$  milliGals

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**RELATIVE INSTRUMENT**

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Remember that the meter is a relative gravity meter. A single reading does not determine gravity. The meter only measures the difference in gravity between two observation locations or over a time interval at one site. If the converted reading is 2789.12 milligals at Station A and 2889.12 milligals at Station B, then gravity at Station B is 100.00 milligals greater than Station A. If gravity at Station A is 980,234.56 milligals, then you have determined gravity at Station B to be 980,234.56 plus 100.00 milligals or 980,334.56 milligals.

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## CHECKING LEVELS AND SENSITIVITY

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**W**henever the meter has been shipped or has received a sharp blow or has been in the hands of a person not experienced with the meter (such as a customs inspector), it is good practice to be certain the levels and sensitivity setting are in proper adjustment. All good operators should know how to perform these checks and adjustments. They should not be delegated to a technician. The technician is not in the field when you bump or drop the meter. They are easy to learn and fundamental to a good understanding of the meter.

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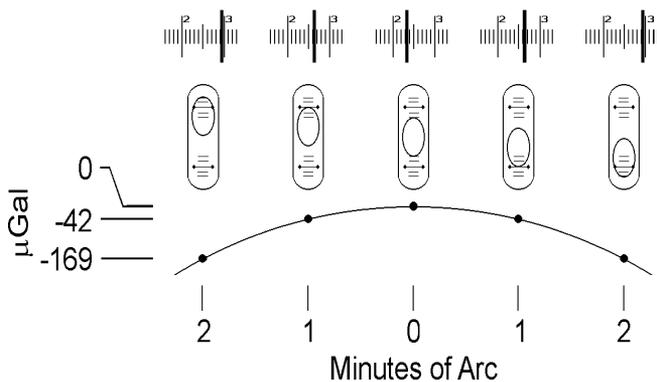
### CHECKING THE TRANSVERSE LEVEL

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The transverse level is also called the cross level. It is at 90 degrees from the direction of the meter's beam. With most meters, the spirit level is on the right side of the meter's lid. The galvanometer for most electronic cross levels is on the left side of the meter's lid.

The purpose of this level is to position the gravity meter, in the transverse plane, so the meter measures maximum gravity. If the meter is tipped to one side or the other (away from or toward the operator) it will not measure the full force of gravity.

If the cross level setting is correct, the gravity should decrease if the meter is tipped away from or toward the observer. That is indicated by the crosshair (and galvo on CPI meters) moving to the right when the meter is tipped off level.



If the meter is nulled to the reading line when the meter is out of level, the gravity reading will be less and less the more the meter is out of level. Be sure the other level, the long or longitudinal level, is in the level position each time the meter is read.

If the meter does not indicate a maximum gravity reading when the cross level is centered, the cross level is out of adjustment. Tilt the meter until the maximum reading is obtained. Remember to always keep the long level centered.

Now while being careful not to move the meter, use the level adjusting tool to center the level bubble. There is a small coverplate on the black lid. It is located on the far side of the cross level window. With a very small screw driver or the blade of a knife, loosen the screw that secures the coverplate. Rotate the coverplate and expose the access hole. The hexagonal level adjusting tool will fit through this hole and into the head of the level's small adjusting screw.

Repeat the testing of the cross level to be certain your adjustment was done accurately. If it was, you should obtain a maximum gravity reading when the cross bubble is in the center.

If the cross level is far out of adjustment, the meter's beam or spring may drag along the side or the other. Tilt meter considerably to one side and the other to determine at what angle the beam becomes free. If the beam moves but is unstable and can not be nulled to the reading line, check the meter's sensitivity (next section).

Some older meters do not have levels that can be adjusted through a small port in the black lid. These older meters must have their black lids removed to reach the level adjustments. See the METER DETAILS section for more information. A special aluminum tube is required to hold the eyepiece while adjusting these older levels with the black lid removed.

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## CHECKING THE SENSITIVITY

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The longitudinal or long level is parallel to the meter's beam. It is used to set the mechanical sensitivity of the meter.

Raising the right side of the meter makes the beam less sensitive to a given change in gravity or spring tension. As the sensitivity becomes greater, the period of the beam becomes longer. If the period becomes too long, it is no longer practical to read the meter by the nulling method. Still more lowering of the meter's right side causes the beam to have an infinite period, and still more lowering of the right side and the beam becomes unstable with the beam accelerating as it moves toward the upper or lower limit of its movement.

The beam is limited in movement by "stops". They are factory adjusted to limit the beam movement to 14 small optical lines. The reading line is usually close to the center of the range of movement. *L and R* places a small label on the black lid indicating the reading line when the meter was last tested at *L and R*. When the beam is clamped, it is pushed down onto the bottom stop. Because of the optical system, the bottom appears toward the left side of the optical scale and the top toward the right.

To check the sensitivity:

- Level the meter.
- Turn on the reading lamp.
- Observe the position of the beam. It will be close to the bottom stop.

- Unclamp the beam.
- Turn the nulling dial to locate the lower and upper stops.
- Position the crosshair about one small optical division above the bottom stop. Be sure to approach from the left (clockwise turn of the nulling dial).
- Turn the nulling dial approximately one milligal clockwise. This would be one full revolution for the Model G and ten full revolutions for the standard Model D.
- Observe the number of small optical divisions the crosshair moves in the eyepiece.
- If the beam moves approximately 9 to 11 small optical divisions, then a long level adjustment is not necessary. (9 to 10 optical divisions if the electrostatic nulling system is used)

If the sensitivity is out of the above range, the long level and sensitivity should be adjusted in small increments, usually about a fourth or a half of a bubble division.

If the sensitivity is too low (less than 9 small optical divisions), lower the right side of the meter a small amount so the level bubble moves away from the eyepiece stalk. Recheck the sensitivity of the meter. If the sensitivity is now within the acceptable range, reset the long level as follows:

- Be careful not to move the meter.
- Open the small level adjusting access hole at the left end of the long level.
- Insert the hexagonal adjusting tool through the access hole into the level adjusting screw.
- Gently turn until the level bubble is centered.

If the sensitivity is too high (greater than 11 small optical divisions), raise the right side of the meter a small amount so the long level bubble moves toward the eyepiece stalk (to the right). Re-check the sensitivity. If the sensitivity is now within the acceptable range, reset the long level with the level adjusting tool as described above.

During all of the above adjustments, be sure the cross level remains with its bubble in the center.

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## CHECKING THE READING LINE

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- Level the meter.
- Turn on the reading lamp.
- Unclamp the meter.
- Use the nulling dial to adjust the crosshair to the reading line as specified on the meter. If the reading line is not known, choose the optical line midway between the beam stops.
- Keeping the cross level in the level position, tilt the long level one division in one direction and record the eyepiece reading.
- Tilt the long level one division to the other side of the level positions and record the eyepiece reading.
- If the crosshair moves upscale approximately the same amount for each tilt, then the chosen reading line is correct.
- If the crosshair moves downscale when the meter is lowered on its right, the assumed reading line is too low.
- If the crosshair moves upscale appreciably more when the meter is lowered on the right (the long level bubble is one division farther away from the eyepiece stalk) than when the meter is raised on its right side, the assumed reading line is too high.
- If the correct reading line was not chosen in the above test, relevel the meter, reposition the crosshair with the nulling dial to a new trial reading line and repeat the above procedures.

The reading line should be checked whenever the long level has been adjusted.

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## STANDARD ACCESSORIES

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### BATTERIES

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**T**wo 12-volt gel-type rechargeable lead-acid batteries are provided with each new meter. They have a capacity of 6.5 amp-hours. An electrical connector is securely mounted on the battery. Since 1984, a 2-pin Cannon KPT02A-8-2S connector has been used. Prior to 1984, a 3-pin Bendix JT06A-8-3S fitting was used. To prolong the life of the batteries, it is important not to deep discharge the batteries and always to recharge them as soon as possible after use.

The batteries are fully charged when shipped but should be recharged before using. Recharge only with the *LaCoste and Romberg* charger. Other chargers may reduce battery life.

Though the acid electrolyte is stabilized in gelatin, the batteries can discharge damaging acid if they become hot and are not upright. Left on their side in a hot vehicle is a likely way to damage the battery and surrounding property!

Do not ship batteries inside the meter carrying case. There is considerable energy and value in close proximity if an accident should occur.

Batteries should be stored in the fully charged state. Preferred storage temperature is 20° C (70° F) or below. The batteries should be recharged every two or three months while in storage. If the temperature is above 20° C more frequent recharging is required to prolong the life of the batteries. Storage at temperatures above 40° C (100° F) should be avoided.

A charging period of 12 to 20 hours is usually sufficient to bring a fully discharged battery to a full charge. A fully charged battery should provide enough energy to maintain the meter for a long field day in all but the coldest weather.

Eventually batteries gradually lose their capacity to fully recharge. When operating time after a full charge is no longer satisfactory, it is time to replace the battery.

## **CHARGER/BATTERY ELIMINATOR**

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The charger/eliminator serves two purposes: to charge the batteries and to provide a regulated 12-volt DC power for the meter when it is not in the field.

The charger/eliminator is powered by 115 or 230 volts  $\pm 10\%$  at 47 to 420 Hertz: AC power only!

FIRST set the input voltage switch to 115 or 230 volts. Chargers shipped before 1989 have the switch on the face of the charger. From 1989 onward, the switch is located inside the charger. AFTER setting the switch, connect the power source. The charger may be damaged if the switch is set to 115 volts and the charger connected to 230 volts power.

A charger that operates from 12-volt DC power is available as an option. It can also operate from 115 or 230 volts AC power.

## **ALUMINUM CARRYING CASE**

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The carrying case is made of anodized aluminum and is divided into two padded compartments. On the left is the meter compartment and on the right the battery compartment. The case should be dried as soon as possible if it becomes damp. This will minimize corrosion to the gravity meter's leveling legs. Good field practice dictates periodic cleaning of the pads and removal of debris accumulated beneath the bottom pads.

Spare fuses and reading lamps are stored in a small box taped to the inside of the carrying case lid. Remove the cushion to expose the fuse and lamp box.

The most common malfunction of the case is a failure of the latches. If prolonged field work in a remote location is anticipated, a spare pair of latches is advisable.

The case is modified for use with meters that are equipped with the analog electrostatic nulling option. The meter side of the case is about 15mm ( $\frac{5}{8}$ -inch) wider.

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## **ALUMINUM BASEPLATE**

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A standard aluminum base plate is supplied with each meter. It has three legs about 50mm (2 inches) long and a bullseye bubble at its center. The low temperature functional limit of the bubble is  $-54^{\circ}\text{C}$  ( $-65^{\circ}\text{F}$ ) and the bubbles can tolerate  $-62^{\circ}\text{C}$  ( $-80^{\circ}\text{F}$ ).

There are several optional baseplates available for special purposes (see options).

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## **CABLES**

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Each new meter is provided with a power extension cable for use with a 12-volt power source other than the standard batteries or eliminator. The cable attaches to the end of the standard meter power cable and has two color coded battery lugs at the other end. Red is positive and black is negative.

Meters with the CPI option are equipped with a recording cable. It is a short two-conductor cable with a miniature phone plug at the meter end and lugs at the recorder end.

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## **ALLEN ADJUSTING TOOL**

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For adjusting the levels, an Allen driver is provided with each new instrument. It has a screw driver handle and a hexagonal shaft and tip. The tool is stored in the carrying case. The tool comes in two lengths: a short one for meters that only have spirit bubble levels and a long one for meters with electronic levels.

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## **SPARE FUSES**

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Spare ATO-3 fuses are stored in a small box taped to the inside of the carrying case lid. Remove the pad from the inside of the lid and the box is apparent.

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## **SPARE LAMPS**

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Meters that have incandescent reading lamps have spare lamps stored in a small box taped to the inside of the carrying case lid. New meters have LED reading lamps and no spares are necessary

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## **MANUAL**

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Each meter is provided with a manual. *L and R* is endeavoring to improve the manual and have it translated into several different languages. Suggestions for improvement or adding additional information would be appreciated.

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## **CALIBRATION TABLE**

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Each meter has its own unique calibration table. Some Model D meters have a single calibration factor. If the table is lost, *L and R* maintains the original, together with the raw data from which the table was generated.

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## **SPECIAL METER SHIPPING CONTAINER**

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The shipping container in which the instrument is shipped from *L and R* is a reusable container. It is important to retain it in good condition for use when the meter is next shipped.

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## SERVICE

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**T**here are three basic types of service:

- Repair a specific part
- General testing, cleaning and adjusting
- Long term servicing

Repairing a specific part is usually charged on a time and material basis. There is a fixed rate for some of the more common repairs.

General testing, cleaning and adjusting is a fixed price. It includes:

- Testing the meter
- Opening
- Cleaning the beam stops
- Adjusting the hysteresis compensator
- Making other internal adjustments
- A 16 hour check of the meter seals
- Flushing meter with dry inert gas
- Sealing meter
- Retesting to verify adjustments were made properly
- Field testing
- Cursory check of calibration (17 milligal range)

The time required for the above is usually one to two weeks.

Long term servicing includes all of the above plus:

- Replacing all seals
- Removing the micrometer screw (two for Model D), cleaning, inspecting and relubricating

- Removing the gear box, cleaning, replacing any questionable micro-bearings or gears and relubricating.

The time required for long term servicing is usually two to three weeks. There is a fixed price for the work. Any significant updates are an additional charge. Long term servicing should be performed every EIGHT TO TEN YEARS. Seals will start failing after that many years due to hardening. The lubrication on the micrometer screw ages and should be cleaned and replaced, regardless of the amount of use.

*L and R* is proud to service and maintain its instruments, regardless of their age. Almost every Model G and Model D meter is still in service, G-1 looks and works like a new meter.

Our service policy is to charge a reasonable price for service and to perform it promptly.

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**WARNING!**

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**DO NOT OPEN THE SENSOR.** It is sealed with dry inert gas. There is nothing in the sensor that can be repaired outside the *L and R* laboratory. Only **SEVERE AND COSTLY** damage can result from opening the sen-

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**WARRANTY**

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**A**ll *LaCoste and Romberg* gravity meters are guaranteed for a period of 1 year after delivery. At the Purchaser's request, *LaCoste and Romberg* will make all necessary adjustments, repairs and parts replacements. All parts will become the property of *LaCoste and Romberg* on an exchange basis. This guarantee will not apply if such adjustments, repair or parts replacement are required because of accident, neglect, misuse, operation on improper power, transportation or causes other than ordinary use. All necessary adjustments, repair or parts replacement will be made at no charge to the Purchaser provided that the Purchaser pays all transportation cost to and from the *LaCoste & Romberg LLC*. laboratory in Austin, Texas. The period of the guarantee is extended by the length of time that the gravity meter is in transit and in the laboratory for repairs. The guarantee is void if the internal sensing element is opened by an unauthorized person.

The foregoing guarantee is in lieu of all other guarantees expressed or implied, and all obligations or liabilities on the part of *LaCoste & Romberg LLC*. for damages, including but not limited to consequential damages arising out of or in connection with the use or performance of the meter.

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# OPTIONS

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## CAPACITANCE BEAM POSITION INDICATOR (CPI)

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**T**his option is sometime referred to as “electronic readout”. It is the most popular and useful of the meter options. It consists of a capacitance bridge sensing the position of the meter’s beam and reporting this to a galvanometer or liquid crystal display (LCD) on the meter lid.

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### ADVANTAGES

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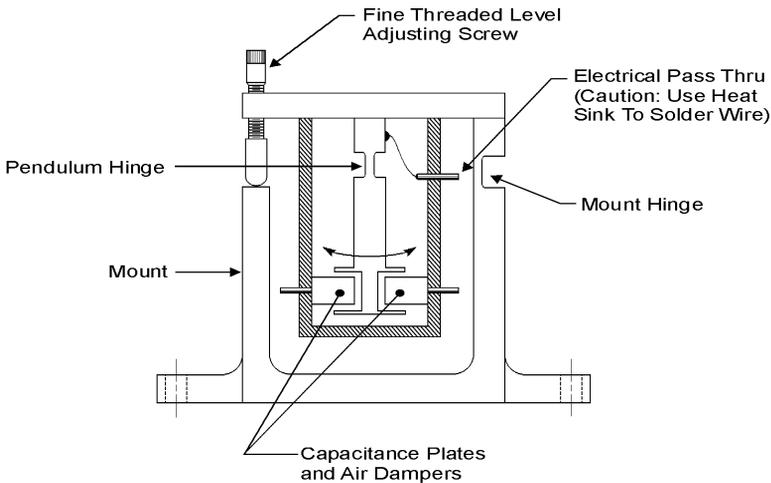
- Operator fatigue is reduced since the microscope need only be used when checking or adjusting the CPI.
- The galvanometer can be set to have greater sensitivity than the optical system, allowing more accurate reading.
- An electric outlet is provided for the signal that drives the galvanometer. A recorder can be driven by this signal to demonstrate earth tides and long period seismic waves.
- An external R-C filter and voltage indicator (galvo or digital multimeter) can be used to read the meter when ground vibration is troublesome.

This option is required for various options such as analog and digital electrostatic nulling and variable damping.

The only noticeable difference between meters with CPI and those without CPI is the addition of the galvo or LCD on the top of the meter and the miniature phone jack outlet on the side of the meter. For more information see the Meter Details section of this manual.

## ELECTRONIC LEVEL (PENDULUM TYPE)

Optional electronic levels are available for the gravity meter. They are hard mounted directly to the sensing element inside the white box. The existing bubble levels are not removed, but revert to a back-up role. Each electronic level is a simple pendulum that is air damped. The position of the pendulum is sensed by a capacitance bridge with the two air dampers being the fixed capacitance plates and the pendulum the moving plate. These levels first became an option in 1979.



## CHARACTERISTICS

- Principle: simple pendulum
- Damping: air
- Linearity: plus / minus 2% full scale
- Natural Period: .26 second / cycle
- Range: plus / minus 10 arc minutes
- Resolution:  $\frac{1}{2}$  arc second
- Readout: capacitive (displacement sensing) with a galvanometer for visual display
- Stability: 1 arc second / month
- Temperature Effect: 1 arc second / 1 degree C.

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## ADVANTAGES

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- Bubble levels must be carefully shaded on a warm or sunny day to prevent variations in level reference of up to 1 arc minute (approximately .04 milligal error).
- The fast, perfectly damped motion of the levels speeds work and reduces operator fatigue.
- Smaller level increments are more easily detected on a galvanometer than with bubble level markings.
- Electronic beam and level readouts make it possible to determine the reading line more accurately than can be done with optics and spirit levels. When using the optics, the reading line is usually determined only to the nearest microscope division, thereby making it accurate only to about a half microscope division. Furthermore the level bubble divisions are not as uniform or as readable as the microammeter divisions of the electronic levels. It is particularly important to use an accurately determined reading line when microgal accuracy is desired.

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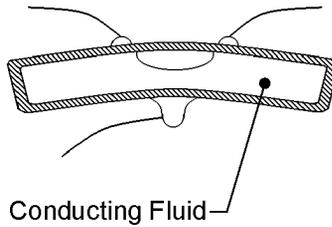
## ELECTRONIC LEVEL (LIQUID TYPE)

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**T**hese levels are a compromise. They are much less expensive than the pendulum type electronic levels. However, they do not have the very fast response and perfect damping of the pendulum levels.

They consist of a bubble inside a curved glass tube. The fluid is a conductor and there are electrodes to sense the change in resistivity as the bubble moves along the glass tube.

They are located below the insulation and just atop the meters sensor. The standard spirit levels can be retained as a back-up. This option was introduced in 1989.



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## VARIABLE DAMPING

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The variable damper is an option for the gravity meter that allows the operator to adjust damping to suit different needs. The gravity meter is identical to the standard meter except for the variable damping feature. Damping can be set at standard damping or at 25 times standard damping. With care, damping can be set at intermediate values.

This option was developed for reading gravity atop frozen lakes. It is useful for observing gravity in areas of severe ground motion. For areas of severe ground motion, the CPI option with an R-C filter should be adequate.

Meters with this option can be recognized by a large nylon plug on the bottom of the meter and two white button switches on the operator side of the black lid. The plug on the bottom side allows access to the engaging device.

When full damping is engaged, the method of reading the meter is slightly different. The two white buttons called “cheater switches”, are used to electrostatically push the beam to the reading line. According to the direction and velocity the beam moves away from the reading line, the nulling dial is turned to the next estimate of the null reading. The beam is once more pushed back to the reading line and the procedure is repeated. With a little practice, the reading can be made almost as fast as normal readings with standard damping.

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## EXTENDED RANGE MODEL D

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If ordered in advance of construction, the range of the Model D meter may be 300 Milligals instead of the standard 200 milligals. This does not cause a reduction in meter sensitivity. All components are the same. The micrometer screw is allowed to travel over a 50% greater length. Laboratory calibration must be done over this extended range and a detailed calibration table is provided over this extended range

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## COARSE AND FINE SCREW CALIBRATION OF MODEL D

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The coarse or ranging micrometer screw of the Model D meter may be equipped with a gearbox, counter and nulling dial. There are several advantages to doing this. The resulting meter has all the advantages of both the Model D and Model G and more.

The meter makes an excellent high precision geodetic meter. If there is a small amount of circular or periodic error in the coarse world-wide range screw, this can be minimized by turning the coarse screw exact integral revolutions. Final balancing can then be finished using the fine nulling screw, which by its design has minimal circular error. The reading technique is illustrated in the Primary Information section of this manual.

The coarse screw gearbox has a ratio of 100 to 1. Thus it is easy to make integral numbers of turns of the screw.

An existing Model D meter can be retrofitted with a gearbox, counter and nulling dial on the coarse screw. The existing gearbox on the fine screw is retained. It has a ratio of 32.5 to 1.

If the option is ordered before construction of the meter, a special gearbox can be utilized that has a ratio of 100 to 1 on the coarse screw and 50 to 1 on the fine screw. (The use of these special meters is described in more detail in a technical paper by Fett and Halliday.)

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## LED READING LAMPS

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If older meters are to be used in very hot climates, the wiring of the instrument can be modified so special LED lights can be substituted for standard incandescent lamps. The LED's generate less heat. All new meter since 1996 are equipped with LED reading lights and LED level lights.

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## DIGITAL THERMOMETER

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A low-power 3.5 digit red LED digital voltmeter is mounted on the black lid. The Meter Temperature function uses a precision centigrade temperature sensor. The temperature sensor is powered from a regulated 5 Volt supply derived from the 12 Volt system power. The temperature sensor is glued with epoxy cement inside an aluminum tube, which is then inserted in the standard thermometer well on the side of the heater box. The output reads in tenths of a degree. By turning a switch, the same voltmeter is used for measuring battery voltage.

All land meters constructed since January 1997 have this as standard equipment. Older meters may be retrofitted.

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## DOUBLE OVEN

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The meters may be mounted in a double oven housing for greater precision in field observations or stationary recording. The inner oven is the same as in the standard meter and is thermostated at the same temperature. The outer oven is thermostated at approximately 38°C.

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## BASE PLATES (LEVELING DISKS)

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There are several types of base plates available. All are 10.5 inches (28 cm) in diameter and have a concave upper surface. They are made of cast aluminum. All have three legs. Most have legs that are 2.5 inches (6 cm) tall. The standard base plate has a bullseye level bubble in the center.

After using the meter for some time, few operators continue to observe the base plate's level bubble. For that reason, *L and R* offers the base plate without the level or the level's machined hole, resulting in a cost savings.

Another variation of the base plate is available without the level, but with a central hole threaded  $\frac{5}{8}$ -inch national coarse. This allows the base plate to be mounted atop a standard surveyors tripod. This is of great advantage for underground observation work in the deep snow or vertical gradient observations.

Finally, there is a base plate with oak wood legs approximately 20 inches (50 cm) long. When using this baseplate, care should be exercised to make proper corrections for the height of the meter above the survey elevation marker.

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## BACKPACK

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**A** backpack is available for carrying the meter and its battery in the standard aluminum case.

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## HIGH SPEED CRANK

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**T**he purpose of this device is to expedite gravity readings between stations where large gravity changes are encountered. This crank makes it possible to turn the dial about 10 times faster. It is a small cylindrical gear box with a small crank handle at one end and two pins at the other end. The pins are inserted into two holes on the top of the nulling dial.

The high speed crank can save time during geodetic surveys with the Model G meter when there are large differences in gravity between readings. It can also be useful with the Model D meter when there are moderate differences in gravity between observations. This is particularly true for periodic repeat surveys.

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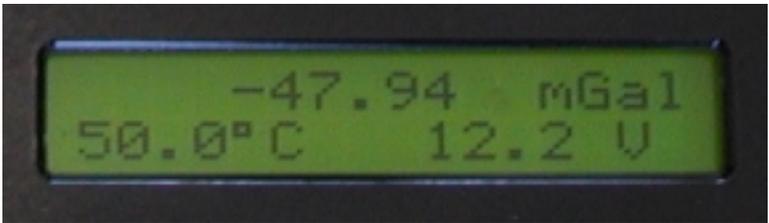
## ALIOD 100 ELECTRONIC FEEDBACK SYSTEM

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This new feedback system is now available as an option with new gravity meters and as an upgrade to your existing meters.\* The Aliod 100 incorporates a new user-friendly interface.

No longer is there any need for a complicated lookup table as this new system displays the gravity directly in mGal on an easy to read LCD display. Meter temperature as well as battery voltage are also displayed on the same easy to read LCD. The new Aliod 100 feedback system has a range of 100 mGal with a precision of 0.01 mGal. The greater range of the Aliod 100 also means good data is no longer dependent on the skill of the operator. Any one who can level and unclamp the gravity meter is able to obtain consistent and accurate gravity data.

The Aliod 100 includes an integrated Data Acquisition system using two 24 bit converters for the levels and a 12 bit converter for the meter temperature and battery voltage. The Aliod 100 also outputs a stream of ASCII data, which can be read using any terminal program on a PC with a RS232C port. The Aliod 100 includes our standard 1 year warranty.



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## TRAINING

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**T**rainning is provided at the *L and R* facilities or in the field or at your facility. Training at our facilities may be on a one-to-one basis or may be an organized course. The average course is two to three days in duration.

- The first day consists of microgravity field observations, learning to check the meter, cursory servicing and troubleshooting.
- On the second day, the field data are entered into the computer, familiarization with the software is acquired and there is elementary modeling and interpretation.
- If a third day is available, additional theory, interpretation, case histories and special techniques are discussed.

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# FIELD PROCEDURES

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## INTRODUCTION

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The following is a guide to help the operator avoid some of the more common problems encountered in conducting a gravity survey. However, the observant and thoughtful operator is always able to further improve his technique, regardless of the months or years of experience he or she has accumulated. For shipping precautions, please refer to that section of the manual.



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## PROMPT DATA REDUCTION

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Prompt reduction of the gravity data allows the operator to know how good or poor his technique is while he still can recall the details of the field work. Thus he can associate a bump to the carrying case or a rough road with irregular and high drift rates. He soon can learn what care in handling the meter must be provided to attain results of a given quality.

One of the fastest methods of learning the quality of the field work and the performance of the meter is to obtain the gravity tide at the time of each base station reading and calculate the tide-corrected drift the meter has just undergone during the time since the previous base reading. The tide correction may be obtained in the field from pre-calculated tables from GRAVPAC or computed on a hand-held computer.

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## METER VIBRATION

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**O**ne of the larger sources of error in a field survey comes from large and irregular meter drift. The main cause of the problem is rough treatment of the meter. The more vibration and bumps, the more irregular the drift. Certain vibration frequencies are worse than others. Snowmobiles and helicopters may cause severe short-term drift. The smoother the ride, the better the meter performance. For very accurate work, it may be necessary to carefully hand carry the meter. If transported in a vehicle, it may be necessary to hand-hold the meter off the seat and minimize the vibration that is transmitted from the vehicle to the instrument. The selection of a field vehicle with softer suspension is usually worthwhile. A vibration isolation carrying case rack is used by some observers.

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## TEMPERATURE EXTREMES

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**I**f the meter goes above or below its thermostated temperature, there will be intolerable instrumental drift. Each instrument is thermostated at a different temperature. Unless especially designed, the thermostated temperature will be between 47°C and 55°C. It is best to use a meter thermostated at the lower temperatures when working in a cold climate, as it will conserve battery power. It is best to use one thermostated at the higher temperatures when working in a hot climate, as it will be less likely to go over temperature.

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### COLD

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When the meter is placed in much colder air, often it will make several loud cracking sounds. This is due to contraction of the fiberglass housing or other superficial parts. Be sure to check the liquid levels after these noises occur.

Spirit levels may change somewhat when the meter is in cold air. They may require re-adjustment after the meter has been in the cold. Electronic levels are within the insulation and are not affected by changes in ambient air temperature, a distinct advantage when working in cold weather. In severe cold weather, electronic levels are required for accurate and efficient work.

Keep the baseplate cold when operating on ice or frozen ground. A warm baseplate will thaw the ground and it will be impossible to keep the meter level long enough for a reading. If the plate is warm, you may use a board or chips of wood between the baseplate feet and the frozen ground. In snow you may wish to use a special plate with long wooden legs (see options).

In severe cold, the standard battery will not last for a full day of field work. This is due in part to the extra power consumed by the meter to keep it at its thermostated temperature. The main limitation is the battery not releasing as much energy when it is cold. Try to keep the battery and spare battery warm so they will yield more energy. With severe cold, some operators use the power extension cable and a larger battery such as a sealed motorcycle battery.

Ni-Cad batteries are generally more expensive, have a shorter life and are more troublesome to work with than are gelatin stabilized lead-acid batteries. However, they are not affected as severely by cold.

For high precision work in cold climates, a double oven meter option is available.

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## **H O T**

There are several methods for keeping the meter cool in hot weather. Avoid allowing the sun to shine directly on the carrying case. A towel or cloth with a short slit cut in its middle can be placed over the carrying case and allow the carrying handle to come through the towel. In dry hot climates the towel can be moistened. Evaporation will provide some cooling. Try to mini-

mize or eliminate use of the reading lamp. It adds considerable heat to the system. In severe heat, a block of frozen gelatin in a well sealed plastic pouch can be carried on the battery side of the carrying case. These are commercially available. If condensation accumulates in the carrying case, it should be dried periodically.

It may be necessary to conduct field work at night and in the early morning hours when air temperature is cooler and when radiation from the sun can be avoided.

Leaving a meter in a parked vehicle with closed windows in a hot climate is a likely way to drive the meter over temperature.

The LED reading lamp option will reduce the internal heat generated if the reading lamps must be used.

The semiproportional heater control option allows the minimal amount of energy flow to the meter when the ambient temperature is approaching the thermostated temperature. It is a distinct advantage if the meter is tending to go above its thermostated temperature.

The CPI electronics generate about  $1\frac{1}{2}$  watts of heat and are located against the side of the sensor. Half of that heat is generated by a single component on the PC board. This component can be mounted on long wires and placed just below the black lid, keeping the heat away from the sensor.

Each meter is normally thermostated at the temperature which gives the smallest change in reading for a given small change in internal temperature. Under prolonged severe heat, if the above field methods do not work, the thermostated temperature can be set to a higher temperature. This will decrease the accuracy of the meter as small changes in internal temperature from heater cycling or use of the reading lamp will have greater effects on the meter. However, for regional gravity surveys these errors may be well within the tolerance of the survey.

The procedure for changing the thermostat setting is given in the Meter Details section of this manual.

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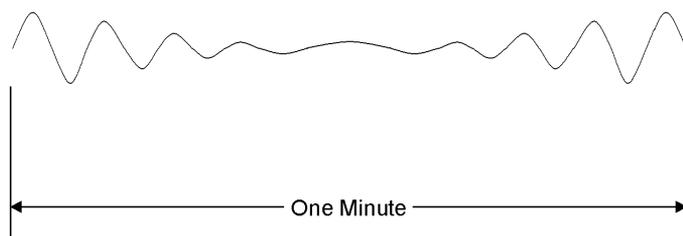
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## MICROSEISM

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**T**he continental crust of the earth is an efficient wave guide for seismic surface waves of certain wave lengths. When ocean waves of longer period strike the coast and reflect seaward, the resulting standing waves can massage the continental shelf and initiate these crustal seismic waves. In North America they can travel half way across the continent. Winter storms in the north pacific are the major causes in western and central North America. After severe storms in the distant North Pacific, gravity observations may be difficult in western states and provinces.

Microseisms usually have a period of about 4 to 5 seconds and, because of constructive and destructive interference, usually build up then die away with about five to twelve cycles per packet of waves.



To observe gravity during times of large amplitude microseisms, the variable damping option can be used. If the meter has the CPI option, another equally satisfactory solution is a simple R-C filter and external galvanometer or digital multimeter. A third option is to use electrostatic feedback nulling with or without additional filtering. Since the time-constant of the feedback loop is set near 90 seconds, the system effectively averages high to medium frequency seismic noise. This can average the oscillations of the microseism.

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## EARTHQUAKES

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**L**ocal earthquakes seldom are a problem during gravity observations. They occur and are gone before they are any inconvenience. This may not be the case with volcanic tremors. In the vicinity of a very active volcano, there may be frequent small tremors. The observer may wait for quiescent periods to observe. If available, the variable damped meter or meter with electrostatic nulling may be of assistance.

Distant earthquakes can delay observations for several hours. This is particularly true for large earthquakes on the opposite side of the earth. Their dispersive waves form a very long wave train when at a great distance from the source. A great earthquake with several major aftershocks can hamper careful gravity observation for days; three days following the 1975 China earthquake, for example.

Often observers have not identified the oscillation of a distant earthquake as such. They often believe the oscillation of the meter to be a malfunctioning of the meter. There is nothing in the design of the meter that could internally provide continuous oscillation. The electrostatic nulling options are an exception. If in doubt about the occurrence of an earthquake, you are welcome to telephone our lab. Usually we have at least one meter recording.

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## VEHICULAR AND MACHINERY VIBRATION

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**T**hough the frequencies may be different than those of microseisms, the solutions to observing may be the same; the variable damping, the R-C filter on the CPI option, electrostatic nulling option. At higher frequencies and larger amplitudes, the R-C filter may be a better solution and the electrostatic nulling option is the best solution. When the heavy damping is engaged on meters with variable damping, there is about 25 times normal damping.

If there is some nonlinearity in the air damper and the vibration is faster in one direction than the other, there may be some error due to “pumping”. Pumping is defined as the displacement of the meter’s mass above or below a rest equilibrium position due to vibration.

Lateral vibration has little or no effect on the meter. The reason for this insensitivity is explained in the section Physics of the Sensor.

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## WIND

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**W**ind movement of the meter is particularly troublesome. It causes two effects that are difficult to separate. It tips the meter out of plumb, this reducing the observed gravity. It also rocks the meter back and forth causing the beam to oscillate. If practical, place the meter in a location sheltered from the wind. If this is not feasible, place the meter so the wind direction is normal (90°) to the direction of the beam. Averaging the oscillations of the beam or galvanometer will not give accurate results, as the meter is out of level a portion of the time and at those times, is not observing the full force of gravity. Strong wind dictates shelter or curtailing gravity observation. The gravity observer can take advantage of these times to reduce data or help the survey crew establish station positions and elevations.

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## BASE SELECTION

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**I**n selecting the location of a local basestation, a site near the center of the survey is best. Less time is wasted returning to the base and the meter undergoes less vibration traveling to and from the base. It is possible to return to the base more frequently and overall accuracy is improved. If the survey area is large, several local bases can be established. The local bases are tied to the main base or regional base several times.

Try to select quiet locations for bases. Also, select locations that will be easy to relocate years later in case the survey may be extended or tied to other surveys in the region. Good field notes describing bases are an indication of a professional observer.

A sheltered base is a great advantage for closing a loop of observations, if weather becomes severe during the survey.

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## RERANGING THE MODEL D

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**T**he standard Model D has a range of 205 to 250 milligals, depending on the meter's calibration factor. This is enough to work over elevation differences of about 1,200 meters (4,000 feet).

If a survey area is mostly at a higher elevation than a base, it might be wise to re-range with the counter set about 1500.00. If the survey area is mostly at a lower elevation than the base, the meter could be reranged with the counter set at about 0500.00.

Once a survey is under way, The meter should not be re-ranged except at a station or base where gravity has already been measured.

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## TRIPOD ON ASPHALTIC PAVEMENT

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**W**hen observing on asphaltic pavement, the standard baseplate will gradually sink into the pavement. In all but the coldest weather, this will prevent the meter from remaining level enough for a reading. If you cannot find a convenient location away from the asphalt, distribute the load of the three legs by placing a board or other flat rigid material between the tripod and the asphalt.

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## TRIPOD IN FROZEN COUNTRY

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**I**f the tripod is above freezing temperature, it will gradually sink into the ice or frozen soil. Instrument leveling will be difficult or impossible. If convenient, keep the tripod cold; outside the vehicle and out of the sun. If this is not convenient, the tripod can be placed atop a board or other rigid item with a low coefficient of thermal conductivity. Even if the non-metal item is warm it will not melt an appreciable amount of ice or soil.

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## RADIO TRANSMITTERS

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**W**hen operating near powerful radio transmitters or when two-way field radios are very close to the gravity meter, they can cause the CPI electronics and/or the galvanometer to be affected. Under these field conditions, revert to the use of the microscope to determine beam position. The optical system is not disturbed by a strong EM field.

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## POWER SUPPLY IN REMOTE AREAS

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**T**he standard charger is designed to keep the gravity meter supplied with power when there are failures of the AC power supply. As long as there is a standard L&R battery connected to the charging portion of the charger/eliminator, the meter will remain on power. When AC power goes off, a relay in the charger/eliminator drops and connects the meter to the battery that was charging. When AC power returns, the relay is energized and reconnects the meter to the eliminator (regulated 12-volt supply) and reconnects the battery to the charger.

If AC power is not available, the L&R 12-volt charger can be used. This optional charger can be powered by unregulated 12-volt DC power or by AC power. At remote locations it can be attached to the battery of a vehicle and used to recharge standard L&R batteries. It does not use a great deal of power and should not excessively draw down a vehicle battery overnight. Connecting to the vehicle power via the cigarette lighter socket is not wise as most modern vehicle's ignition switch disconnects the lighter.

Where there is no AC or DC power available, solar/electric cells can be used to recharge the batteries if there is enough sunlight. A simple modification to the standard L&R charger will permit a panel of solar cells to energize the charger.

Leaving the standard lead-acid battery in a discharged state for a prolonged period drastically reduces its capacity. The practice of using several standard batteries in remote areas and waiting many days before they can be recharged is workable but costly.

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## OBSERVING GRAVITY BELOW GROUND

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**T**here are many reasons for measuring gravity below the earth's surface. If gravity is measured in a mine drift and on the surface, areas of greater density rock can be located and the optimum location selected to stope the mine.

If the ceiling is not too high, the meter can be placed halfway between the floor and ceiling. The significant local anomaly from the missing mass of the mine will cancel itself at the mid elevation. A special baseplate is available for this purpose. It has a flat surface on the center of its bottom and has a standard threaded hole ( $\frac{5}{8}$ -inch N.C.) for mounting atop a surveyor's tripod. The baseplate still has the standard three feet and can be used as a normal baseplate.

For more details there are several technical papers with case histories and more details. A recent paper is:

Casten U., and Gram, Chr., Recent developments in underground gravity surveys, *Geophysical Prospecting*, Vol. 37, pp 73-90, January 1989.

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## VERTICAL GRADIENT MEASUREMENTS

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**I**f the ground surface is irregular, large errors are introduced into vertical gradient observations. Where the ground surface is smooth, vertical gravity gradients may be a useful technique for investigating shallow targets. A meter of high precision is required, such as a Model G with the electrostatic nulling option or a Model D. The meter must be in good repair, especially the hysteresis compensator.

A special tripod can be used that has an upper and lower baseplate with a constant separation between the two plates. This has the advantage of not having to carefully measure the difference in elevation between the upper and lower reading. If a special tripod is not available, a standard baseplate can be used on the ground. After finishing the ground reading, the plate can be left in place while a surveyors tripod is positioned above it and the height above the ground baseplate can then be carefully measured. A special tripod baseplate can then be affixed to the tripod and the upper observation made.

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## MORE THAN ONE METER ON A SURVEY

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**I**f more than one meter is used on a survey, it is best not to intersperse the work of two meters. The effects of any minor irregularities in calibration can be minimized by assigning to each meter its sector of survey area.

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## PERIODIC GRAVITY SURVEYS

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**T**here are many considerations in performing a competent periodic gravity survey.

- Monuments should be permanent. Their location should be carefully selected to minimize probable disruption from future cultural development.
- The same meter or meters should be used to minimize or eliminate the introduction of errors from minor meter calibration errors.
- If more than one meter is used, there is continuity if a meter is lost or sustains massive damage.
- If a survey is repeated for several years, a Model G meter will gradually drift to where a different portion of the micrometer screw is being used. This might introduce small errors due to the limited accuracy of the meter's calibration. The Model D can be reset. Thus using the Model D allows using the same positions on the measuring screw for each repeated survey.
- Upon finishing one observation, the nulling dial and counter should be preset to the approximate reading of the next station. This minimizes mechanical hysteresis of the lever system.
- The orientation of the meter should be in the same direction as previous readings at that station. This is a precaution in case the meter becomes sensitized to magnetic fields.
- Select the time or times of year for the survey to have the most favorable air temperature, winds and rain conditions.

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# METER DETAILS

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## LEVELING SCREWS

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**T**he leveling screws are made of stainless steel. Their threads are  $\frac{1}{4}$ -inch diameter with 48 threads per inch. The tips are ground to a sharp point to minimize the meter moving on the baseplate while the meter is being leveled.

When the meter is at *L* and *R* for standard cleaning and adjusting, the leg tips are resharpened if needed.

The threads of the legs turn in special metal inserts that are glued into the bottom of the white box. To reduce the chance of the stainless steel threads galling, the inserts are made of a lead rich steel. This alloy is capable of corrosion. Always dry the carrying case and meter legs when they become damp. Never store the meter in a damp case. A light lubricant on the threads will reduce the risk of corrosion.

**CAUTION**, do not leave the legs extended too far below the base of the white box. They will punch through the base pad of the carrying case, bump the bottom of the carrying case and jar the meter. Also, there is a greater risk of damage to the threads.

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## NULLING DIAL POINTER

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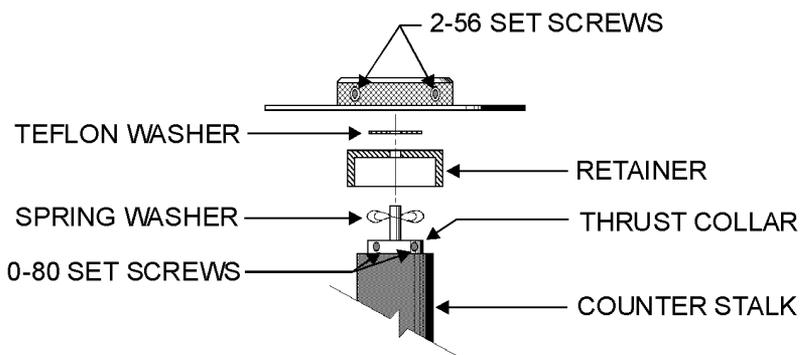
**I**f the instrument has received a hard blow, the meter may shift inside the white box. This can cause the nulling dial and arrestment shaft to be off center as they pass through their holes in the black lid. This is of little consequence other than appearance. However, the dial pointer is fixed to the black lid and may now rub against the dial. To correct this problem, the single hole in the pointer can be filed oblong and the pointer replaced on the black lid a little farther away from the dial.

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## NULLING DIAL

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The nulling dial is a flat aluminum disk with a hundred division marks etched on it and a knurled knob to assist in turning the dial. Except for early meters, the knob has two holes drilled in it to accept the prongs of the high speed crank. The high speed crank is mentioned in the Options section. It is convenient when the nulling dial must be turned through a great range of the meter.



To remove the nulling dial, loosen the two set screws within the knurled knob. Do not put excessive force on the nulling shaft. Hold the screw driver with one hand and the knob with the other hand. Below the dial are three parts that act as an adjustable friction brake for the dial. When replacing the dial, the farther down the dial is pressed against the spring washer, the greater the friction when rotating the dial. The ideal setting is to have just enough friction that there is no backlash of the dial. When the dial is reinstalled on the meter, be sure to phase the number on the dial with the last number on the counter.

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## EYEPIECE

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**T**he focus of the eyepiece (ocular) is adjustable. To move the eyepiece up or down, first loosen the knurled ring below the top of the eyepiece. Turning counterclockwise loosens. While looking through the eyepiece, move it up or down until a good focus is found. Then, retighten the knurled ring to hold the eyepiece in position.

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## ARRESTMENT KNOB

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**T**he arrestment knob is knurled and made of aluminum. It is held on the shaft by two very small set screws. It is positioned very close to the arrestment stalk to minimize the chance of dirt entering the top of the stalk.

If something is dropped on the top of the knob, the knob may be driven down and drag on the stalk. To repair, use a  $\frac{3}{32}$ -inch Allen tool to loosen the knob set screws, raise the knob about a tenth of a millimeter (a few thousandths of an inch) and retighten the set screws.

If the meter is subjected to salt spray or is stored damp, enough corrosion may develop between the knob and the stalk to cause dragging. Repair in the same way as above.

If the knob is very hard to turn and is not dragging on the stalk, the problem is more serious. The bearings or seals in the stalk may require servicing at *L and R*.

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## THE BLACK LID

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**T**he black lid is made from  $\frac{1}{8}$  phenolic board. The color was selected to minimize reflected light which could hamper viewing through the microscope. Each lid is individually fitted to its white box and meter. It is not weather resistant. Two changes are in progress:

- The lids will be interchangeable starting approximately at meter G-1000 and D-180. This will make easier retrofitting the meters with new electronics and LCD display.
- The lid will be more weather resistant.

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## REMOVING BLACK LID

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**T**o remove the black lid, turn the three leveling knobs counter clockwise and lift the level legs up and out of the meter box. Remove the nulling dial and the three brake parts beneath it. Remove the four lid screws, one located at each corner of the lid. Now lift the lid upward. It may be stuck to the top of the white box. Loosen with care.

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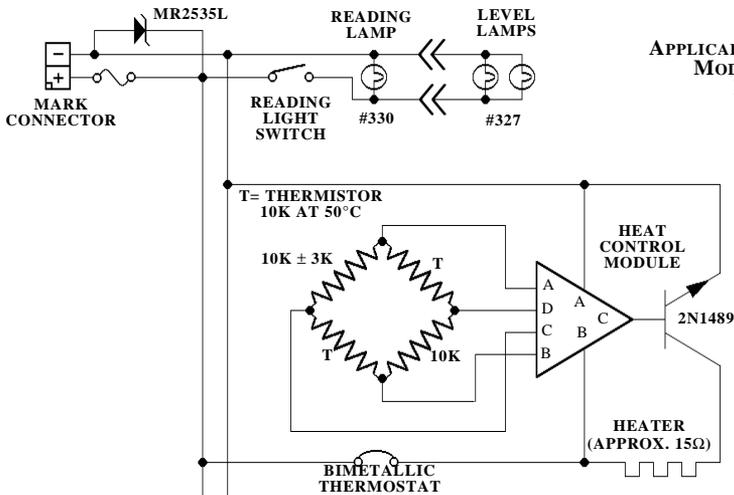
## WINDOWS IN LID

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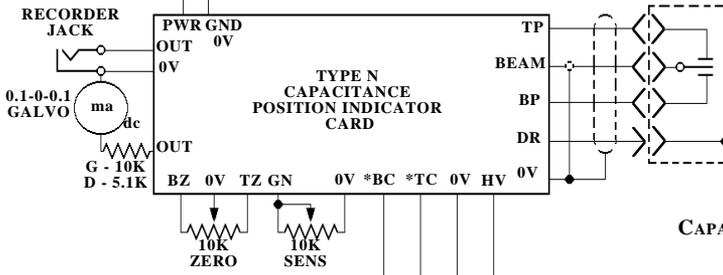
**S**ome of the glues used in the past to fix the window into the bottom side of the black lid were water soluble. When these meters are used in moist conditions, the windows loosen. To repair, remove the black lid, clean away the old glue and reglue. If "Super Glue" is used, only 3 or 4 drops are needed, as surface tension will distribute the glue. Allow to dry completely before replacing the black lid. If not vented, the fumes will condense and make a milky coating on the glass.

If replacements are required and it is not convenient to obtain them from *L and R*, you may have them cut from thin glass. The easiest source of this glass is a microscope slide.

# SCHEMATIC FOR OLDER METERS



APPLICABLE TO ALL MODEL G AND D METERS



\* CONNECT TC & BC TO 0V IF NO SWITCHES

ELECTROSTATIC POSITIONING SWITCHES FOR METER WITH VARIABLE DAMPING OPTION



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## THE FUSE

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**S**tarting approximately in 1980 with meters G553 and D46 the meters have been equipped with a fused safety device which is intended to help protect the electronic circuitry from reversed polarity of the power leads and/or power input over-voltages of greater than 22 volts. This is not to imply tolerance of reversed polarity, or over-voltage greater than about 16 volts.

The fuse is located near the power input connector. The black bakelite meter lid must be removed to replace the fuse. Use only a 3 amp ATO fuse for replacement. Spare fuses are provided with new instruments with this protection. They are located in a small box taped to the inside of the lid of the aluminum carrying case. Do not bypass or use a larger rated fuses.

A blown fuse will shut down all electronic circuitry in the instrument: heater circuit, electronic readout, and level and reading lights.

If you are out of fuses they may be obtained from *L and R* or most automotive parts stores.

Whenever older meters are returned for service, we encourage the retro-fitting of the fuse, especially if the meter has the CPI option.

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## READING LIGHT SWITCH

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**T**his switch is a standard single pole, single throw toggle switch. It can be replaced with any miniature SPST toggle switch.

- Disconnect the 12-volt power
- Remove the black lid
- Remove the two screws on the side of the white box that hold the switch bracket.
- Lift the switch and bracket up to expose the three wires.
- Resolder a new switch. The order of the wires is important.
- Connect the 12-volt power and determine the toggle position for the reading light being off.
- Disconnect the 12-volt power
- Install the new switch on the brass bracket so the toggle is toward the operator when the switch is off.
- Replace the black lid and reconnect the 12-volt power.

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## READING LIGHT

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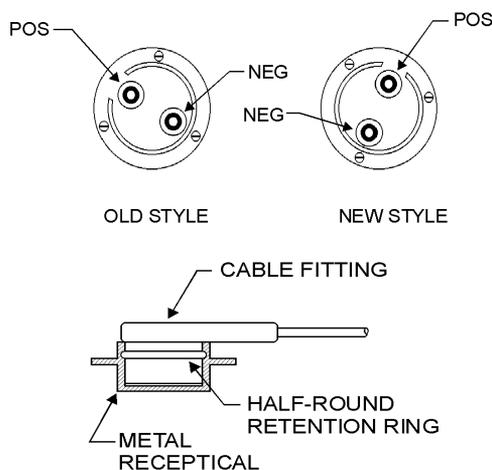
**I**n older meters that have not been converted, the reading light is on the operator's side of the white meter box. It is behind a round aluminum cover plate. The plate is held in place by three screws. The housing for the reading light is adjustable. It holds a No.330 12-volt incandescent aircraft bulb. Spare bulbs are stored in a small container taped to the inside of the carrying case lid. The bulb can be rotated so its filament is optimal for the optics and the bulb holder can be moved to place the bulb in the best position for brightness and sharpness of the image. Two screws secure the bulb holder in place.

A high intensity red LED lamp became standard on all Model G meters without CPI since approximately G-970. It is an option available on all land meters and is of value in hot climates. It

operates from a lower voltage, requires a change in wiring and has a different lamp holder.

## MARK POWER FITTING

On the upper right side of the white box is the electrical fitting that passes 12-volt power into the meter. There are two types. They look almost identical. The early type was used from 1967 through 1984 on meters from about G154 through about G742 and D1 through D105. These fittings are characterized by their cable orientation key being under the cable and by two power pins being inline with the cable. These fittings and their cables are obsolete and can not be obtained. Since changing the power fitting to the new type is more difficult than at first appearance, it is imperative that these obsolete fittings and their obsolete cables be replaced when the meter is at *L and R* for other servicing. Should the obsolete cable fail in field use, the meter would have to be returned to *L and R* or some primitive splice or solder connection made in the field.



The new Mark power fitting can be recognized by the orientation key being on the top and the power pins being 90° from the direction of the cable. Also, there is a half-round groove just inside the socket that accepts a half-round protrusion on the molded cable fitting at the meter end of the power cable. The new Mark fitting solved a serious drawback of the older fitting. The new fitting has

a half-round protrusion on the cable fitting and a matching half-round groove in the metal receptacle. These hold the cable in place and a good electrical contact is assured. Cables with the old type Mark fitting sometimes were bumped loose when returning the meter to the carrying case. The meter would go off power and temperature, resulting in errors in the observations.

Very early Model G meters had an Amphenol 126-216 power connector. Most of these have been replaced with old or new type Mark connectors.

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## BATTERY & CABLE FITTINGS

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**P**rior to 1984 (about G720 and D99) batteries and chargers were equipped with three-pin Bendix JT02A-8-3S connectors. These became very high priced and then obsolete. Since 1984, the less expensive and more common two-pin Cannon KPT06B-8-2S connector has been used. The matching cable connectors are JT06A-8-3P-SR and KPT06B-8-2P, respectively. As meters are serviced at *L and R*, the 3-pin connectors are being updated to 2-pin connectors.

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## LEVELS

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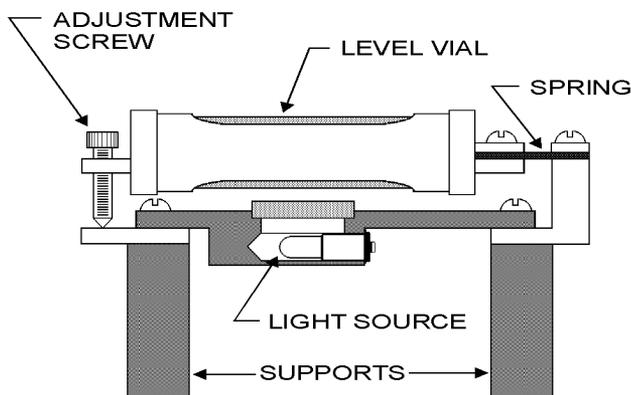
Three types of levels are available for the land meters. The standard and original levels are spirit bubble (liquid) levels. In 1979 electronic levels became an option. These are high precision air damped pendulums. Their position is measured with a capacitance bridge and registered on two galvanometers or an LCD (liquid crystal display). In 1989 inexpensive electronic levels were introduced. They are liquid levels with electrodes and conductive fluid.

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### SPIRIT BUBBLE LEVELS

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These are the original levels used in almost all *L and R* land meters. In most Model G meters their sensitivity is 60 seconds per division and in most Model D meters their sensitivity is 30 seconds per division. They can be stored at temperatures down to  $-51^{\circ}\text{C}$  ( $-60^{\circ}\text{F}$ ). The lowest temperature for correct reading is  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ). The levels in the early meters are illuminated from below by a No. 327 bulb when the reading light switch is turned on. This is a 28-volt aircraft bulb operating at 12-volts. Its lifetime should be very long. It looks almost identical to the reading bulb (No.330). The 330 should NOT be used to illuminate the level.



Since approximately meter G-970, all meters without CPI have high intensity LED lamps for the levels and for optical reading of the meter beam position. Since 1996 all meters are equipped with LED level and reading lamps. These low heat lamps are optionally available on all meters returned for service. They are of great value to meters that will be used in warm climates. The lamps operate from lower voltage and thus the meter wiring is different than for the incandescent No.330 and 327 lamps. Also, the lamp housing are different.

The bubble levels have three distinct disadvantages:

- A small amount of direct sunshine on the levels causes differential heating, fluid density gradients and inaccuracy
- The levels are located just beneath the black lid. On very cold days, there is sometimes enough differential contraction of the vials, housing and supports to cause significant error, assuming the levels had been adjusted in a warm environment.
- The levels are slow to creep to a final position, especially in very cold weather.

The levels are adjusted with a hexagonal allen tool provided with each meter. The adjusting screw is at one end of each level and is reached through a small access hole in the black lid. The hole is covered with a small square black metal plate. Loosen the small screw holding the plate in place and rotate the cover plate to expose the access hole.

Some older Model G meters before approximately G350 do not have externally adjustable levels. It is necessary to remove the black lid to make level adjustments. Two special tools were provided with these meters to facilitate level adjusting. One is an aluminum tube to hold the eyepiece while the black lid is removed and the other is a special wrench for adjusting the level nuts. Many of these meters have been retrofitted with external access level adjusting and retrofitting should be considered when these older meters are at *L and R* for other servicing.

## **ELECTRONIC LEVELS (PENDULUM TYPE)**

These levels are ideal except for their high cost. They overcome all of the above mentioned disadvantages of the spirit bubble levels. For specifications and a diagram, see the Options section.

### **ADJUSTMENT**

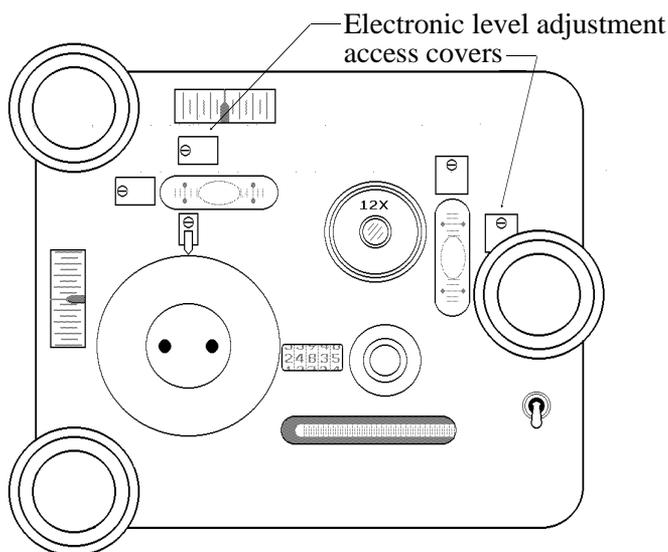
Electronic level adjustment procedures are similar to those used for the spirit levels. The directions for spirit levels can be utilized, realizing that 4 galvanometer increments equal approximately 1 bubble division: 15 seconds of arc for a Model G and 7 or 8 for a Model D. If more or less sensitivity is desired, it may be adjusted at *L and R*.

The longer level adjusting tool is required to adjust the electronic levels, as they are farther below the meter lid than are the spirit levels.

Once adjusted, the pendulum levels are very stable and remain in good adjustment. However, their adjustment should be checked whenever the meter is shipped or encounters a drop or severe bump.

The easiest method of *initially* adjusting the electronic levels is to first adjust the spirit levels in accordance with this manual. Then, with the Allen wrench, reset the electronic level adjustment screws until both leveling galvanometers display 0 (center of their range). The locations of these adjustment screws are shown on the following illustration. Do not readjust the electronic levels on a daily basis as they are more stable than the spirit levels. The optical reading line may increase one small division when going to high latitudes or decrease one small division when going to equatorial latitudes.

When the gravity meter is moved over very large differences in latitude, displacement sensitivity changes can occur. If the sensitivity change is large, both long levels (electronic and spirit) must be readjusted. This will cause a small difference in the reading line position, therefore it should be adjusted also.



## **DETERMINING A MORE PRECISE READING LINE**

- Using the electronic levels, level the gravity meter carefully.
- Using the optical readout, set the microscope cross hair on the reading line specified for the gravity meter. If the reading line is not known, assume a reading line position midway between the beam stops. With the gravity meter nulled at the above optical reading line, adjust the zero of the electronic beam readout microammeter to make it read zero. Use the electronic beam readout in all further adjustments.
- Keeping the cross-level in the level position, tilt the longitudinal level 2 small scale divisions on the longitudinal level microammeter, first in one direction and then in the other. Note both the magnitudes and displacements of the corresponding beam microammeter. Repeat several times to be sure of the results.
- If the beam microammeter moves to the right (upscale in the microscope) the same amount for each tilt, then the chosen reading line is correct.

- If the reading line is not correct, proceed as follows. Make the previously described 2-division long level tilt by lowering the side of the gravity meter which has a single leveling screw. If the beam microammeter then moves upscale more than it does with the opposite tilt, the assumed reading line is too high (too far to the right on the beam microammeter). Otherwise the reading line is too low.
- Shift the reading line 2 microammeter divisions in the direction determined above and repeat the above step. Continue shifting the assumed reading line position until the correct position is found or passed. This procedure will determine the correct position for the reading line within 2 microammeter divisions or better. Continue adjusting until the reading line is determined as well as possible. After this has been done, reset the zero of the beam microammeter to make it read zero at the correct reading line.

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## REPAIR

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If there is a need to replace the pendulum level in the field, care must be exercised. If the wire connected to the side of the level must be resoldered, over heating can damage the interior of the level. The heat should be applied to the tip of the wire lug. A heat sink should be located on the lug between the level housing and heat. A small pair of needle-nose pliers should be adequate as a heat sink.

There is a small chance that a level might stick to one end of the range of travel. A very light tap of the finger on the meter lid will free the pendulum. When the meter is next at *L* and *R* for servicing, the sticking level will be cleaned as part of the standard servicing.

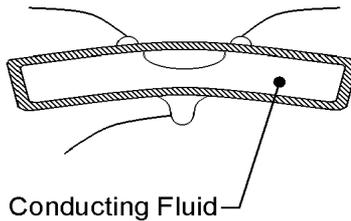
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## ELECTRONIC LEVELS (LIQUID TYPE)

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These levels are a compromise. They are low in cost and they overcome the first two disadvantages of the spirit bubble levels. Optimum damping for a level would be about 70% of critical. The pendulum levels have optimum damping. At thermostated temperature, the liquid electronic levels are damped to approximately 40% to 50% of critical.

They consist of a bubble inside a curved glass tube. The fluid is a conductor and there are electrodes in the tube to sense the change in resistivity as the bubble moves along the curved tube. Since they are located just above the sensor in a thermostated area, they are not affected by ambient air temperature or sunlight.



## CAPACITANCE BEAM POSITION INDICATOR (CPI)

The CPI was mentioned in the Options section of this manual. It is the most popular and important option. It senses the position of the beam with greater accuracy and less fatigue than the microscope. It is a capacitance bridge with a capacitance plate on the beam and a fixed plate above the beam and another fixed plate below the beam.

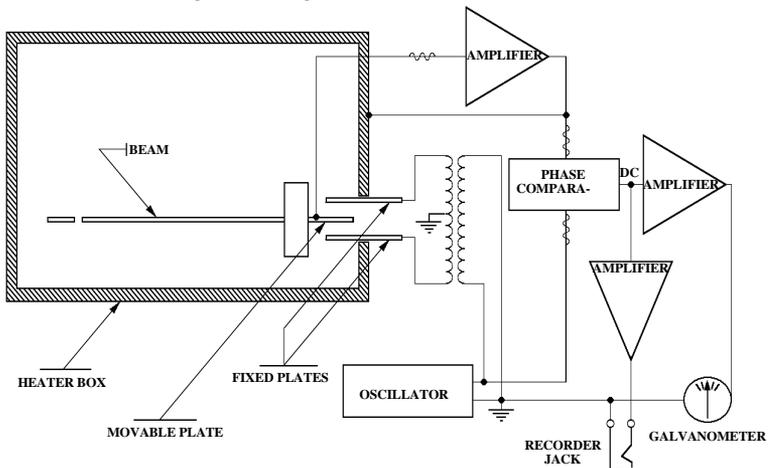
The electronic card of the CPI fits into a pocket on the outside of the meters heater box. The card has had three main types during its evolution: discrete components card, Hybrid card and N-card.

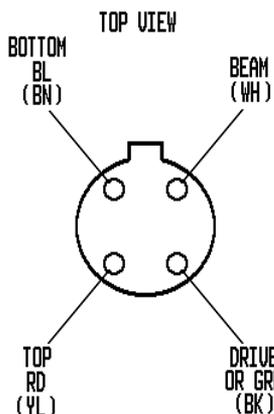
Discrete component cards were used from about G-130 (1967) and the first Model D meters until approximately G-375 and D-10. Hybrid cards were used from then until G-472 and D-25. The Type N card was then introduced.

No Model G meters before G-100 had a CPI as original equipment. Their type of card depends on when they were retro-fitted with CPI.

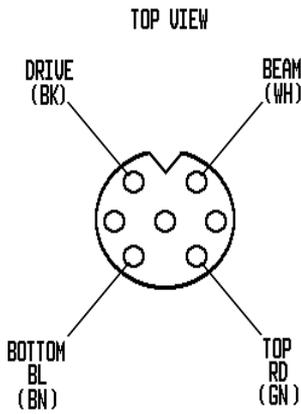
When the Hybrid card is damaged by reverse polarity of the power supply, it is not repairable. The N-card is usually easy to repair.

The following two diagrams show some of the details of the CPI.

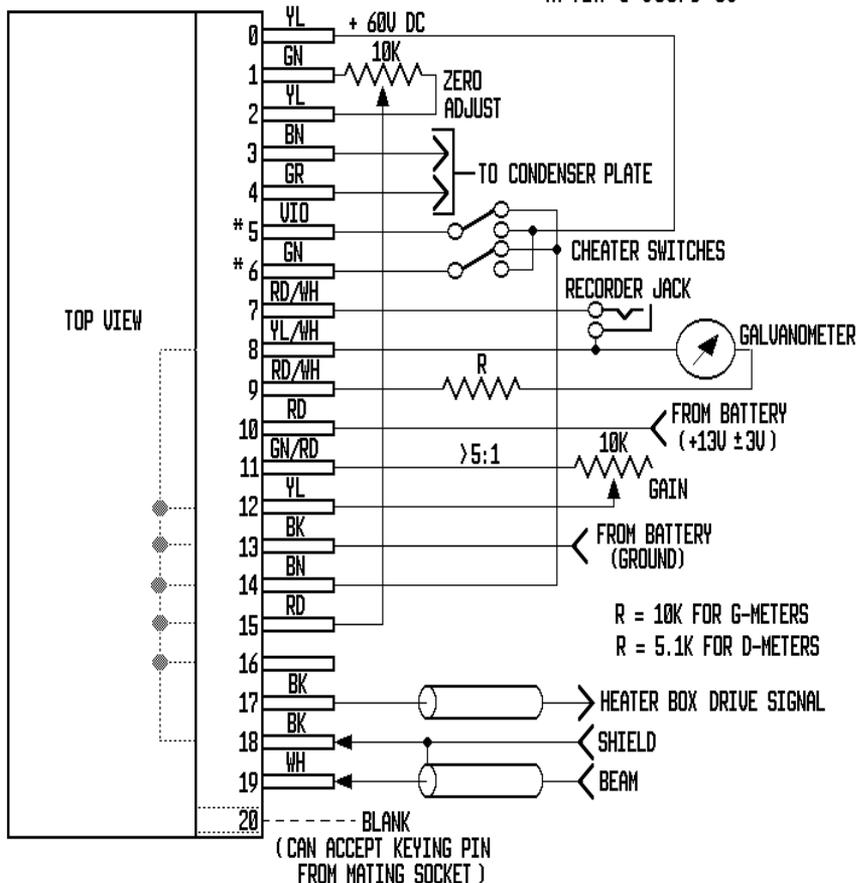




STATHAM CONNECTOR  
BEFORE G-500/D-35



MICROTECH CONNECTOR  
AFTER G-500/D-35



\* PINS 5 & 6 ARE TIED TO PIN 14 IF THE CHEATER SWITCHES ARE NOT USED

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## ADJUSTING GALVO GAIN & ZERO

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**T**here is a small rectangular black cover plate on the far side of the black lid. Beneath it are two variable resistors. One adjusts the gain of the galvo and the other sets the zero position of the galvo. Common gain settings for the Model G are 100 microGals per large galvo division for regional surveys and 50 microGal for more detailed surveys. For Model D, typical settings are 40 microGals for average work and 20 or even 10 microGals per large division for high precision work.

Whenever the galvo gain is adjusted the galvo zero position must be reset. Null the meter with the microscope. When the cross hair is on the reading line, turn the zero variable resistor until the galvo pointer is on the exact center of the dial.

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## GALVO HIGH-LOW SWITCH

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**S**ome meters have an extra switch on the black lid. It allows switching from low galvo sensitivity (gain) to high sensitivity. On most meters the galvo is set so one eyepiece division is equal to one or two galvo divisions. With this switch, the meter is usually set so one eyepiece division equals two galvo divisions on low and five divisions on high. On most meters with the switch, the gain may be set as high as 10 microGals per galvo division.

To set the sensitivity, place the switch in the high position. Set the sensitivity as outlined in the manual, to the desired level. Remember to reset the zero position after any change of galvo sensitivity. Then with the gain switch in the LOW position, adjust the HI-LOW gain pot (variable resistor) to the desired level. This gain pot is just a resistance in series with the galvo.

With the electrostatic nulling option, changing the galvanometer sensitivity will alter the time constant of the feed-back loop and increase the amount of galvanometer jitter induced by the electrostatic nulling system.

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## REPLACING THE GALVANOMETER

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**M**eters before about G467 and D27 have round galvanometers. These are obsolete and new replacements are not available. Occasionally a used one becomes available. There is a short pair of wires on these galvos and an electrical connector. Exchanging them is straightforward.

When the round galvanometer became obsolete, it was replaced with the rectangular galvanometer. These are less satisfactory. A single drop of rain can be drawn into the galvo by surface tension. Condensation on the working surfaces can cause the galvo to be sluggish and inaccurate. After the galvo dries it may work satisfactorily. However, there is a chance that subsequent corrosion may cause the galvo to fail at some time in the future. A very small line of clear silicone rubber between the clear plastic galvo cover and the black lid will give some protection from water but cause some bother whenever the black lid must be removed.

Replacing the rectangular galvanometer requires a soldering iron.

- Disconnect the 12-volt power.
- Remove the black lid, as described earlier.
- Pull the galvo upward out of its pocket in the meter insulation.
- There are two soldering lugs at the base of the galvo. One has a small resistor covered with shrink tubing.
- Make a note of the wire colors and the orientation of the galvo.
- Unsolder the wire that does not have the resistor
- Carefully remove the shrink tubing from around the resistor.
- Unsolder the resistor from the lug.
- Resolder the first wire to the new galvo lug and the resistor to the other lug, paying attention to the orientation of the galvo and wire colors.
- Wrap the resistor with a little tape or shrink tubing.

- Replace the galvo in its pocket.
- Replace the black lid.
- Connect the 12-volt power
- When the meter comes up to thermostated temperature, verify the galvo moves in the same direction as the beam image.
- Check the sensitivity and zero settings of the galvanometer.

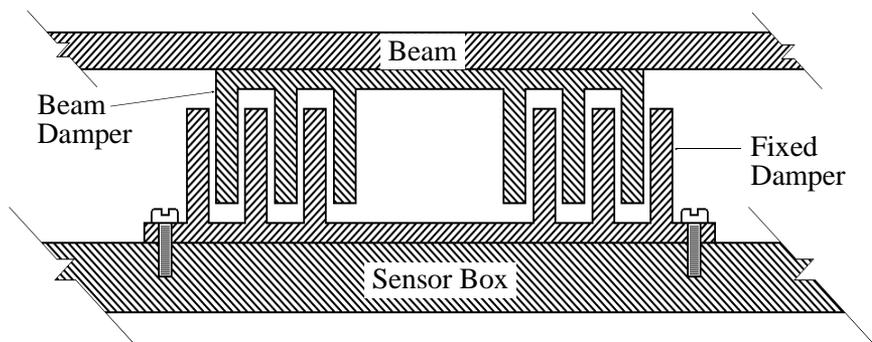
Development is in progress of a liquid crystal display (LCD) that will replace the galvo as well as perform other functions.

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## VARIABLE DAMPING

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**N**ormal beam damping is about 70% of critical damping. The variable damper allows normal beam damping to be increased by a factor of 25. Normal damping is accomplished by two air dampers located on the bottom of the beam. There is a small damper near the back of the beam and a main damper near the front or mass end of the beam. Each damper consists of a set of concentric inverted cups on the bottom of the beam and another set of concentric cups fixed to the bottom of the sensor box. The beam cups and fixed cups interfinger. To pull the cups apart, air must flow up and down several times to reach the inner cup of the damper. Meters with variable damping have extra cups in the main damper and a simple rotary valve to open some of the cups when full damping is not desired.



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## ADJUSTING DAMPER

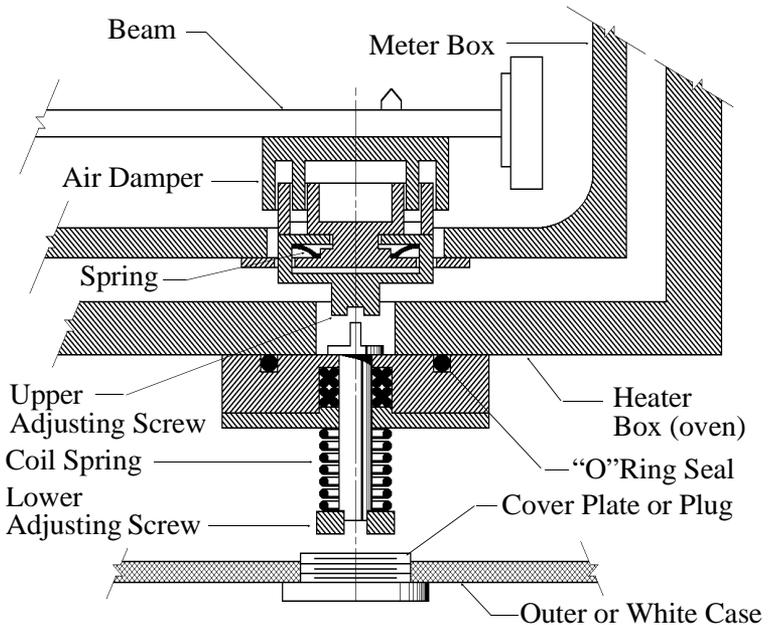
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To adjust the damping, turn the meter on its side and remove the nylon screw on the underside of the white case. Some early models have an aluminum cover plate.

The screwdriver slot of the lower adjusting screw will then be visible. Note on the drawing that a coil spring keeps the lower screw in the downward position. With a screwdriver in the slot of the lower adjusting screw, push inward and engage the slot of the upper adjusting screw. For maximum damping the screw is turned clockwise about one eighth revolution (three quarters of a turn on some earlier meters). A very small amount of torque will be

required to turn the adjusting screw and a positive stop can be felt. As the screwdriver is removed, the coil spring should force the lower adjusting screw away from the upper screw and back to its original position.

For minimum damping (that of a standard gravity meter), the above procedure is reversed. When maximum damping is engaged the damping will be approximately 50% that of the *L and R* underwater gravity meter and about 25 times that of a standard land meter.



## ELECTROSTATIC POSITIONER

So that faster readings may be obtained when maximum damping is engaged, an electrostatic beam positioner is provided. The beam positioner switches are the momentary switches located on the operator side of the top of the gravity meter. These switches are also called "cheater" switches. To move the beam (crosshair or galvo) upscale, the switch on the right is pressed, to move the beam downscale, the switch on the left is pressed. The beam is positioned at the reading line with a touch of the left or right switch. If the crosshair then drifts to the left, the nulling dial must be rotated clockwise to a higher reading. Again the beam is positioned at the

reading line and the process repeated. The slower the crosshair moves away from the reading line the less the meter is away from the null (balanced) reading. The beam positioner will also operate when the meter is set for standard damping but will generally not be needed.

A solid state power supply provides the voltage (about 60 volts) for the beam positioner.

In using the beam positioner, it is important to keep in mind that the electrostatic force can only overcome approximately 75 milligals of spring tension. therefore, if the meter is set more than 75 milligals from the value of gravity, the beam positioner will not move the beam. It will then be necessary to use the spring tension adjustment (nulling dial) in conjunction with the beam positioner initially to get the meter in range of the reading. It may be necessary to tap the meter gently if the beam is slightly sticking on a stop. This may help avoid an excessive amount of dial turning.

For the gravity meter to operate properly it is important that the lower adjusting screw is down and away from the upper adjusting screw (See the cross sectional view).

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### **CAUTIONS:**

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- Too much force on the damper adjustment can shear set pins and render the gravity meter inoperative.
- After changing the damping, be sure the lower adjusting screw has moved down to its original position.
- Make sure the beam positioning switches do not become “stuck” in the down position. Your results will be grossly in error and useless.
- Dust, dirt and moisture are major causes for failure of the beam position switches.
- When reading the gravity meter, be aware of these switches. Do not accidentally depress them.

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## REPLACING THE CHEATER SWITCHES

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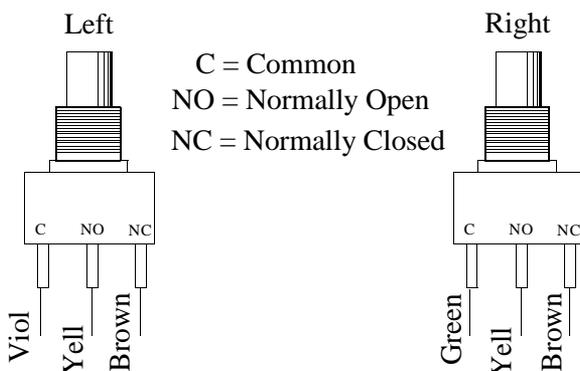
**M**eters with variable damping have two switches on the black lid on the side toward the operator. They are for electrostatically pushing the beam to the null position. These switches can fail when subjected to excessive dust, mud or water. If this occurs in a location where replacement is not available, it is possible to remove the switch, and connect the wires in such a way that will allow the meter to function.

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### TO SERVICE THE SWITCHES

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- Disconnect the 12-volt power.
- Remove the black lid.
- Remove the switch by removing the two screws on the outside of the white box that hold the switch bracket.
- Pull the switch and bracket upward to expose the wires.
- Make a note of wire colors and position.
- Unsolder the wire.
- Follow the diagram.



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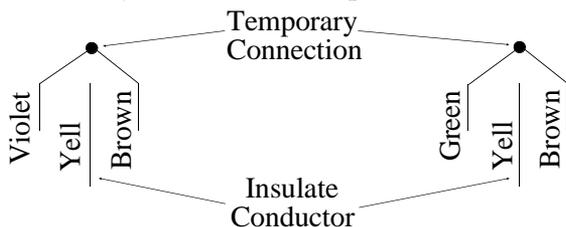
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## CHEATER SWITCH REMOVAL

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To remove the cheater switch temporarily, connect the brown wire to the green or violet wire, depending on which switch is removed. Do not connect the yellow wire to any other wire. Insulate the conductor of the yellow wire with tape.



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## REPLACING THE NULLING COUNTER

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The nulling counter is like an odometer on a car. Failure is very rare. If it does occur, it is best to send the meter to *L and R*. However, if this is difficult, it can be replaced in the field.

**NOTE:**

*This procedure can cause major damage to the instrument if the counter synchronization with the measuring screw is lost. That is the reason the two counters must be set to the same value and the stalk shaft not turned while the counter is not engaged.*

- Disconnect the 12-volt power.
- Remove the black lid.
- Make note of the counter reading.
- Remove the dacron insulation from around the counter and the upper part of the nulling stalk.
- Set the new counter to the exact same reading as the old counter.
- Remove the two brass nuts and washers on the side of the nulling stalk opposite the counter.
- Slide the counter away from the stalk until the gear and the two studs clear the stalk.
- Do not turn the vertical shaft.
- Replace the old counter with the new.
- Note that the holes for the counter studs are slotted. This will allow for adjustment of the gear mesh.
- While tightening the nuts, feel the mesh of the counter gear with the stalk gear by turning the vertical shaft a small amount. The mesh should not be too tight or it will cause excessive bearing wear nor too loose or it will cause excessive gear wear.

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## REPLACING THE HEATER CONTROL MODULE

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**P**rior to mid 1966, a mercury thermostat controlled the heater. From G-125 and D-1 onward, a thermistor bridge has been used. Most of the early meters with mercury thermostats have been retrofitted with thermistor bridges and their mercury thermostats removed.

The heater control module is a brown or black cube about 2x2x2.5cm in size. It has two electrical connectors and red LED light. It is located under the Dacron insulation and rests atop the meters inner aluminum lid. Replacement is straightforward.

- Disconnect the 12-volt power.
- Remove the black lid.
- Remove enough Dacron to expose the module.
- Replace the module.
- Temporarily connect to 12-volt power to verify the red LED lights.
- Replace the Dacron and black lid.
- Connect the 12-volt power.
- Watch the thermometer and verify the temperature comes up to the correct amount.

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## CHANGING OPERATING TEMPERATURE

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### THEORY

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The temperature control system associated with the *Thermistor-Transistor Heating Circuit* is solid state. A temperature-sensing thermistor bridge operates an amplifier and power transistor to control the current to the heating element.

The thermistor bridge contains two legs of thermistors and two legs of balancing resistors. One of the resistor legs normally consists of one  $10\text{k}\Omega$  resistor. This leg is known as the “fixed-leg”. The second resistor leg, with a resistance of  $10\text{k}\Omega \pm 2\text{k}\Omega$ , is known as the “selected-leg”.

In our laboratory the operating temperature is set by choosing the resistor within the selected-leg. It is, therefore, necessary to change the selected-leg resistor(s) to change the temperature of the instrument. Temperature is an inverse function of resistance. A resistance change of  $800\Omega$  results in an approximate inverse temperature change of one degree centigrade.

Because the gravimeter has an optimum operating temperature, we do NOT recommend changing the temperature, however, under extreme environmental conditions, operating at the optimum temperature may result in erratic readings and drifts. In cold conditions this would be caused by the heater not being able to provide enough heat. In hot environments this would be caused by the instrument heating above the optimum temperature. (This would be more noticeable in extremely hot climates than in extremely cold climates.) Temperature adjustment of  $\pm 5^\circ\text{C}$  or more should be avoided if possible. There are field techniques described in another section of the manual that can reduce the effects of extreme ambient air temperatures. These other techniques should be exhausted before considering a change in the operating temperature.

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**PROCEDURE**


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To change the operating temperature less than two degrees, it is necessary only to change the selected-leg resistance. (See exception below ) Remove the black lid of the instrument and enough dacron insulation to expose the heat control module next to the thermometer well.

Gently remove the selected-leg resistor(s) mounted on a green and yellow twisted pair of wires (green and red in some older meters). Remove power to the instrument when cutting or soldering any wires.

To decrease the operating temperature, add (in series) resistance at the rate of about  $1000\Omega/^\circ\text{C}$ . Resistors must be precision film type (RN-55D). Do not change by more than  $2000\Omega$  resistance.

To change the operating temperature more than  $4^\circ\text{C}$ , or if the desired instrument temperature is not within  $4^\circ\text{C}$  of  $50^\circ\text{C}$ , it is necessary to change the fixed-leg resistor *before* changing the selected-leg resistor. This fixed-resistor (normally  $10\text{k}\Omega$  or  $11\text{k}\Omega$ ) is changed to maintain the balance and equal thermistor sensitivity.

To change the fixed-leg resistor, remove power from the instrument and find the brown and purple twisted wires and components. Carefully cut away the outer tube of shrinkable tubing. There will be exposed one  $10\text{k}\Omega$  resistor (the fixed-leg resistor). Remove the fixed-leg resistor and replace it with one of appropriate value (see the table below). Resistors should only be RN-55D metal film. Use shrinkable tubing to cover bare wire and to form the outer tube shield.

<u>FIXED-LEG RESISTOR</u>	<u>DESIRED OPERATING TEMPERATURE (<math>^\circ\text{C}</math>)</u>
15k $\Omega$	40.1-44.0
12k $\Omega$	44.1-48.0
10k $\Omega$	48.1-52.0
9.1k $\Omega$	52.1-56.0
7.5k $\Omega$	56.1-60.0

At this stage, the selected-leg resistor(s) must be balanced. The resistance should be within about  $3000\Omega$  of the fixed-leg resistor. This is more or less a trial and error selection. Begin with a resistor equal to the fixed-leg resistor. Add resistance for a lower temperature; use less resistance for higher temperature.

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## GENERAL NOTES

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Because of resistor and thermistor tolerances, and because thermistor temperature-resistance curves are non-linear, the exact resistance is difficult to predetermine for a specific temperature.

It is sometimes necessary to “tune” the resistance in the selected-leg with one or two smaller valued resistors to get the exact desired temperature.

A few older Thermistor-Transistor Circuit bridges use two watt wire-wound resistors. These resistors are perfectly satisfactory but are larger than the precision film resistors now used.

For further information or assistance contact our laboratory.

**NOTE:** Whenever drastic operating temperature changes are made of more than a couple of degrees, the internal pressure/vacuum must be released. Between the gear box, the arrestment stalk, and the eyepiece stalk, there is a seal cap retained by three 2-56 screws. Loosen all three screws and lift the seal cap. After the temperature change has been made and the temperature stabilizes replace the seal cap and tighten the screws. Caution, be sure there are no dacron fibers on the seal cap nor on the mating surface of the gravity meter sensor lid. If the seal cap is left open, the inert dry gas may be lost from the inside of the meter. This voids the warranty.

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## BIMETALLIC THERMOSTAT

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A small sealed cylinder containing a bimetallic thermostat is located on the side of the heater box. It is in series with the heater wire. If the meter is about to overheat, the bimetallic thermostat will open the circuit and stop the heating before thermal damage can occur.

The most likely cause of the overheating has been the inadvertent reversal of the 12-volt DC power to the meter. This causes the heater control to command the heater to be on, regardless of the temperature sensed by the thermistor bridge. When the bimetallic reaches 69°C, it will open and the temperature will decrease. At some temperature the bimetallic coil will close, power will flow into the heater wires, the temperature will rise to 69°C and the cycle will repeat.

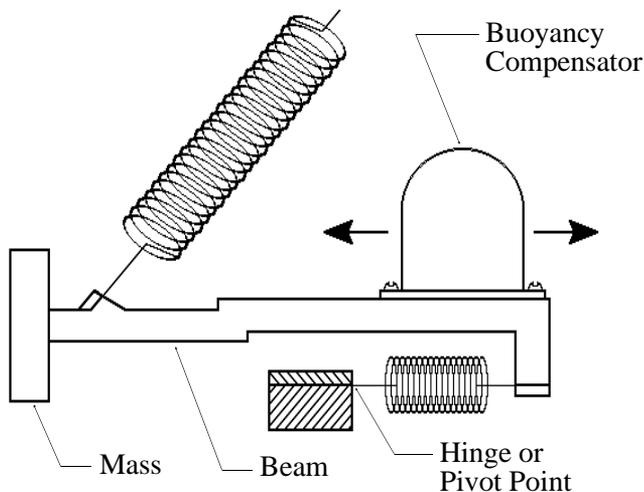
On meters with the AT0-3 fuse and reverse polarity protection, the AT0-3 will prevent the reversed 12-volt polarity current from entering the meter.

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## CHECKING THE METER SEALS

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The meter is sealed. This increases the accuracy of the meter. If the meter were not sealed, a change in atmospheric pressure would cause a change in the buoyancy of the beam mass and would give the false appearance of a change in gravity. In case one of the seals did leak, there is a buoyancy compensator on the meter's beam. It is a large fixed volume of light mass located in back of the beam hinge or pivot point. During construction of the meter, the compensator is positioned on the beam to remove at least 98% of the effect of atmospheric pressure changes, should a leak develop in the sensor enclosure.



If the sensor develops a leak, The compensator will allow an accuracy as good as other gravity meters in good working order. However, the accuracy will be less than optimal and less than desired for careful gravity observations.

On the average, seals begin to fail after eight to ten years. They become hard and brittle. *L and R* recommends “long term servicing” every eight to ten years. (See the section on servicing.)

It is easy to test for a seal failure if a large change in elevation is available. A change in elevation will cause a change in atmospheric pressure. Taking a series of gravity readings after a recent

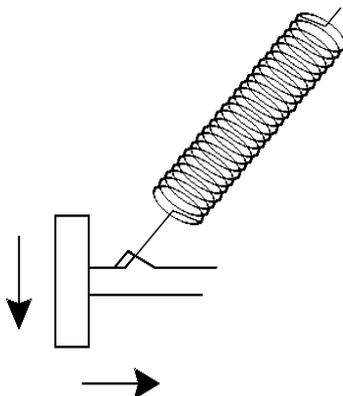
change in the meter's elevation will be revealing. As air leaks into or out of the meter, there will be a change in the readings. The rate of this change will depend on the size of the leak, the magnitude of the recent change in ambient air pressure and how accurately the buoyancy compensator was set during construction of the meter. Remember, at any one location, gravity is changing due to earth tides. This change is at most one microgal per minute. If observations are made every two to five minutes, corrected for earth tides and plotted against time, the resulting curve should be fairly straight and horizontal. If it is not horizontal, it is probable that a meter seal is leaking.

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## CHECKING FOR MECHANICAL HYSTERESIS

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When the beam is clamped, it is pushed down against the adjustable bottom stops. These are set to limit the travel of the beam to  $7\frac{1}{2}$  small optical divisions of downward travel from the null reading line. Clamping stretches the main spring, compared to its length when the beam is unclamped and at the reading line. There is a mechanism in the meter that pushes the beam backwards as it is clamped and that “push” is exactly the amount necessary to shorten the main spring back to its length when it was unclamped and at the reading line.



DUAL MOVEMENT OF BEAM CLAMPING

Were it not for the dual movement of the clamping mechanism, the spring would be stored elongated. It would relax in this stretched position and when unclamped for the next reading, reverse creep would occur. It would take ten to twenty minutes for the meter to stabilize for a reading.

The meter is carefully adjusted during construction. If needed, it is also adjusted each time it receives “standard” servicing. Only a severe blow to the meter will cause the hysteresis compensation to move out of adjustment.

An observant meter reader can notice when the meter is working properly or when it takes too long to “creep” into final null position. Remember that gravity is changing due to earth tides by

up to one microGal per minute. This should not be mistaken for mechanical hysteresis. A computed table of earth tide values will allow the observer to separate the earth tide changes in meter response from the hysteresis changes. For first time testers of meter hysteresis, it simplifies the observation if earth tides are not changing. Such a time can be selected by looking at a table of earth tides.

A more detailed and lengthy test for mechanical hysteresis is performed at *L and R* during “standard” servicing.

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## DOUBLE OVEN

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The purpose of this option is to improve the accuracy of field observations, especially in cold climates and to improve the accuracy of stationary observations when the land meter is used to record earth tides.

The double oven option was introduced in 1991. The meter's standard oven is placed inside an outer oven. The space between the two ovens is rigid urethane thermal insulation. Between the outer oven and the meter box is more urethane insulation. The inner oven is thermostated at its regular temperature (usually between 50°C and 56°C) and the outer oven is thermostated at about 38°C.

The configuration of early models is a cylindrical meter box made of light high-strength aircraft plastic, 30 cm in diameter and 30cm tall. The outer oven is cylindrical aluminum 22 cm in diameter. The black lid is designed to be water resistant.

Electronic levels and CPI are required for this option. The microscope viewer of beam position and the spirit levels are retained within the outer oven for use during factory servicing, but are not visible during normal use. A special baseplate is available with larger diameter, but with three feet in the same position as the standard baseplate.

Because of the careful selection of materials, the meter installed in the double oven option does not weight much more than the standard configuration.

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## STANDARD CHARGER/BATTERY ELIMINATOR

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**T**here have been four major designs of the *L and R* charger/eliminator:

Early chargers were for NiCad batteries: These were provided as original equipment for meters up to G-323 and D-12 or about 1973. Almost all of these have been replaced by newer designs and the NiCad batteries replaced with gelatin stabilized lead-acid batteries.

Next were the early gel-cell battery charger. They are distinguishable by an amp meter, a red power indicator lamp and a single red LED lamp that indicated when the meter was receiving heating power. These chargers were built in 1973 and 1974 and many are still in service.

The more recent charger is similar in appearance to the above, except there are two LED's: one to indicate when the meter is receiving heating power and one to indicate when the battery is receiving more than a trickle charge. These were built between 1974 and 1989.

The present charger no longer has an amp meter. This was the most expensive component on earlier chargers and the part most frequently damaged by mechanical abuse. The amp meter has been replaced by an LED ten-element colored bar display.

When using any of the gel-cell battery chargers, if the AC power source is intermittent, the meter will not go off heat as long as the charger has both a battery and the meter connected to it. When AC power is lost, a relay changes position. It disconnects the battery from the charging circuit and connects it to the gravity meter. When AC power returns, the relay returns the battery to its original charging position and the gravity meter to the regulated 12-volt power.

The chargers are designed to operate from 115 or 230 volts  $\pm 10\%$  from 47 to 420 Hertz AC power. The 115/230 switch is on the face of the one and two LED chargers. It is internal on the new

ten-element LED charger. The charger may be damaged if it is set for 115 volts and connected to 230 volts. The charger will not function properly when set for 230 volts and connected to 115 volts.

The circuit breakers within the chargers can be tripped by a sharp blow as well as excess current. A blow may occur during transportation. If the charger is not working after shipment, first check the breakers. There are two breakers, one on the incoming AC power line and one on the outgoing charger line. Both are 1.5 amp rating. To reset the breakers:

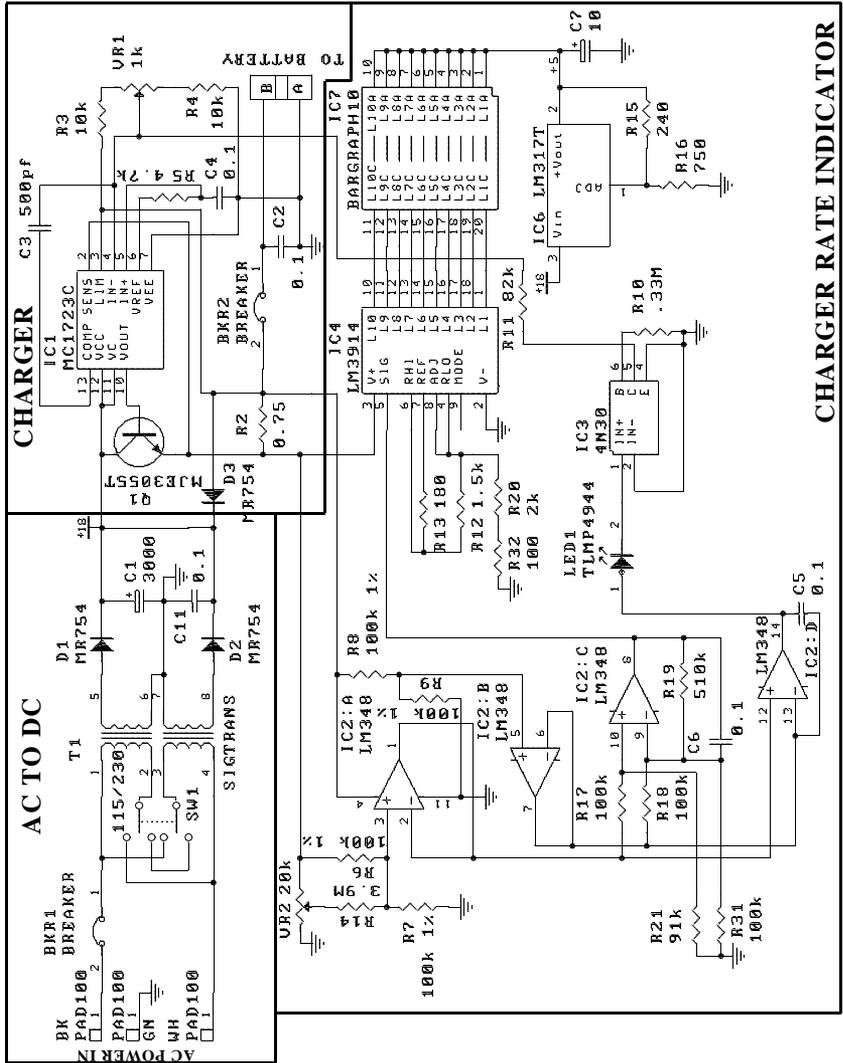
- Disconnect from the AC power
- Turn the charger upside down
- Remove the bottom of the charger (four screws)
- Press in the plungers of the two breakers
- Replace the charger bottom.

If the receptacle for the bottom screws are loose, they may be tightened by pressing the aluminum together a small amount with pliers.

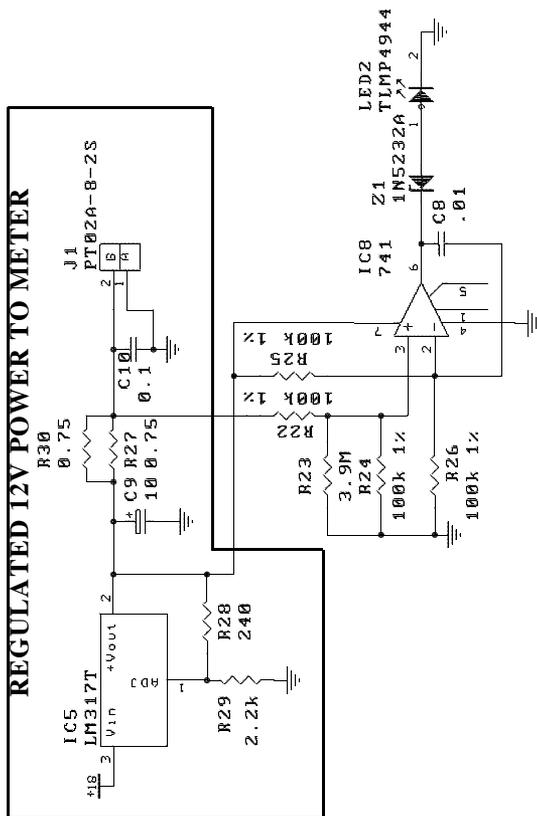
Chargers before 1987 had a separate battery charging cable with a round Amphenol 3-pin fitting at the charger end of the cable. When disconnecting a battery from the charger, this cable always should be disconnected at the battery end first. If the other end of the cable is disconnected first, there are two exposed pins with unfused 12-volt power across them. Severe damage could occur if these were shorted by brushing across a metal surface.

Chargers built after 1986 (with nondetachable charging cable) have a small modification which provides smoother power for those meters using the electrostatic nulling options when their gravity meter is plugged into the charger/eliminator. Earlier charges that have had this modification can be identified by opening and examining the PC board. The modification can be identified by two 0.75 ohm resistors in parallel located close to the relay, or by the small XREG label on the bottom of the charger housing.





TEN-ELEMENT LED CHARGER/ELIMINATOR  
SHEET 1 of 2  
(1989 through PRESENT)



TEN-ELEMENT LED CHARGER/ELIMINATOR  
 SHEET 2 of 2  
 (1989 through PRESENT)

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## HIGH SPEED CRANK

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**T**he high speed crank can expedite gravity reading when there are large gravity differences between gravity stations. It is a small cylindrical gear box with a ratio of 9.5 to 1. There is a small crank at the top for turning while the housing is held by two fingers. At the bottom is a yoke with two pins that fit into matching holes in the top of the meter's nulling dial.

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### OPERATION

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To use the crank simply place it on the top of the nulling dial, matching the two holes in the dial and the two short pins on the gear box.

We strongly urge the operator to use discretion in the rate of speed the dial is turned as it is possible that the life of the counter may be shortened if the dial is rotated too fast. Also, caution should be exercised when approaching the end of travel of the counter (0000.0 and 7000.0 for the Model G and 0000.0 and 2000.0 for the Model D).

The operator will prefer to use the device to bring the counter to an approximate gravity reading, then lift it off the dial and complete the final gravity reading in the usual manner.

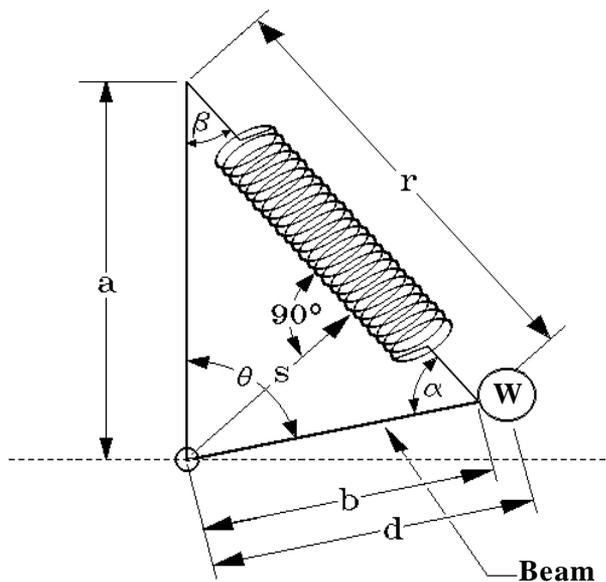
The device is a precision product with high quality gears and bearings throughout. Care should be taken to protect it from dust and dirt as much as possible and to handle it carefully. Its usefulness can be decreased by dropping it and bending the shafts or housing.

**PHYSICS OF THE SENSOR**

In the early days of earthquake seismology, long period horizontal motions could be measured with the horizontal pendulum seismograph. As the axis of rotation became closer to vertical, the period became longer. Theoretically, if the axis is vertical, the period is infinite.

Dr. Romberg posed the question to his student, Lucien LaCoste, how to design a vertical seismograph with the characteristics as good as the existing horizontal pendulum seismograph.

In the illustrated suspension, there are two torques: gravitational and spring. If these two torques balance each other for any angle of the beam, the system will have infinite period. The smallest change in vertical acceleration (or gravity) will cause a large movement.



The torque due to gravity is:

$$T_g = Wd \sin \theta$$

Where  $W$  is the mass and  $d$  is the distance from the mass to the beam's hinge.

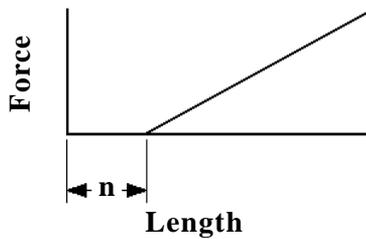
The torque due to the spring is the product of the pull of the spring and the spring's lever arm,  $s$ .

$$s = a \sin \beta.$$

The length of the spring is  $r$  and by the law of sines:

$$r = \frac{b \sin \theta}{\sin \beta}$$

If the spring constant is  $k$  and the length of the spring without force is  $n$ , The spring force is illustrated by this graph.



The torque due to the spring is then:

$$\begin{aligned} T_s &= -k(r-n)s \\ &= kns - krs \\ &= kns - k \frac{b \sin \theta}{\sin \beta} a \sin \beta \\ &= kns - kab \sin \theta \end{aligned}$$

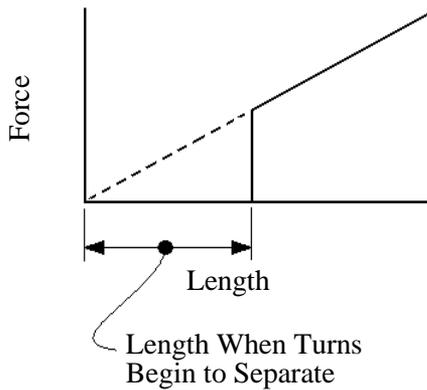
The total torque is:

$$\begin{aligned} T_o &= T_g + T_s \\ &= Wd \sin \theta + kns - kab \sin \theta \\ &= kns + (Wd - kab) \sin \theta \end{aligned}$$

This equation would yield zero torque and would be satisfied for all angles of  $\theta$  if:

$$n = 0 \quad \text{and} \quad Wd - kab = 0$$

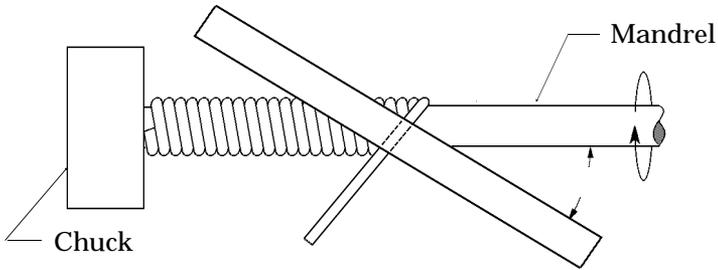
For  $n$  to equal zero, we must have a “zero length spring”. That is, a spring whose force-length graph passes through the origin or, at least, points toward the origin. The turns of a helical spring of zero unstressed length would bump into each other before the spring actually reached zero length. By making a helical spring whose turns press against each other when there is no force on the spring, a “zero length spring” can be made.



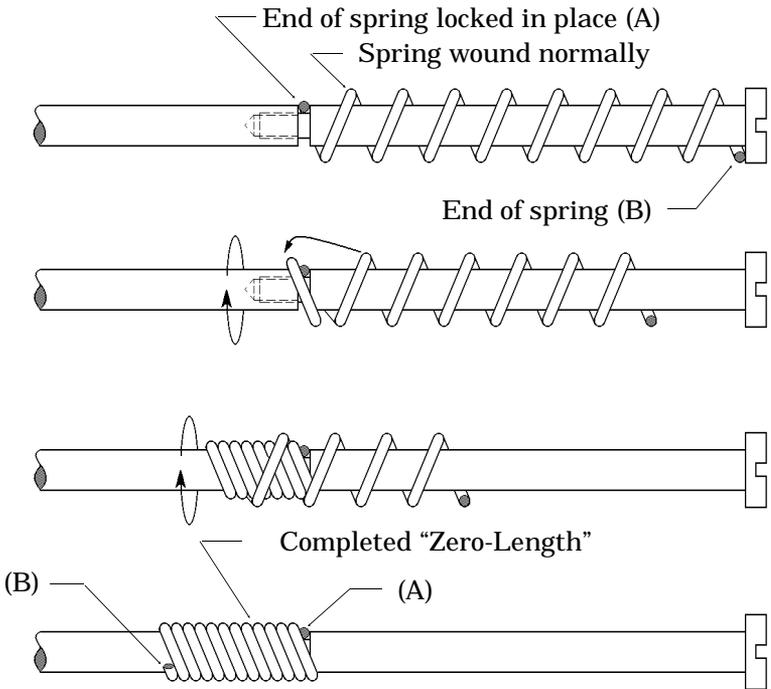
# ZERO LENGTH SPRING

There are several ways to make a zero length spring. A simple zero-length spring is a flat spiral spring. The mechanical properties of a spiral spring are not as convenient as a helical spring.

To make a zero-length helical spring, the spring wire can be wound onto a mandrel. As the wire is wound, it can be twisted.



Another method is to hold the wire at an angle and with tension while winding it on a rotating mandrel.

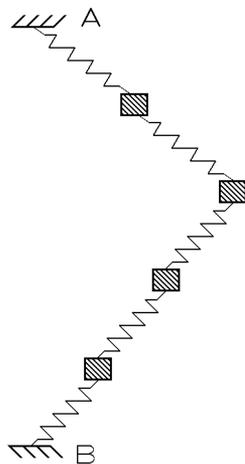
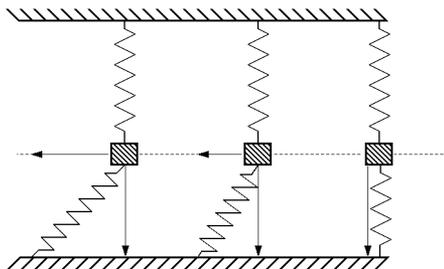


Still another method is to "turn the spring inside out".

The actual spring used in the *L* and *R* meters are “negative-length”. The spring wire is large enough and stiff enough that the spring would not act like an ideal spring if the spring were to be clamped at both ends. Thus, a very fine but strong wire is attached to the top end of the spring and another to the bottom of the spring. The top wire is clamped to the lever system and the bottom wire is clamped to the beam. The effective length of the spring is the combined length of the helical spring and the two fine wires. That combination is “zero-length”. The helical spring by itself is “negative-length”.

## **INSENSITIVITY TO LATERAL VIBRATIONS**

An important feature of the zero length spring suspension is its insensitivity to longitudinal and transverse vibrations (Harrison 1960, LaCoste 1967). Consider the spring to be made of identical masses with segments of weightless zero length spring between the masses. The top end of the spring is attached to A and the bottom to B. Since the spring segments are zero length springs, the forces each spring exerts on the adjacent masses are proportional to the spring length. Therefore, if the masses are equally spaced vertically, the vertical component of force exerted on each mass will be zero regardless of its horizontal position or horizontal motion. Also, the vertical components of force are proportional to the vertical component of spring length. (The vertical component of the force vector remains the same.) Also, the vertical force on A and B will be independent of any horizontal motions.



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**REFERENCES:**

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LaCoste, L., A new type long period vertical seismograph, *Physics*, Vol. 5, pp 178-180, July 1934

LaCoste, L., A simplification in the conditions for the zero-length spring seismograph, *Bull-Seismological Soc. of Am.*, Vol 25, No. 2, April 1935

Harrison, J.C., The measurement of gravity at sea, *Methods and Techniques of Modern Geophysics*, Interscience Publishers, NY, 1960

LaCoste, L., Measurement of Gravity at Sea and in the Air, *Reviews of Geophysics*, pp 477-526, Nov. 1967

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## CALIBRATION

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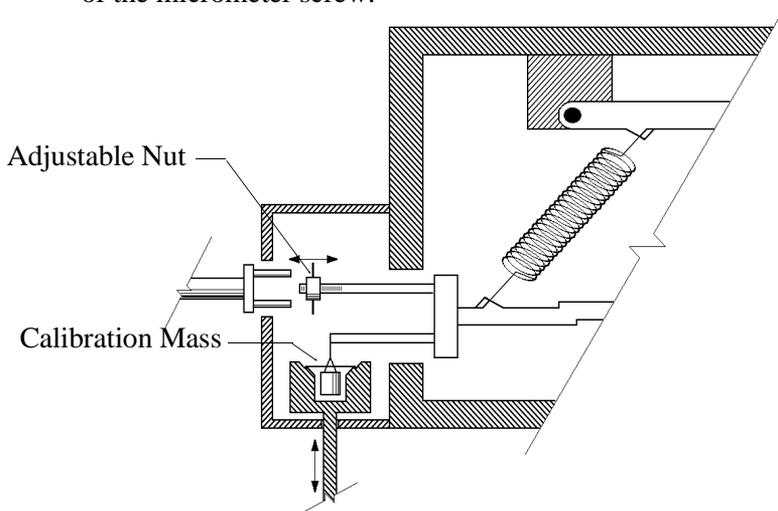
Calibration of the *L and R* gravity meter is accomplished in two states:

- First a relative calibration is obtained at numerous points over the entire range of the meter
- Then the relative calibration data are adjusted to absolute values by field measurements over a known gravity difference

Considering the geometry of the micrometer screw, lever system and suspension, the interval factor curve should be a third-order curve. There will be minute deviations from the ideal third-order curve due to imperfections in the lever system, gear box, micrometer screw and the jewel and pivot where the micrometer screw transfers its movement to the lever system.

To obtain the relative calibration curve, a fixture is attached to the beam mass.

- One part allows a calibration mass to be added and removed from the beam.
- Another part is a long thin screw with a small adjustable nut that allows the meter to be nulled in the lab over the full travel of the micrometer screw.



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## MODEL G RELATIVE CALIBRATION

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First, let us consider the Model G meter with manual observation of the relative calibration data. If the calibration mass corresponds to a change of about 200 milligals and the meter can be read to about 0.01 milligal, then the accuracy of obtaining a relative factor is about one part in 20,000.

The relative calibration is obtained as follows; first the counter is set to 0100.00 then:

- The range adjust nut is positioned so the beam is close to balance
- The counter is adjusted to an accurate null and the counter reading is recorded as an OFF reading
- The calibrating mass is added to the fixture on the beam, the beam is nulled and the counter reading is recorded as an ON reading
- The calibration mass is removed and a second OFF reading is obtained and recorded
- The calibration mass is added and a second ON reading is obtained and recorded.
- The counter is set 200 units higher (0300.00 for the second data point) and the above procedure is repeated at the new counter setting.
- The above procedures are repeated every 200 counter units through counter reading 6900.00.
- Four or five sets of readings are done at arbitrary positions on the screw as independent checks for factor repeatability

The data obtained from the above laboratory observations are processed as follows:

- The two OFF readings are averaged and the two ON readings are averaged for each set of observations

- Let
  - $C_{\text{off}}$  = average counter reading with the calibration mass removed
  - $C_{\text{on}}$  = average counter reading with the mass on the beam
  - $C_{\text{av}}$  = average counter reading  
 $= (C_{\text{off}} + C_{\text{on}}) / 2$
  - $M$  = approximate milligal value of the calibration mass (a constant)
  - $F_r$  = relative factor for  $C_{\text{av}}$   
 $= M / (C_{\text{on}} - C_{\text{off}})$
- A table of  $C_{\text{av}}$  versus  $F_r$  is generated from the observation data at the regular intervals.
- These data are plotted and a smooth curve is drawn through or close to the data points.
- The four or five sets of data taken at arbitrary points are reduced and these points are plotted on the above graph as a check of repeatability.
- A table is constructed by scaling seventy relative factors from the smooth curve through the data points. The values are taken for counter readings starting at 50, 150, 250, etc. through 6950. Name them  $F_{50}$ ,  $F_{150}$  etc.

In 1994 / 95 the above process was computer automated. It allowed repeated runs over the range of the meter, greater accuracy, automated plotting and automated generation of the calibration table.

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## MODEL G ABSOLUTE CALIBRATION

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To adjust the relative factors to absolute factors, the meter must be read at two or more gravity stations of known gravity difference. A single factor is determined. When the relative factors are multiplied by this single conversion factor, the final calibration table can be constructed.

The greater the gravity difference between the calibration stations, the greater would be the accuracy of the conversion factor. Since the relative factors were determined by the manual lab procedure with an accuracy of about one part in 20,000 or 22,000, then it would be appropriate to have similar accuracy in the determination of the conversion factor.

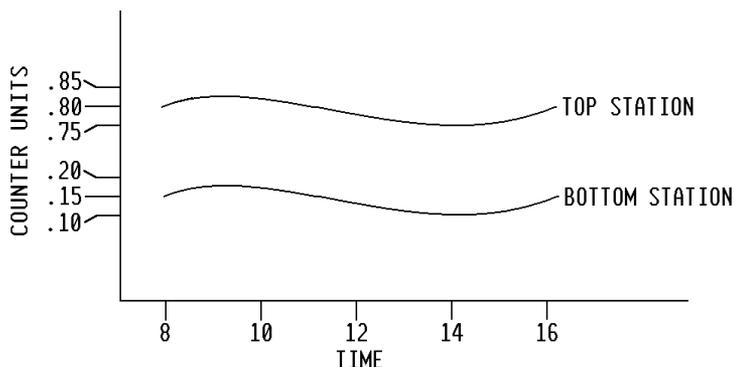
The meter reading can be resolved easily to 0.01 milligal. Therefore a calibration range of 200 or 220 milligals would be appropriate for accuracy consistent with the relative determinations.

The high and low calibration stations should be close to each other to allow the observations to be repeated several times for greater accuracy and a further field check of the meters repeatability under field conditions.

There is little elevation relief and only small gravity changes in the vicinity of the *L and R* laboratory. The closest large change in gravity is 1,000 kilometers to the west, Cloudcroft in the state of New Mexico. Two stations were established accurately. Their gravity difference is approximately 240 milligals.

The field procedure consists of alternately reading the meter at one station then the other station until at least four readings are taken at the top station and four at the bottom station.

The observations at both stations are plotted against times on the same graph. Typical scales would be 0.05 counter unit per centimeter (or 0.10 units per inch) and one hour per two centimeters (or one inch). Two smooth curves are drawn through the upper and lower station data points. The second curve is constructed parallel to the first.



The separation between the two curves is the average counter reading difference  $\Delta C$

If the gravity difference between the two calibration stations is  $\Delta G$ , then the absolute calibration factor over that range of the meter is:

$$F_{\text{abs}} = \Delta G / \Delta C$$

The calibration table for the Model G will consist of 70 calibration factors, one for each 100 counter units. The 70 relative factors determined earlier are multiplied by the absolute calibration factor;  $F_{\text{abs}}$ . The calibration factor to use for counter readings between 0000.00 and 0100.00 is  $F_{50} \times F_{\text{abs}}$  and the calibration factor for the readings between 0100.00 and 0200.00 is  $F_{150} \times F_{\text{abs}}$ , etc. If  $F_{50}$ ,  $F_{150}$  and  $F_{250}$  are 1.02031, 1.02038 and 1.02045 respectively and  $F_{\text{abs}}$  is 1.00321, then the first portion of the final table would be:

Counter Reading	Interval Reading	Cumulative Value
0000	1.02031	000.000
0100	1.02038	102.031
0200	1.02045	204.069
		206.114

See *Converting the Counter Reading to Milligals* in the first section of this manual.

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## MODEL D CALIBRATION

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The standard Model D has a counter range of 2000.00 and utilizes about 62% of the full range of the lever and micrometer system. This is a small enough portion of the third-order interval factor curve that, for most work, it can be approximated by a straight line. By minor adjustment within the meter, the slope of that line can be made almost horizontal. Thus a single calibration factor can be used for the full range of the meter.

Many of the meters between D1 and D109 have been assigned a single calibration factor. The meters were constructed and the factors determined at three points; one near 0100.00, one near mid range and one near 1900.00. These were determined at a field calibration range of 17 milligals located near the *L and R* laboratory. The meter was adjusted the approximate amount necessary to make the factor curve horizontal and returned to the calibration range. If the repeated tests at 0100.00, 1000.00 and 1900.00 indicated the calibration curve very close to horizontal, factors were also determined for counter readings near 0500.00 and 1500.00. If these also plotted on the horizontal line, a single factor was used for the meter.

On occasion, it was difficult to obtain a sufficiently straight line over the range of the counter or to adjust the meter so the interval factor line was horizontal. For those meters, a calibration table was prepared using a smooth curve through the five data points obtained at the Austin 17-milligal calibration range.

Starting with meter D110, the laboratory calibration was used to determine relative calibration factors, then the meters were field calibrated over the 240 milligal range to determine the factor necessary to convert the relative factor to absolute factors. A calibration mass equivalent to about 100 milligals was used and five points were measured to determine the calibration curve. Since the meters did not have enough range to be read over the 240 milligal field range, a temporary counter was placed on the meters to allow them to read a little below 0000.00 and a little above 2000.00.

Though this technique was an improvement of the calibration using the local 17-milligal field range, there were two disadvantages: the 100 milligal calibration mass covered too large a portion of the curve and could smooth some of the curvature and the special counter temporarily required for reading over the 240-milligal range was an inconvenience.

Beginning in 1989 (meter D-145) the laboratory calibrations use a 20 milligal calibration mass so the finer structures of the relative curve can be observed. Also, a new field station was installed along the 240-milligal range. It is approximately 160 milligals greater than the top calibration station at Cloudcroft. The standard counter can be used during field calibration over the 160 milligal range.

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## SELECTION OF CALIBRATION MASS

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There are two important factors in the selection of the calibration mass

- It should be large enough to give accurate data (considering the resolution of reading the meter) yet not so large that there would be significant curvature in the calibration graph over the OFF and ON span.
- The milligal value of the calibration mass should not be a value likely to display aliasing with any potential periodic errors in the meter.

The three most likely periodic errors in the meters are once, twice and four times per revolution of the micrometer screw. Selecting a calibration mass of approximately 220 milligals for the Model G gives three revolutions of the micrometer screw between the OFF and ON of the mass. Selecting a calibration mass of approximately 20 milligals for the Model D gives approximately six revolutions between the OFF and ON of the mass.

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## FUTURE IMPROVEMENTS IN CALIBRATION

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We know that the 240-milligal Cloudcroft calibration range value is slightly low. When the *L and R* meters are used on calibration ranges determined by modern absolute gravimeters, the values determined by the Model G meters are usually low by a few parts in 10,000. We hope to have an absolute meter observe gravity at the Cloudcroft range in the future.

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## HISTORY

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**T**he *LaCoste and Romberg* land gravity meter is based on the zero-length spring suspension. It allows an instrument to be very sensitive to small changes in gravity yet be very compact in size. The size of the basic element is a cube about 5 centimeters on each side. The concept of the zero-length spring was developed by Lucien LaCoste as a graduate student at the University of Texas in 1932. He and his faculty advisor, Dr. Arnold Romberg utilized the concept first to construct long-period vertical seismographs. Their instrument exceeded the period of existing instruments by an order of magnitude (LaCoste 1934).

While teaching at the University of Texas, Drs. LaCoste and Romberg developed the first two gravity meters during 1937 and 1938. The first weighed about 125 pounds (57 kilos) and the second about 100 pounds (45 kilos). Following spring semester in 1939, they took leave of absence from the university to develop and build gravity meters on a full-time basis.

The first production meters weighed about 75 pounds (34 kilos). About 45 were produced from 1939 through 1941. These meters were not barometrically sealed but were compensated for buoyancy effects of changes in air pressure. Their range was 100 milligals and they could be reset to work anywhere on the surface of the earth.

Next came the “25-pound” meters (11 kilos). They had a range of 200 milligals and about 80 were built between 1941 and 1957. There are a few of these that are still in service.

The geodetic meter was first built in 1957. These meters had a world-wide range without resetting. Eight were constructed using the 25-pound meter size and several of its parts. Their range was 6,000 milligals.

The meter was miniaturized and several improvements made. Thus the Model G meter was born in 1959. Since there were a few places atop the Andes not reachable by a 6,000 milligal range, the meters were designed to have a 7,000 milligal range. Their weight

was about 8 pounds (3.6 kilos). They were mounted in white fiberglass boxes with rigid foam insulation and their power consumption was reduced. They were sealed so barometric pressure changes could not effect the buoyancy of the mass. By the end of 1990, over 980 Model G meters were constructed and almost all are still in service.

The Model D meter uses many parts in common with the Model G: the same spring, beam and mass. However, there are two screws for nulling the meter: a coarse reset screw with worldwide range and a fine reading screw with a 200 milligal range. The first Model D was built in 1968 and over 170 were constructed by the end of 1990.

Both the Model G and Model D meters have undergone gradual evolution in design details. As sources of error or potential difficulties were recognized, solutions were gradually developed and implemented. Several changes are under way at this time. Recently linear electrostatic feedback nulling has been added as an option. Model D meters are available with both fine and coarse screws calibrated, allowing greater accuracy in geodetic work. Development is under way for an internal microprocessor to work in conjunction with electronic levels, shaft encoder, calibration factors in memory, temperature sensor, clock and a data memory.

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## A C K N O W L E D G E M E N T S

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**T**he *L and R* gravity meter has gone through some major changes and numerous minor changes during its evolution. Dr. LaCoste is the inventor and source of most of the important ideas that make the meter work so well. His partner, Dr. Romberg, was a resourceful contributor that worked at the firm till he was 85 years old.

Carroll Montigue's careful work on micrometer screws has been crucial and the patience and care of the several meter builders has been essential.

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# SHIPPING PRECAUTIONS

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**P**robably the largest risk to a gravity meter occurs when it is shipped. A few simple precautions can reduce the risk significantly. When the instrument arrives at your job, we want the meter to be in good operating order. When the instrument is returned to us for service, we want the cost to be as low as possible. Several times meters have been returned to us for minor repairs and major damage has occurred during return. Most of the risk during shipping can be reduced if you follow these suggestions:

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## TAPE CLAMP

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**P**lace tape around the clamping screw and the eye piece to prevent the clamp from vibrating loose or curious people from tampering with it.

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## RETRACT LEVELING SCREWS

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**R**etract the leveling screws until they are flush with the bottom of the meter.

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## I. D. INSIDE CASE

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**P**lace a business card or some identification inside the carrying case in case the box and its labels are damaged or separated in customs.

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## NO BATTERIES WITH METER

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**D**o not pack batteries with the meter. Acid has come out of them in hot climates. Also, minor damage could cause a short and incinerate a gravity meter.

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## KEEP LIGHT WEIGHT

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**D**o not pack anything heavy with the meter. Keep the "Special" shipping box as light as possible so people will tend to handle it with more care.

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## FOAM ATOP METER

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**P**lace a piece of foam rubber atop the instrument so it can't vibrate up and down inside the carrying case. Be sure there is nothing to rub on the instrument.

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## USE SPECIAL SHIPPING BOX

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**U**se the *L and R* designed shipping box for the carrying case. Plan ahead: if it has been lost or severely damaged, send for a new one. If the *L and R* box is not available, use a large cardboard container, well padded with SOFT foam rubber. A wood or metal box is not advisable as it does not absorb impact as well as cardboard.

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## FRAGILE SIGNS

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**I**f the large DELICATE INSTRUMENT sign is damaged or obliterated with labels or airbill envelopes, be sure to place a FRAGILE sign on the box. If a fragile shipment is not adequately marked, the insurance company may reject a claim for damages.

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## PACKING ACCESSORIES

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**P**ack the accessories in a separate box. Always place the batteries right-side up. Protect them and other accessories from damaging each other by using plenty of packing in a thoughtful way.

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## TELEPHONE

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**T**elephone the person the instrument is being shipped to and give the airbill number, the shipping company, and the expected arrival time. If the meter does not arrive, an early search can be initiated.

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## DOMESTIC

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**F**rom the US, return to : LaCoste and Romberg LLC, 4807 Spicewood Springs Rd., Bldg 2, Austin, Texas 78759, phone (512) 346-0077. Federal Express is preferred. Their phone is (800) 238-5355.

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## FOREIGN

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**R**eturn to: LaCoste and Romberg Gravity Meters, Inc., Austin, Texas USA, c/o Kuehne & Nagel, Inc., Austin, Texas, U. S. A. Be sure to attach to the outside of the box a certificate of “U.S. goods being returned for repairs”. An example follows.

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## RECEIVING SHIPMENT

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**U**pon receipt of a shipment, it should be inspected promptly and any damage should be reported at once. For an insurance claim to be valid, it must be reported within the limited time prescribed by the insurance company. Save the packing material to prove to the insurance inspector that the shipment was properly packed and adequately labeled.

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## SHIPPING BOX SELECTION

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**T**he proper selection of a shipping box and padding material can save much frustration, money and lost time. A soft box (cardboard for example) will crush and absorb much of the jar of a drop. A hard box (wood or metal) will transmit most of the jar of a drop to the inside of the box. If the packing within the box is dense (dense foam rubber, styrofoam or solid sprayed-in-place plastic) then the jar of a drop will be transmitted to the contents. Very soft foam rubber can absorb several times more jar than dense foam rubber.

When more than one item is in a single box, it is important to protect the items from bumping or rubbing against each other.

Don't even consider shipping the meter in the bare aluminum carrying case.

**WEIGHTS & DIMENSIONS**

**METER**

Length . . . . .	7 <sup>3</sup> / <sub>4</sub> inches . . . . .	19.7 centimeters
Width . . . . .	7 inches . . . . .	17.8 centimeters
Height . . . . .	9 <sup>7</sup> / <sub>8</sub> inches . . . . .	25.1 centimeters
Weight . . . . .	7 pounds . . . . .	3.2 kilograms

**BATTERY**

Length . . . . .	6 inches . . . . .	15.2 centimeters
Width . . . . .	2 <sup>5</sup> / <sub>8</sub> inches . . . . .	6.7 centimeters
Height . . . . .	4 <sup>5</sup> / <sub>8</sub> inches . . . . .	11.7 centimeters
Weight . . . . .	5 pounds . . . . .	2.3 kilograms

**CARRYING CASE**

Length . . . . .	9 <sup>3</sup> / <sub>4</sub> inches . . . . .	24.8 centimeters
Width . . . . .	16 inches . . . . .	40.6 centimeters
Height . . . . .	16 inches . . . . .	40.6 centimeters
Weight . . . . .	10 pounds . . . . .	4.5 kilograms

**METER W/BATTERY & CARRYING CASE**

Weight . . . . .	22 pounds . . . . .	10 kilograms
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## SHIPPING WEIGHTS & DIMENSIONS

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### BOX 1

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Length . . . . .	24 inches . . . . .	60.7 centimeters
Width . . . . .	16 inches . . . . .	40.5 centimeters
Height . . . . .	24 inches . . . . .	60.7 centimeters
Weight . . . . .	32 pounds . . . . .	14.8 kilograms
Volume . . . . .	5.33 cubic feet . . . . .	0.149 cubic meter

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### CONTENTS

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Meter  
 Carrying Case  
 Level Adjusting Tool  
 Spare Fuses  
 Spare Lamps (for older meters)  
 Manual

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### BOX 2

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Length . . . . .	26 inches . . . . .	66.0 centimeters
Width . . . . .	14 inches . . . . .	35.6 centimeters
Height . . . . .	10 inches . . . . .	25.4 centimeters
Weight . . . . .	21 pounds . . . . .	9.5 kilograms
Volume . . . . .	2.11 cubic feet . . . . .	0.060 cubic meter

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### CONTENTS

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Two Gel Type Batteries  
 Charger / Battery Eliminator  
 Power Extension Cable  
 Aluminum Baseplate  
 Recording Cable (if meter has CPI option)

**FOREIGN SHIPPERS DECLARATION  
COVERING THE RETURN OF UNITED STATES MERCHANDISE**

Required: When value of goods exceeds \$1,000.00 UScy

I, \_\_\_\_\_ DECLARE THAT THE ARTICLES SPECIFIED HEREIN ARE, TO THE BEST OF MY KNOWLEDGE AND BELIEF, THE GROWTH, PRODUCE OR MANUFACTURE OF THE UNITED STATES. THAT THEY WERE EXPORTED FROM THE UNITED STATES FROM THE PORT OF \_\_\_\_\_ ON OR ABOUT \_\_\_\_\_ THAT THEY ARE RETURNED WITHOUT HAVING BEEN ADVANCED IN VALUE OR IMPROVED IN CONDITION BY ANY PROCESS OF MANUFACTURE OR OTHER MEANS.

Marks	Qty	Model No.	Description	S/N	Value in U.S.\$
	One	Model G	Lacoste & Romberg Gravity Meter and Parts		

SHIPPED VIA \_\_\_\_\_ DATE \_\_\_\_\_

DATE: \_\_\_\_\_ SIGNATURE \_\_\_\_\_

TITLE \_\_\_\_\_

ADDRESS \_\_\_\_\_

U.S. Customs regulations, Sec 10, 1, revised as of October 1957 provides that shipments of returned U.S. Goods valued over \$1,000.00 requires foreign shippers declaration for FREE ENTRY into the United States.

Customer \_\_\_\_\_