

YSI MODEL 34 CONDUCTANCE-RESISTANCE METER INSTRUCTION MANUAL



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TABLE OF CONTENTS

	<i>Page</i>
GENERAL DESCRIPTION	
Fundamentals	1
Instrument Method	1
SPECIFICATIONS	2
CONDUCTIVITY CELLS	2
TEMPERATURE COMPENSATION	4
INSTRUMENT OPERATION	
Temperature Compensated Conductance Measurement	5
Non-Compensated Conductance Measurement	5
Resistance Measurement	5
Temperature Measurement	5
Recorder Output	5
Batteries	5
CONDUCTIVITY CELL OPERATION	
Conductivity Cell Hookups	
Standard Two-Wire	6
Shielded Two-Wire	7
Four-Wire	8
Shielded Four-Wire	9
Four-Wire Hookup for Four-Element Probe	10
Conductivity Cell Precautions	11
Special Measurement Conditions	
Small Sample Measurement	11
Reagent Grade Water Measurement	11
MAINTENANCE AND CALIBRATION OF CELLS	
Cleaning and Storage	12
Platinum Black Inspection	12
Replatinizing	12
Cell Calibration	12
APPENDICES	
A. Circuit Description	13
B. Warranty	13
C. Schematic	14
D. P.C. Board Layout	15
E. Conductivity System Accuracy Considerations	16
F. Temperature Correction Data for Typical Solutions	18

GENERAL DESCRIPTION

The YSI Model 34 Conductance-Resistance Meter is a field and laboratory instrument which presents direct, precise measurement of conductance, temperature, and temperature compensated conductance or resistance. Speed and reproducibility of measurement are enhanced because the necessity of manually balancing a bridge circuit has been eliminated. The circuit also accommodates a wide range of conductivity cell electrode-to-solution capacitance values with no need for a separate compensating capacitor.

Values are shown on a 3½ digit LCD display. A self-contained battery is kept charged automatically whenever the instrument is line powered. Following field use, a full battery charge may be obtained in less than 18 hours. Battery charger/eliminators are available for use on either 115V or 230V, 50 or 60 Hz power sources.

In addition to the digital display, an analog output is provided at rear panel binding posts for external recording of conductance or resistance. This feature allows the instrument to be used for monitoring, controlling, data logging, and in such applications as conductometric titration for which a continuous record is desired.

A YSI conductivity cell and a YSI 3220 temperature probe are normally used. (Any of the YSI 700 Series temperature probes may be substituted functionally for the 3220, though some may not be compatible with the solutions to be measured.) The meter is calibrated to read directly in sub-multiples of mhos/cm when used with any conductivity cell that has a cell constant K of 1.0/cm. Cells with a constant of 0.1/cm will give a meter reading that is higher by a factor of ten (for example: a reading of 1 μmho with an 0.1/cm cell represents a measured value of 0.1 μmho/cm).

Fundamentals:

The S.I. unit siemens is identical to the more familiar mho, but the dimensions of the cell constant must also be considered when converting observed conductance to conductivity. It has been an unfortunate but common practice to drop the dimensional unit when expressing cell constants. For example, in U.S. practice (cgs metric) we refer to a cell constant of 1.0 when we mean $K = 1.0/\text{cm}$. In the S.I. system (mks metric) a cell constant of 1.0 means 1.0/m, which is equal to 0.01/cm in cgs units.

The Model 34 can be considered to be direct reading in electrolytic conductivity units when working in S.I. and using a sensor with a cell constant of 1 m^{-1} (0.01 cm^{-1}) or in the cgs system when using a sensor with a cell constant of 1 cm^{-1} (100 m^{-1}). However, cells having other constants may also be used, and it should be noted that, regardless of manufacture, the electrical properties of the cell will not be absolutely constant over the wide overall range afforded by this instrument. For maximum accuracy, cell constants should be determined experimentally, using appropriate reference materials having conductivities in the approximate range of interest. (YSI cells are calibrated to an absolute accuracy of ±1% using a reference solution of 0.01 mmol/l KCL; see Cell Calibration.)

The instrument will very accurately display the conductance presented to its input terminals. Conductivity is then determined by multiplying the displayed conductance by the cell constant (being careful to observe the dimensional units of the constant).

The standard measure of electrolytic conductivity is specific conductance; its unit has no name, but is usually expressed by the letter k and defined as the reciprocal of the resistance in ohms of a 1 cm cube of liquid at a specified temperature. The units of conductivity are siemens/meter or mhos/cm. Siemens/meter = mhos/100 cm. (Siemens/cm is

also electrically correct, but prohibited by S.I. Its use should probably be avoided to prevent confusion with the S.I. siemens/meter.)

The observed conductance of a solution depends inversely on the distance d between the electrodes and directly upon their area A:

$$\frac{1}{R} = k \frac{A}{d}$$

For a given cell with fixed electrodes, the ratio d/A is a constant. This ratio is called the cell constant K. (The electrical value of the constant will vary slightly with electrolyte concentration — see Conductivity Cells.) Therefore:

$$k = \frac{K}{R}$$

The standard measure of electrolytic resistivity is specific resistance; the reciprocal of the above relationship. The units of resistivity are ohm-meters or ohm-centimeters.

The observed resistance of a solution varies directly with the distance d between the electrodes and inversely with their area A:

$$R = \frac{\rho d}{A}$$

where ρ is the constant of proportionality of specific resistance. Therefore:

$$\rho = \frac{R}{K}$$

Conductivity is determined by multiplying the measured solution conductance by the cell constant. Resistivity is determined by dividing the measured solution resistance by the cell constant. In either case, care should be taken to observe the dimensions of the cell constant (for SI or cgs units).

For an observed conductance of 100 microsiemens (100 micromhos) and a cell constant $K = 10/\text{m}$:

$$k = 100 \mu\text{S} \times 10/\text{m} = 1 \text{ millisiemens/m}$$

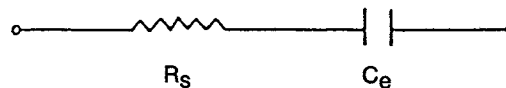
In c.g.s. units the cell constant $K = 10/\text{m}$ becomes $K = 0.1/\text{cm}$ and *the same conductivity* is expressed:

$$k = 100 \mu\text{mhos} \times 0.1/\text{cm} = 10 \mu\text{mhos/cm}$$

Instrument Method:

The Model 34 obtains a conductance reading by varying the amplitude of a square-wave current forced through the cell so that the time-averaged magnitude of the cell voltage over each half-cycle is constant and is equal to a reference voltage. In this condition, the current and the conductance are directly proportional.

The forced current method minimizes the error in measurement, from series capacitance at the conductivity cell, introduced by electrode polarization effects. This may be understood by considering a simplified model of the cell-solution system which consists of a capacitor, C_e , in series with the solution resistance R_s :



During the first half cycle of cell drive, a current of fixed magnitude is forced through the cell. The resulting voltage across the cell then consists of two components: a step voltage across the resistance, and a linear ramp with positive slope across the capacitor.

When the second half cycle of cell drive starts, the current is abruptly switched to flow in the opposite direction with the same magnitude. Here again the voltage across the cell may be considered to be the sum of two components: a step voltage of opposite polarity as before across the resistance, and a linear ramp with negative slope across the capacitor. When the complete cycle of cell voltage is demodulated and filtered, the components due to charging and discharging the capacitor cancel, leaving a voltage proportional to R_S and independent of C_e .

This model is greatly simplified and there are some practical limitations to the method, but reductions in capacitance effect of an order of magnitude are readily achieved in comparison to classical bridge circuits.

Full-wave synchronous demodulation practically eliminates meter sensitivity to drive frequency variations, while shortening response time and rejecting most external interference sources.

Series resistance introduced at the binding post terminals and in the cell cable, adds error in all two-wire conductance measurements. The magnitude of this error is normally negligible because the high conductance of the connecting wires and terminals has little effect on the low conductance of most solutions. This is not the case for concentrated acids where the conductivity may approach one mho/cm. For such measurements, the unit may be used in one of the four-wire arrangements shown in "Conductivity Cell Operation."

SPECIFICATIONS

Operational Temperature Range (Ambient): 0-50°C (32-122°F).
Nominal 25°C (77°F).

Operational Humidity Range: 0-90% relative humidity, noncondensing, on all ranges except the 0-2 MΩ/.01-2 μmho range, in which there may be an additional error of 1 or 2 counts in the least significant digit above 75% relative humidity.

Resolution: .05% of full scale in resistance and conductance .1°C in temperature.

NOTE: All accuracy specifications are subject to an additional error of 1 LSD.

Display Ranges:

Resistance	Conductance	Error in % of Full Scale (Ambient Temperature in °C)		
		24 to 26	10 to 40	0 to 50
0-2 Ω	0-2 Ω	.25%	.40%	.50%
0-20 Ω	0-200mΩ	.10%	.25%	.35%
0-200 Ω	0-20 mΩ	.10%	.25%	.35%
0-2 KΩ	0-2 mΩ	.10%	.25%	.35%
0-20 KΩ	0-200μΩ	.10%	.25%	.35%
0-200KΩ	0-20 μΩ	.10%	.25%	.35%
0-2 MΩ	.01-2μΩ	.10%	.25%	.35%

Temperature Compensation: Selectable/Automatic (temperature must be greater than 5°C or % compensation less than 3%/°C to obtain the following accuracy):

Error: 1% plus the appropriate error given in the ranges listed above ("error" here defines only how well the instrument reading agrees with the algorithm given below)

Algorithm:

$$\text{Compensated Conductivity} = \frac{\text{Uncompensated Conductivity}}{(P/4\%) (.04T - 1) + 1}$$

Where:

T = Temperature in °C, and

P = Selected solution temperature coefficient in %/°C

Temperature Measurement:

Range: -5°C to 50°C

Accuracy: ±.2°C, plus probe error

Conductivity Cell Voltage:

1 volt maximum when in range (balanced)

5 volt maximum when out of range

Recorder Output:

0-2 volts corresponds to full scale

20KΩ minimum load resistance

±2% full scale accuracy (not temperature compensated)

Tracking linearity, ±.1% + .01%/°C away from 25°C, except for the 0-2Ω and 0-2Ω range, where it is ±.25% + .01%/°C away from 25°C

Battery Indicator: Unit will indicate LO BATTERY when too little power remains for accurate function.

Battery Charge Life: Typical full battery charge life is 75 hours (25 hours in the two highest conductance and the two lowest resistance ranges)

Battery Charge Time: 18 hours to full charge

External Charger:

120 VAC RMS ±10%, 60 Hz, .20 A *13.5 VAC Output*

Batteries - C size Ni-Cad

Instrument Size:

10 x 25 x 25 centimeters; 1.6 kilograms

4 x 10 x 10 inches; 3.5 pounds

Electromagnetic Interference: Compliance with new FCC emanation rules (47CFR Part 15 Subpart J) as applicable has been verified on this product design for Class A and Class B environments.

CONDUCTIVITY CELLS

General Description

YSI offers several standard dip and flow-through conductivity cells, each utilizing platinum-iridium electrodes, except YSI 3418 which has platinumized nickel electrodes. These cells have the following specifications:

Part No.	CGS Cell Constant	S.I. Cell Constant	Material	Overall Length	Max O.D.	Chamber I.D.	Chamber Depth
YSI 3401	K = 1.0/cm	K = 100/m	Pyrex 7740	7-1/2"	1"	13/16"	3"
YSI 3402	K = 0.1/cm	K = 10/m	Pyrex 7740	6-1/4"	1"	13/16"	2-1/16"
YSI 3403	K = 1.0/cm	K = 100/m	Pyrex 7740	7"	1/2"	3/8"	2"
YSI 3417	K = 1.0/cm	K = 100/m	ABS Plastic	5-3/4"	1/2"	3/8"	3/4"
YSI 3418	K = 0.1/cm	K = 10/m	ABS Plastic	6-1/4"	1/2"	3/8"	1-3/16"
YSI 3440	K = 10.0/cm	K = 1000/m	Pyrex 7740	8"	1/2"	5/64"	3-3/8"

Flow-Through Cells

YSI 3445	K = 1.0/cm	K = 100/m	Pyrex 7740	5-3/4"	3/4"	3/8"	3"
YSI 3446	K = 0.1/cm	K = 10/m	Pyrex 7740	5-3/4"	1"	13/16"	3"

The nominal volumes of the flow-through cells are 15 ml for the YSI 3445 and 30 ml for the YSI 3446.

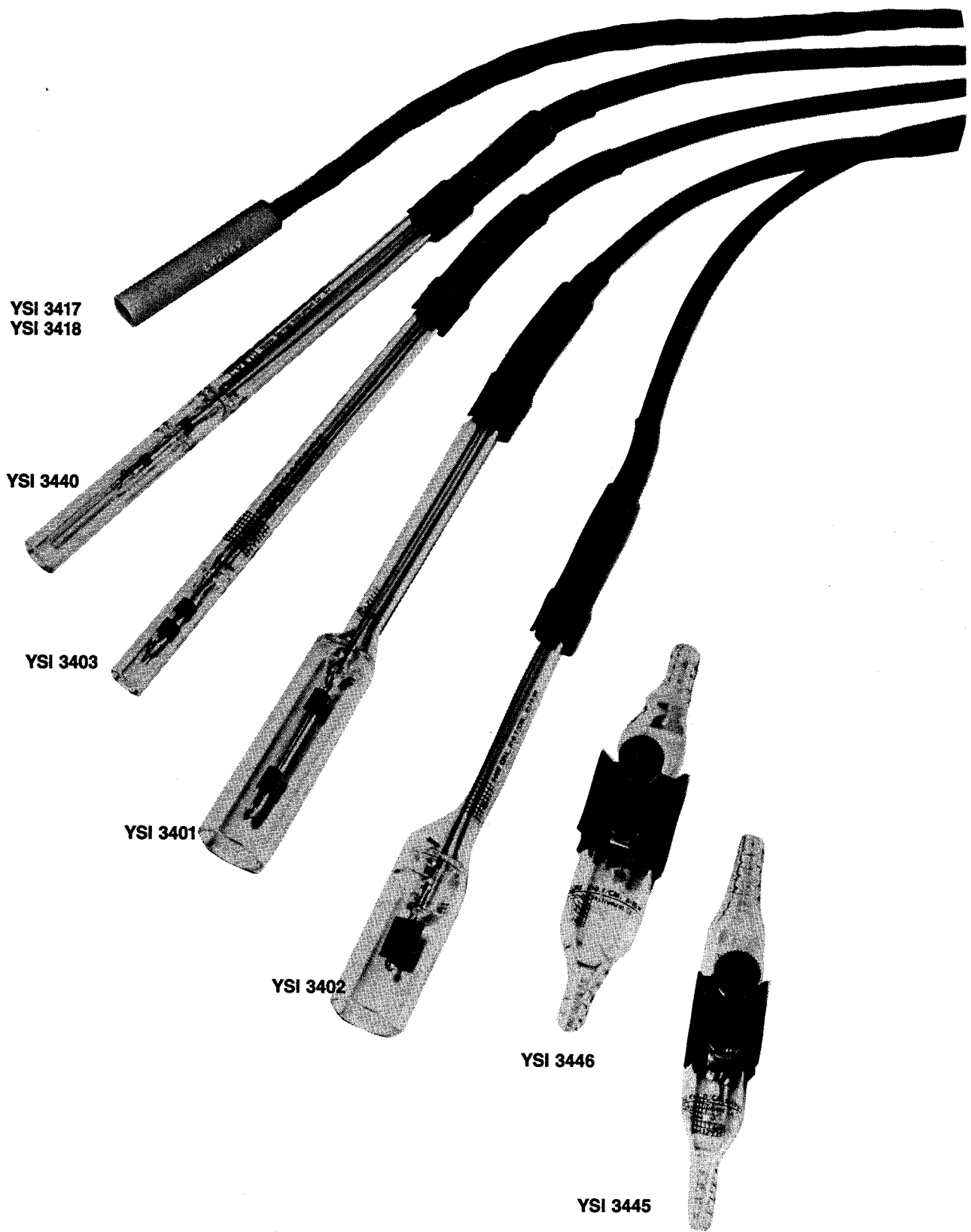
The cell part number and cell constant (K) are fired onto

the Pyrex cells and are stamped on the plastic cells.

Cell constants are calibrated to ±1% accuracy by means of a YSI transfer standard, traceable to OIML Recommendation 56 and NBS standard reference materials. (See Cell Calibration and Standard Solutions.)

Cell Constant

The cell constant (K) is a factor which is used to determine resistivity or conductivity of a solution. In a geometrical sense this factor is, as its name implies, a true constant. However, the electrical properties of a cell do vary with electrolyte concentration and this variation should be taken into consideration if maximum accuracy is desired. Calibration with YSI 3160-3165 Conductivity Calibrator Solutions is recommended. Cell constant is determined by the physical configuration of the cell and its electrodes. Cells with constants of 1.0/cm or greater normally have small, widely spaced electrodes while cells with constants of 0.1/cm or less have larger electrodes which are closely spaced.



YSI 3400 SERIES CONDUCTIVITY CELLS

The user should decide which cell will be more useful based on the conductivities of the solutions in which he will be making measurements. Generally, $K = 1.0/\text{cm}$ cells will give good results with solutions between 20 and 20,000 micromhos. Values below or above this range are best measured with $K = 0.1/\text{cm}$ or $K = 10.0/\text{cm}$ cells. $K = 0.1/\text{cm}$ cells may be used

for any value below 2,000 micromhos, and $K = 10.0/\text{cm}$ cells for any value above 2,000 micromhos.

Conductivity is determined by multiplying the conductance measured in mhos or siemens by the appropriate cell constant (K), being careful to observe the dimensions of the constant.

TEMPERATURE COMPENSATION

By convention, the conductivity of a solution is the conductivity it exhibits at 25°C. The temperature compensation feature of the Model 34 permits correction of the reading to a 25°C value for any solution exhibiting a "slope" of 0% to 4% per degree centigrade. Compensation is continuous between 0 and 4%/°C.

The actual change in electrolytic conductivity with temperature is nonlinear for most solutions and correction would require the use of a polynomial series of the form:

$$\text{Reading}_{(\text{corrected})} = \frac{\text{Reading}_{(\text{uncorrected})}}{(1 + \alpha\Delta T + \beta(\Delta T)^2 + \gamma(T)^3 + \dots)}$$

Where: ΔT is measured temperature minus 25°C.

As a practical matter, the user cannot conveniently deal with more than one coefficient and the higher order terms of the expression must be discarded. Use of the compensation feature is therefore limited to small temperature ranges if accuracy is to be preserved. Compensation is accurate for corrected readings up to five times the uncompensated conductance reading.

The actual correction provided is given by:

$$\text{Reading}_{(\text{compensated})} = \frac{\text{Reading}_{(\text{uncompensated})}}{(P/4)(0.04T-1)+1}$$

Where: T = Temperature in °C

P = Selected solution temperature coefficient in %/°C.

This is a more convenient form of the first expression with higher terms of the series removed, temperature coefficient expressed as a percentage and 25° entered as a reciprocal (1/0.04).

Since different substances and different concentrations of each substance will exhibit different temperature characteristics, it is not possible to assign a single compensation factor for temperature variation. As an appendix to this manual, tables are provided which indicate the appropriate temperature coefficient percentages determined for several typical solutions, described by temperature, chemicals in solution, and chemical concentrations. These tables will also permit the user to calculate manual corrections, if desired, to a better accuracy than is possible with automatic compensation.

Automatic compensation is, of course, most useful when making repeated measurements on the same substances where conductivity and temperature are the only variables. However, the user may occasionally be required to make repeated measurements of a substance whose composition is not sufficiently known to permit the use of published temperature coefficients. In this case, either of the following methods may be used to determine the correct temperature coefficient with the Model 34:

- A. Setting the Model 34 to select the temperature coefficient automatically.
 1. Press .
 2. Measure subject solution at 25°C and record the reading.
 3. Heat or cool solution (ideally, to 5°C more or less than the expected measurement temperature; depending on whether it is greater or less than 25°C. For example, if the expected measurement temperature is 20°C, the second measurement should be made at 15°C).
 4. Press .
 5. Use the knob to adjust the display to the previous reading.
 6. To see what coefficient the instrument has automatically chosen, press .
- B. Determining the Temperature Coefficient empirically: semi-automatic method.

Measure the subject solution at two different temperatures (preferably at 5°C *above* and at 5°C *below* the expected measurement temperature), then perform the following calculation:

$$P = \frac{C_2 - C_1}{(T_2 - T_1)C_1} \times 100$$

Where: P = %/°C

C = Conductance Reading

T = Temperature

Press button and enter the result of this calculation by adjusting the knob. Use of the button will then result in automatically compensated readings for the subject solution at any in-range temperature.

INSTRUMENT OPERATION

Temperature Compensated Conductance Measurement:

1. Connect the instrument to the power battery charger/eliminator. The Model 34 may be used without the charger if batteries are charged.
2. Connect conductivity cell and temperature probe. (See diagrams.)
3. Immerse both cell and probe in the solution to be measured. The electrodes must be submerged and the electrode chamber must be free of trapped air. Tap the cell to remove any bubbles, and dip it two or three times to assure proper wetting (see Conductivity Cell Precautions). If you are using a flow-through cell, connect to fluid lines and fill.
4. Press the $\%$ button. ($\%$ means $\%/^{\circ}\text{C}$ temperature coefficient.)
5. Using the knob, set the desired coefficient into the display (consult published temperature compensation charts for typical solutions, or see Appendix).

Alternatively, determine the coefficient as described in the section on Temperature Compensation.

6. Press UTC and the leftmost range button that gives an on-scale reading.
7. The conductance is displayed on the meter and the units are those printed beneath the range button selected.
8. Conductivity may be determined by multiplying the conductance value by the cell constant K. Units are either $\mu\text{S}/\text{cm}$ or milliS/cm when K is dimensioned in $1/\text{cm}$. Units are $\mu\text{S}/\text{m}$ or $\text{milli S}/\text{m}$ when K is dimensioned in $1/\text{m}$.

Non-Compensated Conductance Measurement:

1. Connect the instrument to the powered battery charger/eliminator. The Model 34 may be used without the charger if batteries are charged.
2. Connect conductivity cell (see diagrams). Temperature probe may be connected if desired.
3. Immerse cell in the solution to be measured. The electrodes must be submerged and the electrode chamber must be free of trapped air. Tap the cell to remove any bubbles, and dip it two or three times to assure proper wetting. If you are using a flow-through cell, connect to fluid lines and fill.
4. Press U and the leftmost range button that gives an on-scale reading.
5. The conductance is displayed on the meter and the units are those printed beneath the range button selected.
6. Conductivity may be determined by multiplying the conductance value by the cell constant K. Units are either $\mu\text{S}/\text{cm}$ or milliS/cm when K is dimensioned in $1/\text{cm}$. Units are $\mu\text{S}/\text{m}$ or $\text{milli S}/\text{m}$ when K is dimensioned in $1/\text{m}$.

Resistance Measurement:

1. Connect the instrument to the powered battery charger/eliminator. The Model 34 may be used without the charger if batteries are charged. NOTE: Resistance measurements are not temperature compensated.

2. Connect conductivity cell (see diagrams). Temperature probe may be connected if desired.
3. Immerse cell into the solution to be measured. The electrodes must be submerged and the electrode chamber must be free of trapped air. Tap the cell to remove any bubbles, and dip it two or three times to assure proper wetting. If you are using a flow-through cell, connect to fluid lines and fill.
4. Press Ω and the rightmost range button that gives an on-scale reading.
5. The resistance is displayed on the meter and the units are those printed beneath the range button selected.
6. Resistivity may be determined by dividing the resistance value by the cell constant K. Units are either $\mu\Omega\text{-cm}$ (micro ohm-centimeters) or $\text{milli}\Omega\text{-cm}$ when K is dimensioned in $1/\text{cm}$. Units are $\mu\Omega\text{-m}$ or $\text{milli}\Omega\text{-m}$ when K is dimensioned in $1/\text{m}$.

Temperature Measurement:

With a temperature probe connected to the instrument, press the $^{\circ}\text{C}$ button to read temperature on the display.

CAUTION: The calibrated temperature range of the Model 34 is -5°C to $+50^{\circ}\text{C}$. For small excursions outside of this range, the instrument will continue to provide a useful indication of temperature but with degraded accuracy. No separate warning is provided of an out-of-range condition when operating in the temperature position.

Recorder Output:

The YSI Model 34 may be connected to any recorder with a $20\text{K } \Omega$ or higher input impedance. The terminals present a 0 to 2 volt signal, proportional to the meter reading.

In *either* the Conductance or the Temperature Compensated Conductance mode, *only* non-temperature compensated signals are presented at the recorder terminals. Temperature values are *not* available at the recorder output. When reading temperature or percent on the display, non-temperature compensated conductance values only are presented at the recorder terminals. In the resistance mode, the resistance value *is* presented at the recorder output terminals.

Batteries

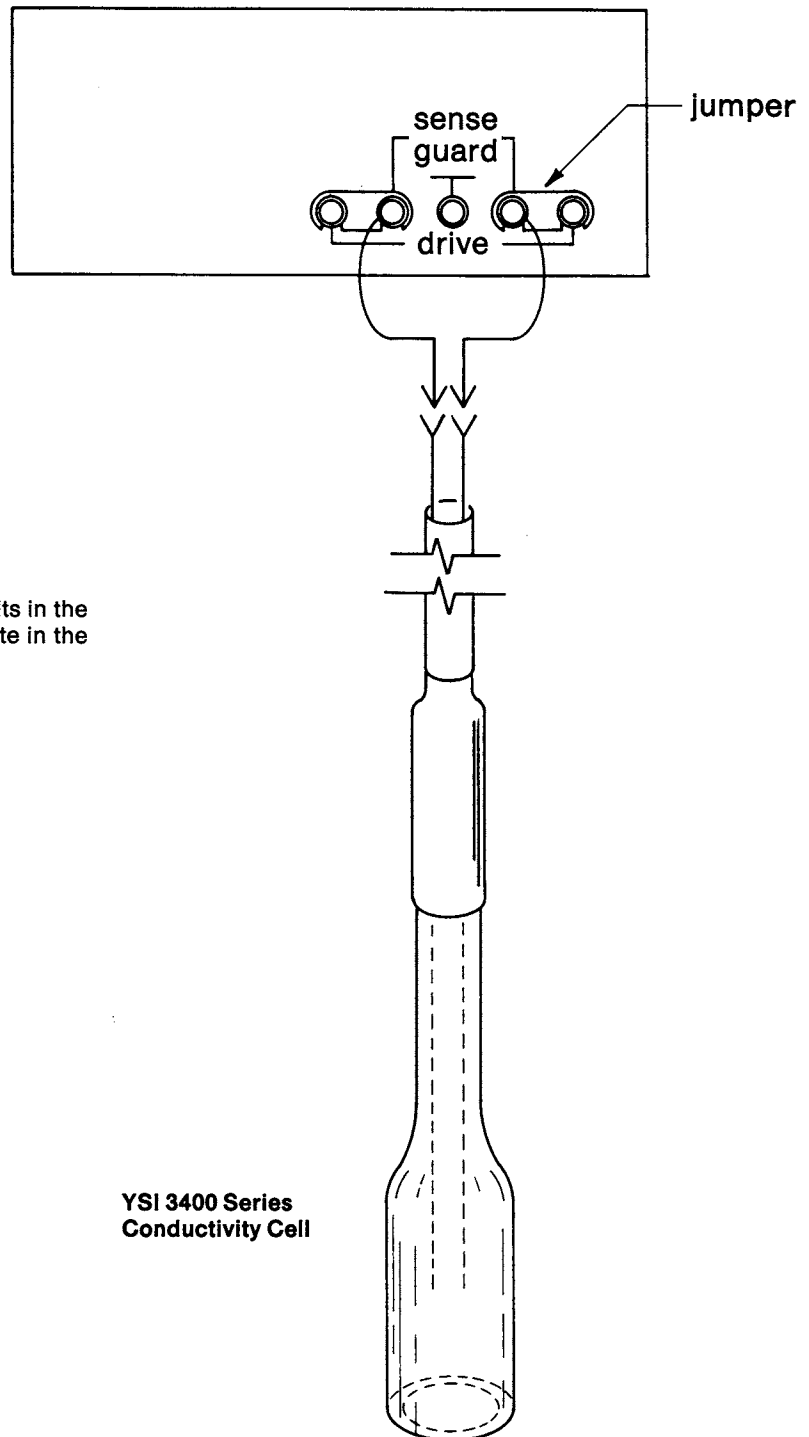
The nickel-cadmium batteries are recharged automatically whenever the instrument is connected to a powered charger/eliminator. 18 hours should be allowed for fully recharging the batteries after they have been depleted. At two cycles per week, batteries have a typical charge-cycle life of five years. When they will no longer take a sufficient charge, the unit may be returned for battery replacement.

CONDUCTIVITY CELL OPERATION

Conductivity Cell Hookups:

All cables, even those supplied with the conductivity cells themselves, affect instrument reading to some degree — though negligibly in the middle ranges. The shielded two-wire, four-wire, and shielded four-wire hookups described

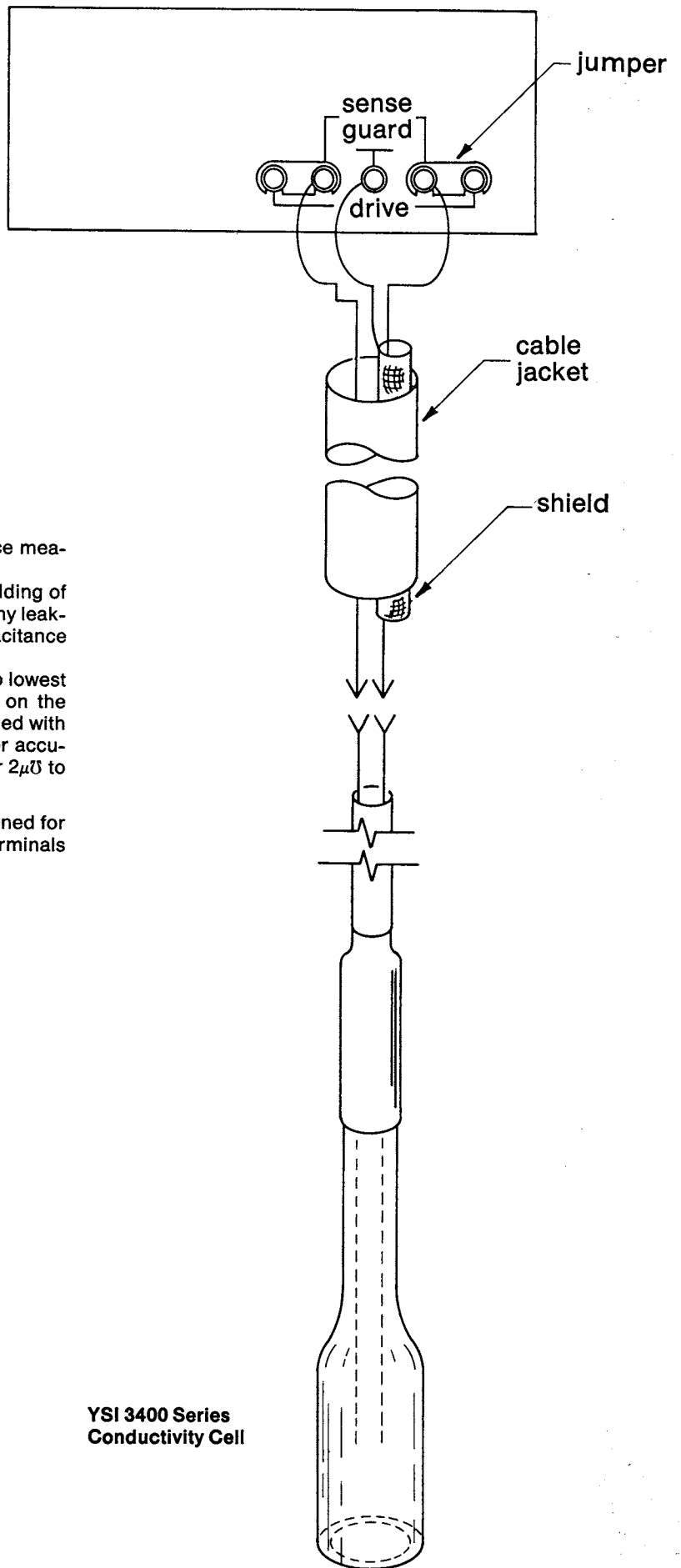
and diagrammed below are designed to minimize or eliminate the effect of cable length and enable the operator to use connecting cables of any reasonable length. (The maximum cable capacitance for all ranges is $.001 \mu\text{F}$.)



Standard Two-Wire

This general purpose connection will give good results in the middle three ranges, but results may be less accurate in the extreme ranges at both ends of the scale.

YSI 3400 Series
Conductivity Cell



Shielded Two Wire

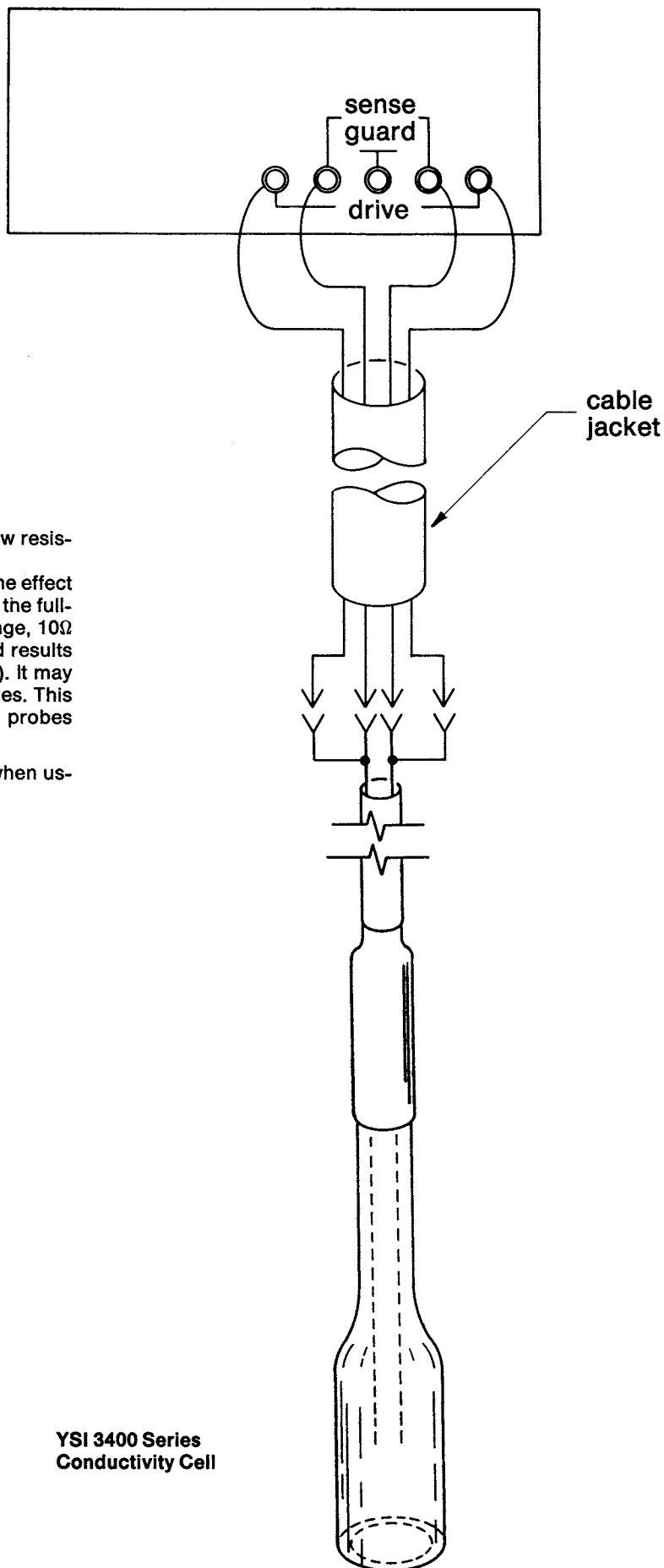
Used for very low conductance or very high resistance measurements.

The GUARD terminal is provided to permit the shielding of one set of sense and drive terminals from the other. Any leakage between these terminals due to resistance or capacitance will result in an error.

The hookup shown will give good results on the two lowest conductance (highest resistance) ranges as well as on the three middle ranges. If a cable longer than that provided with the cell is to be used, this connection is *necessary* for accurate readings for all four upper ranges ($2K\Omega$ to $2M\Omega$ or $2\mu S$ to $2mS$).

IMPORTANT: Note that the shielding is always positioned for connection to one or both of the terminals closest to the side of the instrument.

**YSI 3400 Series
Conductivity Cell**



Four-Wire

Used for measuring very high conductance or very low resistance.

This connection enables the instrument to cancel the effect of lead resistance of the cable. It will cancel up to half the full-scale resistance of the range in use (1Ω in the 2Ω range, 10Ω in the 20Ω range, etc.). This connection will give good results in the lower five ranges (2Ω to $20K\Omega$, or $200\mu S$ to $2S$). It may be used for long cables on any of the four lower ranges. This hookup and the next are also used with 4-element probes (see final hookup diagram).

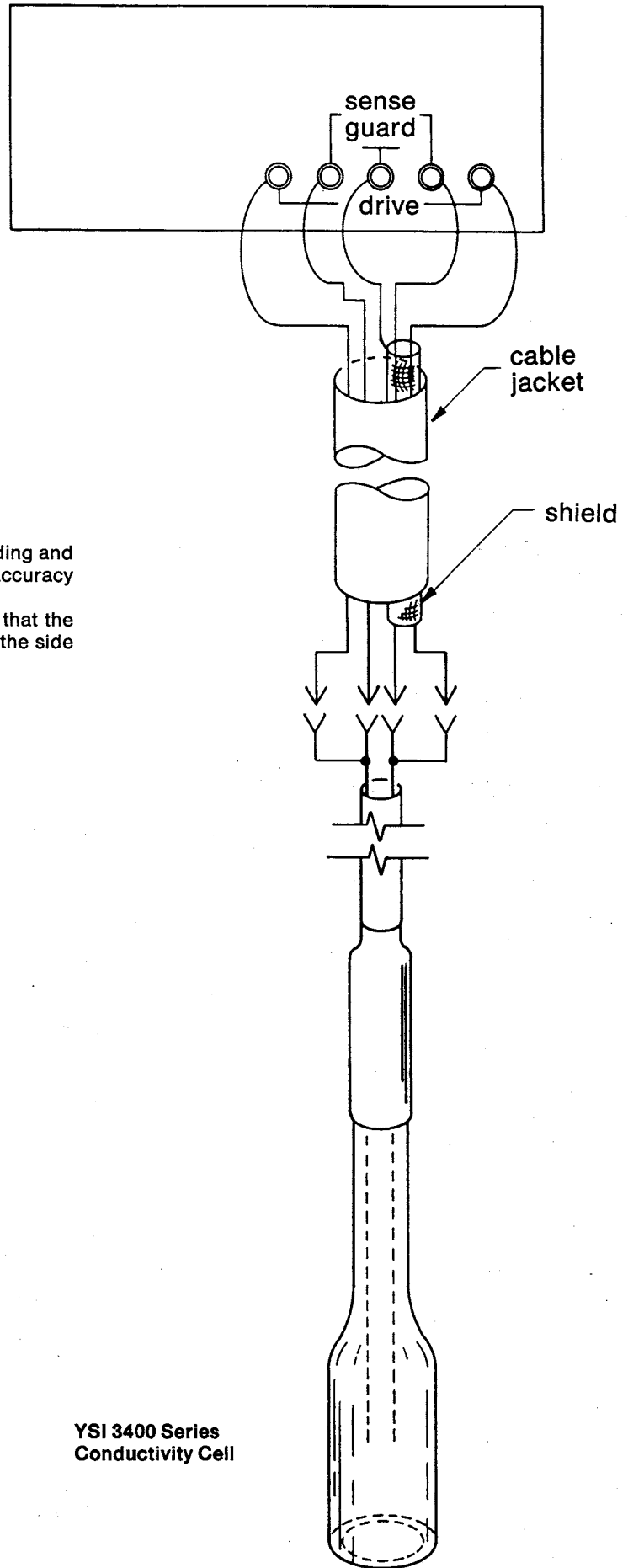
IMPORTANT: The jumper straps must be removed when using either 4-wire hookup.

**YSI 3400 Series
Conductivity Cell**

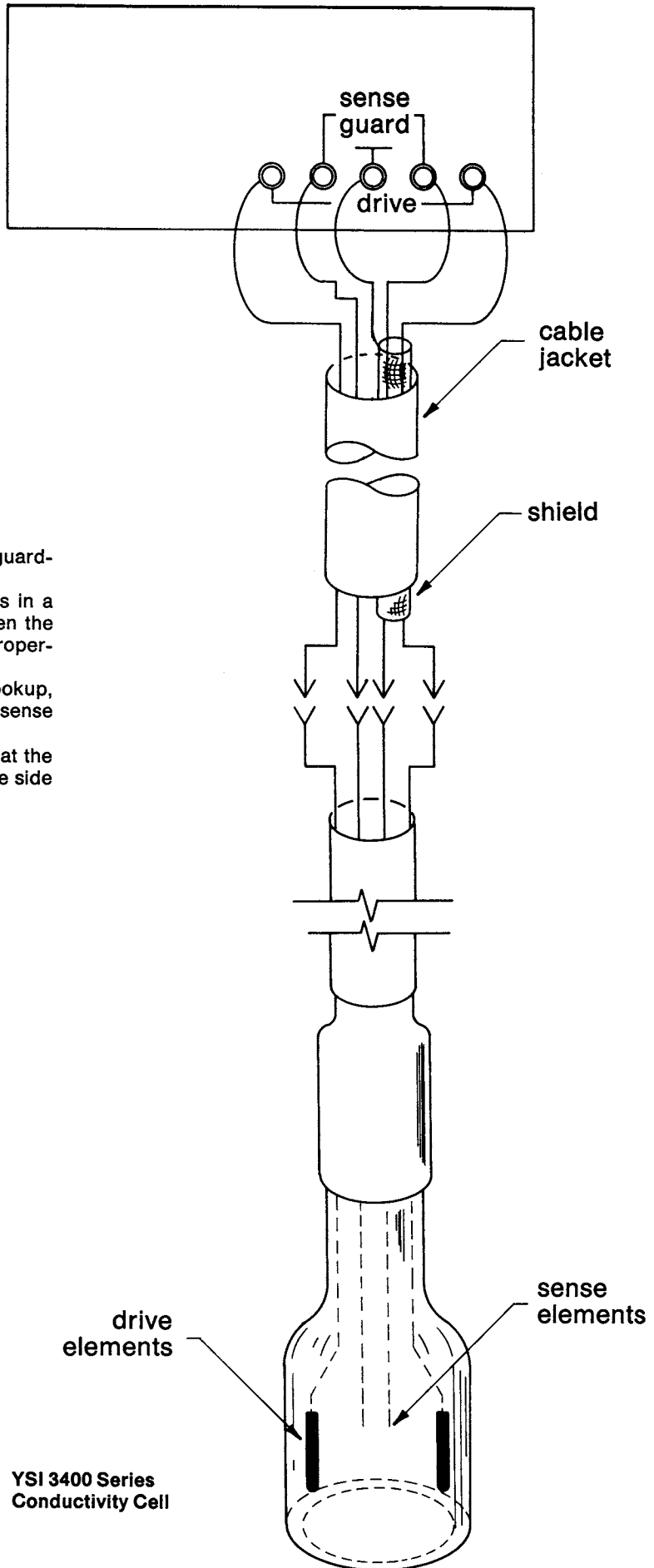
Shielded Four-Wire
Used for all purposes.

This connection combines the advantages of shielding and four-wire hookup. It is the connection on which the accuracy specifications are based.

Be sure that the jumper straps are removed, and that the shielding is on the DRIVE and SENSE wires nearest the side of the instrument.



**YSI 3400 Series
Conductivity Cell**



Four-Wire Hookup for Four-Element Probe

This hookup may be used with or without the guard-connected shield.

Note that there are two different *pairs* of electrodes in a four-element cell. It is important to distinguish between the sensing and driving electrodes, and to connect them properly. Read probe manufacturer's instructions carefully.

If a negative reading on the meter results from this hookup, reverse the connections of *either* the drive pair or the sense pair of electrodes (*but not both*).

Be sure that the jumper straps are removed, and that the shielding is on the DRIVE and SENSE wires nearest the side of the instrument.

YSI 3400 Series
Conductivity Cell

Conductivity Cell Precautions:

After selecting the proper cell, observe the following precautions in order to assure accurate, repeatable results:

1. The cell must be clean before making any measurement. (When working with substances having low conductivity, extraordinary cleanliness may be required.)
2. The cell should be suspended in the solution in such a way that the vent slots are submerged. The electrode chamber should be free of trapped air. (This may be accomplished by tilting the cell slightly and tapping the side.)
3. Dip cells should be at least ¼ inch away from any other object, including the walls or bottom of the solution container.
4. Stirring or flow of solution may be necessary for the highest accuracy in measurement, especially in low-conductivity solutions.
5. If it is possible, the container or system in which measurements are to be made should be isolated from ground potential. If a recording device is attached to the recorder output terminals, it too should be isolated from ground potential if possible. If this is not possible, the Model 34 should be operated on its batteries with the charger/eliminator disconnected to prevent possible ground loop currents which can cause unpredictable errors.
6. The presence of electrical fields and stray currents caused by stirrer motors, heaters, etc., can cause difficulties in obtaining good measurement results. The user should determine the effects of these and make the necessary corrections, either by shielding or by disconnecting
7. The cell should always be handled carefully to decrease the possibility of breakage or loss of calibration accuracy.
8. The cell should never be transferred from one type of solution to another without having first been carefully rinsed.
9. Never store a dirty or contaminated cell.
10. In order to construct an easily calibrated, rugged cell, YSI solders the electrodes and supports in the 3400 Series Cells with gold solder. For this reason, the cells should not be submerged in aqua regia or any solution which might etch or dissolve gold.

Special Measurement Conditions:

Small Sample Measurement

It is not always possible to immerse the conductivity cell in a solution for measurements. If the quantity of solution is not adequate for dipping a cell, a sample must be removed for assay. For this application, any 3400 Series Cell (except 3418) may be inverted and used as a sample holder (after sealing the vent slots in dip cells.) Flow-through cells are particularly convenient for small sample measurement because the correction calculations described below are not necessary. Simply plug one end of the cell, fill and measure.

The selection of a proper cell for small sample applications will depend upon the quantity of solution available and the conductivity of the solution. The 3401 cell ($K=1.0/\text{cm}$) requires 15 ml, the 3402 cell ($K=0.1/\text{cm}$) requires 12 ml, the 3403 cell ($K=1.0/\text{cm}$) requires 3 ml, and the 3417 cell ($K=1.0/\text{cm}$) requires 1 ml. The 3440 cell ($K=10.0/\text{cm}$) requires 3 ml. The 3445 and 3446 flow-through cells ($K=1.0/\text{cm}$ and $0.1/\text{cm}$) require 15 ml and 30 ml respectively.

The electrical conduction field within a sealed, inverted dip cell differs from the electrical field present when the cell is immersed in a solution. When used in this way, the conductance reading displayed must be multiplied by a corrected cell constant, which may be determined as follows:

1. Before sealing the vent slots, immerse the cell in room temperature tap water (or, preferably in a standard solution) and measure conductance.
2. Multiply by the cell constant to determine conductivity.
3. Seal the vent slots and fill the electrode chamber with some of the same solution and again measure conductance. Take care to ensure that neither solution temperature nor composition change during these steps.
4. Multiply by the cell constant to determine conductivity.
5. Divide the difference between the two conductivity determinations by the conductivity obtained in Step 4.
6. The result of Step 5 is a percent variation of cell constant. Add this variation to the constant marked on the cell. This result is the cell constant to use whenever the vent slots are closed.

Example: Cell constant (K) = $1.0/\text{cm}$

Step 1 — Conductance = 1200 micromhos

Step 2 — Conductivity = $1200 \times 1.0/\text{cm} = 1200$ micromhos/cm

Step 3 — Conductance 1000 micromhos

Step 4 — Conductivity = $1000 \times 1.0/\text{cm} = 1000$ micromhos/cm

Step 5 — (Difference = 200 micromhos/cm) divided by 1000 micromhos/cm = 0.20

Cell constant (K) with closed slots = $1.20/\text{cm}$.

Reagent Grade Water Measurement

When making measurements on reagent grade water or other substances having extremely low conductivity, it is recommended that a cell having a constant of $0.1/\text{cm}$ be used. The reason for this becomes clear when you consider that the $1.0/\text{cm}$ cell electronic accuracy on the lowest conductance range is $\pm 0.1\%$ of full scale. 0.1% of $2\mu\text{S}$ is 0.002μ or about 2.0% possible error for a conductance of $0.1\mu\text{S}$. When a cell constant of $0.1/\text{cm}$ is used, the possible error becomes about 0.2% for the same conductivity. In contrast, a substance having a higher conductivity of $19.9\mu\text{S}/\text{cm}$ measured on the $20\mu\text{S}$ scale with a probe having a $1.0/\text{cm}$ cell constant, would have an electronic error of 0.1% or less.

The most sensitive range of the Model 34 (0.01 to $2\mu\text{S}$) provides a meter resolution of $0.001\mu\text{S}$. It is, of course, impossible to make measurements to this degree of precision unless extraordinary precautions are taken in regard to equipment setup, cell cleanliness, electrical interference, etc. Therefore, when operating on this range, some instability in the least significant displayed digit can be considered normal and should be averaged or ignored. (If larger instabilities are encountered, check measurement procedures and see the section on Conductivity Cell Hookups.) Stability of the instrument display is susceptible to environmental electrical noise, and attention to this problem is recommended when measuring in the 0.1 to $2\mu\text{S}$ range.

In laboratory use, if a ring stand or similar apparatus is used to support the probe, the stand should be connected to the GUARD binding post.

Maintenance and Calibration of Cells

Cleaning and Storage

The single most important requirement for accurate and reproducible results in conductivity measurement is a clean cell. A dirty cell will contaminate the solution and cause the conductivity to change.

1. Any one of the foaming acid tile cleaners, such as Dow Chemical "Bathroom Cleaner," will clean the cell adequately. When a stronger cleaning preparation is required, use a solution of 1:1 isopropyl alcohol and 10 Normal HCl.

CAUTION: Cells should not be cleaned in aqua regia or in any solution known to etch platinum or gold.

2. Dip the cell into the solution, making certain it is submerged beyond the vent slots in the electrode chamber. Flow-through cells should be filled and agitated.
3. Agitate the solution for one or two minutes.
4. Remove the cell from the solution and rinse it with several changes of distilled or deionized water. Inspect the platinum black to see if replatinizing is required.
5. It is best to store conductivity cells in deionized water. Cells stored in water will require less frequent platinization. Any cell that has been stored dry should be soaked in distilled water for 24 hours before use.

Platinum Black Inspection

The electrodes of YSI 3400 Cells are coated with platinum black before calibration. This coating is extremely important to cell operation, especially in solutions of high conductivity.

The cell should be inspected periodically. If the coating appears to be thin or if it is flaking off the electrodes, the cell should be cleaned as noted above and the electrodes replatinized.

Replatinizing

A YSI 3139 Platinizing instrument and two-ounce bottles of YSI 3140 Platinizing Solution are available from your dealer. Platinizing is accomplished as follows:

1. Place solution in the platinizing bottle. (Dip cells only.)
2. Connect the cell to the binding posts.
3. Place the cell in the solution with both electrodes submerged. For flow-through cells, plug one end and fill the cell. Use of tubing and a small funnel will simplify this operation.
4. Adjust the current control for 50 mA indication.
5. Reverse polarity to the cell every 30 seconds until both electrodes are covered with a thin black layer. Do not overplatinize.
6. Remove the cell from the solution and disconnect it from the binding posts.
7. Return the platinizing solution to its bottle. It may be reused many times.
8. Rinse the electrodes in running tap water for about 15 minutes.
9. Rinse the cell in distilled or deionized water, and store or use.

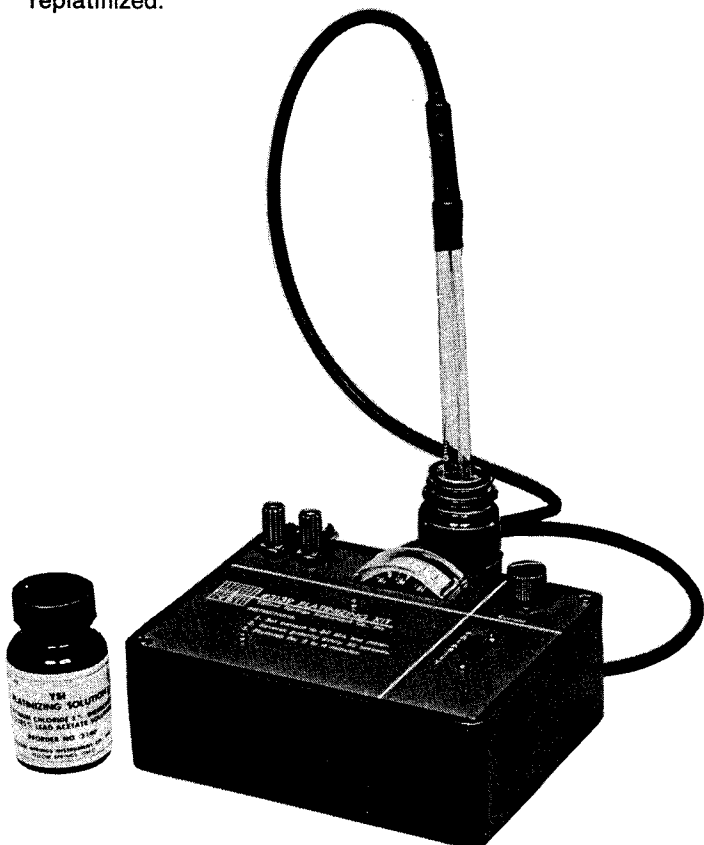
Cell Calibration

The "cell constant" of a conductivity cell may vary slightly with the conductivity of the solution being measured. Calibration may also be affected by electrode fouling, replatinization, or by mechanical shock. A cell and meter can be calibrated together, as a system, with YSI 3161-3165 Conductivity Calibrator Solutions at 1000, 10,000 and 100,000 microsiemens/cm.

Part No.	Size	Conductivity at 25.00°C
3161	Quart	1,000 microsiemens/cm $\pm 0.50\%$
3163	Quart	10,000 microsiemens/cm $\pm 0.25\%$
3165	Quart	100,000 microsiemens/cm $\pm 0.25\%$

Directions for calibration at other than 25.00°C are included with the Conductivity Calibrator Solutions.

In calculating the cell constant in absolute terms, the uncertainty of the meter calibration must be added to the tolerance of the Conductivity Calibrator Solution.



The YSI 3139 Platinizing Kit in use.

APPENDIX

A. Circuit Description

The conductivity cell is driven by a power boosted op-amp whose DC output is kept very close to zero by an additional op-amp integrator. The output of this power stage is a symmetrical square wave whose amplitude is controlled by a DC input voltage, and the feedback from the voltage across the reference resistor (selected by decade switch). The result is an AC current source driving the cell. The voltage across the cell is detected by the sense leads (hence 4-wire operation) buffered by two op-amps which feed a fully balanced, center sampled, synchronous demodulator. This demodulator is set up with a gain of 1 except in the 20 mV/20Ω decade range when the gain is 10. The output of this demodulator is then fed to a summing integrator whose output is the voltage input to the power stage when the instrument is in the conductance mode. In the resistance mode, the input voltage to the power stage is a fixed voltage, and the output of the demodulator is simply filtered and fed to the digital panel meter.

The signal from the temperature probe is sensed by an active resistance bridge which is implemented with a single-stage amplifier. In the temperature mode, this amplifier drives the DPM directly.

In the temperature compensated conductance mode, the output of the temperature circuit is applied to one side of the compensation control (clockwise side) and the other to a reference. The wiper is then connected to the VREF input of the DVM, providing a variable, temperature compensated

reading. It does not affect the output at the recorder terminals because it does not affect the circuit described in the first paragraph above.

The power supply is an external transformer that powers a conventional bridge rectifier and filter. A three terminal regulator is configured as a voltage limited constant current source which charges the ten cell NiCad battery pack. The voltage is regulated to 10 volts by a current limited op-amp regulator. The LED "battery" light comes on whenever the battery voltage drops below 10 volts. The +10 is split to ±5 by an op-amp driving this common point (ground).

B. Warranty

All YSI products are warranted for one year against defects in workmanship and materials when used for their intended purposes and maintained according to manufacturer's instructions. Damage due to accidents, misuse, tampering, or failure to perform prescribed maintenance is not covered. This warranty is limited to repair or replacement at no charge.

If Service Is Required:

Contact the dealer from whom you bought the instrument.

Report the date of purchase, model, serial number, and the nature of the failure. If the repair is not covered by warranty, you will be notified of the charge for repair or replacement.

When shipping any instrument, be sure that it is properly packaged for complete protection.

Required Notice:

(The Federal Communications Commission defines this product as a *Computing Device* and requires the following notice):

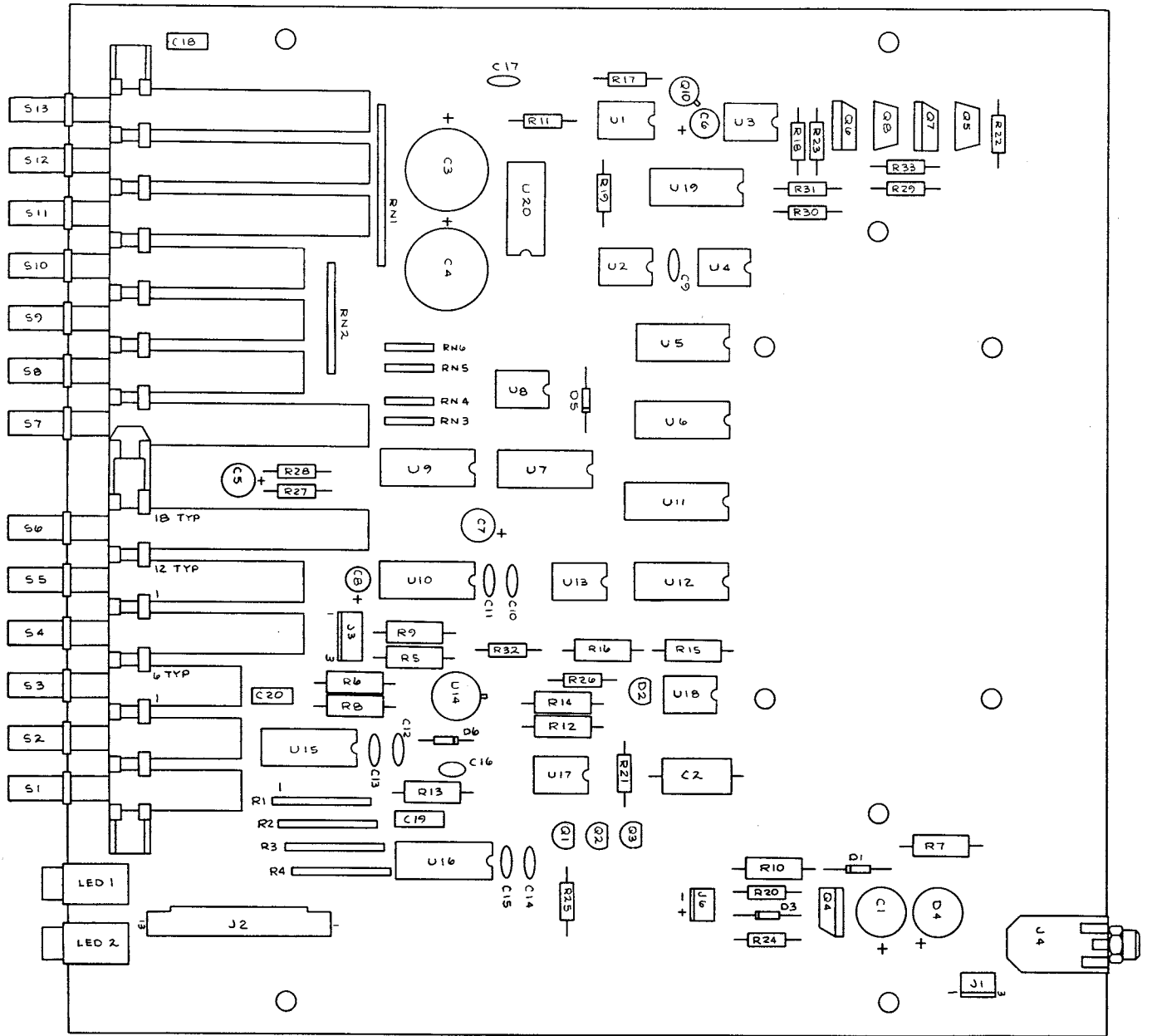
This equipment generates and uses radio frequency energy and if not installed and used properly, that is, in strict accordance with the manufacturer's instructions, may cause interference to radio and television reception. It has been type tested and found to comply with the limits for a Class B computing device in accordance with the specifications in Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference in a residential installation. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does not cause interference to radio or television reception, which can be determined by turning the equip-

ment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- reorient the receiving antenna
- relocate the computer with respect to the receiver
- move the computer away from the receiver
- plug the computer into a different outlet so that computer and receiver are on different branch circuits

If necessary, the user should consult the dealer or an experienced radio/television technician for additional suggestions. The user may find the following booklet prepared by the Federal Communications Commission helpful: *"How to Identify and Resolve Radio-TV Interference Problems."* This booklet is available from the U.S. Government Printing Office, Washington, DC 20402, Stock No. 004-000-00345-4.

D. PC Board Layout



This schematic is representative only, and may be slightly different from the circuit in your instrument.

CONDUCTIVITY SYSTEM ACCURACY CONSIDERATIONS

System accuracy, for conductivity determinations, is the sum of the errors contributed by the environment and the various components of the measurement setup. Included are:

- Instrument accuracy
- Cell-constant error
- Solution temperature offset
- Cell contamination (including air bubbles)
- Cell platinization problems
- Electrical noise
- Contact resistance
- Cable series resistance and shunt capacitances
- Cell series and shunt capacitances
- Galvanic effects and miscellaneous

Only the first three of these need be of major concern for typical measurements, although the user should also be careful to see that cells are clean and maintained in good condition at all times. Additional discussion of these and other factors affecting system accuracy is provided below.

Instrument Accuracy

Instrument error, worst case for this purpose, is the stated accuracy for the range being used. Note that instrument accuracy for the Model 34 is specified for each range and for ambient temperature ranges as well (see Specifications). It should be noted that many instruments have different specifications for different ranges and that claims are sometimes misleading. For example, the YSI Models 31 and 31A have dial ranges which are greater than the effective measurement range for which an accuracy statement can be provided.

Cell-Constant Error

Some manufacturers provide cells to only a nominal cell-constant value (± 10 to 20%). It is then the user's responsibility to determine the actual cell constant for the range of concentration values in which the cell is to be used. Although YSI does much better than this (see below) there is really nothing wrong with the practice described. Conductivity is found by multiplying a measured conductance value by the cell constant; if the constant is found to be, for example, 1.07/cm rather than 1.00/cm, it can be used with equal accuracy, if somewhat less convenience. Conductivity authorities also consider the cell constant to be non-linear and ASTM specifies different cells for different concentration ranges.

YSI cells are calibrated to within one percent of the stated cell constant at a single point and we consider these products to be usefully linear over most instrument ranges. We do, however, also recommend that $K = 0.1/\text{cm}$ cells be used in measuring very low conductivity solutions and that $K = 10.0/\text{cm}$ be used in measuring very high conductivity solutions. The cell constant can be calibrated to +0.35% accuracy with YSI 3160-3265 Calibrator Solutions.

Temperature Error

The solution temperature error is the product of the temperature coefficient and the temperature offset from 25°C, expressed as a percentage of the reading which would have been obtained at 25°C. The error is not necessarily a linear function of temperature.

Automatic temperature compensation cannot totally eliminate this error but YSI instruments which offer this feature will limit it to 1% of full scale on the range being used, if the proper coefficient is dialed in.

Temperature measurement error is a problem for either automatic compensation or manual temperature correction.

Total Error

Considering only the above three factors, system accuracy

under worst case conditions will be $\pm 2\frac{1}{2}\%$, but considerably less if recommended and properly calibrated cells, instrument ranges and automatic temperature compensation are used. Additional errors, which can essentially be eliminated with proper handling, are described below.

Cell Contamination

This error source might usually be more properly described as one in which the cell is contaminating the solution being measured, often through carry-over from previous measurements. The instrument might be correctly reporting the conductivity seen but that reading does not accurately represent the value of the bulk solution. Errors will be most serious when measuring low conductivity solutions and can then be of an order of magnitude or more.

The user should carefully follow the cleaning instructions provided before attempting low conductivity measurements with a cell of unknown history or one which has been previously used in higher value solutions.

An entirely different form of contamination is sometimes seen as a buildup of foreign material directly on cell electrodes. While perhaps rare, examples have turned up where such deposits have markedly reduced the effectiveness of platinization, which in turn reduces the so-called double-layer capacitance and the electrical coupling to the solution being measured. The result is a lower conductance reading (see Cell Platinization Errors below).

Cell Platinization Errors

Most YSI instruments are quite forgiving of a cell which has begun to lose its electrode coating of platinum black. However significant errors can be introduced when measuring solutions having high conductivity values. The effect of poor platinization is a reduction of the apparent double-layer or series capacitance in the cell, which in turn appears as a frequency-dependent reactance which is difficult to balance in bridge instruments or to cancel completely with bi-polar drive approaches.

Instructions for electrode inspection and replatinization when necessary should be carefully followed before attempting critical measurements of any kind.

Electrical-Noise Errors

Electrical noise can be a problem in any measurement range, but will contribute the most error and be the most difficult to eliminate for the lowest conductance settings. The noise may be either line-conducted or radiated or both and therefore may require revised lead dress, grounding, shielding or all three. Often all that is necessary is to make sure that parallel leads are of equal length and twisted together and that line-powered instruments are properly grounded. Additional tips on electrical interference reduction will be found in most conductance instruction manuals.

Contact Resistance

It is perhaps only common sense to suggest that a good contact be made between cell leads and instrument terminals, but the magnitude of error that can result from a fraction of an ohm of contact resistance on the highest conductivity range is not always appreciated. Lugs should be clean and free of mechanical distortion. They should fit squarely on terminal posts which should be properly tightened. Leads should also be inspected to verify that no physical damage has occurred which might degrade electrical contact.

Cable Series Resistance and Shunt Capacitance

The short cables provided as a part of regular cell assemblies will introduce negligible error for most measurements. How-

ever, if longer cables are required or if extraordinary accuracy is necessary, special precautions and/or cable calibration may be prudent.

When working with solutions having very high conductivity values (more than 200 millimhos/cm), a cable resistance of a tenth of an ohm will introduce an error of 2% or more.

When working with solutions having very low conductivity values (less than 2 micromhos/cm) a cable capacitance of only 100 picofarads will produce errors of 0.3% or more on some instruments. Modern YSI forced-current models can accommodate shunt capacitance ten times greater than this, down to 1 micromho/cm conductivity, with no significant capacitance error. However caution is still advised when working on our lowest conductivity ranges with ultra-pure waters, etc.

Cell Series and Shunt Capacitances

Most commercial cells intended for laboratory use have negligible shunt capacitance, a few tens of picofarads at most. The capacitance between leads of long cables will generally be of much greater concern (see above). However, special cells having very low constants are sometimes constructed for experimental or industrial applications. For example, process-stream cells having constants of $K = 0.001/\text{cm}$ are known, if not common. Such cells use many interleaved closely-spaced plates of relatively large surface area and therefore exhibit relatively large shunt capacitances.

Although it may be possible to "balance out" even such large shunt reactance effects, a better approach will be to calibrate the measurement for the particular concentration range of interest. Since these unusual cells are placed in service because of special conditions, it can be assumed that the nature of those conditions is understood well enough to also permit special in-situ calibration procedures.

We have already touched upon the series or "double-layer" capacitance effect in the discussion of platinization. It is desir-

able that this capacitance be as large as possible and platinization helps to achieve this. Indeed, for most measurements series capacitance is so large that its effects can be ignored. The value of this capacitance is not a constant, it varies with solution concentration among other things, but for a properly platinized commercial cell the value is reported to be in the hundreds or even thousands of microfarads. However, not all cells are equal and instruments differ in their abilities to accommodate lower values of capacitance without error.

For some work, cells with very high constants are desirable ($K = 100/\text{cm}$ or above) and such cells are occasionally constructed as needed, sometimes of little more than a pair of parallel wires. In this case, the series capacitance will be too low for any range of accuracy. However, the practice is quite acceptable if special calibration procedures are used and the user recognizes that his equipment will now have very poor linearity.

Galvanic and Miscellaneous Effects

In addition to the error sources described above, there is yet another class of contributors that can be ignored for all but the most meticulous of laboratory measurements. Such errors are always small and are generally completely masked by the error budget for cell-constant calibration, instrument accuracy, etc. However, they do exist. Examples range from parasitic reactances associated with the solution container and its proximity to external objects, to the minor galvanic effects resulting from oxide formation or deposition on electrodes. Only trial and error in the actual measurement environment can be suggested as an approach to reduce such errors.

If the reading does not change as the setup is "tweaked," errors due to such factors can be considered too small to see. (Lead reversal is one example of adjustments which might be tried).

F. Temperature Correction Data for Typical Solutions

1. Sodium Chloride* (NaCl)

Saturated solutions at all temps.

Concentration: 0.5 mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	134.50	1.86
5	155.55	1.91
10	177.90	1.95
15	201.40	1.99
20	225.92	2.02
25	251.30	2.05
30	277.40	2.08

Concentration: 1 x 10 ⁻¹ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	25.90	1.78
5	29.64	1.82
10	33.61	1.86
15	37.79	1.90
20	42.14	1.93
25	46.65	1.96
30	51.28	1.99
35	56.01	2.01
37.5	58.40	2.02
40	60.81	2.02
45	65.65	2.04
50	70.50	2.05

Concentration: 1 x 10 ⁻² mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	5.77	1.83
5	6.65	1.88
10	7.58	1.92
15	8.57	1.96
20	9.60	1.99
25	10.66	2.02
30	11.75	2.04
35	12.86	2.06
37.5	13.42	2.07
40	13.99	2.08
45	15.14	2.10
50	16.30	2.12

Concentration: 1 x 10 ⁻³ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.632	1.87
5	.731	1.92
10	.836	1.97
15	.948	2.01
20	1.064	2.05
25	1.186	2.09
30	1.312	2.12
35	1.442	2.16
37.5	1.508	2.17
40	1.575	2.19
45	1.711	2.21
50	1.850	2.24

Concentration: 1 x 10 ⁻⁴ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.066	1.88
5	.076	1.93
10	.087	1.98
15	.099	2.02
20	.111	2.07
25	.124	2.11
30	.137	2.15
35	.151	2.19
37.5	.158	2.20
40	.165	2.22
45	.180	2.25
50	.195	2.29

2. Potassium Chloride** (KCl)

Concentration: 1 mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	65.10	1.67
5	73.89	1.70
10	82.97	1.72
15	92.33	1.75
20	101.97	1.77
25	111.90	1.80

Concentration: 1 x 10 ⁻¹ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	7.13	1.78
5	8.22	1.80
10	9.34	1.83
15	10.48	1.85
20	11.65	1.88
25	12.86	1.90
30	14.10	1.93
35	15.38	1.96
37.5	16.04	1.98
40	16.70	1.99
45	18.05	2.02
50	19.43	2.04

Concentration: 1 x 10 ⁻² mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.773	1.81
5	.892	1.84
10	1.015	1.87
15	1.143	1.90
20	1.275	1.93
25	1.412	1.96
30	1.553	1.99
35	1.697	2.02
37.5	1.771	2.03
40	1.845	2.05
45	1.997	2.07
50	2.151	2.09

Concentration: 1 x 10 ⁻³ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.080	1.84
5	.092	1.88
10	.105	1.92
15	.119	1.96
20	.133	1.99
25	.147	2.02
30	.162	2.05
35	.178	2.07
37.5	.186	2.08
40	.194	2.09
45	.210	2.11
50	.226	2.13

3. Lithium Chloride* (LiCl)

Concentration: 1 mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	39.85	1.82
5	46.01	1.85
10	52.42	1.89
15	59.07	1.92
20	65.97	1.95
25	73.10	1.98
30	80.47	2.02
35	88.08	2.05
37.5	91.97	2.07
40	95.92	2.08
45	103.99	2.11
50	112.30	2.15

Concentration: 1 x 10 ⁻¹ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	5.07	1.87
5	5.98	1.85
10	6.87	1.85
15	7.75	1.85
20	8.62	1.85
25	9.50	1.86
30	10.40	1.88
35	11.31	1.91
37.5	11.78	1.92
40	12.26	1.94
45	13.26	1.98
50	14.30	2.02

Concentration: 1 x 10 ⁻² mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.567	1.88
5	.659	1.92
10	.755	1.96
15	.856	2.00
20	.961	2.04
25	1.070	2.08
30	1.183	2.12
35	1.301	2.16
37.5	1.362	2.18
40	1.423	2.20
45	1.549	2.24
50	1.680	2.28

Concentration: 1 x 10 ⁻³ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.059	1.93
5	.068	2.03
10	.078	2.12
15	.089	2.19
20	.101	2.25
25	.114	2.28
30	.127	2.31
35	.140	2.32
37.5	.147	2.32
40	.154	2.31
45	.166	2.29
50	.178	2.25

4. Potassium Nitrate** (KNO₃)

Concentration: 1 x 10 ⁻¹ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	6.68	1.78
5	7.71	1.79
10	8.75	1.81
15	9.81	1.83
20	10.90	1.85
25	12.01	1.87
30	13.15	1.90
35	14.32	1.92
37.5	14.92	1.94
40	15.52	1.95
45	16.75	1.97
50	18.00	2.00

Concentration: 1 x 10 ⁻² mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.756	1.77
5	.868	1.80
10	.984	1.83
15	1.105	1.86
20	1.229	1.88
25	1.357	1.90
30	1.488	1.93
35	1.622	1.95
37.5	1.690	1.96
40	1.759	1.97
45	1.898	1.99
50	2.040	2.01

5. Ammonium Chloride* (NH₄Cl)

Concentration: 1 mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	64.10	1.60
5	74.36	1.53
10	83.77	1.45
15	92.35	1.37
20	100.10	1.29
25	107.00	1.21

Concentration: 1 x 10 ⁻¹ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	6.96	1.82
5	7.98	1.88
10	9.09	1.93
15	10.27	1.97
20	11.50	2.00
25	12.78	2.03
30	14.09	2.06
35	15.43	2.07
37.5	16.10	2.08
40	16.78	2.08
45	18.12	2.09
50	19.450	2.09

Concentration: 1 x 10 ⁻² mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.764	1.84
5	.889	1.86
10	1.015	1.86
15	1.144	1.91
20	1.277	1.94
25	1.414	1.97
30	1.557	2.02
35	1.706	2.06
37.5	1.782	2.08
40	1.860	2.10
45	2.020	2.14
50	2.186	2.18

Concentration: 1 x 10 ⁻³ mole/liter		
°C	millisiemens/cm	%/°C (to 25°C)
0	.078	1.88
5	.092	1.90
10	.105	1.91
15	.119	1.93
20	.133	1.95
25	.148	1.98
30	.162	2.01
35	.178	2.04
37.5	.186	2.06
40	.194	2.07
45	.210	2.11
50	.227	2.15

*Charts developed by computer interpolation of data from CRC Handbook of Chemistry and Physics, 42nd Ed., p. 2606, The Chemical Rubber Company, Cleveland.

**Charts developed by computer interpolation of data from International Critical Tables, Vol. VI, pp. 229-253, McGraw Hill, N.Y.