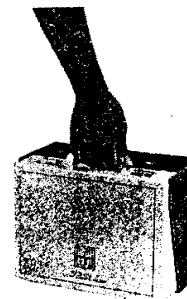


INSTRUCTION MANUAL YSI MODEL 32 CONDUCTANCE METER



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PRICE INCLUDING HANDLING \$10.00

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GENERAL DESCRIPTION

The YSI Model 32 Conductance Meter is designed for precise, direct measurement of conductance, temperature, or temperature compensated conductance. The basic Model 32 is a laboratory instrument, while the 32FL is used for both laboratory and field work and contains a battery that is kept charged automatically whenever the instrument is line powered. The 32FL is fitted with a handle and removable cover.

A temperature probe and a conductivity cell are used: a YSI 3220 series thermistor temperature sensor*, and a YSI conductivity cell. 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 constants of 0.1/cm or 10.0/cm will give meter readings that are higher or lower 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.)

In S.I. units, 1 siemens equals 1 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 unit of length when expressing a cell constant. For example, we refer to a cell constant of 1.0 when we mean K = 1.0/cm. In the S.I. system, a cell constant of 1.0 means 1.0/m which is equal to 0.01/cm in c.g.s. units.

A conductance reading is obtained by varying the current to hold an AC voltage constant across the conductivity cell load. The circuit minimizes both series and parallel capacitance effects. The reading is displayed directly on a digital panel meter. Conductance measurements may be automatically compensated for temperature after manual selection of a desired temperature correction coefficient. (Note that this feature greatly extends the range of conditions and substances over which automatic compensation can accurately occur as compared with other instruments which also feature "automatic compensation.")

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 1cm cube of liquid at a specified temperature. The units of specific conductance are siemens/meter or mhos/cm (siemens/meter = mhos/100cm).

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, called the cell constant K . Therefore

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

*YSI 700 series thermistor temperature sensors are also usable for temperature measurement but some 700 series units may not be compatible with the solutions being measured.

Conductivity is determined by multiplying the measured solution conductance by the cell constant K (being careful to observe the dimensions of the constant).

For an observed conductance of 100 micromhos (or 100 microsiemens) and a cell constant $K = 0.1/\text{cm}$:

$$k = 100\mu\text{S} \times 0.1/\text{cm} = 10\mu\text{S}/\text{cm}^{**}$$

In S.I. Units, the cell constant $K = 0.1/\text{cm}$ would become $K = 10/\text{m}$ and the same conductivity is expressed:

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

SPECIFICATIONS

Range	Accuracy	Resolution
10.0-200 millimhos	$\pm 1.0\%$ full scale	100 micromhos
1.0- 20 millimhos	$\pm 0.2\%$ full scale	10 micromhos
0.1- 2 millimhos	$\pm 0.2\%$ full scale	1 micromho
10.0-200 micromhos	$\pm 0.2\%$ full scale	0.1 micromho
1.0- 20 micromhos	$\pm 0.2\%$ full scale	0.01 micromho
0.1- 2 micromhos	$\pm 1.0\%$ full scale	0.001 micromho

Temperature Measurement Range: -5°C to $+50^\circ\text{C}$.

Stability: 10 nanomho/nanosiemens

Temperature Measurement Accuracy:

$\pm 0.1^\circ\text{C}$ ± 1 resolution digit, not including probe.

($\pm 0.5^\circ\text{C}$ max. including probe tolerance and linearity)

Temperature Compensation Accuracy:

$\pm 1\%$ (full scale) $\pm 1/2$ of selected temperature coefficient percentage (0-4%) for corrected readings up to five times the uncompensated conductance (includes probe and instrument temperature accuracy effects).

Readout: Liquid Crystal Display.

Recorder Output:

0-2 Volts, 1kΩ load minimum, temperature and conductance only.

Voltage Applied to Conductivity Probe:

2.0 Volts peak-to-peak maximum continuous (balanced).

13.5 Volts peak-to-peak maximum (unbalanced).

Ambient Temperature Range: -5°C to $+50^\circ\text{C}$.

Storage Temperature Range: -55°C to $+50^\circ\text{C}$.

Power Requirements:

115 VAC $\pm 10\%$, 0.10 Amperes maximum or 230 VAC $\pm 10\%$, 0.05 Amperes maximum at 50-60 Hz; 11.5 watts maximum.

(Rechargeable battery powered version also available.)

Instrument Size:

6-11/16 x 11-1/4 x 8-11/16 in.; 5 lbs. nominal.

(17 x 28.6 x 22 cm.; 2.3 kg.)

FL Models: 8.2 lbs. nominal (3.7 kg).

Battery Charge (FL Models)

A full battery charge will provide 24 hours or more of continuous operation.

**There is no universally recognized symbol for the unit mho. YSI has followed the popular engineering practice of representing the mho by means of the inverted letter omega.

OPERATING PROCEDURE

INSTRUMENT CONTROLS

Function Switch

Controls power and selects Temperature, Conductance, or Temperature Compensated Conductance as the value to be measured.

Range Switch

Selects range of conductance to be measured.

Temperature Compensation Dial

Adjusts displayed reading to the value which would be obtained at 25°C. Major divisions equal 1%/°C; minor divisions equal .05%/°C. The compensation feature should not be used if the corrected reading is greater than five times the uncompensated conductance.

MAKING CONDUCTANCE MEASUREMENTS

1. Connect the instrument to an appropriate power source and set the Function Switch to the CONDUCTANCE position.
2. Immerse the conductivity cell in the unknown solution. 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, be sure it is completely full.
3. Connect the conductivity cell leads to the terminals provided.
4. Rotate the Range Switch to the *lowest* range position which gives a reading (within range) on the display. An over-range value is indicated by a "1" followed by blanks. An under-range value is indicated by a reading followed by a small letter "u". Readings may be in error when operating in the under-range condition. On the 0.1-2 micromho range; allow extra time to stabilize.
5. The conductance value of the solution is displayed on the meter. The units in which it is to be read are determined by the Range Switch, either in milliohm or in $\mu\Omega$ (or milli and μ siemens).
6. Conductivity may be determined by multiplying the conductance value by the cell constant K. Units are either $\mu\Omega/\text{cm}$ or milliohm/cm when K is dimensioned in 1/cm. Units are $\mu\text{S}/\text{m}$ or milli S/m when K is dimensioned in 1/m.

MAKING TEMPERATURE COMPENSATED CONDUCTANCE MEASUREMENTS

1. Connect the instrument to an appropriate power source and set the Function Switch to the Temperature Compensated Conductance position.
2. Immerse the conductivity cell in the unknown solution. 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, be sure it is completely full.
3. Connect the conductivity cell leads to the terminals provided.
4. Rotate the Temperature Compensation control to the desired %/°C and plug in the temperature probe. See note below.
5. Rotate the Range Switch to the *lowest* range position which gives a reading (within range) on the display. An over-range value is indicated by a "1" followed by blanks. An under-range value is indicated by a reading followed by a small letter "u". Readings may be in error when operating in the under-range condition. On the 0.1-2 micromho range; allow extra time to stabilize.

A Note on Temperature Compensation

The temperature compensation dial provides an automatic correction of the reading to the equivalent value which would have been obtained at a solution temperature of 25°C. The action of the control is continuous between temperature coefficient settings of 0 to 4% per degree celcius and calibrations are marked at intervals of 0.05%/°C.

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

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

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 = Dial setting 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 instruction booklet, tables are provided which indicate the appropriate temperature compensation 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.

The compensation dial will ordinarily be left in a fixed position appropriate to a single test substance. Automatic compensation is, of course, most useful when making repeated measurements on the same substance where conduc-

tivity 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, the correct setting of the compensation dial may be determined empirically by means of the following procedure:

1. Divide a sample of the test substance into two parts.
2. Heat or cool one part to exactly 25°C. Heat or cool the second part to a temperature several degrees above or below 25°C.
3. With the temperature compensation feature turned off, measure the conductivity of the 25°C sample.
4. With the temperature compensation turned on, measure the conductivity of the second sample, then adjust the compensation dial until the indicated reading agrees exactly with that obtained for the 25°C sample. The compensation dial may now be left in this position and the instrument will automatically temperature compensate later readings of the same substance (in the same general range of concentration and range of temperature of the second sample).

MAKING TEMPERATURE MEASUREMENTS

1. Connect the instrument to an appropriate power source and set the Function Switch to the TEMPERATURE °C position.
2. Plug in the probe lead and immerse the temperature probe in the liquid to be measured.
3. Read the meter display in °C.

CAUTION

The calibrated temperature range of the Model 32 is -5°C to +50°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.

MAKING MEASUREMENTS OF REAGENT GRADE WATER

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/cm be used. The reason for this becomes clear when you consider that the worst case electronic accuracy using a 1.0/cm cell on the lowest range is $\pm 1\%$ of the full scale (0.2% on mid-ranges). 1% of $2\mu\text{S}$ is $0.02\mu\text{S}$ or about 20% possible error for a conductance of $0.1\mu\text{S}$. When a cell constant of 0.1/cm is used, the possible error becomes $0.002\mu\text{S}/\text{cm}$ or about 2%. In contrast, a substance having a conductivity of $19.9\mu\text{S}/\text{cm}$ measured on the $20\mu\text{S}$ scale with a probe having a 1.0/cm cell constant would have an electronic error of 0.2% or less.

The most sensitive range of the Model 32 (0.1 to $2\mu\text{mhos}$) provides a meter resolution of $0.001\mu\text{mhos}$. It is, of course, impossible to make measurements to this degree of precision unless extraordinary precautions are taken in regard to equipment set-up, 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, see the section on Measurement Techniques in the following discussion of conductivity cells.) When operating on AC, a grounded power receptacle should always be used.

Stability of the instrument display is dependent upon environmental electrical

noise, and on the 0.1-2 micromho/microsiemens range attention to this limitation is recommended.

1. Lab Solutions. It is recommended that the probe support ring stand be grounded to the (-) recorder jack.
2. Calibrating Decade Resistor: The decade shield (housing) should be grounded to (-) recorder jack.
3. Field/Industrial Measurements. The (-) recorder jack is connected to the A.C. ground cable through the chassis. The right most probe jack is maintained at a virtual ground with respect to this potential. These circuits must remain electrically isolated.
4. Stability Check. A fixed resistor of from 5 to 9 Megohms attached to a 4 ft. length of unshielded #18 twisted-pair cable (I.N. 080401) may be used to verify the stability specifications on the 0.1-2 micromho/microsiemens range.

RECORDER OUTPUT

The YSI Model 32 may be connected to any recorder with a $1\text{k}\Omega$ or higher input impedance. The terminals present a 0 to 2 volt signal, proportional to the meter reading.

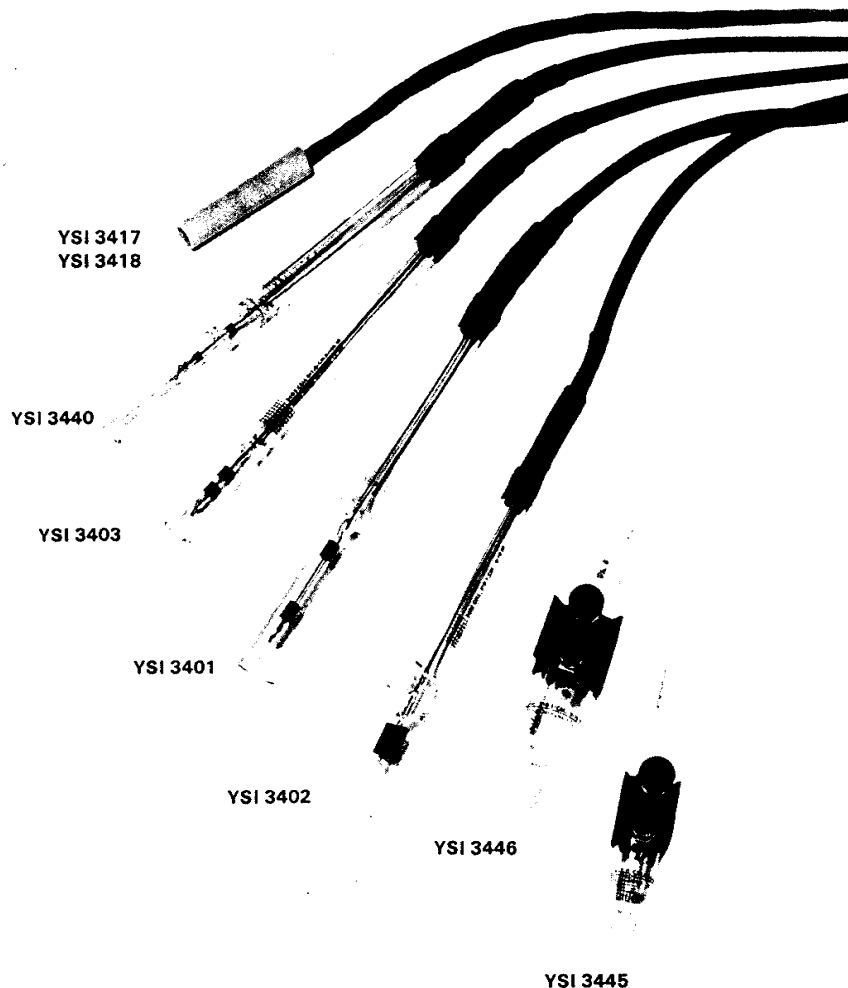
The temperature signal is present when the Function Switch is set for the Temperature mode. In *either* the Conductance or the Temperature Compensated Conductance mode, *only* non-temperature compensated signals are presented at the recorder terminals.

BATTERY (Only on instruments so equipped)

The battery is of the sealed lead acid type. It is recharged automatically when the instrument is plugged in (whether the Function Switch is turned Off or On). If the battery has been permitted to discharge completely, about one hour will be needed after plugging in the instrument before it can be used. Fifteen hours should be allowed for fully recharging the battery after heavy use before again operating the instrument in the portable mode. Specifications may be degraded if the instrument is operated on a battery having a low state of charge.

CALIBRATION

The instrument was fully calibrated and tested at the factory before shipment. If components are replaced, or the instrument has been in service for a long time, a calibration check may be desirable. The YSI Service Department at the factory can provide prompt calibration.



YSI 3400 Series Conductivity Cells

CONDUCTIVITY CELLS

General Description

YSI offers several standard dip and flow-through conductivity cells, each utilizing platinized platinum-iridium electrodes, except YSI 3418 which has platinized 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
Dip Cells							
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"

Part No.	cgs Cell Constant	S.I. Cell Constant	Material	Overall Length	Max O.D.	Chamber I.D.	Chamber Depth
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 $\pm 1\%$ accuracy against 0.01 normal KCl solution by means of a YSI transfer standard. (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. 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.

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/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/cm or K = 10.0/cm cells. K = 0.1/cm cells may be used for any value below 2,000 micromhos, and K = 10.0/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.

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 or in the case of flow-through cells, connected to a fluid line so that the cell is completely filled with the solution to be measured. 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 1/4 inch away from any other object, including the walls or bottom of the solution container.
4. Stirring or flow of solution is necessary for the highest accuracy in measurement, especially in low-conductivity solutions.
5. 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 during measurement those units which cause trouble.

6. The cell should always be handled carefully to decrease the possibility of breakage or loss of calibration accuracy.
7. The cell should never be transferred from one type of solution to another without having first been carefully rinsed.
8. Never store a dirty or contaminated cell.
9. In order to construct an easily calibrated, rugged cell, YSI solders the electrodes and supports in the 3440 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 small sample may be used 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 ($K = 1.0/\text{cm}$) required 15 ml, the 3402 cell ($K = 0.1/\text{cm}$) requires 12 ml, the 3403 cell ($K = 1.0/\text{cm}$) requires 3 ml, 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 indicated 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 = $1200 \times 1.0/\text{cm} = 1200 \text{ micromhos/cm}$

Step 3 — Conductance = 1000 micromhos

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

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/cm be used.

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.



The YSI 3139 Platinizing Instrument in use.

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 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 #3160-3165 Conductivity Calibrator Solutions to an accuracy of approximately $\pm 0.25\%$ at 1000, 10,000 and 100,000 micromho/cm.

Part No.	Size	Conductivity at 25.00°C
YSI 3160	Gallon	1000 micromho/cm $\pm 0.35\%$ -0.25%
YSI 3161	Quart	1000 micromho/cm $\pm 0.35\%$ -0.25%
YSI 3162	Gallon	10,000 micromho/cm $\pm 0.25\%$
YSI 3163	Quart	10,000 micromho/cm $\pm 0.25\%$
YSI 3164	Gallon	100,000 micromho/cm $\pm 0.25\%$
YSI 3165	Quart	100,000 micromho/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.

GENERAL WARRANTY

All YSI products are warranted for one year against defects in workmanship and materials when used for their intended purpose and maintained according to manufacturer's instructions. Damages from accidents, misuse, tampering, or failure to perform prescribed maintenance are not covered. Shelf life for reagents, membranes, and other supplies in the original unopened package is warranted for the period of time indicated by their expiration date. This warranty is limited to repair or replacement at no charge.

RETURN INSTRUCTIONS

If your product has failed as a result of what you believe to be defects in workmanship or materials, please contact the dealer from whom you purchased the product. If the product was purchased directly from YSI, contact:

Service Department
Yellow Springs Instrument Co., Inc.
P.O. Box 279
Yellow Springs, OH 45387
Phone: (513) 767-7241
Telex: 20-5437

Report the date of purchase, serial number, type product, and the nature of the failure. If it is determined by the dealer or YSI that the repair is not covered by the warranty, you will be notified of that determination and the charge for repair or replacement.

In instances where the return of the product to the dealer or YSI is necessary, instructions for return will be furnished.

APPENDIX 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. 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 $\pm 0.35\%$ accuracy with YSI 3160-3165 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 $\pm 3\%$, 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 bipolar 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. However, 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 desirable 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).

TEMPERATURE CORRECTION DATA FOR TYPICAL SOLUTIONS¹

A. Potassium Nitrate* (KNO_3)

Concentration: 1×10^{-1} mole/liter			Concentration: 1×10^{-2} mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	6.68	1.78	0	.756	1.77
5	7.71	1.79	5	.868	1.80
10	8.75	1.81	10	.984	1.83
15	9.81	1.83	15	1.105	1.86
20	10.90	1.85	20	1.229	1.88
25	12.01	1.87	25	1.357	1.90
30	13.15	1.90	30	1.488	1.93
35	14.32	1.92	35	1.622	1.95
37.5	14.92	1.94	37.5	1.690	1.96
40	15.52	1.95	40	1.759	1.97
45	16.75	1.97	45	1.898	1.99
50	18.00	2.00	50	2.040	2.01

B. Lithium Chloride* (LiCl)

Concentration: 1 mole/liter			Concentration: 1×10^{-1} mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	39.85	1.82	0	5.07	1.87
5	46.01	1.85	5	5.98	1.85
10	52.42	1.89	10	6.87	1.85
15	59.07	1.92	15	7.75	1.85
20	65.97	1.95	20	8.62	1.85
25	73.10	1.98	25	9.50	1.86
30	80.47	2.02	30	10.40	1.88
35	88.08	2.05	35	11.31	1.91
37.5	91.97	2.07	37.5	11.78	1.92
40	95.92	2.08	40	12.26	1.94
45	103.99	2.11	45	13.26	1.98
50	112.30	2.15	50	14.30	2.02

Concentration: 1×10^{-2} mole/liter			Concentration: 1×10^{-3} mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	.567	1.88	0	.059	1.93
5	.659	1.92	5	.068	2.03
10	.755	1.96	10	.078	2.12
15	.856	2.00	15	.089	2.19
20	.961	2.04	20	.101	2.25
25	1.070	2.08	25	.114	2.28
30	1.183	2.12	30	.127	2.31
35	1.301	2.16	35	.140	2.32
37.5	1.362	2.18	37.5	.147	2.32
40	1.423	2.20	40	.154	2.31
45	1.549	2.24	45	.166	2.29
50	1.680	2.28	50	.178	2.25

¹Charts developed by computer interpolation of data from sources listed.

*International Critical Tables, Vol. VI, pp. 229-253, McGraw Hill, N.Y.

C. Sodium Chloride** (NaCl)

Saturated solutions at all temps.			Concentration: 0.5 mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	134.50	1.86	0	25.90	1.78
5	155.55	1.91	5	29.64	1.82
10	177.90	1.95	10	33.61	1.86
15	201.40	1.99	15	37.79	1.90
20	225.92	2.02	20	42.14	1.93
25	251.30	2.05	25	46.65	1.96
30	277.40	2.08	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: 1×10^{-1} mole/liter			Concentration: 1×10^{-2} mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	5.77	1.83	0	.632	1.87
5	6.65	1.88	5	.731	1.92
10	7.58	1.92	10	.836	1.97
15	8.57	1.96	15	.948	2.01
20	9.60	1.99	20	1.064	2.05
25	10.66	2.02	25	1.186	2.09
30	11.75	2.04	30	1.312	2.12
35	12.86	2.06	35	1.442	2.16
37.5	13.42	2.07	37.5	1.508	2.17
40	13.99	2.08	40	1.575	2.19
45	15.14	2.10	45	1.711	2.21
50	16.30	2.12	50	1.850	2.24

Concentration: 1×10^{-3} mole/liter

°C	millimhos/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	

sodium atomic weight 22.99
chlorine " " 35.45
58.44
 $58.44 \times 10^{-3} = 58.44 \text{ mg/L}$
for 124 ms @ 25°C

D. Potassium Chloride* (KCl)

Concentration: 1 mole/liter			Concentration: 1×10^{-1} mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	65.10	1.67	0	7.13	1.78
5	73.89	1.70	5	8.22	1.80
10	82.97	1.72	10	9.34	1.83
15	92.33	1.75	15	10.48	1.85
20	101.97	1.77	20	11.65	1.88
25	111.90	1.80	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: 1×10^{-2} mole/liter			Concentration: 1×10^{-3} mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	.773	1.81	0	.080	1.84
5	.892	1.84	5	.092	1.88
10	1.015	1.87	10	.105	1.92
15	1.143	1.90	15	.119	1.96
20	1.275	1.93	20	.133	1.99
25	1.412	1.96	25	.147	2.02
30	1.553	1.99	30	.162	2.05
35	1.697	2.02	35	.178	2.07
37.5	1.771	2.03	37.5	.186	2.08
40	1.845	2.05	40	.194	2.09
45	1.997	2.07	45	.210	2.11
50	2.151	2.09	50	.226	2.13

0.524523 grams of KCl to 1000 grams of 0.1 M water
 E. Ammonium Chloride* (NH₄Cl) *for 1000 ms solution*

Concentration: 1 mole/liter			Concentration: 1×10^{-1} mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	64.10	1.60	0	6.96	1.82
5	74.36	1.53	5	7.98	1.88
10	83.77	1.45	10	9.09	1.93
15	92.35	1.37	15	10.27	1.97
20	100.10	1.29	20	11.50	2.00
25	107.00	1.21	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

**CRC Handbook of Chemistry and Physics, 42nd Ed., p. 2606. The Chemical Rubber Company, Cleveland.

Concentration: 1×10^{-2} mole/liter			Concentration: 1×10^{-3} mole/liter		
°C	millimhos/cm	%/°C (to 25°C)	°C	millimhos/cm	%/°C (to 25°C)
0	.764	1.84	0	.078	1.88
5	.889	1.86	5	.092	1.90
10	1.015	1.88	10	.105	1.91
15	1.144	1.91	15	.119	1.93
20	1.277	1.94	20	.133	1.95
25	1.414	1.97	25	.148	1.98
30	1.557	2.02	30	.162	2.01
35	1.706	2.06	35	.178	2.04
37.5	1.782	2.08	37.5	.186	2.06
40	1.860	2.10	40	.194	2.07
45	2.020	2.14	45	.210	2.11
50	2.186	2.18	50	.227	2.15

