HORIBA

Portable Conductivity Meter

ES-12

ES-14

Instruction manual

CODE: 040683000

Preface

This manual explains the use of HORIBA ES series handy conductivity meters. It covers two models, the ES-12 and the ES-14.
First, the manual acquaints you with the steps necessary to set up your ES meter and then it takes you through the basic steps involved in measuring electrical conductivity.
Later, when you are ready to use some of the more advanced functions available on your ES meter, you will find that this instruction manual is organized so that it may be used as a handy reference guide to these applications.

- The information contained in the instruction manual is subject to change without notice, as improvements are made in specifications, and does not represent a commitment on the part of HORIBA, Ltd.
- This instruction manual is included with your HORIBA ES series conductivity meter to help you make full use of the instrument. We have tried to anticipate most circumstances in which the ES series conductivity meter might be effectively used. If, however, you are in doubt about a certain application or your instrument does not seem to be functioning properly, please contact your local HORIBA service center or HORIBA representative.
- Please note that HORIBA cannot accept responsibility for any damage to the ES series conductivity meter or malfunction that may occur as the result of operating the ES meter in a manner or situation not recommended in this instruction manual.
- No part of this instruction manual may be reproduced or altered in any way without written permission from HORIBA, Ltd.

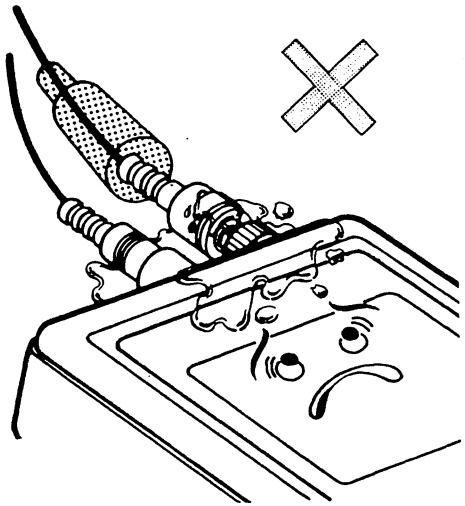
Contents

Introduction

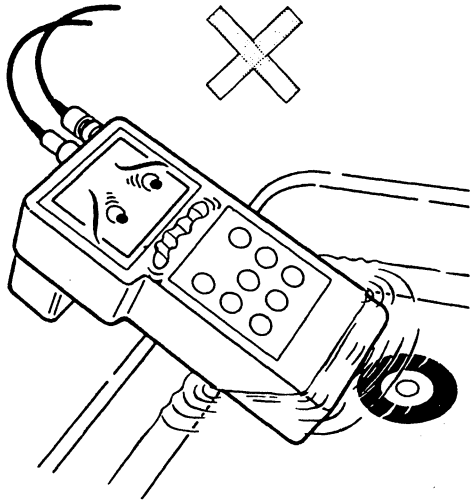
1. Handling precautions

To ensure the safe and accurate use of your meter, observe the following precautions.

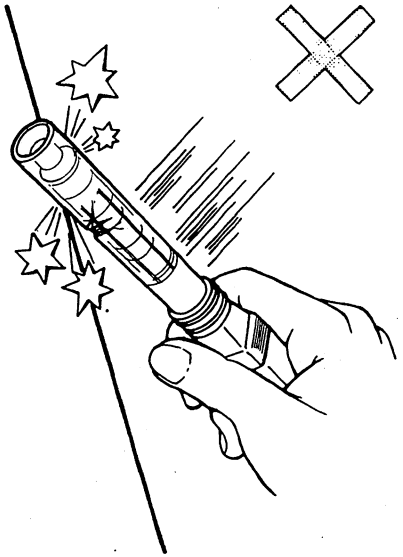
- **Do not touch the electrode or instrument connectors or let them come in contact with water. If the insulation is damaged, the meter may produce inaccurate readings.**



- **Do not place the meter unit in liquids. The meter is drip-proof but not water proof. Immersion can damage the internal circuitry.**

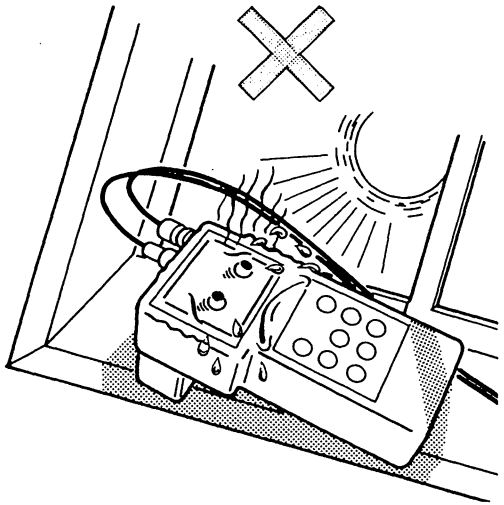


- **Do not jar the electrode.**
- **Do not operate the keys with hard objects, such as pencils.**



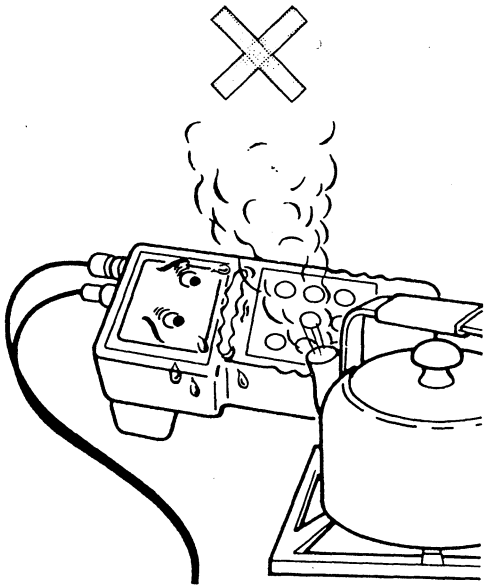
● **Do not leave the meter in direct sunlight.**

Exposing the LCD to ultraviolet rays will reduce the quality of the display.



※LCD : Liquid Crystal Display

● **Do not subject the meter to dust, vibration, moisture, or abrupt changes in temperature.**



● **Never use the unit with strong acids (especially when hot) or organic substances such as methylethylketone (MEK).**

The electrode (#3582) is made of the materials shown below. If infused in the above substances, corrosion or cracking may occur, leading to damage or failure of the electrode.

Exposed electrode materials

Outer tube	PSF
Electrode plates	Titanium and platinum black
Stem	PPS

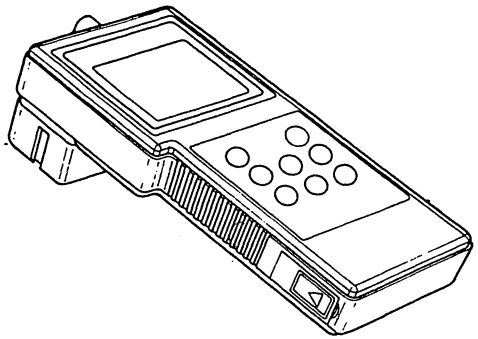
● **Always use a 6F22 (S-006P) dry-cell battery. If you are not going to use the meter for a while, remove the battery from the unit.**

● **When you are using an AC power supply, use only the proper AC adaptor (HORIBA Model AC-10).**

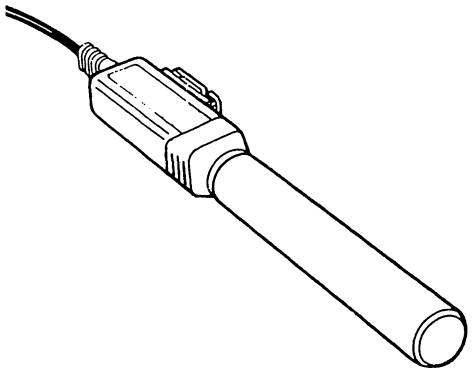
2. Unpacking your ES meter

The following items are included in your ES meter package. Check to make sure that nothing is missing or damaged.

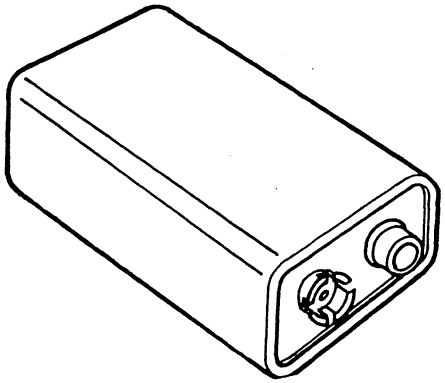
- ES meter main unit



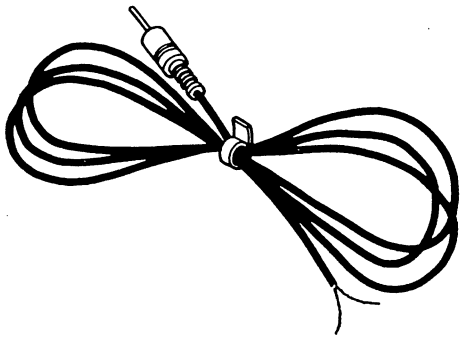
- Conductivity electrode (#3582-10D)



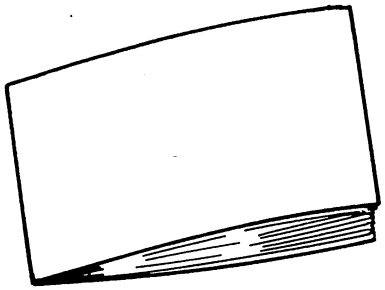
- Dry-cell battery 6F22 (S-006P)



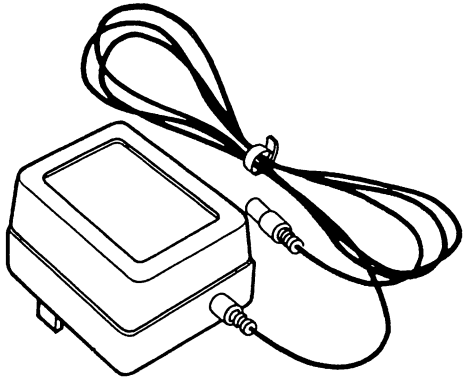
● 2 meter output cord



● Instruction manual



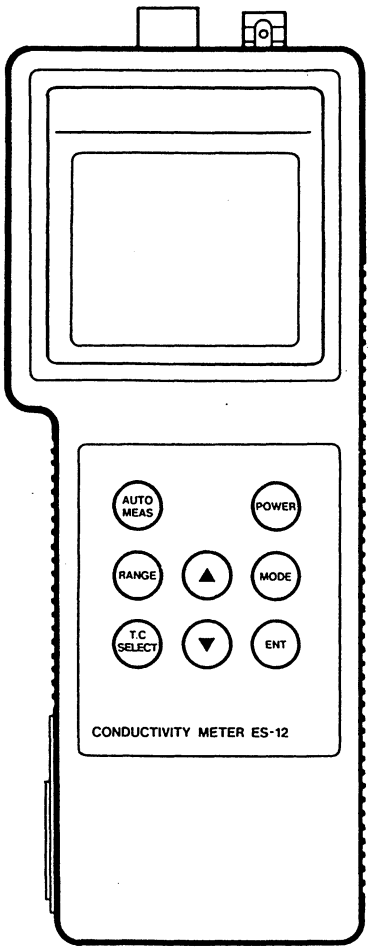
● Optional AC adaptor (AC-10)



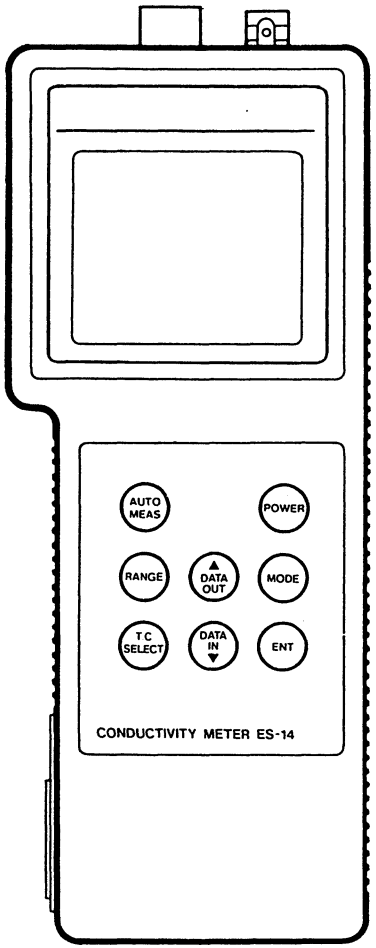
3. Introducing the ES series

There are two ES series meters, the ES-12 and ES-14.

● ES-12



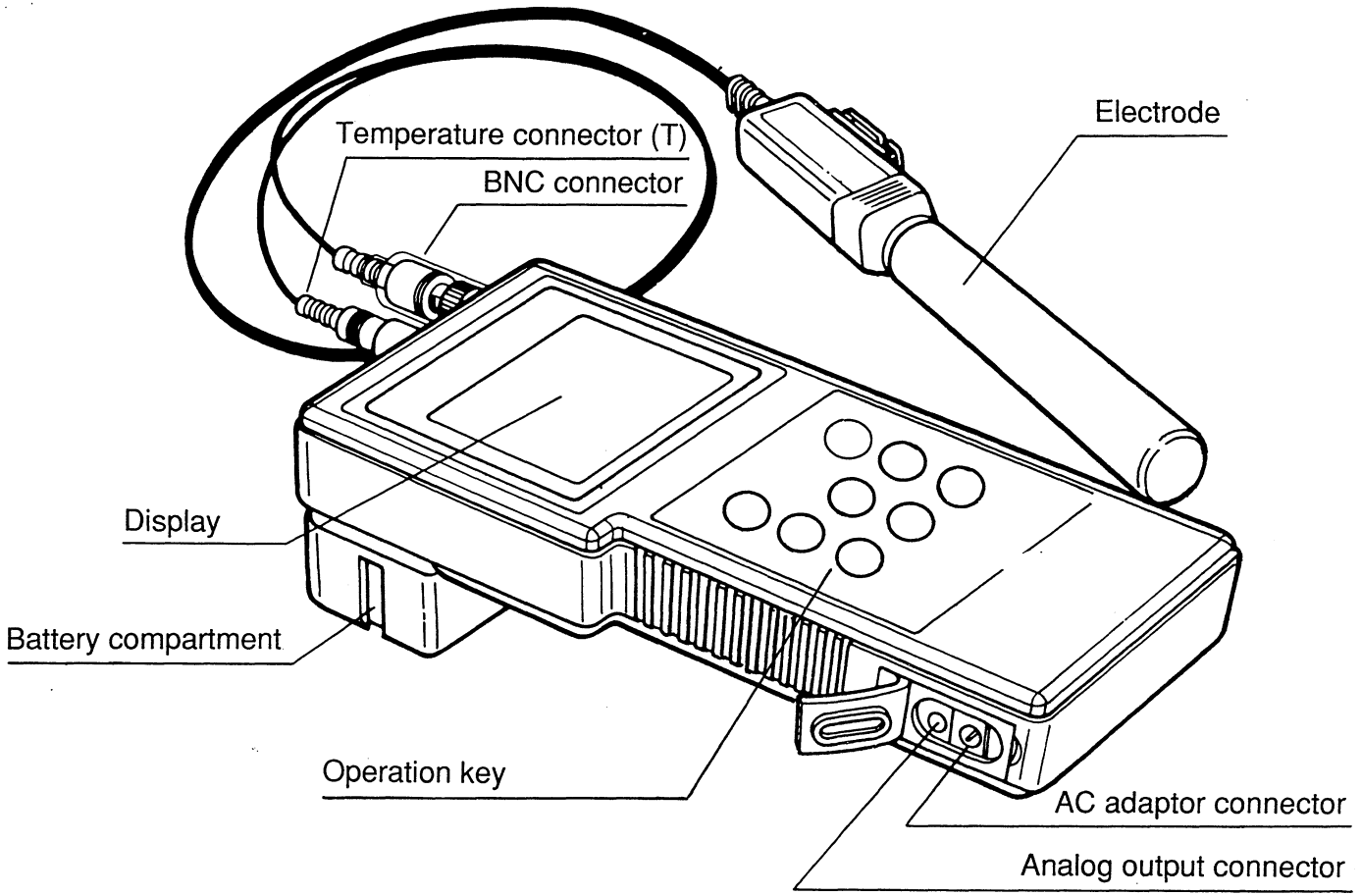
● ES-14



Item	ES-12	ES-14
Conductivity measurement	●	●
Resistivity measurement	●	●
Sodium chloride concentration measurement		●
Simultaneous temperature readout	●	●
Auto hold function	●	●
Data memory function		●

4. Meter parts

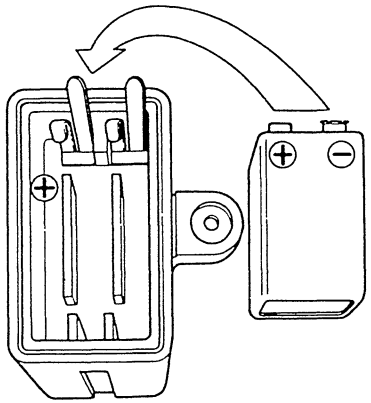
The ES series meter has the following parts (model ES-14 is shown).



5. Battery insertion and replacement

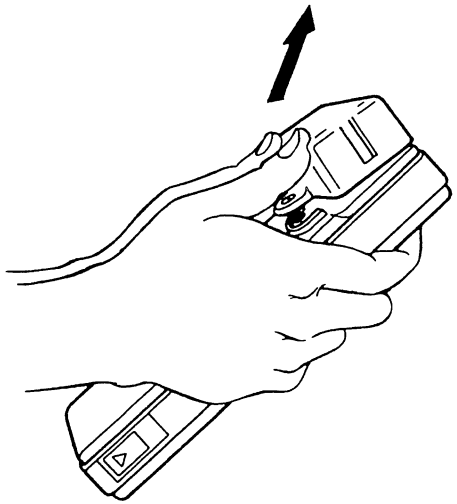
- The unit is delivered without a battery inserted.
  When the battery is exhausted, the indication "ERR 5" (battery alarm) appears on the display. In such a case, insert or replace the battery as follows.

- **Be sure to insert the battery with correct polarity.**
- **Set the POWER key to OFF before replacing the battery. Data stored in the internal memory will be preserved.**



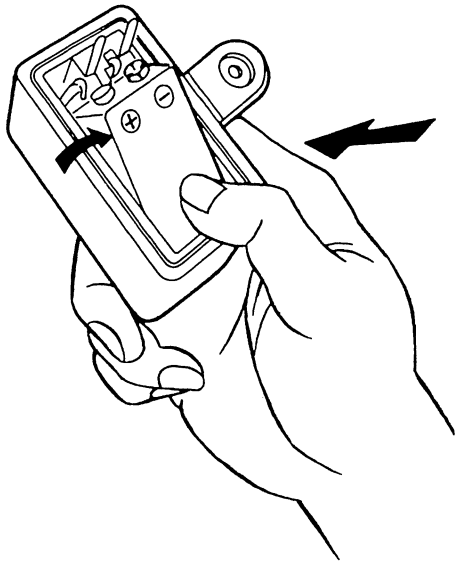
- Loosen the fastening screw of the battery compartment and pull the compartment outward.

- Push toward the electrode cable connector.

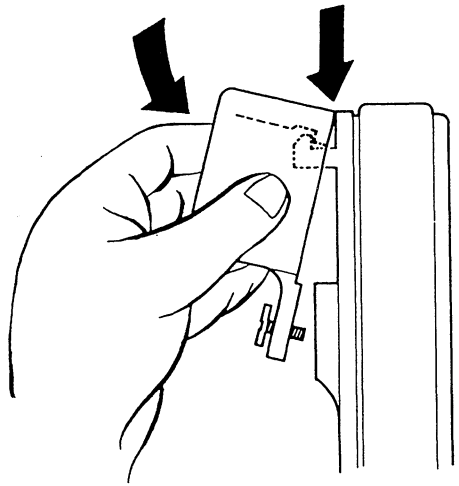


- Remove the battery and insert a new battery.

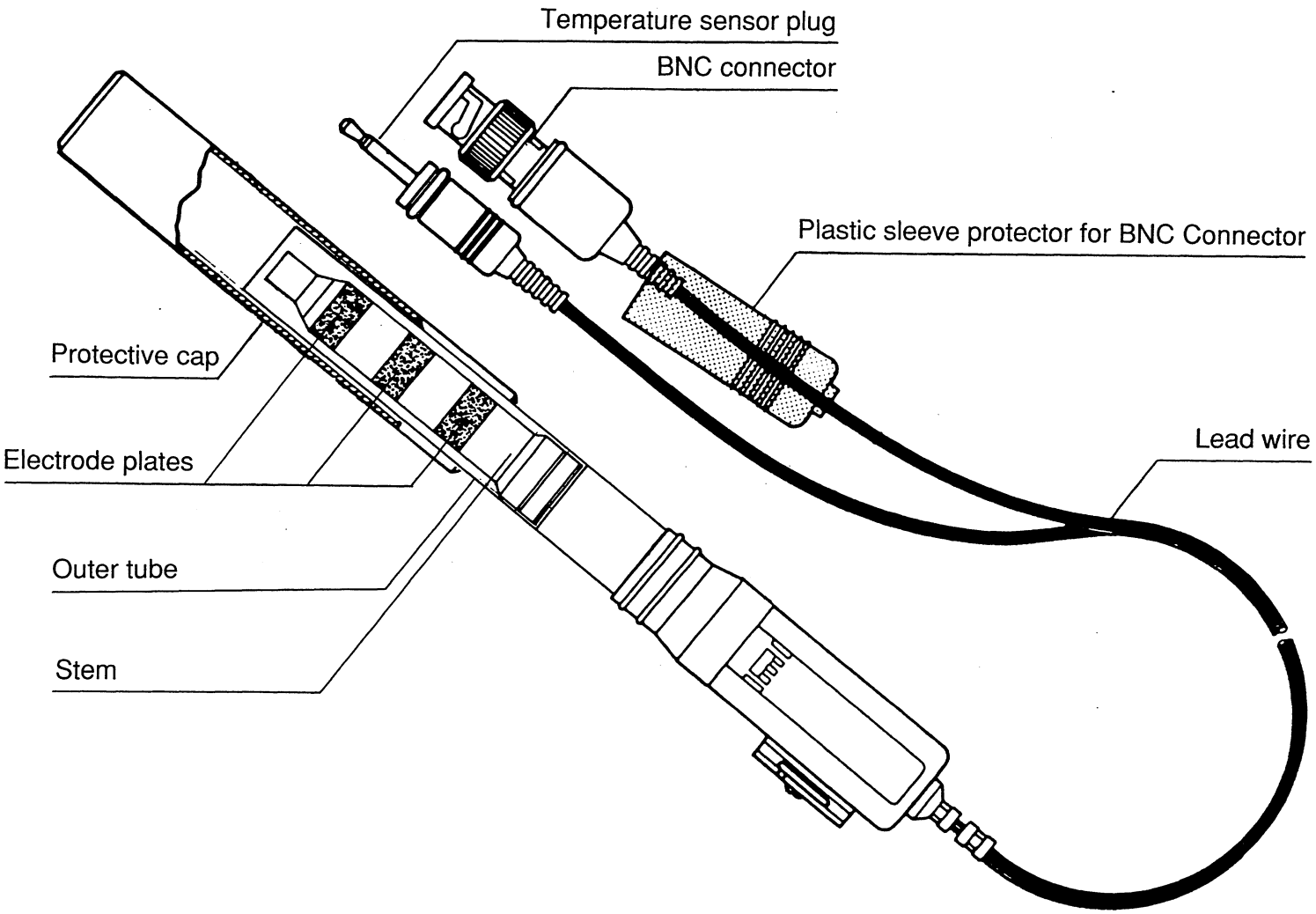
- Make sure the battery is inserted with correct polarity. Reversing the polarity will not damage the meter, but the meter will not work.



- Attaching the compartment.
  Hook the compartment onto the meter, and tighten the fastening screw again.
  Attach so that surfaces are level.



6. Electrode parts



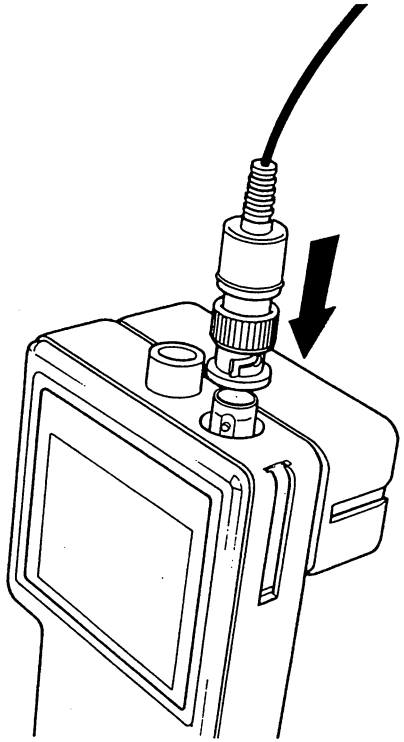
7. Attaching the electrode

When you attach the electrode, be careful not to get water on the connector or touch the connector with dirty hands.

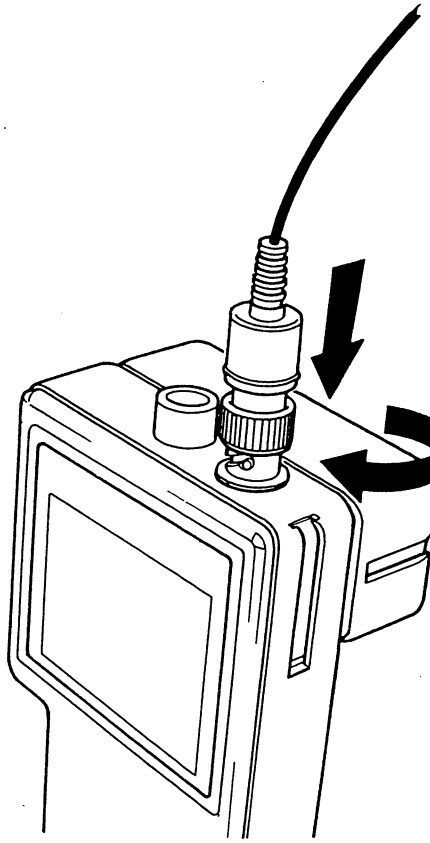
Electrode connector

1. Insert the connector.
   Place the connector over the receptor on the meter. Slide the groove in the connector over the knob on the receptor.

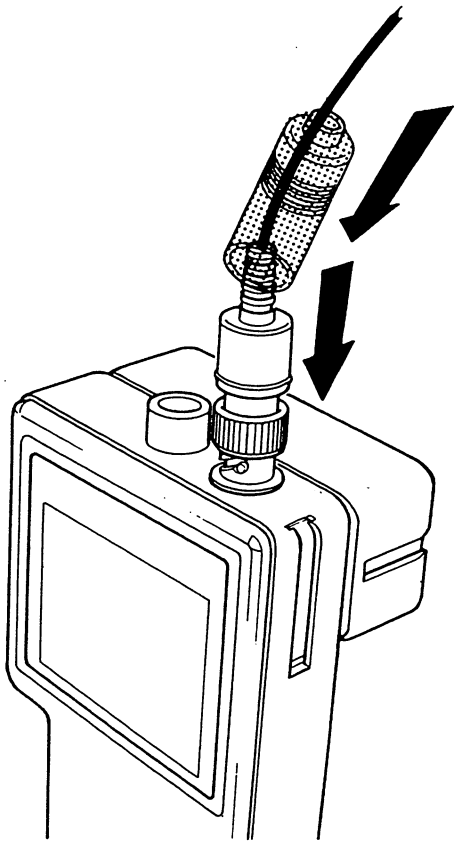
* Don't force against the direction of the groove.



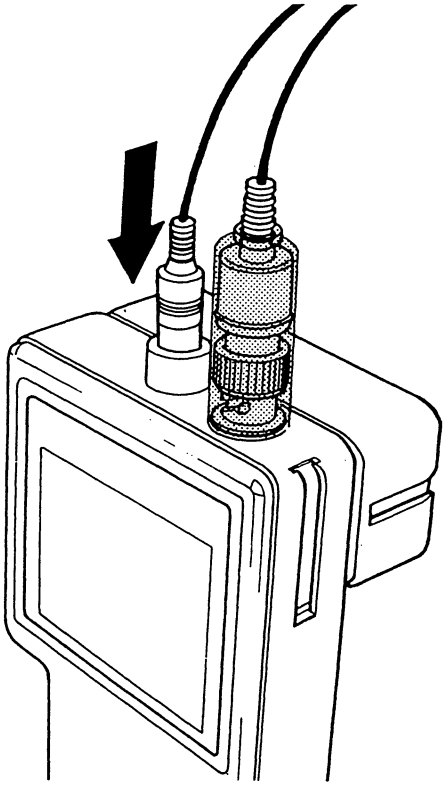
2. Rotate it clockwise toward the groove.



3. Put the cover over the connector.

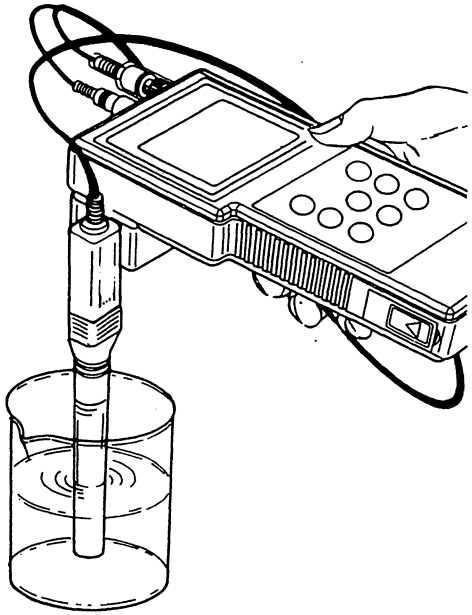


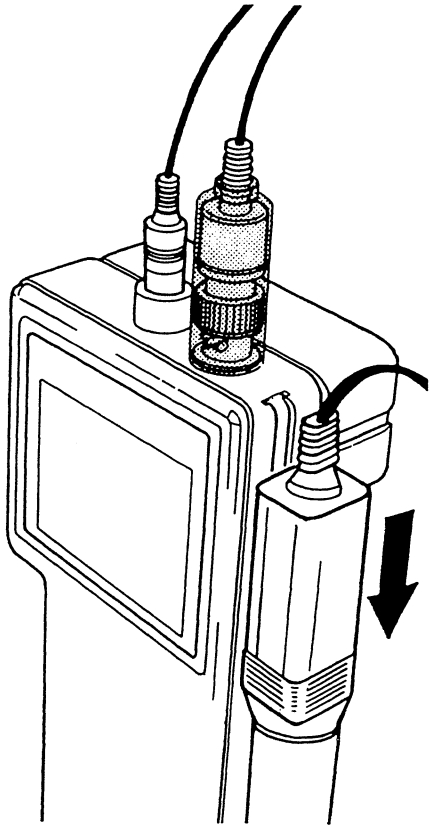
Temperature connector
Insert the temperature sensor plug in the connector.



Mounting the electrode to the unit
Grooves on the right side of the unit and on both sides of the battery case allow attaching the electrode to the main unit.

Example





8. Display

The LCD of this unit shows the measured values for conductivity or resistivity (ES-14: also NaCl concentration) and the temperature of the solution at the time of measurement. Various other indications showing the operating status of the unit are also provided.

❶ Measurement mode/setup mode indication

MEAS	Lit	Measurement mode
SET	Lit	Setup mode

❷ Auto range indication

A.RANGE	Lit	Auto range selection
A.RANGE	Out	Manual range selection

❸ Auto hold indication

HOLD	Flashing	Potential tracking
HOLD	Lit	Potential stable, hold enabled

❹ Electrode aging check

SENS	Flashing	Checking
SENS	Lit	Measurement with compensation

❺ Data display

- Conductivity, resistivity, NaCl concentration (ES-14)
- Cell constant setting, calibration factor
- Temperature coefficient setting

❻ Data memory, recall, error number indication

IN DATA	Data memory (ES-14)
OUT DATA	Data recall (ES-14)
ERR	Error

❼ 1. Sample temperature
2. During cell constant setting and calibration, nominal cell constant is displayed x 0.1, x 1, x 10.

❽ Temperature conversion mode indication

T.C MODE 2%↙

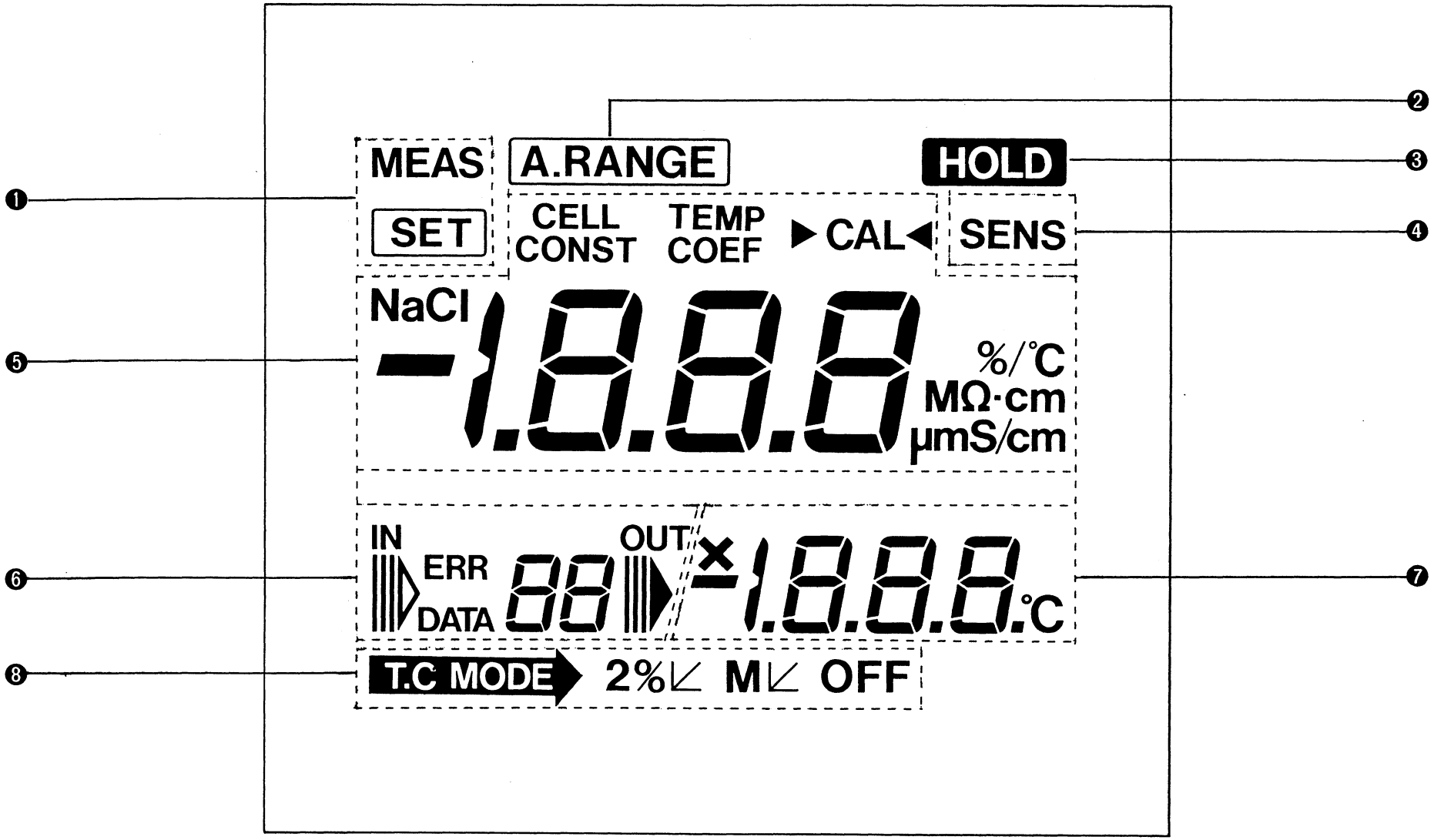
Conversion with preset temperature coefficient of 2%/°C (at 25°C)

T.C MODE M↙

Conversion with a freely definable temperature coefficient

T.C MODE OFF

No temperature conversion (temperature coefficient 0%/°C)


MEAS
A.RANGE
HOLD
SET
CELL CONST
TEMP COEF
▶CAL◀
SENS
NaCl
-1.8.8.8
%/°C
MΩ·cm
µmS/cm
IN
ERR
DATA
88
OUT
-1.8.8.8
°C
T.C MODE
2%∠
M∠
OFF
❶
❷
❸
❹
❺
❻
❼
❽

9. Key names

This unit has eight round control keys which operate as toggle switches or selectors. The functions of the keys are described in this chapter.

❶ **POWER** key
Turns the unit on and off. When the unit is turned on, the initial screen appears on the display.
If nothing is connected to the analog output and no key is operated for about 30 minutes, the unit shuts itself off automatically.

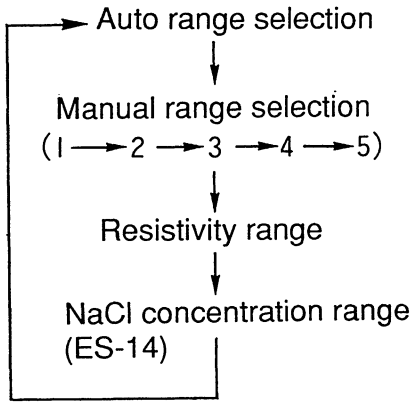
❷ **AUTO MEAS**
(Auto measurement) key
Serves to start or cancel the measurement. The key is also used to return to the measurement mode from the setup mode.

❸ **UP** key/**DATA OUT** key
- **UP** key
  In the setup mode, the key serves as **UP** key to change setting values.
- **DATA OUT** key (ES-14)
  In the measurement mode, this key serves to recall data stored in the memory of the unit. Each push of the key brings up the next stored data.

❹ **DOWN** key/**DATA IN** key
- **DOWN** key
  In the setup mode, the key serves as **DOWN** key to change setting values.
- **DATA IN** key (ES-14)
  In the measurement mode, this key serves to store data in the memory of the unit. With each push, the memory number is incremented.
  A maximum of 10 data can be stored.

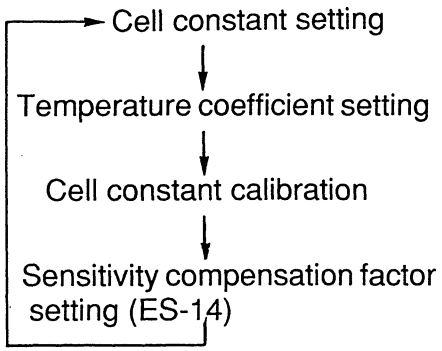
❺ **T.C. SELECT** key
Selects the temperature coefficient 2%/ °C, a manually input temperature coefficient M∠, or turns temperature conversion off.

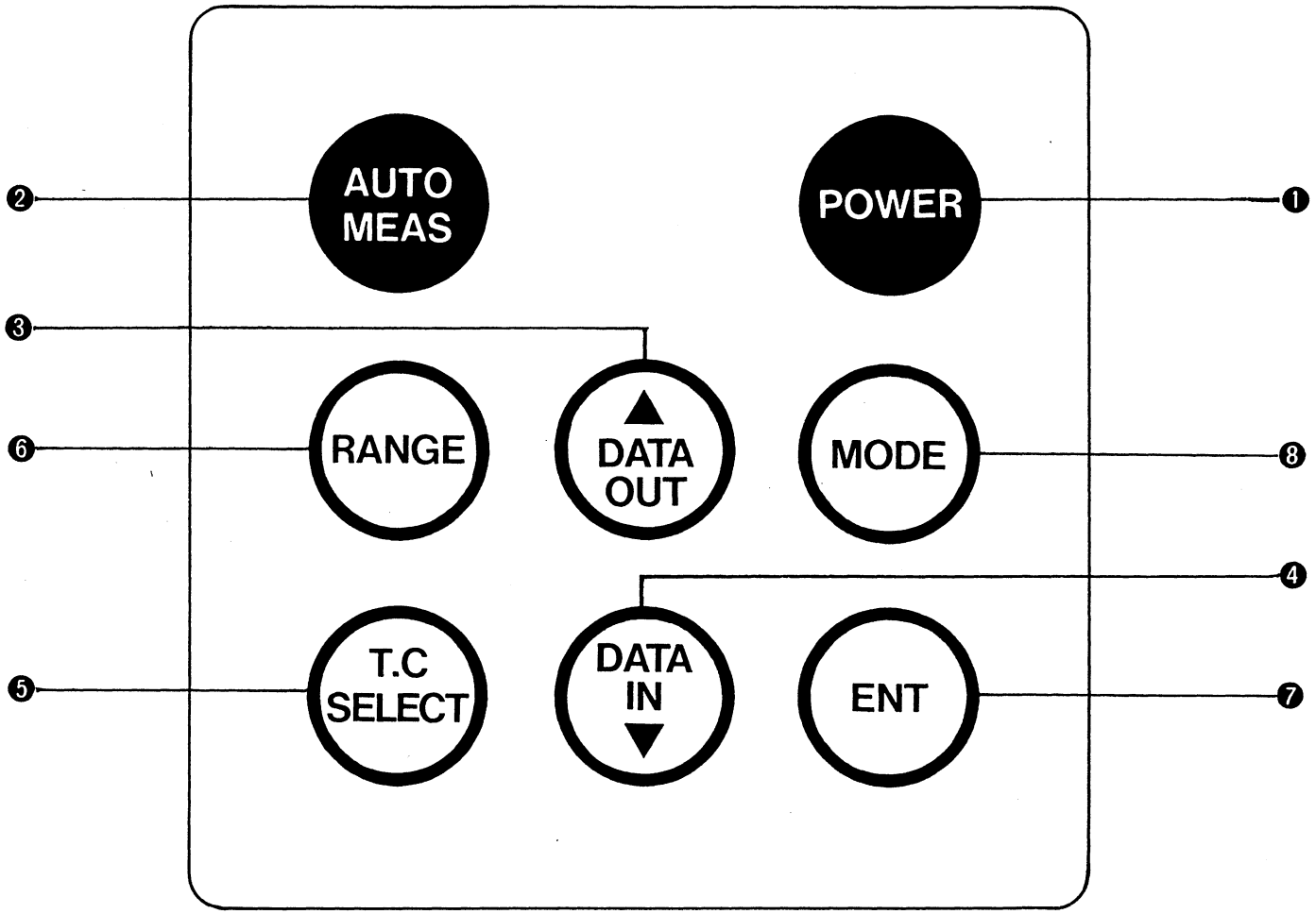
❻ **RANGE** key
In the measurement mode, each push of this key cycles through the following settings:



❼ **ENTER** key
Serves to enter values selected with the **UP** and **DOWN** keys in the setup mode.

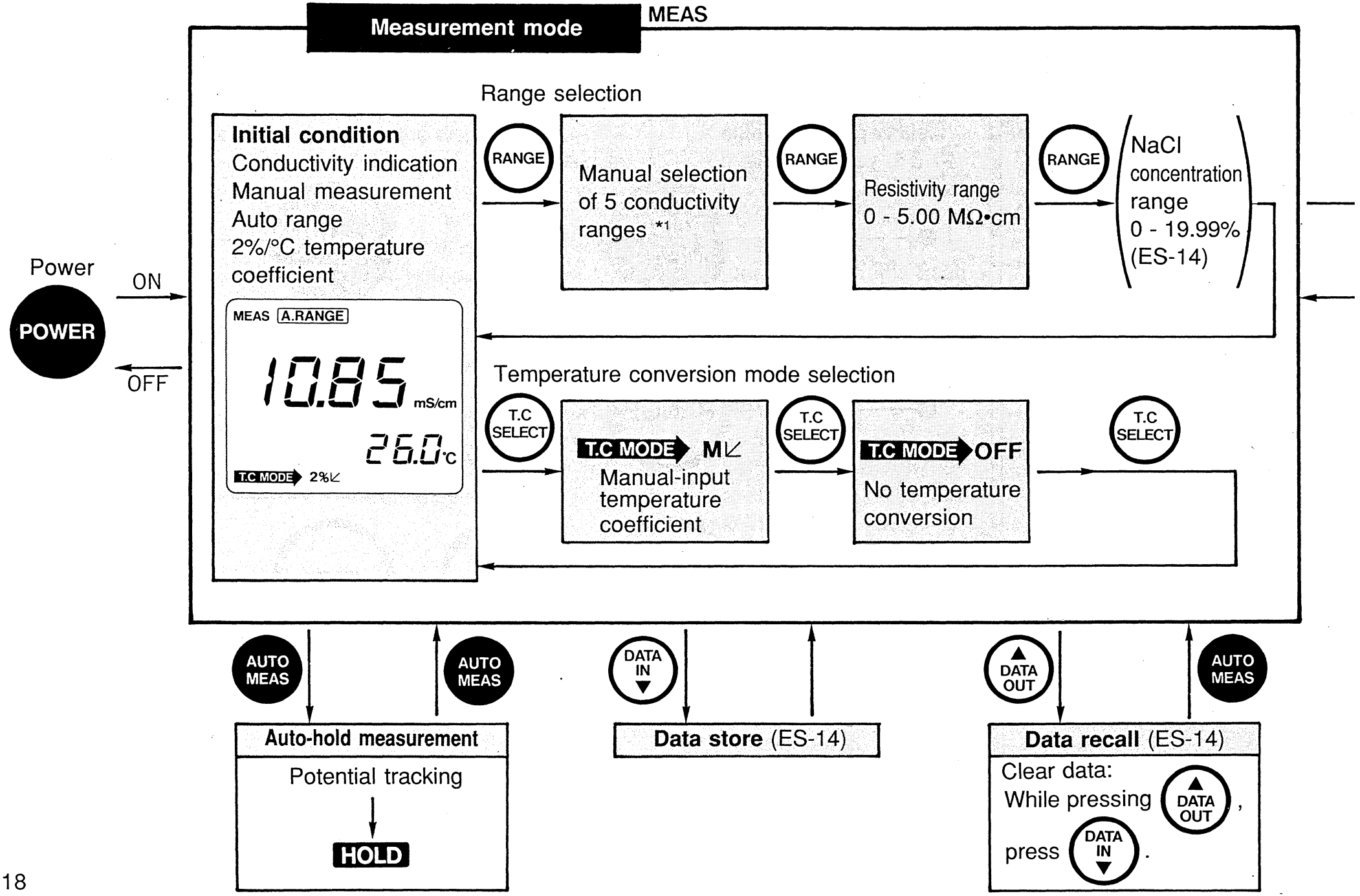
❽ **MODE** key
From the measurement mode, each push of this key cycles through the following settings:

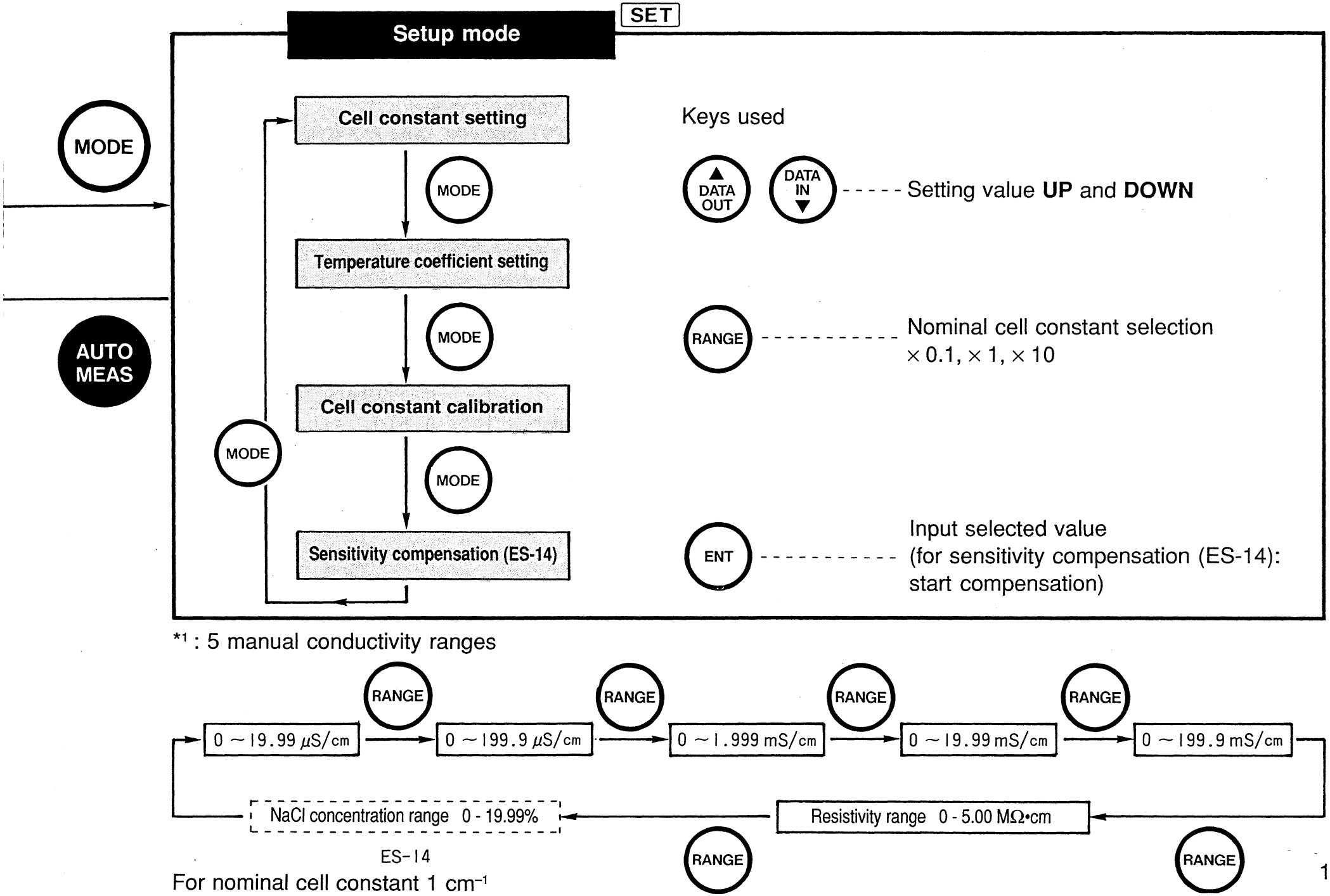




The above illustration shows the (DATA OUT) and (DATA IN) keys of the ES-14 as **UP** and **DOWN** keys for values in the setup mode.
On the ES-12, (▲) and (▼) keys serve as **UP** and **DOWN** keys.

10. Operation modes and key functions



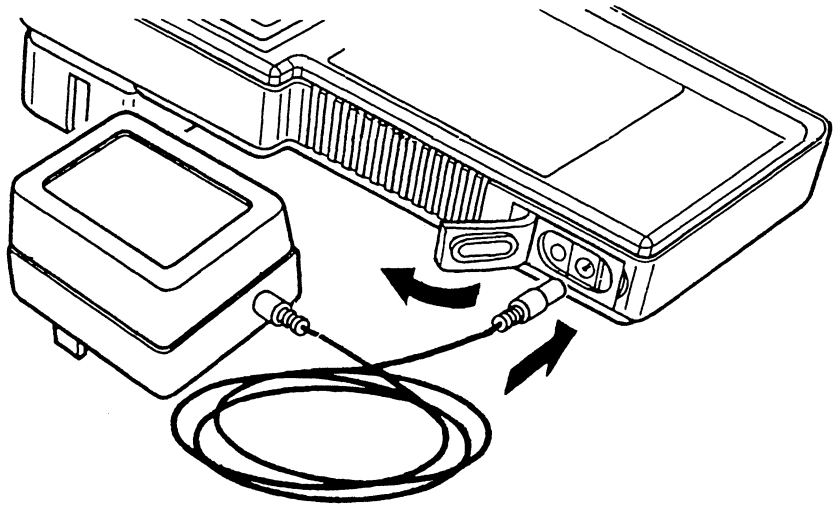

Setup mode
SET
MODE
AUTO MEAS
Cell constant setting
Temperature coefficient setting
Cell constant calibration
Sensitivity compensation (ES-14)
MODE
Keys used
DATA OUT
DATA IN
Setting value UP and DOWN
RANGE
Nominal cell constant selection
× 0.1, × 1, × 10
ENT
Input selected value
(for sensitivity compensation (ES-14):
start compensation)
*1 : 5 manual conductivity ranges
0 ~ 19.99 µS/cm
0 ~ 199.9 µS/cm
0 ~ 1.999 mS/cm
0 ~ 19.99 mS/cm
0 ~ 199.9 mS/cm
NaCl concentration range 0 - 19.99%
Resistivity range 0 - 5.00 MΩ•cm
ES-14
For nominal cell constant 1 cm⁻¹

11. Using the AC adaptor

With the optional AC adaptor, the meter can be operated from an AC power supply.
Data in memory will not be lost even if the AC adaptor is disconnected after the unit was switched off.
Use only the proper AC adaptor (HORIBA Model AC-10). When not using the adaptor, disconnect it from the meter.

To connect the adaptor, proceed as follows.

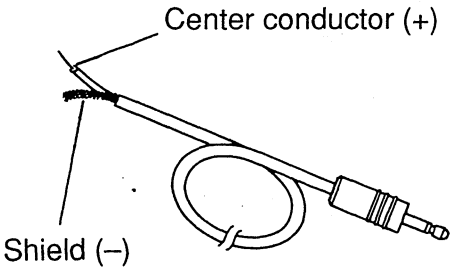
1. Turn off the meter.
2. Open the rubber cover on the side of the unit and plug in the cable from the adaptor.



12. Analog output

The analog output terminal supplies a voltage which corresponds to the measurement value. The voltage range for conductivity, resistivity, and NaCl concentration (ES- 14) is as shown in the table below.

	Measurement display range	Analog output
Conductivity	0 - 19.99 µS/cm 0 - 199.9 µS/cm 0 - 1.999 mS/cm 0 - 19.99 mS/cm 0 - 199.9 mS/cm	0 - 1 VDC/F.S.
Resistivity	0 - 5.00 MΩ • cm	0 - 250 VDC/F.S.
NaCl concentration (ES-14)	0 - 19.99 %	0 - 1 VDC/F.S.

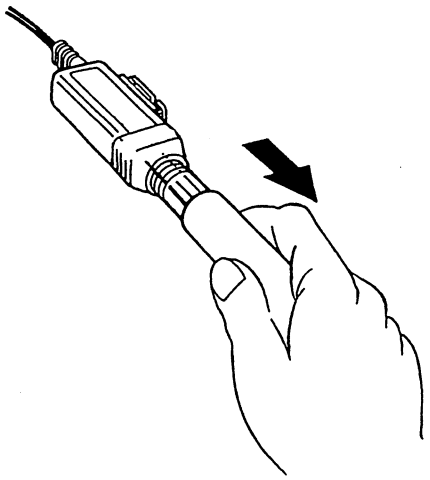


Open the rubber cover on the side of the unit and connect the output cable. The output voltage corresponds to the continuous measurement value also while the hold function for the display is used. While recalling stored data and during the setup mode, the analog output maintains the immediately preceding measurement value.

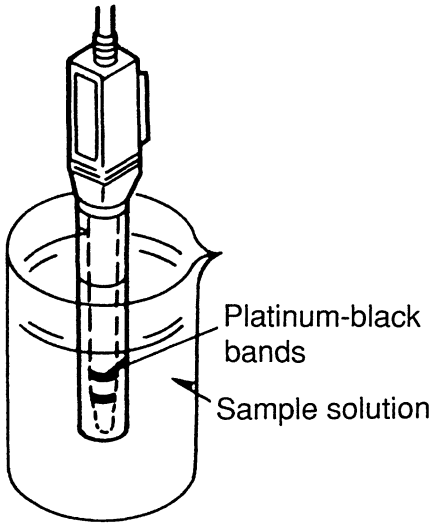
Measuring Conductivity

1. Preparing the electrode

● Remove the protective cap.

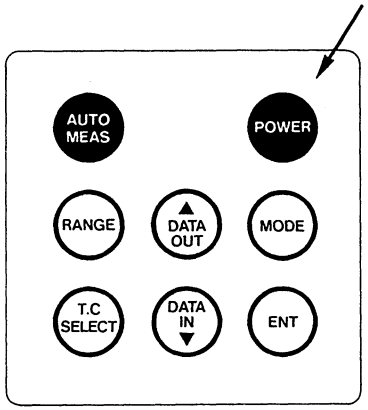


● Insert the electrode in the sample solution.



2. Turning the meter on

● Press the **POWER** key.



The display will be similar to the one shown here.

Manual measurement

MEAS

Conductivity indication

mS/cm · µS/cm

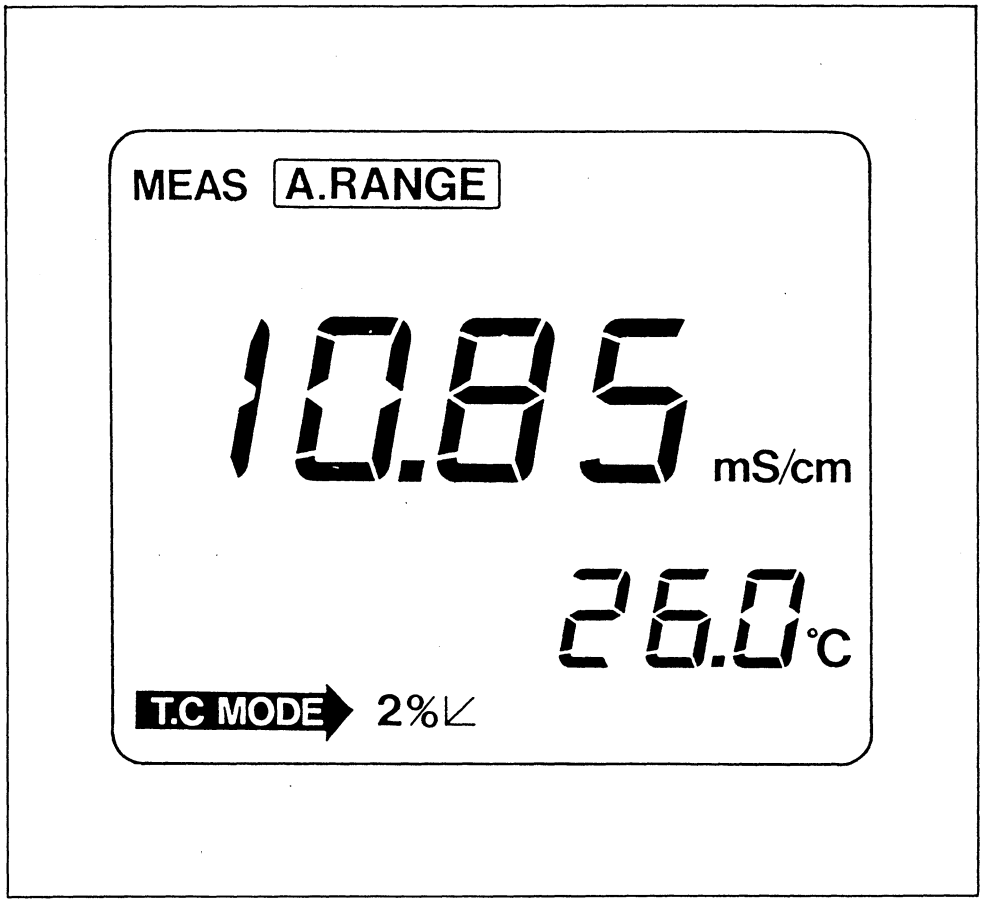
Auto range

A.RANGE

2%/°C temperature conversion

T.C MODE 2%⩗

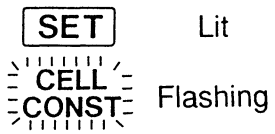
are selected automatically



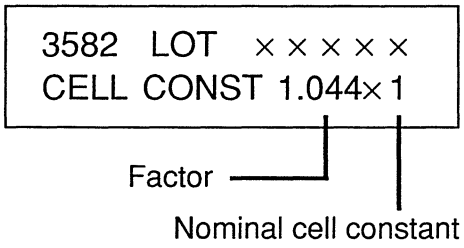
3. Setting the cell constant

The first time you use your ES Meter, you will need to input the value for the cell constant. Should you subsequently change electrodes, you will need to reset the value for the cell constant.

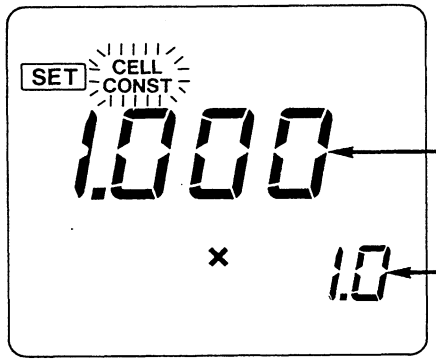
- Press the **MODE** key to select the mode for setting the cell constant.



- The cell constant is marked on the base of the electrode.

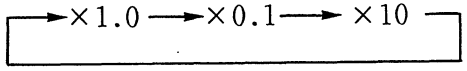


- Input the cell constant marked on the electrode.



Press the **UP** and **DOWN** keys to set the factor.
The setting range is 0.7 - 1.3.

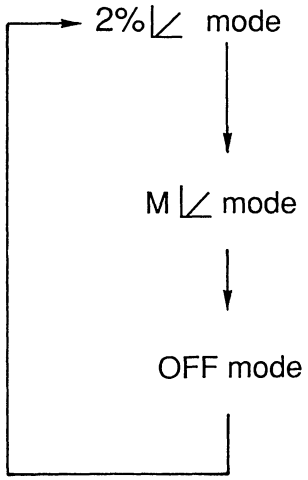
Use the **RANGE** key to set the nominal cell constant. With each push of the key, the setting cycles as follows:



- After the factor and nominal cell constant has been input, press the **ENT** key. The displayed cell constant is stored in memory and the setting process is completed.
- Press the **AUTO MEAS** key to return to the measurement mode.

4. Automatic temperature conversion

Use the **T.C. SELECT** key to cycle through the three temperature coefficient modes.



2%⌊ mode **2%⌊**
Temperature conversion for conductivity reading and output is carried out with a temperature coefficient of 2%/ °C (at 25°C).

M⌊ mode **M⌊**
Temperature coefficient for conversion of conductivity reading and output can be manually set in the range from 0.00 to 10.00%/ °C (at 25°C).

Temperature conversion off
OFF
Conductivity is displayed and output as measured, without temperature conversion.

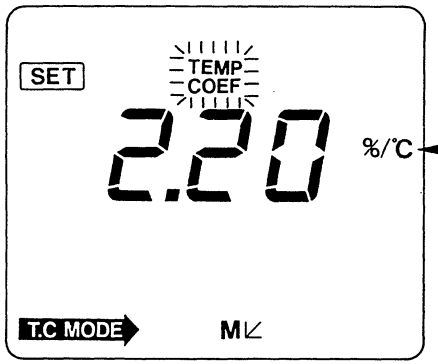
Entering the temperature coefficient for M⌊ mode

- Press the **MODE** key to activate the temperature coefficient setting mode.

SET Lit

TEMP COEF Flashing

- Enter the temperature coefficient.



Press the **UP** and **DOWN** keys to set the temperature coefficient.

- When the desired value has been set, press the **ENT** key. The displayed temperature coefficient is stored in memory and the setting process is completed.

TEMP COEF Flashing

↓

TEMP COEF Lit

- Press the **AUTO MEAS** key to return to the measurement mode. The M⌊ indication appears, and temperature conversion is carried out with the selected temperature coefficient.

5. Selecting the conductivity measurement range and measurement item

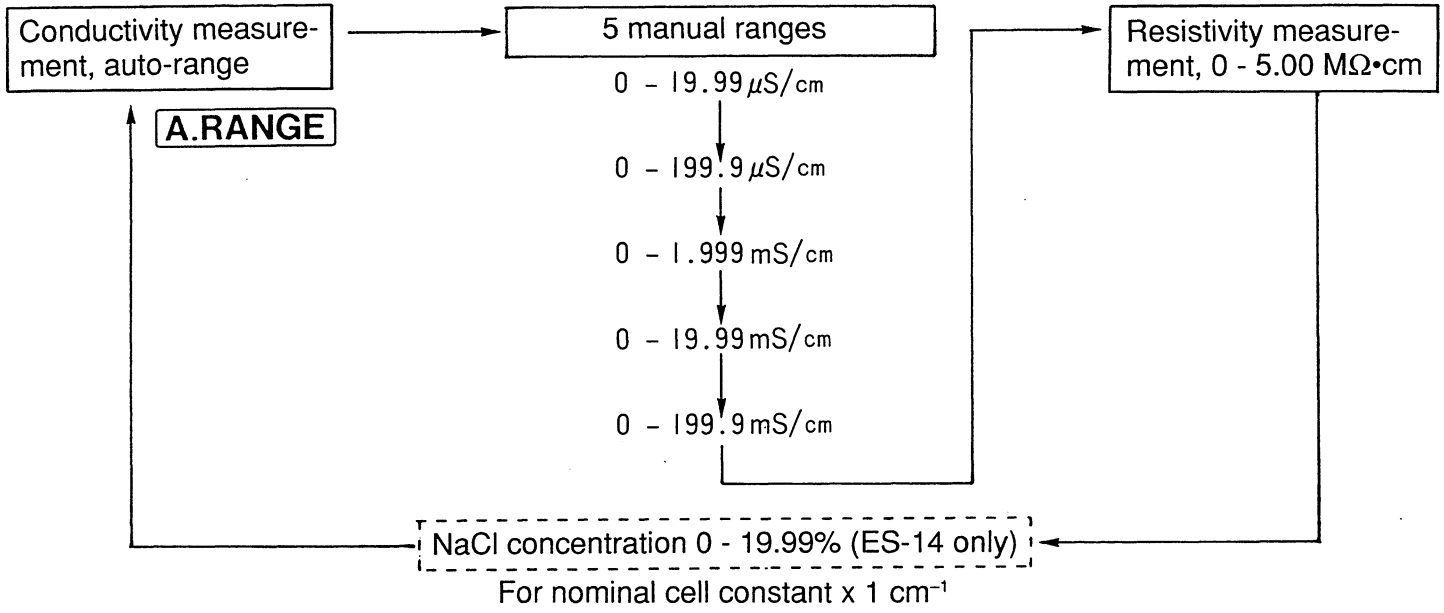
The measurement range differs, depending on the type of conductivity electrode (see table at right).

● **For NaCl concentration measurements, use electrodes with a cell constant of 1 cm^{-1}, 10 cm^{-1}.**

Measurement item	Range	Nominal cell constant		
Conductivity	**A. RANGE** Lit ↓ Auto range	× 0.1	× 1.0 (standard electrode)	× 10
	Manual range setting (5 ranges)	0 - 1.999 µS/cm 0 - 19.99 µS/cm 0 - 199.9 µS/cm 0 - 1.999 mS/cm 0 - 19.99 mS/cm	0 - 19.99 µS/cm 0 - 199.9 µS/cm 0 - 1.999 mS/cm 0 - 19.99 mS/cm 0 - 199.9 mS/cm	0 - 199.9 µS/cm 0 - 1.999 mS/cm 0 - 19.99 mS/cm 0 - 199.9 mS/cm 0 - 1999 mS/cm
Resistivity	1 range	0 - 50.0 MΩ • cm	0 - 5.00 MΩ • cm	0 - 0.500 MΩ • cm
NaCl concentration (ES-14 only)	1 range	0 - 19.99 % *		

* Solution temperature range: 15 - 55°C

● With each push of the **RANGE** key, the unit cycles through the following measurement ranges and measurement items.

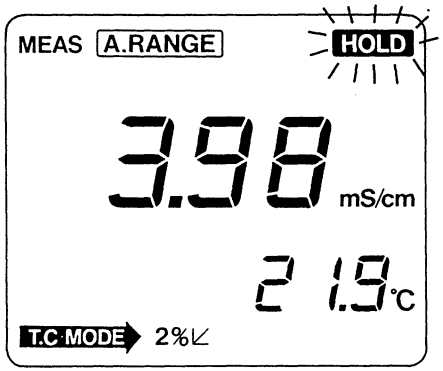


6. Readout modes

This unit offers either auto-hold or manual measurement.

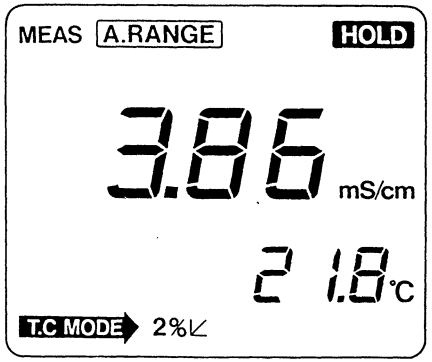
Auto-hold measurement
The unit automatically determines if the measurement potential has stabilized and then holds that measurement value on the display.

- Insert the electrode in the sample solution and press the **AUTO MEAS** key. The indication flashes until the potential has stabilized.



- To interrupt the measurement while the **HOLD** is still flashing, press the **AUTO MEAS** key again.

When the potential has stabilized, the measurement value is held on the display.
The **HOLD** stops flashing and stays constantly lit.

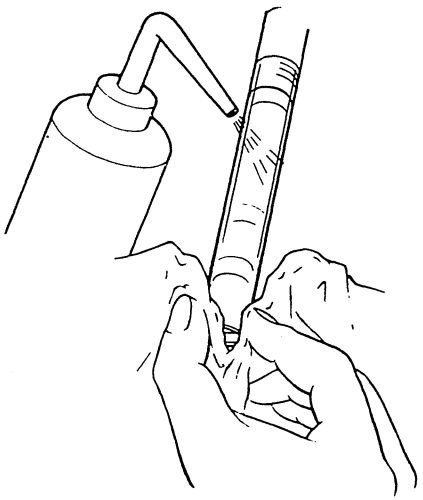


- To release the displayed value, press the **AUTO MEAS** key again.

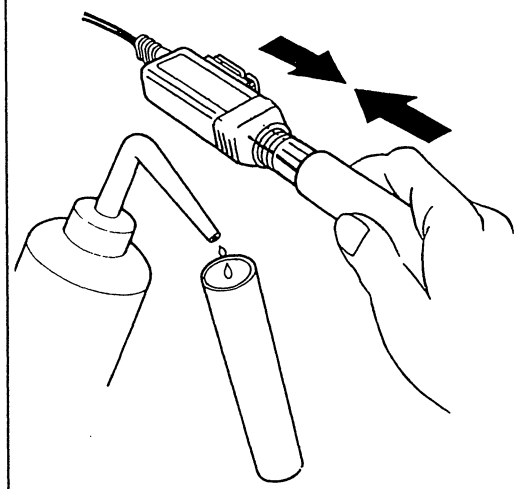
Manual measurement
In this mode, the measured value is continuously updated on the display. This mode is active after switching the unit on (initial condition), and while pausing the auto- hold measurement or after releasing the auto-hold display.

7. After measurement

- Use pure water to thoroughly clean the electrode and remove any solution remnants.



- Clean the inside of the protective cap with pure water, drain the water, and fill in a small amount of pure water to moisten the sponge. Then cover the electrode with the protective cap.



- Turn off the unit.

Data Memory Function (Model ES-14)

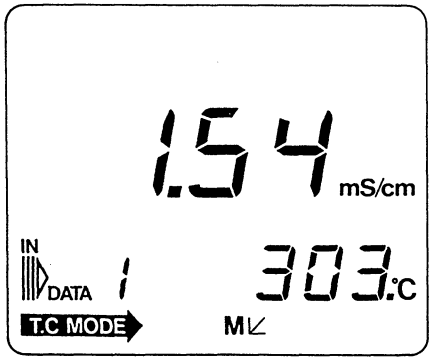
Data Memory Function (Model ES-14)

1. Storing data in memory

The **DATA IN** key serves to store data in the memory of the unit. When the key is pressed, the measured value for conductivity, resistivity and NaCl concentration, and the temperature and temperature conversion mode are stored. Up to 10 sets of data can be stored.

The DATA IN key will not work when HOLD is flashing, or when there are already 10 sets of data in memory.

● Press **DATA IN** key.
DATA IN and the data number will be shown and the meter will be put on hold for two seconds.



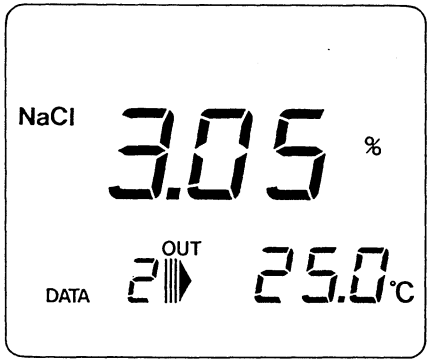
● When the data are stored, HOLD is automatically suspended and the meter returns to the measuring mode.

2. Reading data from memory

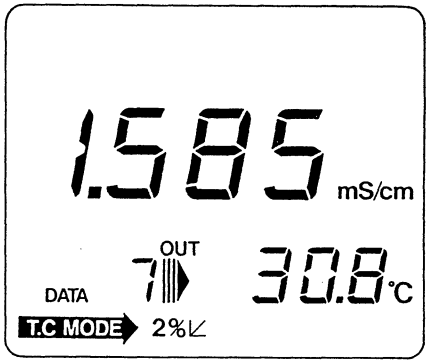
The **DATA OUT** key serves to display data stored in the memory of the unit.

The DATA OUT key will not work when HOLD is flashing and when in the setting mode.

- Press the **DATA OUT** key. The indication "DATA OUT", the data number and the data are shown on the display.
  The example shows recall of data number 2.

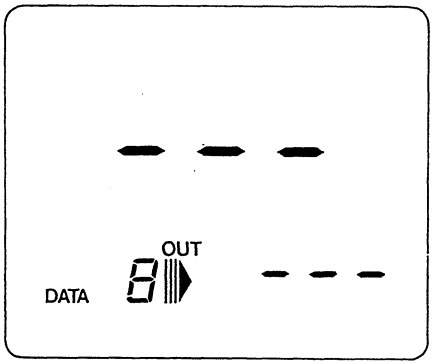


- With each push of the **DATA OUT** key, the memory number is incremented and the next stored data are shown.
  The example shows recall of data number 7.



- Press the **AUTO MEAS** key to return to the measuring mode.

- If no data are stored in a memory number, the display reads "—".



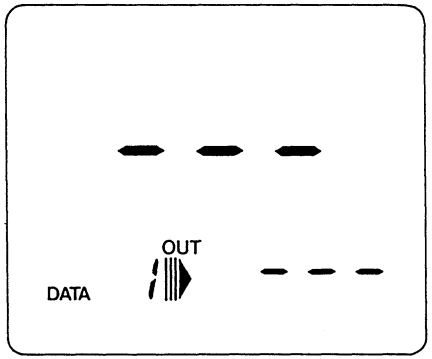
3. Erasing data

You can erase data stored in memory. All data in memory are deleted simultaneously, you cannot selectively delete values.

All data in memory are deleted. You cannot selectively delete values.

- While holding down **DATA OUT** key, press **DATA IN** key.

Verify that the data have been deleted by pressing **DATA OUT** key. When data have been deleted, the display reads "—" for each item.



Care & Diagnostics

Care & Diagnostics

1. Error codes

This unit provides a function to indicate basic operation errors or other problems by error numbers and short messages which are shown on the display. When such an error occurs, two short beeps are also sounded as a warning indication.
If a key is pressed in a mode which does not allow use of that key, three short beeps are sounded.

The possible seven error indications are explained below.

Error number	Cause	Display indication
ERR1	Sample outside of measurement range	1 SCALE OVER
ERR2	Temperature outside of measurement range	2 TEMP OVER
ERR3	Electrode instable	3 STABY
ERR4	Cell constant outside of automatic calibration range	4 CAL
ERR5	Low power supply voltage	5 BATTERY
ERR6	Amplifier problem	6 AMPLIFIER
ERR7	Electrode problem	7 ELECTRODE (ES-14)

2. Care of the electrode cell

Keep clean for accuracy
It is important that you keep the electrode always clean to ensure precise measurements. Before changing electrolyte solutions, carefully rinse off the old electrolyte, using de-ionized water (pure water), and wipe the electrode with clean tissue paper or gauze. Take care not to scratch or damage the cell.

- Normal cleaning
  Rinse the electrode in de-ionized water (pure water) at least three times, and then wipe the electrode with clean tissue paper or gauze.

- Intensive cleaning
  If the electrode has become very contaminated, wash it carefully with a mild neutral detergent or pure water. Then be sure to rinse is in de-ionized water (pure water) at least three times.

ATTENTION!
Never leave the electrode immersed in concentrated hydrochloric acid after finishing measurements.

Storing for short periods
Leave the electrode immersed in a container of de-ionized water (pure water). Make sure that the platinum-black bands are completely under water.
Do not allow the platinum-black bands to dry out, as this will adversely affect measurement precision.

Storing for long periods
Disconnect the electrode from the main unit and remove it from the electrode holder. Then carefully wash the electrode in de-ionized water (pure water) and keep the electrode immersed so that the platinum-black bands are completely under water.

3. Calibration procedure for cell constant

The cell constant of the electrode was measured at the factory. The value is marked on the inspection seal on the electrode. However, under certain usage conditions the cell constant may change over time, making a repeated calibration desirable.

Preparing a standard solution of potassium chloride

Provide commercially available potassium chloride powder of the highest grade, and remove all moisture by drying it out thoroughly under heat at 105°C for 2 hours. Then place it in a desiccator to cool down. Measure out the powder to the amount shown in the table at right, and prepare the potassium chloride solution as described.

ATTENTION!

Store the standard solution in tightly sealed laboratory glass jar or a polyethylene container. Do not store solutions for a long time, as this will impair precision.

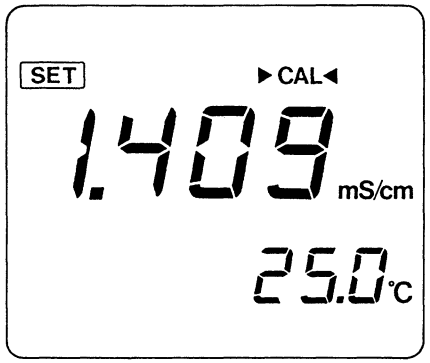
Cell constant	Electrode model number	KCl solution concentration	Temperature	Conductivity	KCl amount
1 (cm^{-1})	#3582-10D	0.01N	0 °C	0.774 mS/cm	0.7440g
			18 °C	1.220 mS/cm	
			25 °C	1.409 mS/cm	

Calibration procedure
Rinse the electrode several times in pure water. Follow this by several rinses in potassium chloride solution. Then immerse the electrode in the potassium chloride solution, making sure that no bubbles remain in the tube. Bring the solution to a constant temperature of 25±0.5°C.

- Press the **MODE** key to activate the cell constant calibration mode.

SET Lit

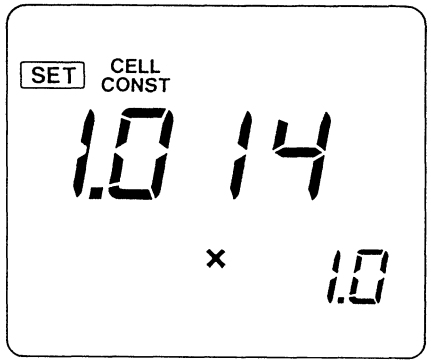
▶CAL◀ Flashing



The **UP** and **DOWN** keys serve to change the numbers, and the **RANGE** key changes the decimal point and the unit.
Use these keys to enter the conductivity value of the standard potassium chloride solution.

- Press the **ENT** key. The selected cell constant is shown on the display and stored in memory.

CELL CONST Lit



- Press the **AUTO MEAS** key to return to the measurement mode.

ATTENTION!
The temperature coefficient during cell constant calibration is 0% / °C.

4. Checking and compensating for electrode sensitivity losses due to aging

Peeling or severe contamination of the platinum-black bands on the titanium electrode can lead to a degradation in sensitivity which causes measurement errors with high-conductivity solutions (20 mS/cm or above).
If such losses are suspected and high-conductivity solutions are to be measured, the electrode sensitivity must first be checked, using a standard solution.
With the ES-14, the SENS mode can be used to automatically compensate for sensitivity losses and maintain measurement precision without changing the electrode.
The ES-12 does not have a function for sensitivity compensation.
When measuring solutions with conductivity under 20 mS/cm, compensation for sensitivity losses is not required.

1. Checking electrode sensitivity

● **Standard solution :** IN KCl solution
(111.8 mS/cm at 25°C)

Temperature (°C)	Conductivity (mS/cm)
15	92.5
20	102.1
25	111.8

* Before checking sensitivity, be sure to rinse the electrode and titanium band in pure water and wipe off all moisture with cleaning tissue or the like.

● **Sensitivity check**
Immerse the electrode in the standard solution and measure conductivity in the SENS mode. If the measured value differs from the values in the above table by more than 10%, sensitivity compensation is recommended.

2. Sensitivity compensation (ES-14)

- Immerse the electrode in the standard solution.
- Press the **MODE** key to activate the sensitivity compensation setup mode.

SET Lit

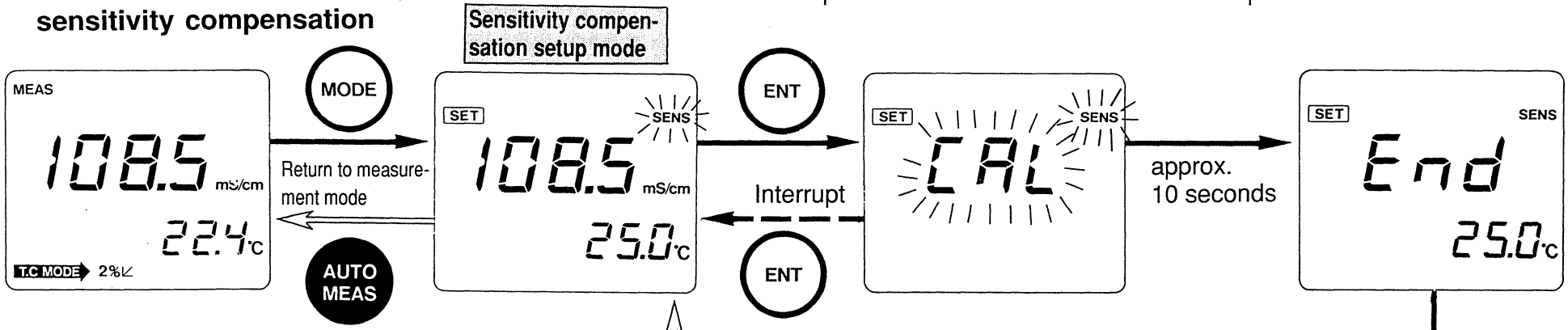
SENS Flashing

- Press the **ENT** key. SENS is flashing and the indication CAL flashes on the display for about 10 seconds. Then the indication End appears. After about 2 seconds, the data value is displayed and the compensation process is completed.

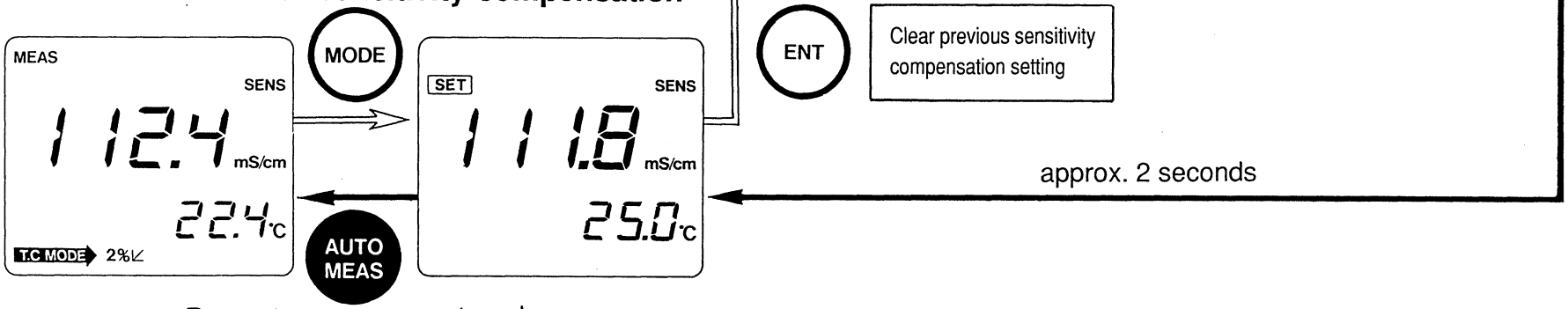
If the indication "ERR7" appears after pressing the ENT key, electrode sensitivity has deteriorated to an extent which exceeds the possible compensation range. In such a case, clean the electrode once more and repeat the process. If "ERR7" appears again, replace the electrode if solutions from 20 to 199.9 mS/cm are to be measured.

- Press the **AUTO MEAS** key to return to the measurement mode. If a sensitivity compensation value was set, the indication SENS remains lit.

- **Measurement without sensitivity compensation**



- **Measurement with sensitivity compensation**



Return to measurement mode

To clear a previously set sensitivity compensation value, proceed as follows.

● Press the **MODE** key in the measurement mode (after sensitivity compensation has been performed).

SET , **SENS** Lit

● Press the **ENT** key.
The setting is cleared.

SET Lit

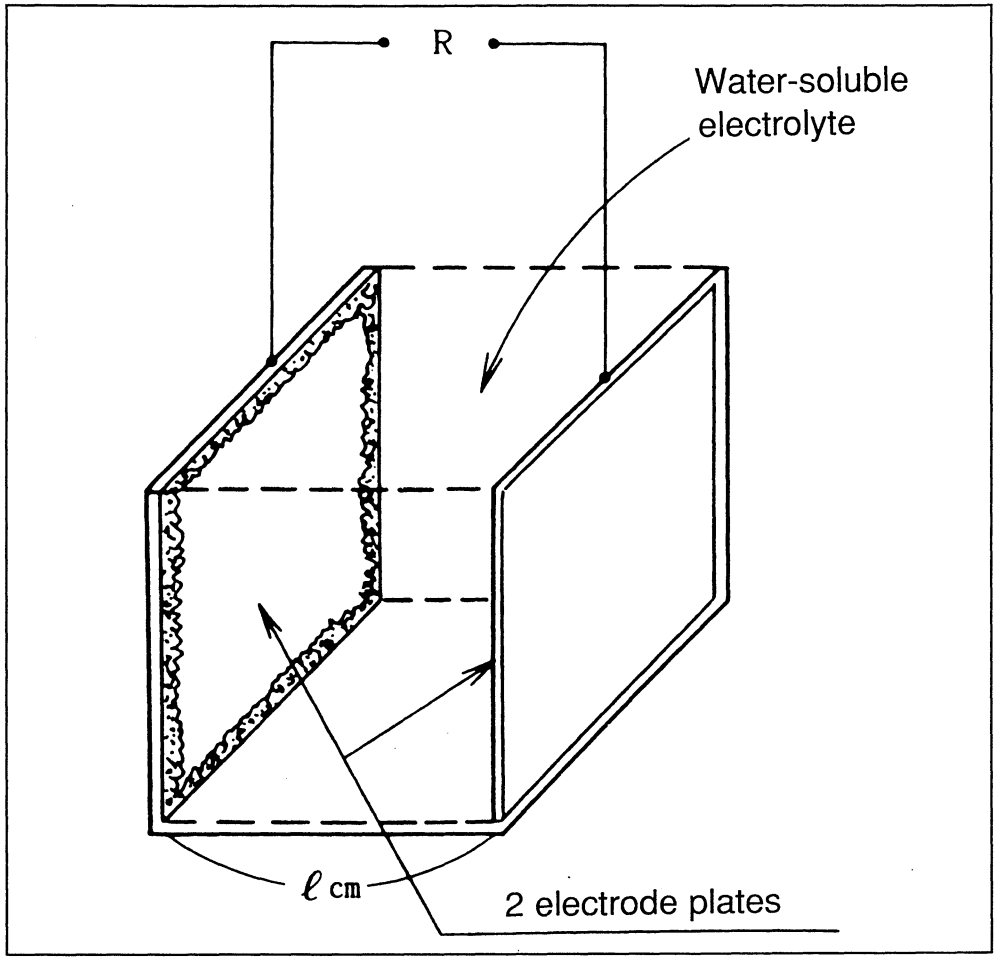
SENS Flashing

● Press the **AUTO MEAS** key to return to the measurement mode.

Technical Reference & Specifications

1. What is conductivity?

In general, conductivity is a value that represents how easily electrical charge can be transported through a conductor.
Conductors are substances that permit the movement of electrical charge with relative ease. Conductors may be classified into two types.
One type is an electrode. Electrodes are substances where charge is carried by the movement of electrons. Electrodes can be either metals or semiconductors; they can be solid or liquid.
The other type of conductor is an electrolyte. Electrolytes are chemical phases where charge is carried by a movement of ions. Electrolytes can be of quite different consistencies; they may be liquid solutions, fused salts, or even solids.
Here we shall consider conductivity by ion movement in water-soluble electrolyte solutions.
Fig. 1 shows a conductivity cell; this is an electrochemical cell for measuring the conductivity of an electrolyte solution. This cell consists of two electrodes, an anode and a cathode, separated by an electrolyte solution. The two electrodes are in the shape of plates of identical size, both having an identical surface area of a cm^2. They are aligned in parallel and are separated by the distance l . The space between them is filled completely with a water-soluble electrolyte solution. Alternating current flows through both electrode plates.



Conductivity cell : an electrochemical cell for measuring conductivity

The negatively charged ions (anions) in the electrolyte migrate toward the anode; the positively charged ions (cations) move toward the cathode. The result is the flow of electrical current by ion movement.

The resistance to the movement of charge between the two electrodes is in inverse proportion to their surface area and in direct proportion to the distance between them. This is true for both electron movement in metal electrodes and ion movement in electrolytes. This relationship may be expressed by equation 1.

$$R = r \cdot \frac{l}{a} = rJ \qquad (1)$$

In this equation,

R = the resistance in ohms (Ω)
r = the resistivity (Ω • cm)
a = the surface area of the electrode (cm^2)
l = the distance between the electrodes (cm)
J = the cell constant (cm^{-1})

The resistivity r(jzcm) is the index of how difficult it is for current to flow through the solution. This is a constant, determined for each electrolyte. The reciprocal of r is called the conductivity, L , where L = 1/r. (Properly speaking, in electrochemical terms, the conductivity is a proportionality constant of the electrolyte, which is an intrinsic property of the solution; and L is the conductance, the inverse of resistance for a certain segment of the electrolyte. The value of L is directly proportional to the surface area of the electrodes and is inversely proportional to the distance between them.) However, since we are dealing here with an electrochemical cell of fixed dimensions, we can use the terms conductance and conductivity interchangeably as an index of how easily current can flow through an electrolyte, and L will be referred to as the conductivity. This is accepted general practice.

L is expressed in units of siemens (S, i.e. $ohms^{-1}$) per centimeter, (S/cm) Using L , equation 1 can be reformulated as equation 2:

$$R = \frac{J}{L} \qquad (2)$$

From equation 2 it is clear that if we have a conductivity cell with a cell constant, J , of 1 (i.e. 1 cm^{-1}), then the inverse of the electrolyte resistivity, R , (in ohms) will be the conductivity, L , in S/cm. (A conductivity cell with a cell constant of 1 is defined as an electrochemical cell where each of the electrode plates has a surface area of 1 cm^2 and the electrodes are aligned in parallel and separated by a distance of 1 cm.)

Conductivity can be defined in this way; however, since it will fluctuate depending on the temperature of the electrolyte, in general, conductivity is specified at a standard reference temperature of 25°C.

The graph in Fig. 1 on page 49 can be used to convert resistivity to conductivity. Since the conductivity of the electrolyte is based on ion movement, it is natural that the concentration of ions in the solution will have a great bearing on this. Therefore, the conductivity can provide us with valuable indicators in gathering data on the nature of the ions in the solution, so the results of conductivity measurements are widely used in the electrochemical field.

2. Compensating for temperature differences

Temperature coefficient and temperature conversion

In general, the conductivity of an electrolyte varies greatly according to its temperature. As we have seen, the conductive properties of an electrolyte are determined by the ions in the solution. As the temperature rises, molecular movement, including that of the ions in the solution, increases dramatically. This causes an increase in conductivity. The amount of change in conductivity per degree centigrade is referred to as the temperature coefficient. The temperature coefficient of an electrolyte is expressed in percent divided by degrees centigrade (%/°C) at a particular temperature.

Since the temperature coefficient is obtained based on the direct efforts of temperature on the conductivity of an electrolyte, strictly speaking, the results should be curvilinear. That is to say, for most electrolyte solutions with an ion concentration of 0.001 mol/l or less, the temperature coefficient will be constant. However, for solutions with a high ion concentration, the temperature coefficient will not be constant. High- concentration solutions of some strong electrolytes, such as acids or tale salt, will show only a small fluctuation of the temperature coefficient, while some strongly alkaline solutions, such as sodium hydroxide, will show a great fluctuation. Where there are only small fluctuations in the temperature coefficient, for all practical purposes the change in conductivity according to temperature can be considered to approximate a straight-line function.

It naturally follows that since conductivity changes according to temperature, any comparisons of the conductivity of electrolyte solutions must be made at the same temperature.

The automatic temperature conversion function of HORIBA's ES series of conductivity meters can automatically compensate for the temperature at which a solution is being measured and give you the correct readout of the equivalent conductivity of the electrolyte at 25°C. Models in the ES series offer automatic temperature conversion using two different modes for the temperature coefficient: (1) the coefficient mode of 2%/°C; (2) the manual input single-coefficient straight-line mode (the M∠ mode).

Using a temperature coefficient of 2%/°C (2% ∠ mode)

It is standard procedure to measure conductivity at a reference temperature of 25°C ± 0.5°C (standard conductivity = conductivity at 25°C). When absolute precision is not required, the readouts from a conventional temperature-converting measuring device are generally sufficient. Most conductivity-measuring devices are set to follow standard procedure and therefore calculate based on a temperature coefficient of 2%/°C, at 25°C. (This corresponds to the "2% ∠ mode" on the HORIBA ES series conductivity meters.) When the HORIBA meter is set to the 2% ∠ mode, it behaves like a standard temperature-converting conductivity-measuring device, allowing you to measure conductivity at any temperature with a preset temperature coefficient of 2%/°C at 25°C.

In general, except for strong acid or strong alkaline solutions, almost all electrolyte solutions have this temperature coefficient of 2%/°C at 25°C. In most cases, unless one is measuring a sample solution at extreme temperatures, the 2%∠ mode on the ES series conductivity meter is sufficient to convert to an equivalent conductivity value at a different temperature in determining the conductivity of a solution.

Fig. 2 is a temperature-conversion chart. You can use this to convert conductivity measurements taken at different reference temperatures to values at the standard equivalent reference temperature of 25°C.

Of course, when many different types of solutions are to be measured, some of these will have temperature coefficients quite different from that of sodium chloride, and the 2% ∠ mode will not always give an accurate reading.

In these cases, you can use the manual input single- coefficient straight-line mode (the M ∠ mode). This mode allows you to input any temperature coefficient from 0%/°C to 10%/°C for your sample solution, resulting in very precise measurements.

Manual input single-coefficient straight-line mode (M ∠)

In the M ∠ mode, it is assumed that the conductivity measured at any particular temperature will vary from 0% to 10% per degree °C and this will be converted to an equivalent value for the conductivity measured at a specified reference temperature, t_0. This reference temperature can either be the temperature at which the temperature coefficient was determined, or it can be the temperature for which you are trying to convert your readings. This is shown in equation 3.

$$Lt_0 = Lt / \{ 1 + \frac{\alpha_0}{100} (t - t_0) \} \qquad (3)$$

Here,

t_0 = the reference temperature (°C)

Lt_0 = the conductivity converted to an equivalent value in terms of the reference temperature, i.e. what the conductivity of the sample solution would be if measured at the reference temperature

α_0 = the temperature coefficient of the sample solution measured at the reference temperature

t = the temperature at the time the sample solution was measured

Lt = the conductivity of the sample solution measured at the temperature t

Temperature coefficient calculated as a straight-line function

If the temperature coefficient is not known, it is possible to obtain it by measuring the conductivity of a sample of the solution to be used. This is done by measuring the conductivity at two points, where one point, t_1 , is near the reference temperature and the other point, t_2, is at a temperature slightly distant from the reference temperature. These values are used to calculate the temperature coefficient according to equation 4.

$$\alpha_0 = 100 (L_1 - L_2) / \{ L_2 (t_1 - t_2) - L_1 (t_2 - t_0) \} \qquad (4)$$

L_1 is the conductivity of the sample of the solution at temperature t_1 and L_2 is the conductivity at temperature t_2.

Temperature coefficient calculated from a temperature curve

It is also possible, by using the least-square rule, to calculate the temperature coefficient with measured values of the conductivity at two or more points along a temperature curve. Where the temperature curve approaches a straight line, if only a small deviation is obtained, the temperature coefficient can be calculated with equation 4 by using either a recursive equation for the temperature and conductivity (L = at + b) or plotting any two points on a graph. Also, published charts are available that give the temperature coefficient at various temperatures. If these standard values are used, it will be necessary to calculate the temperature coefficient at the reference temperature for which the temperature is converted. It should be set to the value (α_0) obtained from equation 5.

$$\alpha_0 = \alpha t \; / \; \{ \; 1 - \frac{\alpha t}{100} (t - t_0) \; \} \qquad (5)$$

(α_0) is the temperature coefficient (%/°C) of the sample solution at the reference temperature, and (αt) is the temperature coefficient (%/°C) of the sample solution measured at the temperature t.

3. Measuring sodium chloride concentration

The model ES-14 can be used as a sodium chloride concentration meter, to measure the amount of sodium chloride in the sample solution. As Fig. 5 shows, when the temperature of the sample is constant, conductivity has a fixed relationship with the sodium chloride concentration of the electrolyte solution. This means that if both the conductivity and the temperature are known, the corresponding sodium chloride concentration is predictable. Model ES-14 uses this principle to operate as a sodium chloride concentration meter.

Since the ability of the ES-14 to function as a sodium chloride concentration meter is based entirely on its measurements of conductivity, it follows that the accuracy of its sodium chloride concentration calculations depends on the assumption that the active ingredient responsible for the conductivity in the solution is in fact sodium chloride. Naturally, the correlation between the actual concentration of sodium chloride in the sample solution and the amount calculated by the ES-14 will depend on the chemical composition of the sample. However, in samples where sodium chloride is the main ingredient of the electrolyte solution, this ability of the ES-14 to calculate sodium chloride concentration is sufficiently accurate for most quality control and inspection standards.

When functioning as a sodium chloride concentration meter, the ES-14 can be used in a wide range of possible applications for many different types of solutions. It should be kept in mind, however, that the dual-function electrode of the ES-10 series conductivity meter is a delicate instrument. The electrode bands used in the electrode's conductivity cell are coated with a sensitive substance called platinum-black. This platinum-black coating can become contaminated with foreign matter or damaged by immersing the electrode in the wrong solutions. In particular, you should avoid immersing it in solutions that contain oil, organic solvents, or particulate matter.

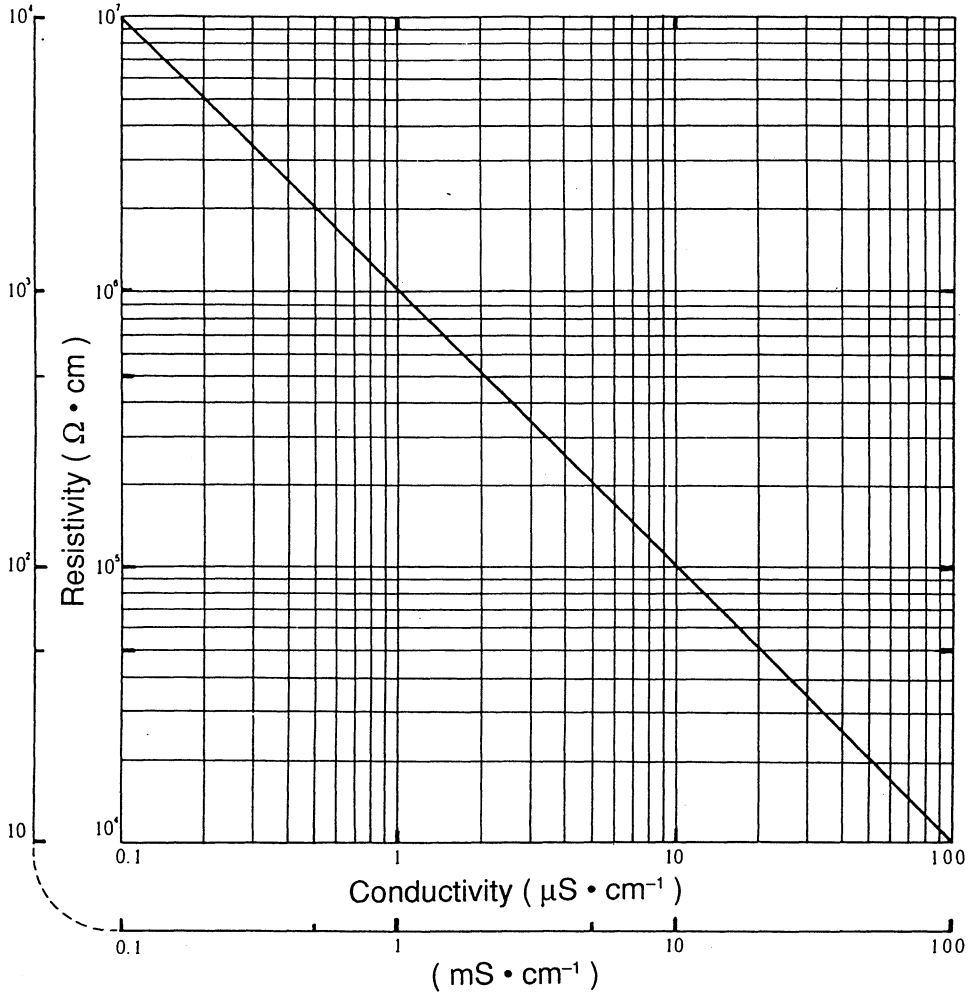
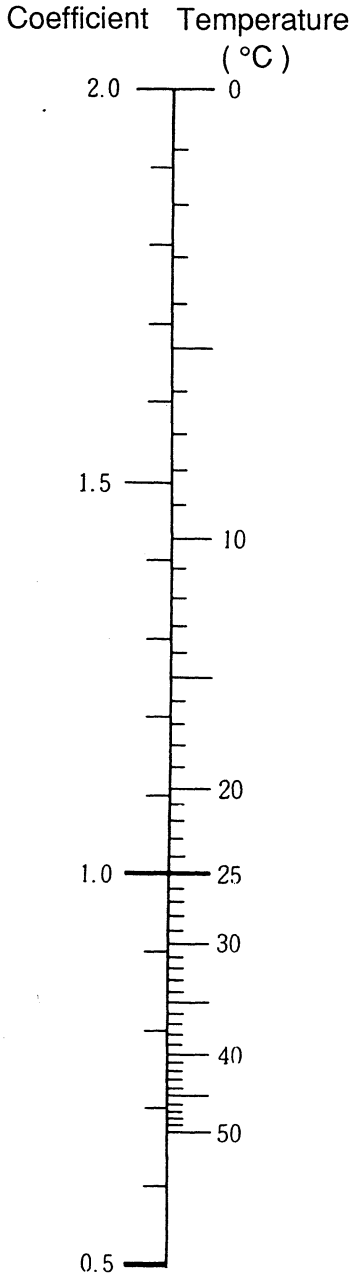


Fig. 1 Converting the resistance ratio to conductivity



How to use this chart

Example 1

The conductivity of a well water sample at 15°C is 650 µS • cm⁻¹. What is the conductivity at 25°C (reference temperature) ?

The chart at left shows a coefficient of 1.25 for a temperature of 15°C. Multiply the measured conductivity by this coefficient :

$$950 \times 1.25 \approx 1.190\ \mu S \cdot cm^{-1}$$

Example 2

Tap water has a conductivity of 120 µS • cm⁻¹ at 25°C (reference temperature). What is the conductivity at 30°C?

The chart at left shows a coefficient of 0.91 for a temperature of 30°C. Multiply the reference conductivity by this coefficient:

$$120 \div 0.91 \approx 132\ \mu S \cdot cm^{-1}$$

Note:

This chart does not apply to strong alkaline or acidic solutions such as NH_3 , HCl , or H_2SO_4. It applies to aqueous solutions with a concentration of up to about 2 ~ 3%. The values calculated with this chart are approximate.

Fig. 2 Temperature conversion chart for conductivity
(reference temperature = 25°C)

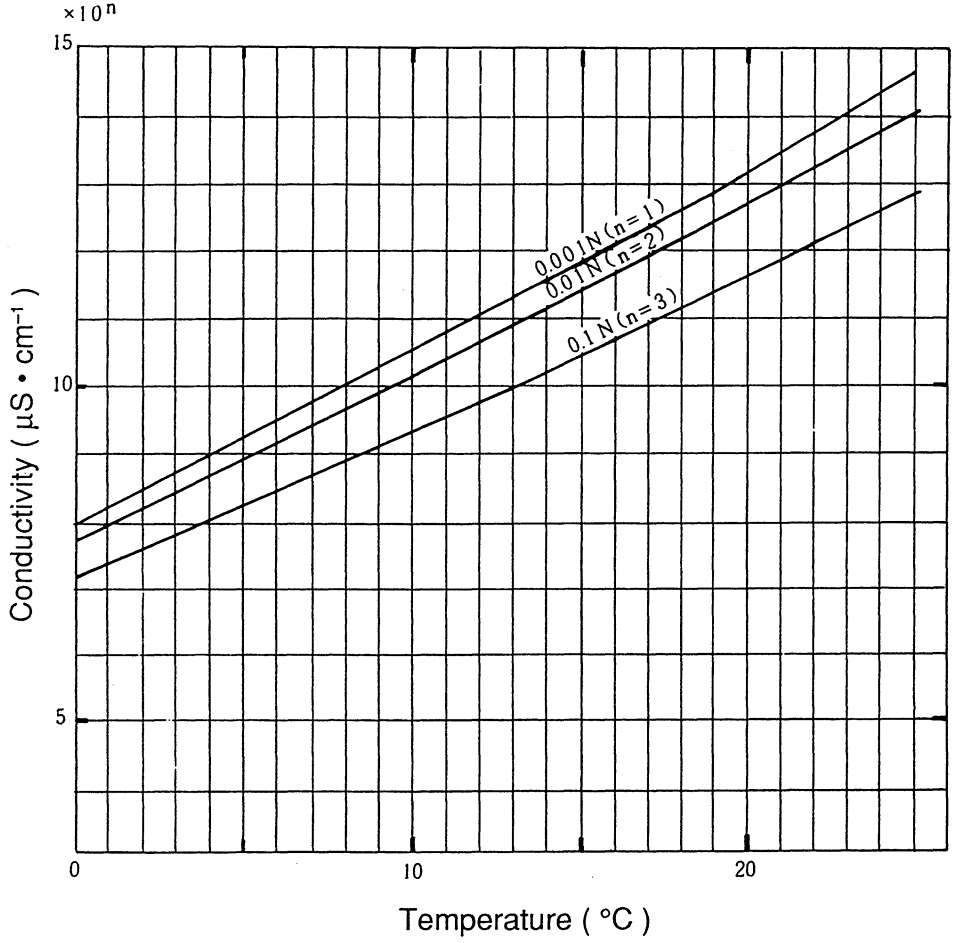


Fig. 3 Temperature-conductivity characteristics of standard potassium chloride solution
Source : Japanese Industrial Standards (JIS)

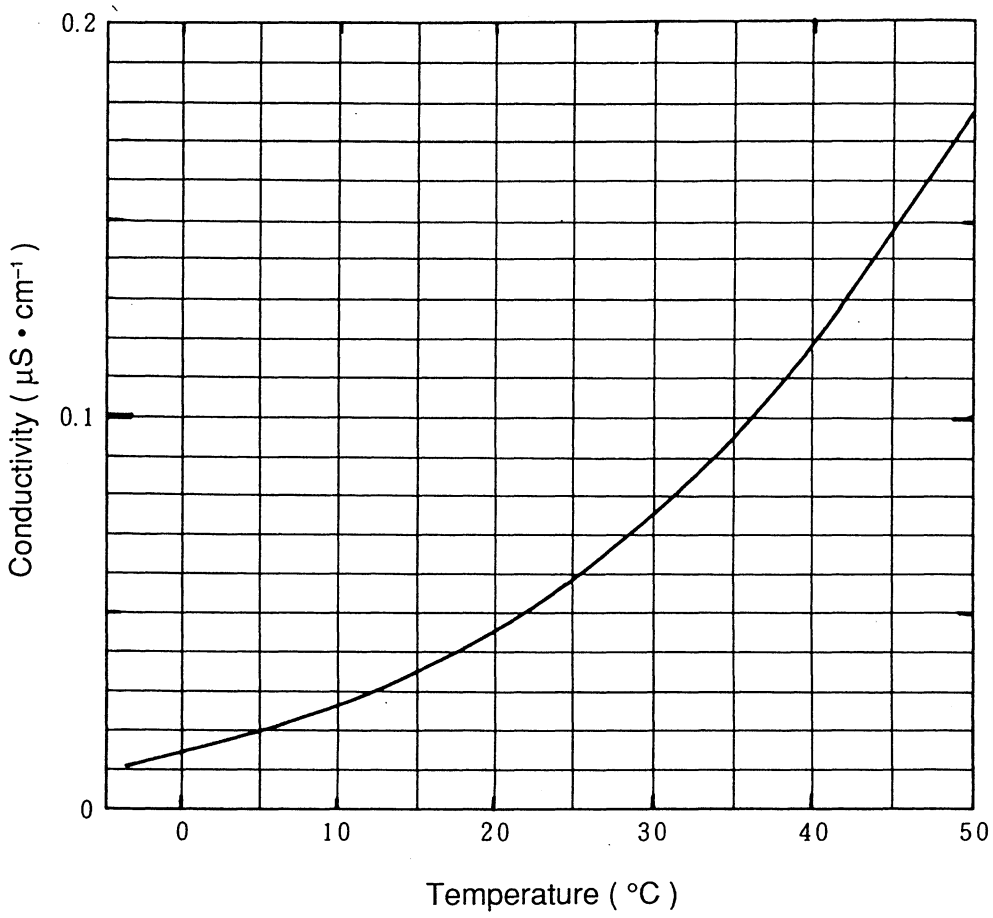


Fig. 4 Temperature-conductivity characteristics of de-ionized water (10 μSeimens maximum)

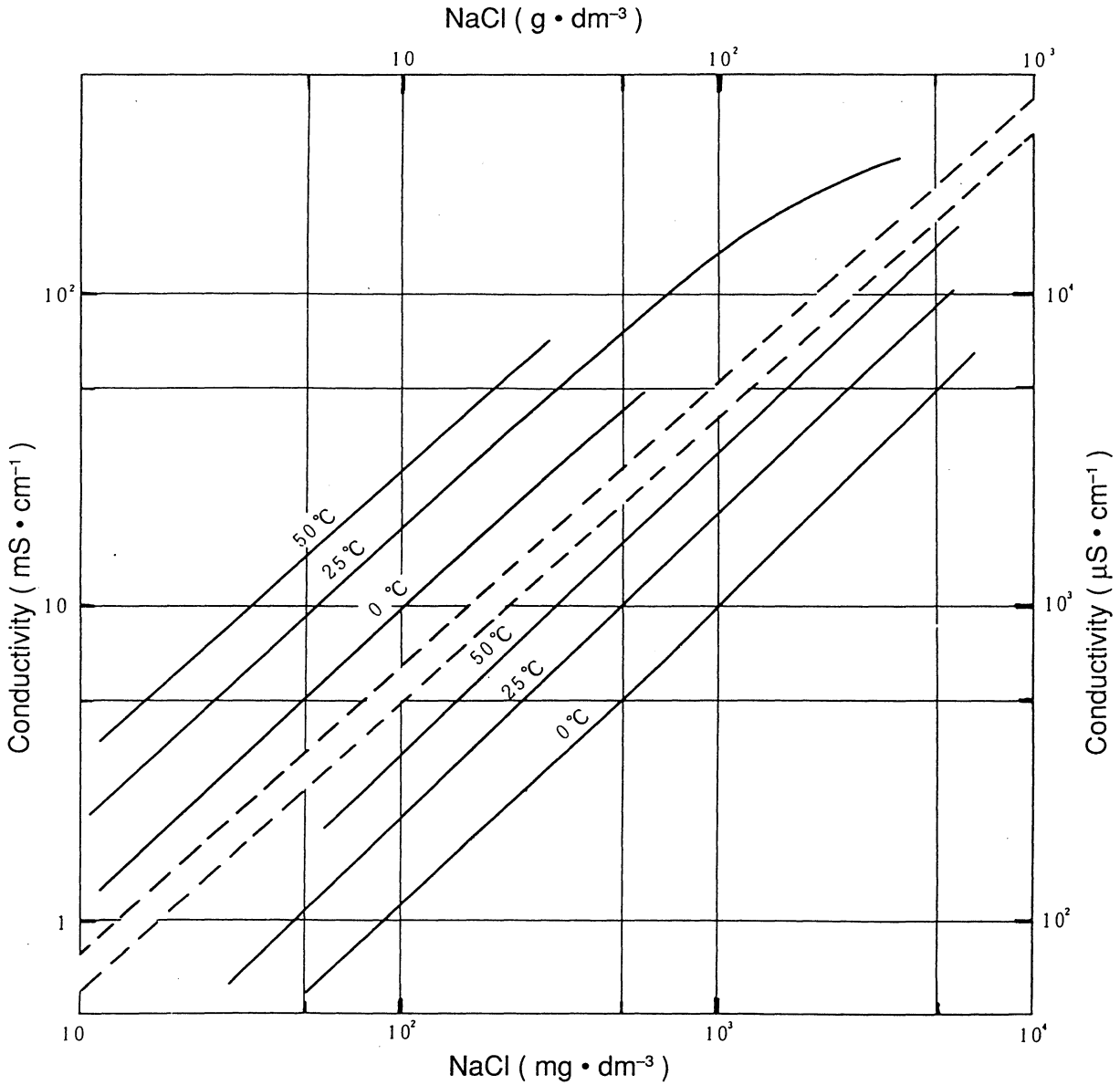


Fig. 5 Sodium chroride concentration and conductivity

4. Conductivity and related temperature coefficients of representative substances (at 25°C)

Substance	Concentration wt %	Conductivity 10^4 S•cm^{-1}	Temperature coefficient % / °C
NaOH	5	1969	2.01
(15°C)	10	3124	2.17
	15	3463	2.49
	20	3270	2.99
	30	2022	4.50
	40	1164	6.48
KOH	25.2	5403	2.09
(15°C)	29.4	5434	2.21
	33.6	5221	2.36
	42.0	4212	2.83
NH_3	0.10	2.51	2.46
(15°C)	1.60	8.67	2.38
	4.01	10.95	2.50
	8.03	10.38	2.62
	16.15	6.32	3.01
	30.5	1.93	—
HF	1.5	198	7.20
	4.8	593	6.66
	24.5	2832	5.83
HCl	5	3948	1.58
	10	6302	1.56
	20	7615	1.54
	30	6620	1.52
	40	5152	—
H_2SO_4	5	2085	1.21
	10	3915	1.28
	20	6527	1.45
	40	6800	1.78
	50	5405	1.93
	60	3726	2.13
	80	1105	3.49
	100.14	187	0.30

Substance	Concentration wt %	Conductivity 10^4 S•cm^{-1}	Temperature coefficient % / °C
HNO_3	6.2	3123	1.47
	12.4	5418	1.42
	31.0	7819	1.39
	49.6	6341	1.57
	62.0	4964	1.57
H_3PO_4	10	566	1.04
(15°C)	20	1129	1.14
	40	2070	1.50
	45	2087	1.61
	50	2073	1.74
NaCl	5	672	2.17
	10	1211	2.14
	15	1642	2.12
	20	1957	2.16
	25	2135	2.27
Na_2SO_4	5	409	2.36
	10	687	2.49
	15	886	2.56
Na_2CO_3	5	456	2.52
	10	705	2.71
	15	836	2.94
KCl	5	690	2.01
	10	1359	1.88
	15	2020	1.79
	20	2677	1.68
	21	2810	1.66
KBr	5	465	2.06
(15°C)	10	928	1.94
	20	1907	1.77
KCN	3.25	507	2.07
(15°C)	6.5	1026	1.93

Substance	Concentration wt %	Conductivity 10^4 S•cm^{-1}	Temperature coefficient % / °C
NH_4Cl	5	918	1.98
	10	1776	1.86
	15	2586	1.71
	20	3365	1.61
	25	4025	1.54
$(NH_4)_2SO_4$	5	552	2.15
(15°C)	10	1010	2.03
	20	1779	1.93
	30	2292	1.91
NH_4NO_3	5	590	2.03
(15°C)	10	1117	1.94
	30	2841	1.68
	50	3622	1.56
$CuSO_4$	2.5	109	2.13
	5	189	2.16
	10	320	2.18
	15	421	2.31
CH_3COOH	1	5.84	—
	10	15.26	1.69
	15	16.19	1.74
	20	16.05	1.79
	30	14.01	1.86
	40	10.81	1.96
	60	4.56	2.06

5. Specifications

Model		ES-12	ES-14
Measuring System		Conductivity: AC bipolar, Temperature: thermistor	
Measuring Range	Conductivity	● Standard electrode (#3582-10D, cell constant 1 cm^{-1}) 0 - 19.99, 199.9 μS/cm 1.999, 19.99, 199.9 mS/cm (5 ranges) ● Low-concentration electrode (#3551-10D, cell constant 0.1 cm^{-1}) Ranges above ×0.1 ● High-concentration electrode (#3553-10D, cell constant 10 cm^{-1}) Ranges above ×10	
	Resistivity	● Standard electrode (#3582-10D, cell constant 1 cm^{-1}) 0 - 5.00 MΩ • cm ● Low-concentration electrode (#3551-10D, cell constant 0.1 cm^{-1}) Ranges above ×10 ● High-concentration electrode (#3553-10D, cell constant 10 cm^{-1}) Ranges above ×0.1	
	Sodium Chloride Concentration	————	0 - 19.99%*
Liquid temperature		0 - 100.0°C	

* Liquid temperature : 15 - 55 °C

Model	ES-12	ES-14
Repeatability	Conductivity: ±0.5% F.S. ±1 digit, Temperature: ±0.1°C ±1 digit	
Display	LCD (simultaneous display of conductivity, resistivity, temperature)	LCD (simultaneous display of conductivity, resistivity, NaCl concentration, temperature)
Temperature Conversion	Liquid temperature (ATC): 0 - 100°C, Conversion coefficient: 0 - 10.00%/°C (variable), Reference temperature: 25°C (fixed)	
Auto-Hold	Yes	
Data Store	———	Yes, maximum 10 data
Analog Output	Conductivity measurement value, NaCl concentration (ES-14): 0 - 1 V DC F.S. Resistivity: 0 - 250 mV DC	
Power Supply	Dry-cell battery 6F22 (S-006P), Battery life: approx. 30 hours With auto power-off function Input for AC optional adapter	
Ambient Temperature	0 - 45°C	
Dimensions	197 (H) × 78 (W) × 55 (D) mm	
Weight	Approx. 350g	

6. Accessories

Part Name	Model	Capacity	Part No.
Dip-type electrode	#3582-10D (Standard electrode)	Cell constant 1 cm^{-1} 1 µS/cm - 100 mS/cm	9056-0015-00
	#3551-10D	Cell constant 0.1 cm^{-1} 0.1 µS/cm - 10 mS/cm	9056-0008-00
	#3552-10D	Cell constant 1 cm^{-1} 1 µS/cm - 100 mS/cm	9056-0009-00
	#3553-10D	Cell constant 10 cm^{-1} 10 µS/cm - 1 S/cm	9056-0010-00
Flow-type electrode	#3561-10D	Cell constant 0.1 cm^{-1} 0.1 µS/cm - 10 mS/cm	9056-0011-00
	#3562-10D	Cell constant 1 cm^{-1} 1 µS/cm - 100 mS/cm	9056-0012-00
	#3573-10C	Cell constant 10 cm^{-1} 10 µS/cm - 1 S/cm	9056-0013-00
	#3574-10C	Cell constant 10 cm^{-1} 10 µS/cm - 1 S/cm	9056-0014-00
AC adaptor	AC-10		9078-0001-00
Output cables			9078-0002-00
Carrying case			9078-0003-00
Electrode stand			9078-0004-00

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