Technical Assistance
HYDROLOGY PROJECT
World Bank & Government of The Netherlands funded

Training module # WQ - 08

Understanding electrical conductivity

New Delhi, May 1999

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with
HALCROW, TAHAL, CES, ORG & JPS

Table of contents

1. Module context

This module is a stand-alone module and no prior training in other modules is needed to complete this module successfully. It discusses basic concepts of electrical conductivity measurement. Other available, related modules in this category are listed in the table below.

While designing a training course, the relationship between this module and the others, would be maintained by keeping them close together in the syllabus and place them in a logical sequence. The actual selection of the topics and the depth of training would, of course, depend on the training needs of the participants, i.e. their knowledge level and skills performance upon the start of the course..

No.	Module title	Code	
1	*Basic water quality concepts*	WQ - 01	• Become familiar with common water quality parameters • Appreciate important water quality issues
2	*Basic chemistry concepts*	WQ - 02	• Convert units from one to another • Understand the basic concepts of quantitative chemistry • Report analytical results with the correct number of significant digits
3	*How to prepare standard solutions*	WQ - 04	• Recognise different types of glassware • Use an analytical balance and maintain it • Prepare standard solutions
4	*How to measure electrical conductivity*	WQ - 09	• Measure electrical conductivity • Appreciate the effect of ion concentration and type on EC value

2. Module profile

Title	:	Understanding electrical conductivity
Target group	:	HIS function(s): Q1, Q2, Q3, Q5
Duration	:	One session of 90 minutes
Objectives	:	After training, the participants will be able to: • Define electrical conductivity • Understand significance of EC measurement • Use correct EC unit
Key concepts	:	• Definition of EC • Principle of EC meter/cell constraint • Temperature correction • Conductivity factors
Training methods	:	Lecture, discussion
Training tools required	:	Board, flipchart, OHS
Handouts	:	As provided in the module
Further reading	:	• Chemistry for Environmental Engineering, C.N. Sawyer, P. L. McCarty and C. F. Parkin, McGraw-Hill, 1994.

3. Session plan

No	Activities	Time	Tools
1	***Preparations***		
2	***Introduction*** • Define EC, factors affecting & the significance of EC, text section 8.1	10 min	OHS
3	***EC measurement*** • Describe the principle of EC meter and its parts, theory involved in EC measurement and the concept of cell constant, text section 8.2 & 8.4	20 min	OHS
4	***Units of measurement*** • Explain different units with emphasis on EC units and conversion from one to anotherusing factor label methord, text section 8.3	15 min	OHS
5	***Cell constant and temperature correction*** • Explain the importance of cell constant and the standard used for the calibration of EC meter. Introduce the idea of temperature correction, text section 8.5 & 8.6	10 min	OHS
6	***Conductivity factors*** • Describe the concept, and demonstrate how to calculate EC value from the given concentration of ions, text section 8.7	15 min	OHS
7	***Use of EC measurement*** Explain EC application to check purity of distilled water	5 min	OHS
8	***Conclusion*** Wrap up by asking answers to questions 1 to 12 listed at the end of the main text orally	15 min	

4. Overhead/flipchart master

OHS format guidelines

Type of text	Style	Setting
Headings:	OHS-Title	Arial 30-36, with bottom border line (not: underline)
Text:	OHS-lev1 OHS-lev2	Arial 24-26, maximum two levels
Case:		Sentence case. Avoid full text in UPPERCASE.
Italics:		Use occasionally and in a consistent way
Listings:	OHS-lev1 OHS-lev1-Numbered	Big bullets. Numbers for definite series of steps. Avoid roman numbers and letters.
Colours:		None, as these get lost in photocopying and some colours do not reproduce at all.
Formulas/Equations	OHS-Equation	Use of a table will ease horizontal alignment over more lines (columns) Use equation editor for advanced formatting only

Electrical conductivity

1. The concept
2. Applications of EC
3. Theory of EC measurement
4. Units of EC measurement
5. Cell constant
6. Temperature correction
7. Conductivity factor
8. Calculating EC

1. Electrical conductivity: the concept

Ability of water to conduct electricity depends on:

- Concentration of ions
- Type of ions
- Temperature *of solution*

1. Electrical conductivity: the concept

- Measure at site, likely to change due to precipitation of ions
- Gives an estimate of total ion concentration

TDS (mg/L) = A x EC (μS/cm)

where A = 0.55 – 0.9

2. Application of EC

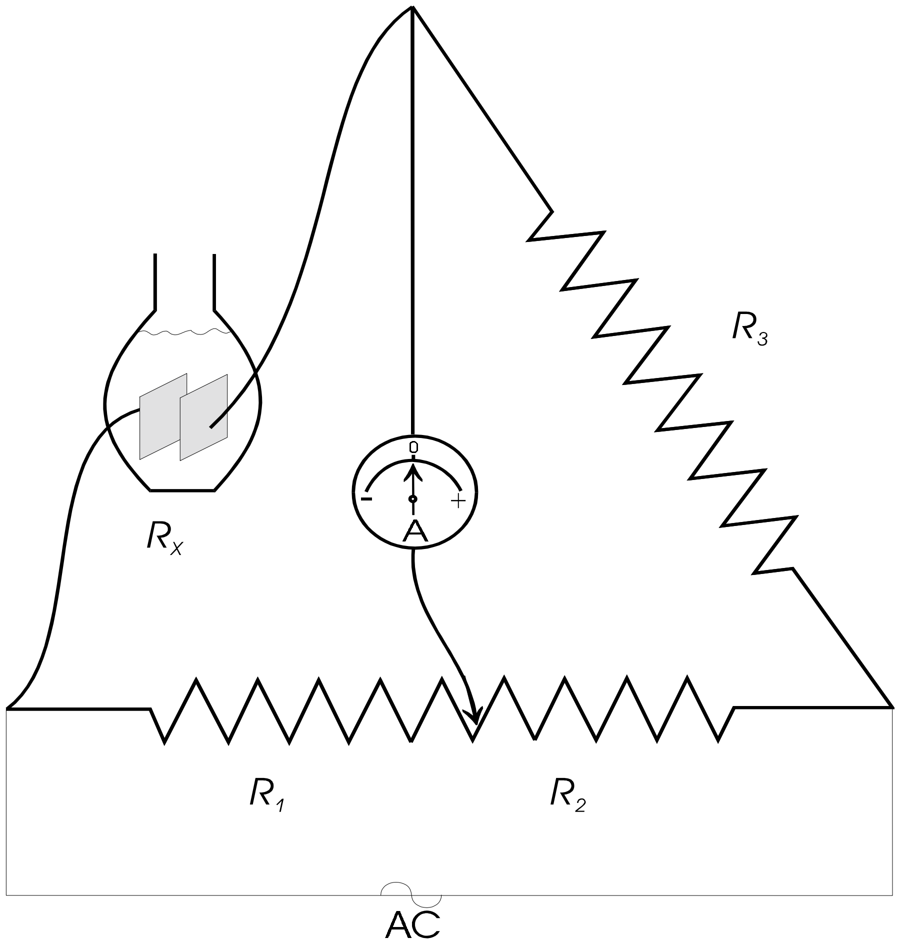
EC as indicator of :

- Purity of distilled / de-ionised water
- Total dissolved solids
- Freshness of samples

3. Theory of EC measurement

- Resistance to current flow between two plates, dipped in water.
- EC meter

3. Theory of EC measurement: principle



Theory of EC measurement (2)

Ohm's law relates:

- potential (**V**)
- current (**I**)
- and resistance ***(R)***

$$\mathbf{V = R \times I}$$

Theory of EC measurement (3)

$$V = R \times I$$

R depends on:

L: distance between plates

A: their cross-sectional area

$$R = \rho \times L/A$$

where ρ = specific resistance

3. Theory of EC measurement

$$\mathbf{R = \rho \times L/A}$$

EC is the reciprocal of specific resistance:

$$\mathbf{EC = 1/\rho = 1/R \times L/A}$$

where L/A is called cell constant K_c

$$\mathbf{K_c = R \times EC}$$

4. Units of EC measurement (1)

- Unit of cell constant

$$\mathbf{K_c = L\ (cm)\ /\ A\ (cm^2) = 1/cm}$$

- Unit of conductance (**1/R**) is reciprocal of ohm (**mho**) or siemens (**S**)
- Unit of electrical conductivity

$$\mathbf{EC = 1/R \times K_c = S/cm}$$

4. Units of EC measurement

multiply	by	to obtain
μS/m	0.001	mS/m
μS/cm	0.1	mS/m
mmho/cm	100	mS/m

5. Cell constant

- depends on:
  - area of plates
  - distance between plates
- calculated from resistance of a standard

$$\mathbf{K_c = R \times EC}$$

EC of 0.01 mol/L KCl is 141.2 mS/m **at 25°C**

6. Temperature correction

- EC increases with temperature
- Correction
  - 0.0191 mS/m per °C
  - applicable for temperature around 25°C
- Report EC value at 25°C

7. Conductivity Factors

Ion	Conductivity Factor (μS/cm per mg/L)
Cations	
Ca^{2+}	2.60
Mg^{2+}	3.82
K^+	1.84
Na^+	2.13
Anions	
HCO_3^-	0.715
Cl^-	2.14
SO_4^{2-}	1.54
NO_3^-	1.15

8. Calculating EC : example

Given the following analysis of a water sample, estimate the EC value in μS/cm and mS/m.

Ion	**Conc. (mg/L)**	**Factor (μS/cm per mg/L)**	**EC μS/cm**
Ca^{2+}	85.0	2.60	221.0
Mg^{2+}	43.0	3.82	164.3
K^{+}	2.9	1.84	5.3
Na^{+}	92.0	2.13	196.0
HCO_3^{-}	362.0	0.716	258.8
Cl^{-}	131.0	2.14	280.3
SO_4^{2-}	89.0	1.54	137.1
NO_3^{-}	20.0	1.15	23.0
	Total	1285.8	

Electrical Conductivity = 1285.8 μS/cm

9. Calculating EC: example

Electrical Conductivity=1285.8 μS/cm

$$= 1285.8 \frac{\mu S}{cm} \times \frac{1\ mS}{10^3 \mu S} \times \frac{10^2 cm}{1\ m}$$

$$= 128.58 \frac{mS}{m}$$

5. Evaluation sheets

Questions:

1. Why is the parameter EC an in-situ parameter?
2. What are the three most important factors affecting EC measurement?
3. What is the SI unit of expression of conductivity? What is the traditional unit?
4. What is the temperature at which the conductivity value must be reported?
5. If the conductivity meter does not have a temperature compensation facility, what should be done to report the conductivity value at 25°C?
6. What is the standard used for the calibration of EC meter?
7. What are the necessary reagents for conductivity measurements?
8. What are the essential parts of EC emter?
9. What is a cell constant?
10. Why should the cell constant be verified often?
11. How is the cell properly kept when not in use?
12. Why is the relation between EC and TDS not of an exact nature?
13. For a water having the characteristics given below at 23.5°C, determine the Electrical Conductivity value analytically at 25°C and the corresponding constant ‘A’.

Constituent	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2}
Constration (mg/L	200.0	12.2	39.1	230.0	610.0	71.0	480.0

6. Handout

Electrical conductivity

1. The concept
2. Applications of EC
3. Theory of EC measurement
4. Units of EC measurement
5. Cell constant
6. Temperature correction
7. Conductivity factor
8. Calculating EC

1. Electrical conductivity: the concept

- Ability of water to conduct electricity depends on:
  - Concentration of ions
  - Type of ions
  - Temperature *of solution*
- Measure at site, likely to change due to precipitation of ions
- Gives an estimate of total ion concentration

TDS (mg/L) = A x EC (μS/cm)
where A = 0.55 – 0.9

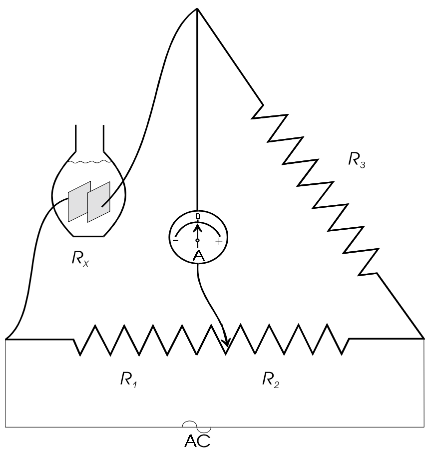
2. Application of EC

EC as indicator of :

- Purity of distilled / de-ionised water
- Total dissolved solids
- Freshness of samples

Theory of EC measurement

- Resistance to current flow between two plates, dipped in water.
- EC meter



Principle: Theory of EC measurement (2)

Ohm's law relates:

- potential (**V**)
- current (**I**)
- and resistance ***(R)***

$$V = R \times I$$

R depends on:

L: distance between plates
A: their cross-sectional area

$$R = \rho \times L/A$$

where ρ = specific resistance

$$R = \rho \times L/A$$

EC is the reciprocal of specific resistance:

$$EC = 1/\rho = 1/R \times L/A$$

where L/A is called cell constant K_c

$$K_c = R \times EC$$

4. Units of EC measurement (1)

- Unit of cell constant

$$K_c = L\ (cm)\ /\ A\ (cm^2) = 1/cm$$

- Unit of conductance (**1/R**) is reciprocal of ohm (**mho**) or siemens (**S**)
- Unit of electrical conductivity

$$EC = 1/R \times K_c = S/cm$$

Conversion:

Multiply	by	to obtain
μS/m	0.001	mS/m
μS/cm	0.1	mS/m
mmho/cm	100	mS/m

5. Cell constant

- depends on:
  - area of plates
  - distance between plates
- calculated from resistance of a standard

$$K_c = R \times EC$$

EC of 0.01 mol/L KCl is 141.2 mS/m **at 25°C**

6. Temperature correction

- EC increases with temperature
- Correction
  - 0.0191 mS/m per °C
  - applicable for temperature around 25°C
- Report EC value at 25°C

7. Conductivity Factors

Ion	**Conductivity Factor (μS/cm per mg/L)**
Cations	
Ca^{2+}	2.60
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K^+	1.84
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Anions	
HCO_3^-	0.715
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8. Calculating EC : example

Given the following analysis of a water sample, estimate the EC value in μS/cm and mS/m.

Ion	**Conc. (mg/L)**	**Factor (μS/cm per mg/L)**	**EC μS/cm**
Ca^{2+}	85.0	2.60	221.0
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SO_4^{2-}	89.0	1.54	137.1
NO_3^-	20.0	1.15	23.0
		Total	1285.8

Electrical Conductivity = 1285.8 μS/cm

$$= 1285.8 \; \frac{\mu S}{cm} \times \frac{1 \; mS}{10^3 \mu S} \times \frac{10^2 cm}{1 \; m}$$

$$= 128.58 \; \frac{mS}{m}$$

Add copy of Main text in chapter 8, for all participants

7. Additional handout

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

8. Main text

Contents

Electrical conductivity

1. Introduction

As in the case of metallic conductors, electrical current can flow through a solution of an electrolyte also. For metallic conductors: current is carried by electrons, chemical properties of metal are not changed and an increase in temperature increases resistance. The characteristics of current flow in electrolytes in these respects are different: the current is carried by ions, chemical changes occur in the solution and an increase in temperature decreases the resistance.

Electrical conductivity (EC) is a measure of the ability of water to conduct an electric current and depends on:

Concentration of the ions (higher concentration, higher EC)

Temperature of the solution (high temperature, higher EC)

Specific nature of the ions (higher specific ability and higher valence, higher EC)

Conductivity changes with storage time and temperature. The measurement should therefore be made in situ (dipping the electrode in the stream or well water) or in the field directly after sampling. The determination of the electrical conductivity is a rapid and convenient means of estimating the concentration of ions in solution. Since each ion has its own specific ability to conduct current, EC is only an estimate of the total ion concentration.

2. Equations and dimensions

Ohm's law defines the relation between potential (V) and current (I). The resistance (R) is the ratio between V and I:

$$R = \frac{V}{I} \qquad (1)$$

The resistance depends upon the dimensions of the conductor, length, L, in cm, cross-sectional area, A, in cm^2 and the specific resistance, ρ, in ohm.cm, of the conductor:

$$R = \rho \times \frac{L}{A} \qquad (2)$$

In the present case our interest is in specific conductance or electrical conductivity (which is the preferred term), the reciprocal of specific resistance, κ, in 1/ohm.cm or Siemens per centimetre, S/cm, which can be thought of as the conductance offered by $1cm^3$ of electrolyte:

$$\kappa = \frac{1}{\rho} = \frac{L}{A} \times \frac{1}{R} \qquad (3)$$

The resistance of the electrolyte is measured across two plates dipped in the liquid and held at a fixed distance apart in a conductivity cell. The ratio L/A for the cell is called cell constant, K_c, and has the dimensions 1/cm. The value of the constant is determined by measuring the resistance of a standard solution of known conductivity:

$$K_c = R\kappa \qquad (4)$$

3. Unit of measurement and reporting

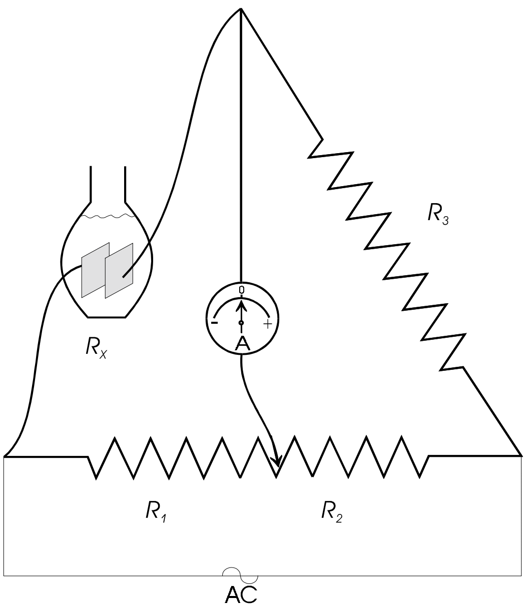
In the international system of units (SI) the electrical conductivity is expressed in Siemens which is the reciprocal of resistance in ohm. The older unit for conductance was mho. Report conductivity as milli Siemens per meter at 25°C ($mS.m^{-1}$). See table for conversions.

Table 1 Conversion table

Multiply	by	to obtain
μS/m	0.001	mS/m
μS/cm	0.1	mS/m
mS/cm	0.01	mS/m
μmho/cm	0.1	mS/m
mmho/cm	100	mS/m

4. Apparatus

An apparatus called a conductivity meter that consists of a conductivity cell and a meter measures conductivity. The conductivity cell consists of two electrodes (platinum plates) rigidly held at a constant distance from each other and are connected by cables to the meter. The meter consists of a Wheatstone bridge circuit as shown in the figure. The source of electric current in the meter applies a potential to the plates and the meter measures the electrical resistance of the solution. In order to avoid change of apparent resistance with time due to chemical reactions (polarisation effect at the electrodes) alternating current is used. Some meters read resistance (ohm) while others read in units of conductivity (milli-Siemens per meter). Platinised electrodes must be in good condition (clean, black-coated) and require replating if readings of the standard solution become erratic. Replating should be done in the laboratory. The cell should always be kept in distilled water when not in use, and thoroughly rinsed in distilled water after measurement.



5. The cell constant (calibration)

The design of the plates in the conductivity cell (size, shape, position and condition) determines the conductivity measured and is reflected in the so-called cell constant (K_c). Typical values for K_c are 0.1 to 2.0. The cell constant can be determined by using the conductivity meter to measure the resistance of a standard solution of 0.0100 mol/L potassium chloride (KCl). The conductivity of the solution (141.2 mS/m at 25°C) multiplied by the measured resistance gives the value of K_c, Equation 4. The cell constant is subject to slow changes in time, even under ideal conditions. Thus, determination of the cell constant must be done regularly.

6. Temperature correction

Conductivity is highly temperature dependent. Electrolyte conductivity increases with temperature at a rate of 0.0191 mS/m.°C for a standard KCl solution of 0.0100M.

For natural waters, this temperature coefficient is only approximately the same as that of the standard KCl solution. Thus, the more the sample temperature deviates from 25°C the greater the uncertainty in applying the temperature correction. Always record the temperature of a sample (±0.1°C) and report the measured conductivity at 25°C (using a temperature coefficient of 0.0191 mS/m.°C)

Most of the modern conductivity meters have a facility to calculate the specific conductivity at 25°C using a built in temperature compensation from 0 to 60°C. The compensation can be manual (measure temperature separately and adjust meter to this) or automatic (there is a temperature electrode connected to the meter).

7. Conductivity factor for different ions

Current is carried by both cations and anions, but to a different degree. The conductivity due to divalent cations is more than that of mono-valent cations. However, it is not true for anions. The conductivity factors for major ions present in water are listed below.

Table 2 Conductivity Factors for ions commonly found in water

Ion	**Conductivity Factor µS/cm per mg/L**
Cations	
Ca^{2+}	2.60
Mg^{2+}	3.82
K^+	1.84
Na+	2.13
Anions	
HCO_3^-	0.715
Cl^-	2.14
SO_4^{2-}	1.54
NO_3^-	1.15

The conductivity of a water sample can be approximated using the following relationship

$$EC = \sum (C_i \times f_i)$$

in which

EC = electrical conductivity, µS/ cm

Ci = concentration of ionic specie i in solution, mg / L

f_i = conductivity factor for ionic specie i

Example 1

Given the following analysis of a water sample, estimate the EC value in μ S/cm and mS/m.

Cations: Ca^{2+} = 85.0 mg/L, Mg^{2+} = 43.0 mg/L, K^+ = 2.9 mg/L, Na^+ = 92.0 mg/L
Anions: HCO_3^-=362.0 mg/L, Cl^-=131.0 mg/L, SO_4^{2-}=89.0 mg/L, NO_3^-=20.0 mg/L
Calculate the electrical conductivity of each ion using the data given in Table 3.

Table 3 Ion specific conductivity's

Ion	Conc. mg/L	Factor µS/cm per mg/L	Conductivity µS/cm
Ca^{2+}	85.0	2.60	221.0
Mg^{2+}	43.0	3.82	164.3
K^+	2.9	1.84	5.3
Na^+	92.0	2.13	196.0
HCO_3^-	362.0	0.716	258.8
Cl^-	131.0	2.14	280.3
SO_4^{2-}	89.0	1.54	137.1
NO_3^-	20.0	1.15	23.0
			Total 1285.8

*Electrical Conductivity = 1285.8 µS/cm = 1285.8 X 0.1 = 128.58 mS/m (*Table 1*).*

8. Use of EC measurement

- **Check purity of distilled or de-ionised water**

  Table 4 Gradation of water for laboratory use.

Gradation of water	Use of water	EC (mS/m)
Type I	use at detection limit of method	<0.01
Type II	routine quantitative analysis	<0.1
Type III	washing and qualitative analysis	<1

- **Relations with many individual constituents and TDS can be established.**
  The relationship between TDS (mg/L) and EC (µS/cm) is often described by a constant, that varies according to chemical composition: TDS = A x EC, where A is in the range of 0.55 to 0.9. Typically the constant is high for chloride-rich waters and low for sulphate-rich waters.

- **Check deterioration of samples in time (effect of storage)**
  If EC is checked at time of sampling and again prior to analysis in the laboratory, the change in EC is a measure for the 'freshness' of the sample.

Example 2

For the water sample given in the example in 7, calculate TDS and the corresponding constant 'A'.

Ion	Conc. mg/L
Ca^{2+}	85.0
Mg^{2+}	43.0
K^{+}	2.9
Na^{+}	92.0
HCO_3^{-}	362.0
Cl^{-}	131.0
SO_4^{2-}	89.0
NO_3^{-}	20.0
$\sum$ = 824.9	

TDS in the sample = 824.9 mg/L. EC value = 1285.8 µS/cm.

TDS = A x EC
824.9 = A x 1285.8
A = 0.64

9. Questions

1. Why is the parameter EC an in-situ parameter?
2. What are the three most important factors affecting EC measurement?
3. What is the SI unit of expression of conductivity? What is the traditional unit?
4. What is the temperature at which the conductivity value must be reported?
5. If the conductivity meter does not have a temperature compensation facility, what should be done to report the conductivity value at 25oC?
6. What is the standard used for the calibration of EC meter?
7. What are the necessary reagents for conductivity measurements?
8. What are the essential parts of EC meter?
9. What is the cell constant?
10. Why should the cell constant be verified often?
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12. Why is the relation between EC and TDS not of an exact nature?
13. For a water having the characteristics given below at 23.5°C, determine the Electrical Conductivity value analytically at 25°C and the corresponding constant 'A'.

Constituent	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
Concentration (mg/L)	200.0	12.2	39.1	230.0	610.0	71.0	480.0