

# Chapter 12

## 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:

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

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

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

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

$$k = \frac{1}{\rho} = \frac{L}{A} \times \frac{1}{R} \quad (3)$$

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<sub>c</sub>, and has the dimensions 1/cm. The value of the constant is determined by measuring the resistance of a standard solution of known conductivity:

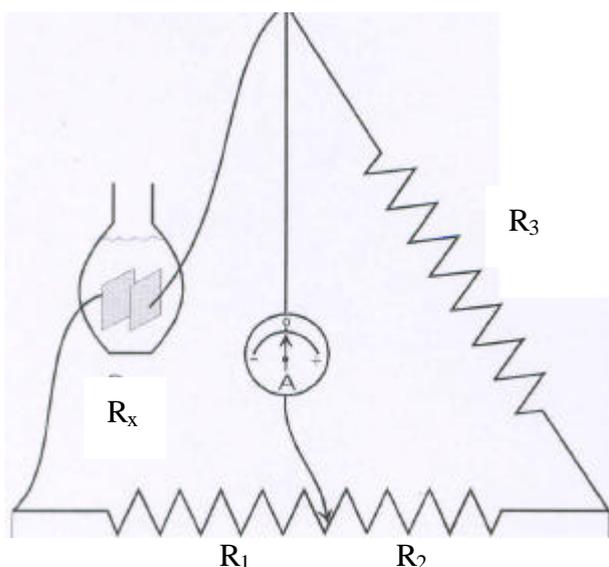
$$K_c = R \cdot k \quad (4)$$

### 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 ( $\text{mS}\cdot\text{m}^{-1}$ ). See table for conversions.

### 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 0.0100mol/L potassium chloride (KCl). The conductivity of the solution (141.2  $\text{mS}/\text{m}$  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  $\text{mS}/\text{m}^\circ\text{C}$  for a standard KCl solution of 0.0100 m.

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 ( $\pm 0.1^\circ\text{C}$ ) 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 $\mu\text{S/cm per mg/L}$
Cations	
$\text{Ca}^{2+}$	2.60
$\text{Mg}^{2+}$	3.82
$\text{K}^+$	1.84
$\text{Na}^+$	2.13
Anions	
$\text{HCO}_3^-$	0.715
$\text{Cl}^-$	2.14
$\text{SO}_4^{2-}$	1.54
$\text{NO}_3^-$	1.15

The conductivity of a water sample can be approximated using the following relationship  $\text{EC} = \sum (C_i \times f_i)$

in which

EC = electrical conductivity,  $\mu\text{S/cm}$

$C_i$  = 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  $\mu\text{S/cm}$  and  $\text{mS/m}$ .

Cations:  $\text{Ca}^{2+} = 85.0 \text{ mg/L}$ ,  $\text{Mg}^{2+} = 43.0 \text{ mg/L}$ ,  $\text{K}^+ = 2.9 \text{ mg/L}$ ,  $\text{Na}^+ = 92.0 \text{ mg/L}$

Anions:  $\text{HCO}_3^- = 362.0 \text{ mg/L}$ ,  $\text{Cl}^- = 131.0 \text{ mg/L}$ ,  $\text{SO}_4^{2-} = 89.0 \text{ mg/L}$ ,  $\text{NO}_3^- = 20.0 \text{ mg/L}$

Calculate the electrical conductivity of each ion using the data given in Table 3.

**Table 3 Ion specific conductivity's**

Ion	Cone. mg/L	Factor $\mu\text{S/cm per mg/L}$	Conductivity $\mu\text{S/cm}$
$\text{Ca}^{2+}$	85.0	2.60	221.0
$\text{Mg}^{2+}$	43.0	3.82	164.3
$\text{K}^+$	2.9	1.84	5.3
$\text{Na}^+$	92.0	2.13	196.0
$\text{HCO}_3$	362.0	0.716	258.8
Cl	131.0	2.14	280.3
$\text{SO}_4^{2-}$	89.0	1.54	137.1
$\text{NO}_3$	20.0	1.15	23.0
			Total 1285.8

*Electrical Conductivity* =  $1285.8 \mu\text{S/cm} = 1285.8 \times 0.1 = 128.58 \text{ mS/m}$  (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 ( $\mu\text{S/cm}$ ) is often described by a constant, that varies according to chemical composition:  $\text{TDS} = A \times \text{EC}$ , where A is in the range of 0.55 to 0.9. Typically the constant is high for chloride-rich waters and low for sulphaterich 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 1, calculate TDS and the corresponding constant 'A'.

Ion	Cone. Mg/L
Ca <sup>2+</sup>	85.0
Mg <sup>2+</sup>	43.0
K <sup>+</sup>	2.9
Na <sup>+</sup>	92.0
HCO <sub>3</sub>	362.0
Cl	131.0
SO <sub>4</sub> <sup>2-</sup>	89.0
NO <sub>3</sub> <sup>-</sup>	20.0
$\Sigma = 824.9$	

TDS in the sample = 824.9 mg/L. EC value = 1285.8  $\mu$ S/cm.

$$\begin{aligned} \text{TDS} &= A \times \text{EC} \\ 824.9 &= A \times 1285.8 \\ &= 0.64 \end{aligned}$$

## OPERATION OF CONDUCTIVITY METER

### Measurement of the conductivity

1. Connect the conductivity electrode to the measuring instrument.
2. Press the <Φ>key. (display test appears briefly on the display, after this, the measuring instrument automatically switches to the measuring mode.)
3. Select the parameter (TDS, Salinity, Conductivity) by pressing <M>key.
4. Immerse the electrode in the water sample.
5. Press <AR> Key to activate auto read.
6. Press <Run/Enter> Key to start the auto read measurement, AR flashes on the display until a stable measured value is reached, this can be terminated at any time with <Run/Enter> Key.

### Storing the data

1. Press the <STO>key in the measuring mode (display number with the number of the next free memory location).
2. Press <Run/Enter>key.
3. Enter the ID number with <∇ ><Δ>.
4. Terminate the save with <Run/Enter>key.

### To see the data memory

1. Press <RCL>Key.(display SEr disp)
2. Press <Run/Enter>key (display number at which data store)
3. Press <Run/Enter>key (display identification number).
4. Press <Run/Enter>key (display day, month)
5. Press <Run/Enter>key (display time)
6. Press <M>key to return in measuring mode.

### Calibration

1. Connect the conductivity Electrode to the measuring instrument.
  2. Immerse the electrode in the electrolyte solution provided with the instrument.
  2. Press the <Cal>in the measuring mode (display Cell).
  3. Press <Run/Enter>key (display CAL and cell constant value, it should be 0.450-0.500Cm<sup>-1</sup>)
- note** :- At this point ,this procedure can be terminated with<M>.

### Precautions

1. Always keep the electrode dry before and after use with absorbent paper. Need to Calibrate after a fixed interval.