

8. Electrolytes and conductivity

teacher guide

Goal of the task

This unit is unlike most of the other units in that it concerns science teaching rather than mathematics. The activity considers some aspects of properties of electrolytes. Two different phases can be clearly distinguished: the experimental stage in which students acquire data using data loggers, and the processing stage where students elaborate results and use TI InterActive! to answer the questions. The main intention of the unit is to understand the relationship between electrolytic solution conductivity and the properties of the ions present.

The experimental activity consists of:

- Use of a conductivity probe to collect preliminary data relating to the electrolytic conductivity of distilled water and other equimolar solutions (NaCl, CaCl₂, AlCl₃),
- Consideration of an acid-base reaction of neutralization, to measure the electrolytic conductivity variation through use of two titres with different solubility.

Students should understand the effect of ionic charges on the electrolytic conductivity of a solution and be able to determine the equivalence point through a conductimetric titration. Furthermore students should understand how the electrolytic conductivity of solutions is influenced by the substance's solubility.

TI InterActive! will be used as a tool to import data from a CBL 2/TI-83 Plus system, as a text editing environment where students produce their written reports, as a data list managing tool and as a data graphing tool.

Globally speaking, the task has an experimental approach and is structured as follows:

- Introductory phase,
- Experimental lab activity,
- Analysis and processing of data,
- Report phase.

Target group and required time

The target group of this unit is 15-18 year old students who have the required prerequisite knowledge. The required time for the unit is:

- 2 hours classroom teaching which includes the description of the task, checking of prerequisite knowledge, remedial work and discussion of the results,
- 2 hours in the chemistry lab to carry out the experiment and gather data,
- 2 hours in the computer lab for data processing, data analysis and for writing the final report.

Preliminary TI InterActive! skills

Students require basic computer skills in file management, word processing, spread sheets and printing documents. Students should also be able to do the following using TII:

- produce graphs (trace),
- apply commands from the algebra menu such as 'solve' and 'approximate',
- Use TII text editor functionalities,
- Import data lists from TI-83 Plus,

- Use the List Editor,
- Calculate regression equation,
- Display data graphs and equations.

Specific skills for this unit include the ability to use a CBL 2, TI-83 Plus and the Datamate application.

Preliminary knowledge of chemistry and mathematics

The required preliminary chemical knowledge includes:

- Periodic system of elements,
- Chemical nomenclature,
- Equations and chemical reactions,
- Ionic dissociation,
- Solution concentration,
- Conductivity.

The required preliminary mathematical knowledge includes:

- Understanding the meaning of a regression equation in a data series,
- Ability to interpret the graphs of a data series and regression equation.

File organization

The task consists of the following linked TII files:

- Notebook: The file in which the student writes the solutions. This is the starting point and contains hyperlinks to the other files.
- Main_Task: Contains the task for the students.
- Main_Task_Hint: Provides suggestions on the development Lab_Activity and information on the procedure to perform.
- Main_Task_Solution: Provides Main_Task results and answers to the questions.
- Lab_Activity: Contains lists of required materials and procedures.
- Lab_Activity_Hint: Provides step by step suggestions for the lab activities.
- Control: Proposes some elements of reflection to verify if the task has been carried out correctly.
- Control_Hint: Provides support/help for the Control_Task.
- Control_Solution: Contains Control task results and answers to the questions.
- Additional: Provides some supplementary questions for interested students.
- Additional_Task_Hints: Provides suggestions about how to carry out the Additional_Task.
- Additional_Task_Solution: Contains Additional task results and questions.

The hyperlinks only work if the files are installed in the map c:\TII\Conductivity. Students can start with the Notebook file in c:\TII\Conductivity

Classroom organisation

We recommend that the unit is introduced to the students by pointing out the ionic nature of electrolytes and the way in which electric charges affect the concentration of the substances.

Topics to address are:

- Concentration of solutions,
- Electrolytes and conductivity,
- Volumetric titrations and equivalence point,
- Conductimetric titration.

The experimental activity can be performed by groups of 2/3 students while analysis of data using TI InterActive! can be performed individually or by student groups depending on PC availability.

For homework it can be useful to give students exercises on molarity and normality and to revise concepts of electrolytic dissociation and solubility.

The students' final product is a lab report which can be evaluated by the teacher on the issues of:

- Correctness of experimental procedure and data processing,
- Completeness,
- Quality of answers to questions.

Technical hints

To install the task, double click on Conductivity.exe file. Students can start with Notebook file in c:\TII\Conductivity.

The experimental stage of the task consists of two lab activities: Lab Activity 1 and Lab Activity 2. The first one is of an introductory nature and involves measuring the conductivity of equimolar substances with different ionic charges (Cl^- , 2Cl^- , 3Cl^-). The second activity consists of conductimetric titration of two hydroxides (NaOH and $\text{Ba}(\text{OH})_2$ about 0.1N) with H_2SO_4 0.1N (?). In order to measure the required volume of hydroxide to titrate it can be useful to fill a burette from which every group takes their sample.

Titration can be carried out using two methods:

- a. Conventional, by using a 25-50 mL glass burette with support and a CBL 2/TI-83 Plus to run conductivity probe and to acquire data;
- b. Using a CBL 2/TI-83 Plus system to manage the acquisition of data with a conductivity probe and a step motor burette managed through Vernier DCU (Digital Control Unit).

It is useful to have a magnetic stirrer.

The file Lab_Activity contains a complete list of materials needed. Step_Motor_Burette_T_H contains the connection diagram for the step motor burette to the DCU and CBL 2. The control of the step motor burette through the DCU and CBL 2/TI-83 Plus requires use of a program for TI-83 Plus. Enclosed in the task folder you will find, as example, the file program "Titratio.8XP" which is useful to control the CMA Step Motor Burette. The entire program listing is included as Titration_Progr.txt.

By using a TI-GRAPH LINK it is possible to open a new program file and to insert through copy/paste the entire file listing. The program can be copied into the calculator RAM and used to control the Step motor burette.

Probe calibration is very easy using an auto-ID sensor and Datamate. It is advisable to set the range to 20.000 μS .

If you use the Step motor burette, it is also helpful to initially calibrate the conductivity probe using Datamate and then exit from this software before starting the program for DCU/Step motor burette control (ex. Titratio.8XP).

In order to prepare a $\text{Ba}(\text{OH})_2 \cong 0.1\text{N}$ solution, dissolve about 2 g of barium hydroxide octahydrate into 100 mL of distilled water. Wait for two days and then filter the solution.

Didactical suggestions

Crucial steps in the unit are the collection of experimental data, analysis of the data and discussion of results. The teacher should stress the role of ions' electric charges in the electrolytic conductivity of solutions, the meaning of titration and equivalence point, as well as the meaning of solubility product constant.

Electrolytic conductivity

The conductivity (Λ) of a solution is the reciprocal value of the resistance that an electrical current met to go through the volume of solution between two electrodes.

This resistance depends both on the volume of solution between the electrodes and the specific resistance (resistivity “ ρ ”) of the solution, so conductivity may be better defined as

$$\Lambda = \frac{1}{\rho * \frac{l}{S}} \text{ or } \Lambda = \frac{1}{\rho} * \frac{S}{l}$$

where:

l = conductor length (cm),

S = section area (cm²)

Fixing: χ (specific conductivity) = $\frac{1}{\rho}$ and $K = \frac{S}{l}$.

Conductimetry main law is: $\Lambda = \chi * K$.

As: $1 S$ (Siemens) = $\frac{1}{\Omega}$ and this is a very large measure, in conductimetry we use μS ($1 S \times 10^{-6}$).

When K has a unitary value, then Λ (conductivity) becomes numerically equal to χ (the specific conductivity). Several conductivity sensors (Vernier, CMA) have $K = 1.0 \text{ cm}^{-1}$ and these sensors actually measure specific conductivity rather than conductivity.

If we require conductivity then we may express our measure as μS and if we want specific conductivity we express our measure as $\mu S/\text{cm}$.

Electrolytic conductivity of a solution depends on:

- ions' concentrations,
- ionic charges,
- ion's migration speed,
- temperature.

Solubility product constant

A generic salt $A^+ B^-$ into solution will make the following equilibrium between the dissociated part and the undissociated part: $A^+ B^- \rightleftharpoons A^+ + B^-$

The equilibrium constant will be expressed as: $K = \frac{[A^+][B^-]}{[AB]}$.

$[AB]$ (undissociated solute concentration) can be considered constant and unitary, so it can be included in K . If we indicate as K_{ps} (solubility product constant) the term: $k * [AB]$, the equilibrium constant expression becomes: $K_{ps} = [A^+][B^-]$.

8.1 Main Task

intro

Read the information sheet for a summary of the formulas on electrolytic conductivity and solubility.

task

- a.** Do Lab Activity 1. For a description click on the Lab Activity link at the bottom of this page. **Hint 1**
- b.** Do Lab Activity 2. Use the Lab Activity link once more.
- c.** Process the data:
- (i)** Import the experimental data from the two lab activities into the Notebook file.
 - (ii)** Display the data related to Lab Activity 1 in a histogram. Label the graph “Graph 1”.
 - (iii)** Display the data related to Lab Activity 2 in a x-y line graph. Label the graphs “Graph2” and “Graph3”.
 - (iv)** Use Graph2 and Graph3 to determine the regression equation of the data and use this to calculate the equivalent point of the two titrated substances: barium hydroxide and sodium hydroxide.
- d.** Order the samples displayed in Graph1 (H₂O, NaCl, CaCl₂, AlCl₃) from 1 to 4 as conductivity changes. Can you see a relation between the measured conductivity and the number of chloride ions into the three tested saline solutions?
- e.** What does the equivalence point mean?
- f.** How can you recognize the equivalence point in a conductimetric titration?
- g.** For tested solutions, which value does conductivity approach at the equivalence point?
- h.** How can you explain the differences between Graph2 and Graph3?

8.2 Additional Task

task

Now 10 mL of barium hydroxide reacts exactly with 10.63 mL of sulphuric acid 0.1N. 100 mL of distilled water are also added.

Hint 2

- a.** Calculate barium hydroxide normality and number of moles held in 10 mL of its solution.
- b.** Predict whether barium sulphate, the salt produced from the reaction of acid-base neutralization, could form a precipitate ($K_{sp}(\text{BaSO}_4, 298 \text{ K}) = 1.1 \times 10^{-10}$).

8.3 Control Task

task

Consider the titration of sulphuric acid/sodium hydroxide.

Hint 3

- a.** What salt is formed during the neutralization reaction?
- b.** Is a precipitate formation visible?
- c.** Try to write the solubility equation for the salt produced during the titration and an expression for the product solubility constant.
- d.** If the concentration of the salt produced through the reaction is 290 g/L (add 10 H₂O molecules to the molecular mass of the salt), how much should the solubility product constant be?

8.4 Lab Activity

intro

This lab activities includes two experiments:

Lab Activity 1 concerns measuring the electrolytic conductivity of different substances.

Lab Activity 2 concerns barium hydroxide and sodium hydroxide conductimetric titration with sulphuric acid.

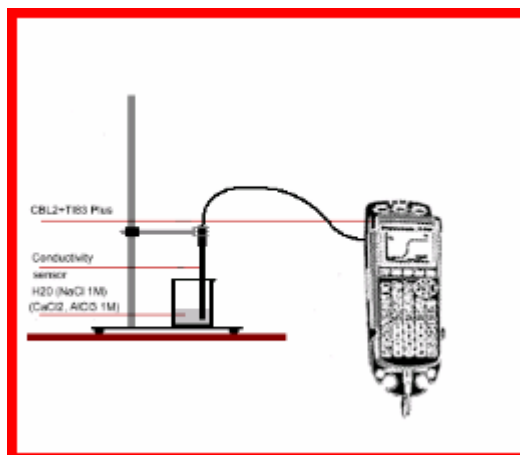
lab1

Lab Activity 1

Hint 4

Materials needed:

- CBL 2/TI-83 Plus system
- Conductivity probe
- Distilled water
- 1 M NaCl solution
- 1 M CaCl₂ solution
- 1 M AlCl₃ solution
- 4 100 mL beakers
- PVC wash bottle with distilled water
- dropper
- Paper towel



Procedure:

- Add 50 mL of distilled water into each labelled beaker.
- Add to three beakers respectively 10 drops of each solution to test: 1 M NaCl, 1 M CaCl₂, 1 M AlCl₃.
- Start Datamate.
- Calibrate the conductivity probe (range 20,000 μ S).
- Set the system choosing "Event with entry" mode.
- Dip the probe into the beaker containing only distilled water. When the reading is steady, press the ENTER button and insert "1" to refer to the distilled water sample.
- Extract the probe, dry it and then dip it into the second sample. When the reading is steady, press the ENTER button and insert "2" for the NaCl sample.
- Continue with the other samples, inserting 3 for CaCl₂ and 4 for AlCl₃.
- Save data lists, L1 as *test* and L2 as *con*.

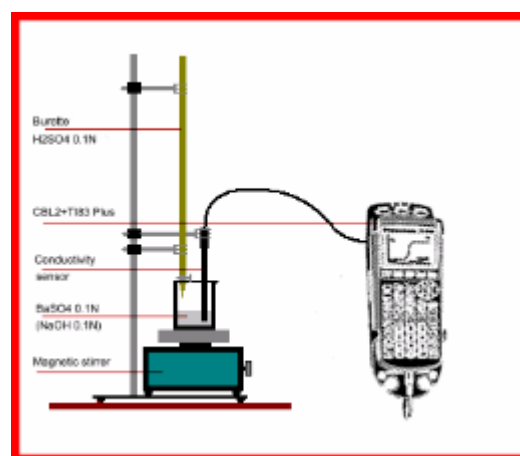
lab2

Lab Activity 2

Hint 5

Materials needed:

- CBL 2/TI-83 Plus system
- Conductivity probe
- Distilled water
- Ba(OH)₂ roughly 0.1 N
- NaOH roughly 0.1 N
- H₂SO₄ 0.1N
- N° 1 200 mL beaker
- Magnetic stirrer
- 25 mL burette or CMA Step motor Burette with DCU Vernier
- 50 mL burette with Ba(OH)₂ (to dispense 10 mL to each work group)
- 50 mL burette with NaOH (to dispense 10 mL to each work group)
- 100 mL graduated cylinder
- PVC wash bottle with distilled water
- Paper towel



Procedure using 25 mL glass burette:

- a. Using an appropriate burette measure 10 mL $\text{Ba}(\text{OH})_2$ in the 200 mL beaker.
- b. Add 100 mL of distilled water.
- c. Fill the 25 mL burette with H_2SO_4 0.1N.
- d. Start Datamate.
- e. Calibrate the conductivity probe (range 20,000 μS).
- f. Set the system choosing "Event with entry" mode.
- g. Dip the conductivity probe into the sample.
- h. Turn on the magnetic stirrer to regulate the speed.
- i. When the reading is steady press the ENTER button and insert "0".
- j. Add 1 mL H_2SO_4 0.1N.
- k. When the reading is steady, press the ENTER button. Insert the titrant volume added as "1".
- l. Continue to add H_2SO_4 0.1N as conductivity. After the conductivity reaches a minimum value, it increases and will approach the starting value.
- m. Save the data lists. For the barium hydroxide titration save L1 as *vol1* and L2 as *C_Ba*. and for sodium hydroxide save L1 as *vol2* and L2 as *C_Na*.
- n. Repeat this procedure with NaOH instead of $\text{Ba}(\text{OH})_2$.

Procedure using CMA Step motor Burette and Vernier DCU:

- a. Using an appropriate burette measure 10 mL $\text{Ba}(\text{OH})_2$ 0.1N in the 200 mL beaker.
- b. Add 100 mL of distilled water.
- c. Link the DCU to the digital CBL 2 channel.
- d. Link the DCU to the Step motor Burette.
- e. Fill the burette syringe with H_2SO_4 0.1N.
- f. Start Datamate.
- g. Calibrate the conductivity probe (range 20,000 μS).
- h. Close Datamate.
- i. Dip the conductivity probe into the sample.
- j. Start the Titration program or another program to control the Step motor Burette.
- k. Turn on the magnetic stirrer to regulate the speed.
- l. Add 1 mL H_2SO_4 0.1N.
- m. When the reading is steady press the ENTER button and insert "1".
- n. Continue to add H_2SO_4 0.1N as conductivity. After the conductivity reaches a minimum value, it increases and will approach the starting value.
- o. Save the data lists. For the barium hydroxide titration save L1 as *vol1* and L2 as *C_Ba*. and for sodium hydroxide save L1 as *vol2* and L2 as *C_Na*.
- p. Repeat this procedure with NaOH instead of $\text{Ba}(\text{OH})_2$.

8.5 Hints

hint 1

- a.**
- Write the chemical equation for the acid-base neutralization reaction.
 - Calculate the equivalent amount of sulphuric acid held into 10.63mL of 0.1 N reacted solution. Remember to express the volume of the substance in litres.
 - Comment on the mean of the chemical equivalent and look for the existing ratio between the reacted equivalents of sulphuric acid and the corresponding number of barium hydroxide's equivalents.
 - After you have found the barium hydroxide's equivalents, calculate the normality value.
 - Comment on the difference between normality and molarity. Use the barium hydroxide number of equivalents to calculate the corresponding number of moles.
- b.**
- Use:
 - The chemical equation of the acid-base neutralization reaction between sulphuric acid and barium hydroxide
 - The number of moles of reacted barium hydroxide (already calculated)
 - The total solution volume (as indicated in the text of the question)
 - The barium sulphate constant of solubility product
 - Calculate the barium sulphate molarity (referring to total solution volume).
 - Write the barium sulphate solubility equation.
 - Use the stoichiometric coefficients to help determine the concentration of ionic species (g-ions/L) which is present relative to the barium sulphate molarity (already calculated).
 - Write the relationship for the barium sulphate constant of solubility product.
 - Calculate the value of the ionic product of the ionic species and compare the result with the barium sulphate K_{sp} .
 - If the calculated result is greater than K_{sp} this means that the precipitate will be barium sulphate.

hint 2

- a.**
- Write the chemical equation for the acid-base neutralization reaction.
 - Calculate the equivalent amount of sulphuric acid held into 10.63mL of 0.1 N reacted solution. Remember to express the volume of the substance in litres.
 - Comment on the mean of the chemical equivalent and look for the existing ratio between the reacted equivalents of sulphuric acid and the corresponding number of barium hydroxide's equivalents.
 - After you have found the barium hydroxide's equivalents, calculate the normality value.
 - Comment on the difference between normality and molarity. Use the barium hydroxide number of equivalents to calculate the corresponding number of moles.
- b.**
- Use:
 - The chemical equation of the acid-base neutralization reaction between sulphuric acid and barium hydroxide
 - The number of moles of reacted barium hydroxide (already calculated)
 - The total solution volume (as indicated in the text of the question)
 - The barium sulphate constant of solubility product
 - Calculate the barium sulphate molarity (referring to total solution volume).
 - Write the barium sulphate solubility equation.
 - Use the stoichiometric coefficients to help determine the concentration of ionic species (g-ions/L) which is present relative to the barium sulphate molarity (already calculated).
 - Write the relationship for the barium sulphate constant of solubility product.
 - Calculate the value of the ionic product of the ionic species and compare the result with the barium sulphate K_{sp} .
 - If the calculated result is greater than K_{sp} this means that the precipitate will be barium sulphate.

hint 3

- a.** Write the chemical equation for the neutralization reaction between sodium hydroxide and sulphuric acid.
- b.** Observe the water solution during titration to verify that that solution is clear.

- c. The solubility equation symbolizes the process through which the salt liberates its ions due to water dissolution. The expression of solubility product refers to the equilibrium constant (solubility product constant) of the salt solubility equation.
- d. Calculate the number of moles corresponding to salt quantity (290 g).
Determine the number of g-ions/L formed by salt dissolution.
Substitute the the ions' concentration into the expression for the solubility product constant.

hint 4

- (i) Acquire data with Datamate
- a. Link the TI-83 Plus to the CBL 2.
 - b. Link the Conductivity probe to CH1 channel on CBL 2.
 - c. Start Datamate.
 - d. Calibrate the Conductivity Probe:
 - On the probe select the medium range: 0–2000 μS
 - Press:
 - 1: SETUP
 - 2: CALIBRATE
 - 2: CALIBRATE NOW
 - With the sensor dry (in the air) wait until the tension reading becomes stable and then press ENTER.
 - Insert “0” as the first value. Press ENTER
 - Dip the probe tip into the calibration standard solution (1000 μS).
Wait until the reading is stable and then press ENTER.
 - Type “1000” and press ENTER.
 - Return to the SETUP menu by pressing 1:OK.
 - e. Sampling mode setup:
 - Press 1:SETUP.
 - Select MODE and then press ENTER.
 - Choose 3: EVENTS WITH ENTRY.
 - Return to the main menu by pressing 1:OK.
 - f. Collect data
 - Dip the probe into the first sample (distilled water).
 - Press 2:START.
 - Wait for a few minutes. When the reading is steady, press ENTER.
 - Type “1” and press ENTER.
 - Rinse the probe with distilled water, dry the probe and then dip it in the second sample.
 - When the reading is steady, press ENTER.
 - Type “2” and press ENTER.
 - Repeat this procedure for the other samples. At the end press STO➔.
 - Quit Datamate.
- (ii) To save data lists
- a. Press the CLEAR button.
 - b. Type:
 - L1 STO ➔ test
 - L2 STO ➔ cond

hint 5

- (i) Acquire data with Datamate:
- a. Link the TI-83 Plus to the CBL 2.
 - b. Link the Conductivity probe to CH1 channel on the CBL 2.
 - c. Start Datamate.

- d. Calibrate the Conductivity Probe:
- On the probe select the medium range: 0–2000 μS .
 - Press:
 - 1: SETUP
 - 2: CALIBRATE
 - 2: CALIBRATE NOW
 - With the sensor dry (in the air) wait until the tension reading becomes stable and then press ENTER.
 - Insert “0” as first value. Press ENTER.
 - To dip the probe tip in the calibration standard solution (1000 μS). Wait the stable reading and then press ENTER
 - Type “1000” and press ENTER.
 - Return to the SETUP menu by pressing 1:OK.
- e. Sampling mode setup:
- Press 1:SETUP.
 - Select MODE and then press ENTER.
 - Choose 3: EVENTS WITH ENTRY
 - Return to the main menu by pressing 1:OK.
- f. Collect data
- Start the magnetic stirrer and regulate the speed.
 - Dip the probe in to the $\text{Ba}(\text{OH})_2$ solution.
 - Press 2:START.
 - Wait for a few minutes.
 - When the reading is stable note the conductivity value and press ENTER.
 - Type “0” (mL of added titrant) and press ENTER.
 - Add 0.5 mL of 0.1N H_2SO_4 .
 - When the reading is stable press ENTER.
 - Type “0.5” and press ENTER.
 - Repeat the procedure adding 0.5 mL of 0.1N H_2SO_4 from time to time.
 - Continue until the conductivity approaches the starting value.
 - At the end press STO× key.
 - Close Datamate.

(ii) To save data lists

- a. Press the CLEAR button.
- b. Type:
- For $\text{Ba}(\text{OH})_2$ titration:
 - L1 STO \rightarrow vol_1
 - L2 STO \rightarrow C_Ba
 - For NaOH titration:
 - L1 STO \rightarrow vol_2
 - L2 STO \rightarrow C_Na