

Experiment ADS-CEK-1: Conductivity of Solutions

Background

Conductivity is the ability of a substance to conduct an electric current. The principle by which conductivity is measured is fairly easy - two electrodes are placed in the solution, a potential is applied across the electrodes, and the current is measured. Conductivity (G) is the inverse of resistivity (R).

This can be determined from the voltage and current values according to Ohm's law:

$$G = I/R = I \text{ (amps)} / E \text{ (volts)}$$

Since the ions in a solution facilitate the conductance of an electrical current, the conductivity of a solution is proportional to its ion concentration. Conductivity is generally measured in microsiemens (uS). Microsiemens are the modern units of the inverse of resistivity or mho.

In some situations, however, conductivity may not correlate directly to concentration. The graphs below illustrate the relationship between conductivity and ion concentration for two common solutions. Notice that the graph is linear for the sodium chloride solution, but not for a highly concentrated sulfuric acid solution. Ionic interactions can alter the linear relationship between conductivity and concentration in some highly concentrated solutions.

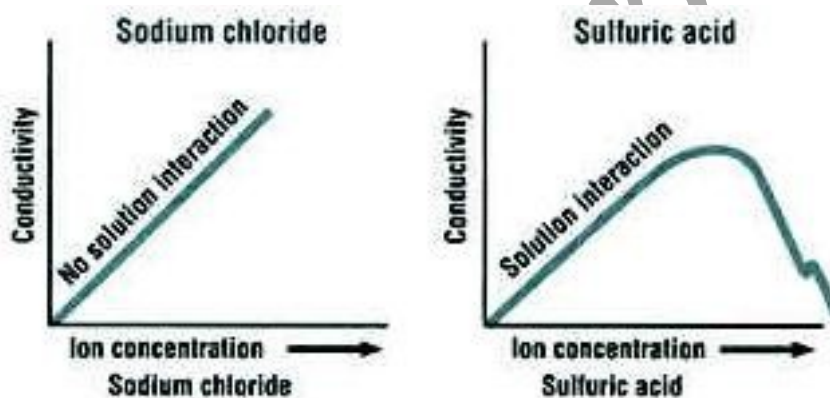


Figure ADS-CEK-1-B1: Graphs showing the concentration vs. conductivity of two different solutions.

Ions that move through solution easily are better conductors. Small, fast moving ions like hydrogen (H^+) have a greater conductivity than do larger ions like bromide ion (Br^-), or heavily hydrated ions like the sulfate ion (SO_4^{2-}).

Conductivity is a useful method for measuring how good a conductor a substance will be. Conductive substances are usually referred to as electrolytes. Thus, electrolytes are compounds that dissolve in water and dissociate into ions. In solutions of electrolytes, several different substances may be present, including complete, whole molecules and dissociated ions.

Strong electrolytes dissociate completely into ions. A 1.0 M solution of the strong ionic electrolyte “AB” contains 1.0 M “A⁺” ions, 1.0 M “B⁻” ions, and 0.0 M “AB” molecules. In other words, the ions are the only substances present in a solution of a strong electrolyte. Diluting a 1.0 M solution of “AB” with water to 0.50 M reduces the concentration of ions by one half, which also reduces the conductivity of the solution by one half.

Weak electrolytes dissociate incompletely, or do not fully separate into their respective ions. A 1.0 M solution of a weak electrolyte “CD” may contain less than 0.20 M “C⁺” ions, the same molarity of “D⁻” ions, and greater than 0.80 M “CD” molecules. In a solution of a weak electrolyte the main substance present is the entire molecule, not necessarily the dissociated ions.

The dissociation of a weak electrolyte is an equilibrium process, in which molecules are constantly dissociating, a forward reaction, and reforming, the reverse reaction, at identical rates. At equilibrium, the forward and reverse processes occur at the same rate, so molecules dissociate and reform at the same rate, and the concentrations of the molecule, its positive ions and its negative ions all remain constant.

The probability of spontaneous dissociation of a molecule is constant, but the probability of reformation of the molecule from its ions depends on the concentration of ions present; low concentration makes reformation infrequent which makes the reverse reaction slower. This means that diluting a weak electrolytic solution slows down the reverse reaction more than it slows down the forward reaction. After dilution, dissociation outpaces reformation until the concentrations of the ions rise, their reformation rate increases, and the rate of the reverse reaction rises to match that of the forward reaction. As a result, dilution leads to dissociation of additional molecules before equilibrium is reached again. So diluting a 1.0 M solution of a weak electrolyte to 0.50 M with water reduces the conductivity, but by less than the 50% expected with strong electrolytes.

In this experiment, students will test the conductivity of a variety of strong, weak, and non-electrolyte solutions using a conductivity meter. Various electrolyte concentrations will also be studied to see how concentration affects conductivity.

Additional exercises may include relating conductivity to temperature, measuring the conductivity of water samples from a variety of sources, and correlating conductivity to pH.

Experiment ADS-CEK-1: Conductivity of Solutions

Equipment Required

PC or Mac Computer

ADS or ADS MAX Board, USB cable, Power Supply Cable

CMN-100 conductivity meter

100 ml beakers (11)

250 ml beaker

Wash bottle

500 ml beaker for waste deionized water

Deionized water

Conductivity standard solutions (see Appendix)

Conductivity testing solutions (see Appendix)

Note: To ease setup, connect the sensor to the A-ADS-IA adapter *before* plugging the adapter into the board. To disconnect, unplug the adapter from the board *first*, then remove the sensor.

Setup (ADS)

1. Locate the CMN-100 conductivity meter and plug the connector of the CMN-100 into the Channel 1 port on the A-ADS-IA.

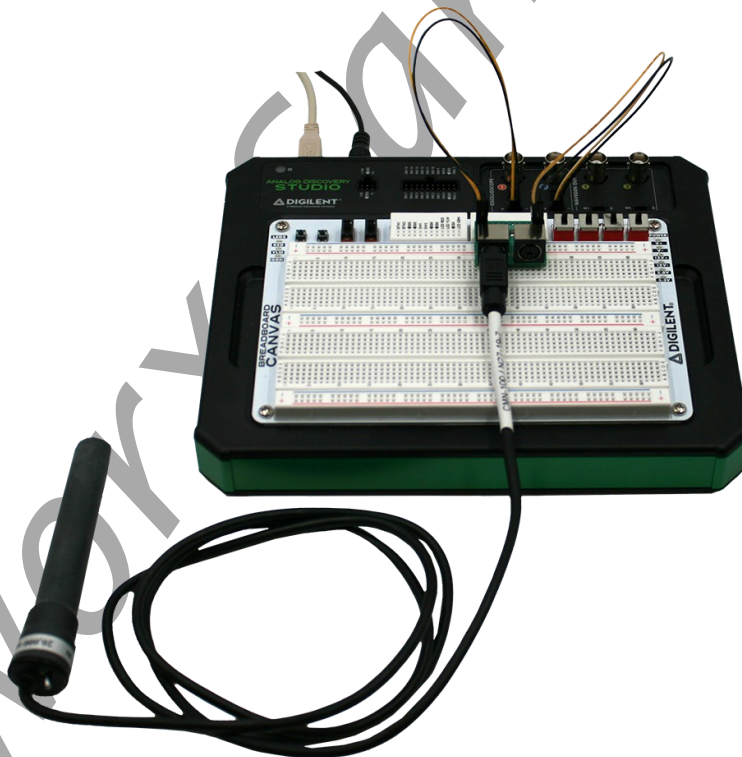


Figure ADS-CEK-1-S1: The CMN-100 conductivity meter plugged into Channel 1 on the ADS.

Setup (ADS MAX)

If using the ADS MAX, setup instructions will be the same. Channel connections are labeled on the A-ADS-IA board, as shown below.

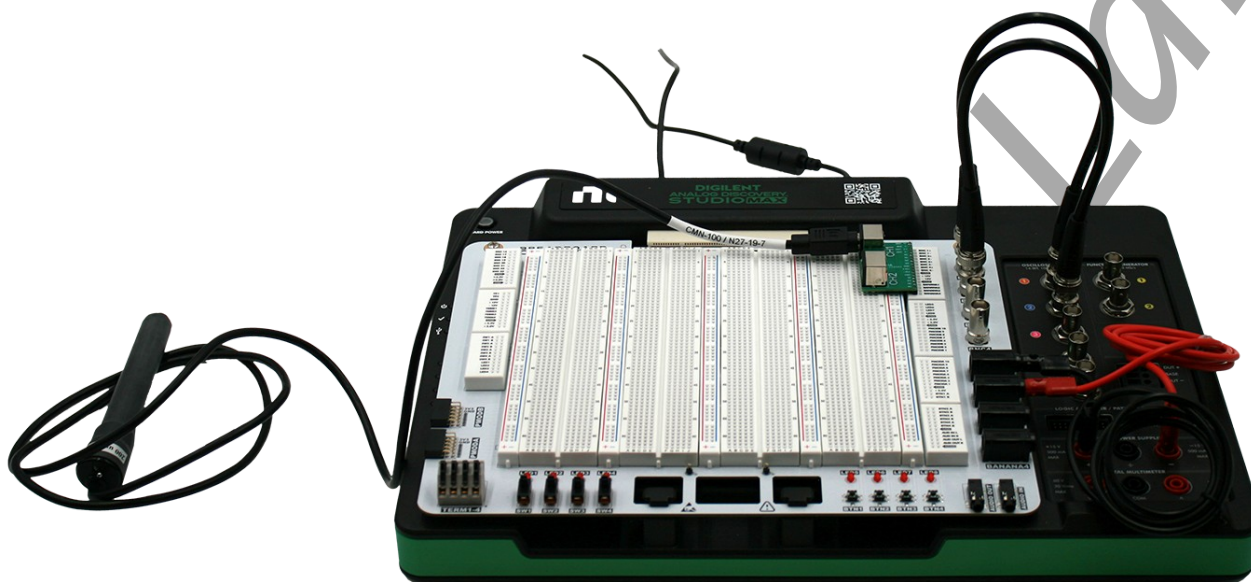


Figure ADS-CEK-1-S2: The CMN-100 Channel 1 connection on the ADS MAX Board.

Calibration of the Conductivity Meter

Note: For calibration purposes, set the conductivity selector switch to the 0-20,000 μS position.

1. Rinse the CMN-100 conductivity meter with deionized water while holding the electrode over a 500 ml beaker.
2. Place the tip of the conductivity meter in a 250 ml beaker containing enough room temperature deionized water to submerge the tip. Keep the electrode in deionized water for at least five minutes.
3. Prepare two 100 ml beakers, each filled with 50 ml of the conductivity standard solutions used for calibration. The solutions should be at room temperature. One beaker is filled with a solution of 2000 μS NaCl and the other is filled with a 10,000 μS NaCl solution.
4. Each beaker should be filled with enough solution to cover the tip of the conductivity meter.
5. Place the beaker containing the 2000 μS solution next to the meter. Remove the meter from the deionized water and blot any extra drops of water. Carefully lower the tip of the electrode into the beaker of NaCl so that the tip does not hit the bottom.
6. Click Record. After a few seconds, the trace will reach a stable baseline toward the top of the

recording channel. Type **2000** in the Mark box. Click the mark button to mark the stable baseline of the recording. Continue recording while changing the beakers of solutions.

7. Remove the conductivity meter from the beaker of 2000 uS NaCl solution. Hold the meter over the beaker used for collecting deionized waste water and rinse it well with deionized water. Blot any extra drops of water.
8. Place the beaker of 10,000 uS NaCl solution close to the meter. Carefully lower the conductivity meter into the beaker so it does not forcefully hit bottom.
9. As you continue to record, the trace will reach a stable baseline. Type **10,000** in the Mark box. Click the mark button to mark the stable baseline of the recording. This marks the output of the CMN-100 conductivity meter in this standard solution.
10. The recording will look like the recording shown.
11. Click Stop to halt the recording.
12. Select Save As in the File menu, type a name for the file. Click on the Save button to save the data file.
13. Remove the conductivity meter from the beaker of solution. Hold the meter over the beaker used for collecting deionized waste water, and rinse it well with deionized water from a wash bottle. Blot any extra drops of water and place the meter in another beaker of deionized water.

Units Conversion

1. Scroll to the beginning of the calibration data for the CMN-100 conductivity meter.
2. Use the Display Time icons to adjust the Display Time of the Main window to show the data collected at 2000 uS and 10,000 uS on the Main window at the same time.
3. Click the 2-Cursor icon so that two cursors appear on the Main window. Place one cursor on the flat section of data collected when the CMN-100 conductivity meter was in the 2000 uS solution and the second cursor on the flat section of data collected when the meter was in the 10,000 uS solution.
4. To convert the voltages at the positions of the cursors to conductivity values in uS, use the Simple Units Conversion dialogue window. Click V2-V1 on the conductivity channel, then select Units, and select Simple.

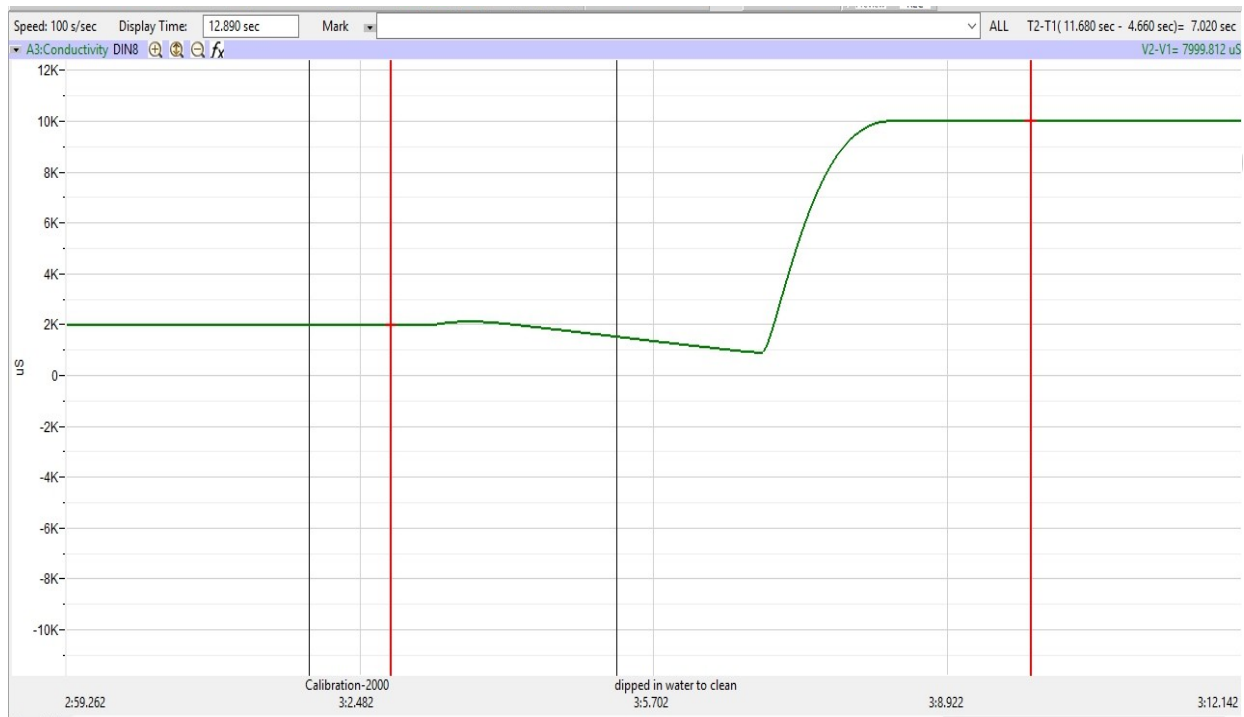


Figure ADS-CEK-1-S3: Conductivity calibration data recorded showing the positions of the cursors for changing the recorded voltage to conductivity in uS.

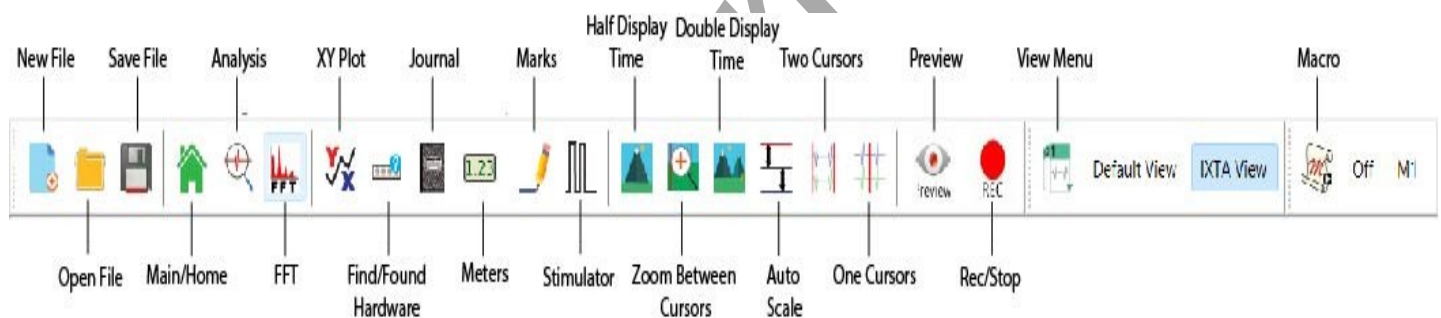


Figure ADS-CEK-1-S4: The LabScribe toolbar.

5. On the units conversion window, make sure 2 point calibration is selected in the pull-down menu in the upper-left corner of the window. Put a check mark in the box next to Apply units to all blocks.
 - Notice that the voltages from the positions of the cursors are automatically entered into the value equations.
 - Enter the two calibration solutions used in the calibration recording in the corresponding boxes on the right side of the conversion equations. Enter the name of the units, uS, in box below these values.
 - Click on the OK button in the lower right corner of the window to activate the units conversion.

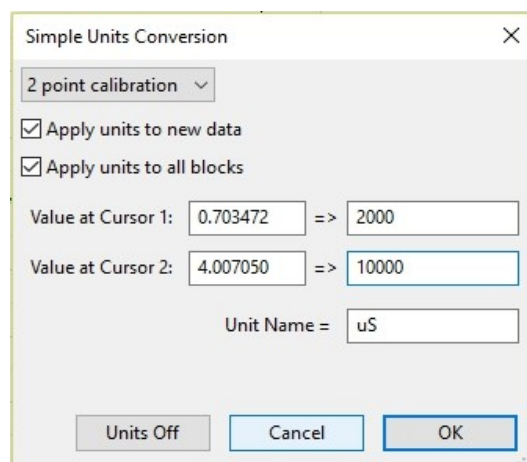


Figure ADS-CEK-1-S5: The Simple Units Conversion dialog window for conductivity conversion.

Experiment ADS-CEK-1: Conductivity of Solutions

Exercise 1: The Conductivity of Various Electrolytes.

Aim: To determine the conductivity of different electrolyte solutions.

Approximate Time: 60 minutes

Procedure:

Note: Always begin testing samples with the conductivity selector switch in the 0-200 μS range. While recording the conductivity of each test sample, toggle the switch to the 0-20,000 μS position. This is especially important for measuring solutions with higher conductivities.

1. Fill a 100 ml beaker with approximately 50 ml of 0.05M NaCl. Fill a 250 ml beaker with 100ml deionized water.
2. Make sure the conductivity selector switch is in the 0-200 μS position.
3. With the CMN-100 conductivity meter in the beaker of deionized water, click Record.
4. When the recording on the Conductivity channel reaches a stable baseline, type **DI Water** in the Mark box. Click the mark button to mark the recording.
5. Type **0.05M NaCl** in the Mark box.
6. Remove the meter from the deionized water and carefully blot the tip.
7. Place the CMN-100 in the beaker of 0.05 M NaCl.
8. When the recording on the Conductivity channel reaches a stable baseline click the mark button to mark the recording. The recording should look like the image below.

Note: You may need to toggle the conductivity selector switch to the 0-20,000 μS range to get an accurate reading of conductivity.

9. Click Stop to halt the recording.
10. Select Save in the File menu.
11. Remove the conductivity meter from the beaker. Hold the meter over the 500 ml beaker used for collecting waste deionized water, and rinse it with a wash bottle. Blot any drops of DI water from the meter and place the meter in a beaker containing fresh DI water. The meter will be used in the next section of the exercise.

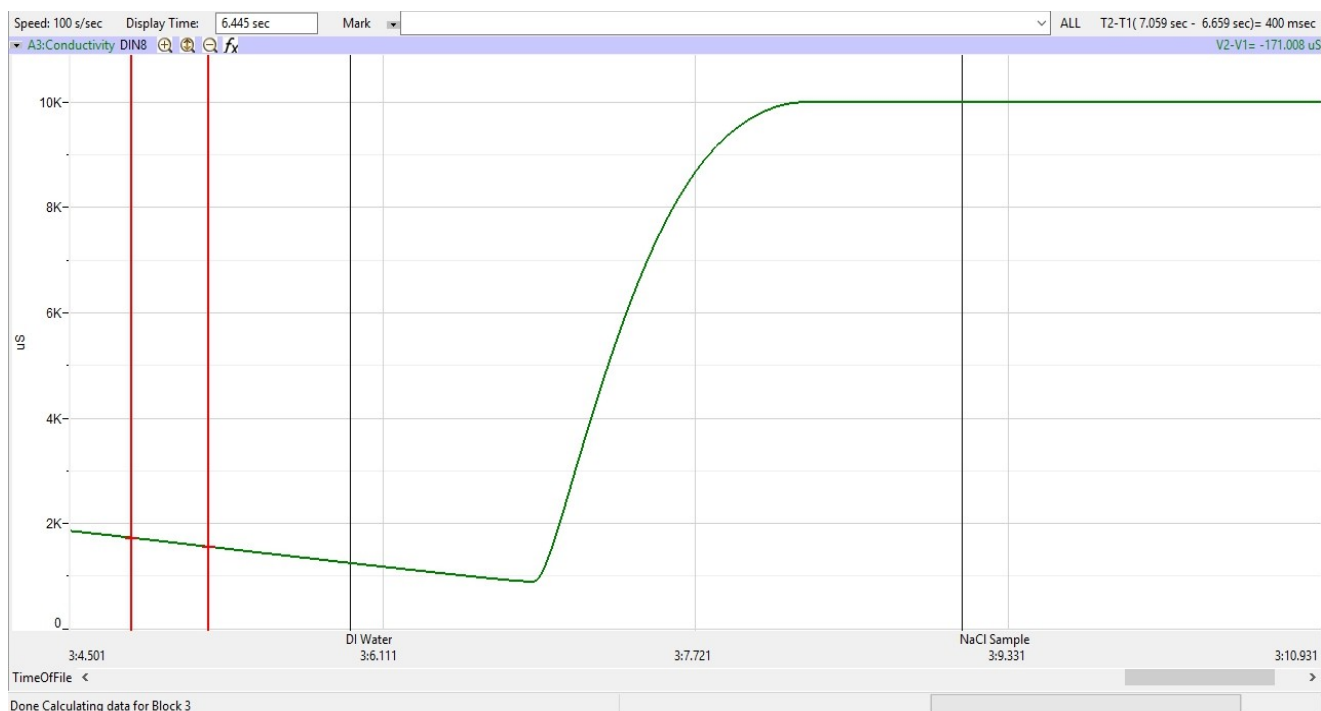


Figure GB-6-L1: Recording showing the conductivity of a solution in the Main window.

12. Repeat steps 1 through 11 using the following solutions.

- 0.05 M CaCl_2
- 0.05 M AlCl_3
- 0.05 M $\text{HC}_2\text{H}_3\text{O}_2$
- 0.05 M H_3PO_4
- 0.05 M H_3BO_3
- 0.05 M HCl
- 5% $\text{C}_2\text{H}_4\text{O}_2$
- 5% $\text{C}_3\text{H}_7\text{OH}$

Note: Be sure to mark the recording appropriately for each of these solutions for ease of data analysis.

13. Place the CMN-100 conductivity probe in a beaker of fresh deionized water during data analysis.

Data Analysis

1. Scroll to the section of data for deionized water and 0.05 M NaCl recorded during Exercise 1.
2. Use the Display Time icons on the LabScribe toolbar to position this section of recording on the Main window. The required data can also be selected by:
 - Placing the cursors on either side of the section of data needed. Place one cursor on the stable conductivity value recorded from pure deionized water. Place the second cursor on the stable conductivity value recorded after moving the meter to the 0.05 M NaCl solution.
 - Clicking the Zoom between Cursors button on the LabScribe toolbar to expand the segment of data to the width of the Main window.
3. Look at the Function Table that is above the uppermost channel displayed in the Analysis window. The mathematical functions that are listed should include Value1 and Value2. The values for these parameters from each channel are seen in the table across the top margin of each channel.
4. Once the cursors are placed in the correct positions for determining the conductivity, the values can be recorded in the on-line notebook of LabScribe by typing the names and values directly into the Journal.
5. The functions in the channel pull-down menus of the Analysis window can also be used to enter the names and values of the parameters from the recording to the Journal. To use these functions:
 - Place the cursors at the locations used to measure the conductivity from the Conductivity channel.
 - Transfer the name of the mathematical function used to determine the conductivity to the Journal using the Add Title to Journal function in the Conductivity channel pull-down menu.
 - Transfer the value for the conductivity to the Journal using the Add Ch. Data to Journal function in the Conductivity channel pull-down menu.
6. Place one cursor on the stable conductivity value of the pure deionized water. Place the second cursor on a stable point in the recording of the 0.05 M NaCl solution.
7. Measure the values for the following parameters from the Conductivity channel for the region of data selected:
 - Conductivity-DI Water, which is Value1 on the Conductivity channel.
 - Conductivity-NaCl, which is Value2 on the Conductivity channel.
8. Record the values for these parameters in the Journal using one of the procedures described in Step 5, and on Table 1.
9. Click the down arrow next to the Mark box to choose the next section of data.
 - Highlight and click on the next Mark on the list - CaCl₂.
 - This will automatically move the recording to the section of data with that Mark.

10. Repeat steps 3 through 8 for the 0.05 M CaCl_2 solution.
11. Repeat step 9, moving to the next Mark on the list - AlCl_3 .
12. Repeat steps 3 through 8 for the 0.05 M solution of AlCl_3 .
13. Continue steps 3 through 9 for each of the successive solutions, recording conductivity values in μS on the data table.

Exercise 2: The Effect of Concentration on the Conductivity of Solutions

Aim: To determine the effect of concentration on the conductivity of various solutions.

Approximate Time: 30 minutes

Note: Always begin testing samples with the conductivity selector switch in the 0-200 μS range. While recording the conductivity of each test sample, toggle the switch to the 0-20,000 μS position. This is especially important for measuring solutions with higher conductivities.

Procedure:

1. Add 50 ml deionized water to a 100 ml beaker.
2. Place the CMN-100 conductivity meter in the beaker and click Record.
3. When the recording on the Conductivity channel reaches a stable baseline, type **DI Water** in the Mark box. Click the mark button to mark the recording.
4. Add 1 drop of 1.0 M NaCl solution to the deionized water. Carefully swirl the CMN-100 to ensure thorough mixing.
5. Type **1 drop** in the Mark box. Click the mark button to mark the recording as it reaches a stable level.
6. Type **2 drops** in the Mark box as a second drop of 1.0 M NaCl solution is added to the beaker. Click the mark button to mark the recording as it reaches a stable level.
7. Type **3 drops** in the Mark box as a third drop of 1.0 M NaCl solution is added to the beaker. Click the mark button to mark the recording as it reaches a stable level.
8. Continue following these steps until 10 drops of 1.0 M NaCl have been added to the beaker.
9. Click Stop to halt the recording.
10. Select Save in the File menu.
11. Remove the conductivity meter from the beaker. Hold the meter over the beaker used for collecting waste deionized water, and rinse it with a wash bottle. Blot any drops of DI water from the meter and place the meter in the beaker containing fresh DI water. The meter will be used in the next section of the exercise.
12. Repeat steps 1 through 11 for both 1.0 M CaCl_2 and 1.0 M AlCl_3 .
13. Discard the contents of each beaker as directed by your instructor.

Note: Remove the conductivity meter from the beaker. Hold the meter over the beaker used for collecting waste deionized water, and rinse it with a wash bottle. Blot any drops of DI water from the meter and place the meter in the beaker containing fresh DI water. Make sure the CMN-100 is clean and dry prior to storage.

Data Analysis

1. Scroll to the section of data for deionized water and 1 drop of 1.0 M NaCl recorded during Exercise 2.
2. Use the Display Time icons on the LabScribe toolbar to position this section of recording on the Main window. The required data can also be selected by:
 - Placing the cursors on either side of the section of data needed. Place one cursor on the stable conductivity value recorded from pure deionized water. Place the second cursor on the stable conductivity value recorded after adding 1 drop of 1.0 M NaCl.
 - Clicking the Zoom between Cursors button on the LabScribe toolbar to expand the segment of data to the width of the Main window.
3. Look at the Function Table that is above the uppermost channel displayed in the Analysis window. The mathematical functions that are listed should include Title, Value1, and Value2. The values for these parameters from each channel are seen in the table across the top margin of each channel.
4. Once the cursors are placed in the correct positions for determining the conductivity, the values can be recorded in the on-line notebook of LabScribe by typing the names and values directly into the Journal.
5. The functions in the channel pull-down menus of the Analysis window can also be used to enter the names and values of the parameters from the recording to the Journal. To use these functions:
 - Place the cursors at the locations used to measure the conductivity from the Conductivity channel.
 - Transfer the name of the mathematical function used to determine the conductivity to the Journal using the Add Title to Journal function in the Conductivity channel pull-down menu.
 - Transfer the value for the conductivity to the Journal using the Add Ch. Data to Journal function in the Conductivity channel pull-down menu.
6. Place one cursor on the stable conductivity value of the pure deionized water. Place the second cursor on a data point in the recording of the 1 drop of 1.0 M NaCl solution.
7. Measure the values for the following parameters from the Conductivity channel for the region of data selected:
 - Conductivity-DI Water, which is Value1 on the Conductivity channel.
 - Conductivity-1, which is Value2 on the Conductivity channel.

8. Record the values for these parameters in the Journal using one of the procedures described in Step 5, and on Table 2.
9. Click the down arrow next to the Mark box to choose the next section of data.
 - Highlight and click on the next Mark on the list - CaCl_2 .
 - This will automatically move the recording to the section of data with that Mark.
10. Repeat steps 1 through 9 for CaCl_2 .
11. Repeat steps 1 through 9 for AlCl_3 .

Data Tables

Table ADS-CEK-1-L1: Data Table for Exercise 1 - Conductivity of Different Solutions

Conductivity Values for Various Solutions		
Solution	Deionized water prior to test (uS)	Conductivity of Solution (uS)
0.05 M NaCl		
0.05 M CaCl_2		
0.05 M AlCl_3		
0.05 M $\text{HC}_2\text{H}_3\text{O}_2$		
0.05 M H_3PO_4		
0.05 M H_3BO_3		
0.05 M HCl		
5% $\text{C}_2\text{H}_4\text{O}_2$ (acetic acid)		
5% $\text{C}_3\text{H}_7\text{OH}$ (isopropyl alcohol)		

Table ADS-CEK-1-L2: Data Table for Exercise 2 - Concentration

Effect of Concentration on Conductivity					
1.0 M NaCl		1.0 M CaCl ₂		1.0 M AlCl ₃	
# of drops	Conductivity (uS)	# of drops	Conductivity (uS)	# of drops	Conductivity (uS)
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	
8		8		8	
9		9		9	
10		10		10	

Questions

Exercise 1

1. Which solution had the highest conductivity? The lowest?
2. What is the main contributor to the difference in conductivity values between the solutions tested?
3. What is the reason that acetic acid and isopropyl alcohol showed little, if any, conductivity?
4. How do strong and weak electrolytes compare in their conductivity values?

Exercise 2

1. What was the effect of adding drops of 1.0 M NaCl to deionized water?
2. What was the effect of adding drops of 1.0 M CaCl₂ to deionized water?
3. What was the effect of adding drops of 1.0 M AlCl₃ to deionized water?
4. Graph Concentration vs. Conductivity for each of the 3 solutions.

Experiment ADS-CEK-1: Conductivity of Solutions

Note: Calibration standards can also be purchased from any company selling chemical solutions. Standard solutions need to be single salt, either NaCl or KCl.

Appendix: Solutions

Conductivity Calibration Solutions

Standard	NaCl g/L deionized water
1000 uS	0.491
2000 uS	1.005
10,000 uS	5.566

Electrolyte and Non-Electrolyte Solutions

Various Electrolyte and Non-Electrolyte Testing Solutions

Solution	Concentration g/L deionized water
0.05 M NaCl	2.92
0.05 M CaCl ₂	5.55
0.05 M AlCl ₃	6.67
0.05 M HC ₂ H ₃ O ₂	3.00
0.05 M H ₃ PO ₄	4.90
0.05 M H ₃ BO ₃	3.09
0.05 M HCl	1.82
5% C ₂ H ₄ O ₂ (acetic acid)	50ml glacial acetic acid in 950 ml DI H ₂ O
5% C ₃ H ₇ OH (isopropyl alcohol)	71ml 70% alcohol in 929 ml DI H ₂ O

1.0 M Electrolyte Solutions

Solution	Concentration g/L deionized water
1.0 M NaCl	58.4
1.0 M CaCl ₂	111.0
1.0 M AlCl ₃	133.4