Last name .... Date..
First name .... Degree program name ....

Excercise B19

Conductivity - electrical conduction of electrolyte solutions

Part 1. Determination of electrical conductivity of electrolytes

Solution	Conductivity κ [µS/cm] (Mean ± Standard Deviation)	Temperature t [^oC]
H_2O (distilled)		
1% NaCl		
……….% NaCl		
……….% NaCl		
………………		
………………..		

Equation of the fitted line: …………………....…………………..………… , r = ……..………

Saline conductivity (...….%NaCl): ..…………......…………… [µS/cm], **Δx rel** = ……..……..…(%)

Part 2. Determination of the relationship between electrical conductivity and temperature

Nr	NaCl concentration [%]	equation of the fitted line	r
1			
2			

AIM

The aim of the experiment is to study the phenomenon of ability of aqueous electrolyte solutions to conduct an electric current. The conductivity κ is a measure of the electrical conductivity of electrolyte solutions and, for a given type of electrolyte, depends on the concentration and temperature. In this experiment, the dependence of ionic conductivity on temperature and concentration of a strong electrolyte solution - sodium chloride (NaCl) - will be studied.

THEORY

Ionic conduction.

The ability of matter to conduct electricity is widely utilized in technical, biological, pharmaceutical, environmental and biomedical sciences. Electric current, i.e. the flow of charged particles, is present both in nature (e.g. lightning discharges or the conduction of nerve impulses through nerve cells) and in electrical circuits and installations in our homes.

There are two types of conduction: **electronic and ionic**. In the case of electronic conduction, the charge carriers are electrons. This type of conductivity occurs in metallic conductors (metals, semiconductors, superconductors**). In the case of ionic conduction, the charge carriers are ions (both cations and anions).** The movement of electrolyte ions in an eclectic field (induced by a potential difference) is shown in Figure 1. Ionic conduction occurs in electrolytic conductors, which include solutions of salts, acids and bases and salts in the molten or solid state. In aqueous solutions, these substances dissociate and appear as ions. Electrolytes are divided into strong and weak electrolytes:

- **Strong** electrolytes (e.g. NaCl, KCl, HNO3) dissociate completely in aqueous solution (only the ions are present) and conduct electricity efficiently.
- **Weak** electrolytes (e.g. vinegar CH_3COOH, tap water): dissolved compounds undergo partial dissociation and conduct electricity poorly.
- We can also recognise non-electrolytes: solutions that do not conduct electricity (pure water, sugar solution)

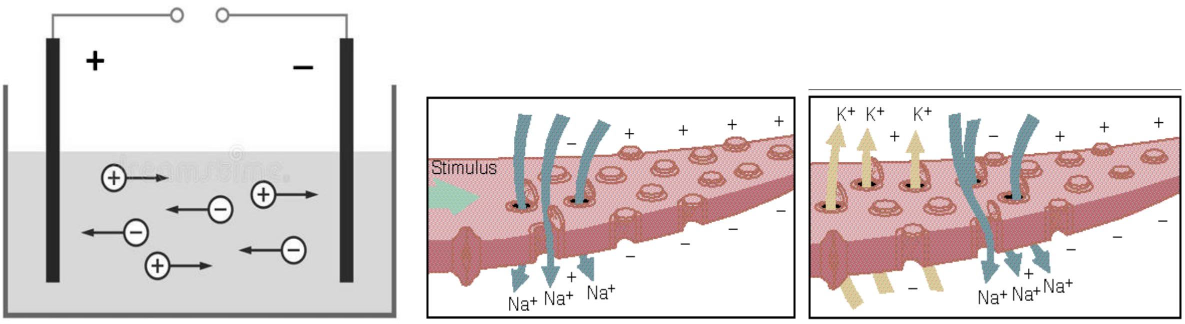


Fig. 1. Ionic conductivity of the electrolyte. The movement of ions in an electric field enables the conduction of current through an electrolyte solution. Nerve impulse propagation: due to the occurrence of a stimulus, ion channels present in the cell membrane of nerve cells open up and sodium (Na+) and potassium (K+) ions flow across the cell membrane.

Electrical conduction in biophysics refers to the ability of biological matter, such as tissues, cells and body fluids, to conduct electricity. This phenomenon is due to the presence of ions such as **sodium (Na^+), potassium (K^+), or calcium (Ca^{2+})** in biological systems. The movement of these ions is essential for basic **physiological functions** such as the transmission of information in the nervous system (nerve impulses), muscle work and heart contractions. The flow of ions through the specified membrane proteins (ion channels) of the nerve cell is shown in Figure 1. Electrolyte imbalances can interfere with proper electrical conduction and cause pathological conditions such as cardiac arrhythmias.

The phenomenon of electrical conductivity of electrolytes is also exploited **in medical diagnostics and therapy**. Examples include electrocardiography (ECG) for assessing heart function, or iontophoresis, an electrotherapeutic method that allows non-invasive transdermal application of drugs in the form of ions by an electric field. Ionic conductivity measurements are also one of the analytical methods used in drug production (tracking the progress of a reaction or the crystallisation of an active substance) and in assessing the **quality (purity) of water**, both in **research and pharmaceutical laboratories** and in **environmental research**.

Electric conductivity

According to Ohm's law, the flowing current is opposed by the resistance of the conductor, which we call electrical resistance R. The electrical resistance depends on the geometrical properties of the conductor (l - length, s - surface area) and its specific resistance ρ:

$$R = \frac{l}{s}\,\rho \;\; [\Omega]$$

Electrical conductance L of a solution is the reciprocal of its resistance. It is the basic quantity describing the movement of ions in electrolyte solutions. The unit of conductance is Simens (1S = $1\Omega^{-1-}$).

$$L = \frac{1}{R} = \frac{s}{l}\frac{1}{\rho} \;\; [\mathrm{S}]$$

The electrical conductivity κ is the reciprocal of the specific resistance. The SI unit of electrical conductivity is Simens per metre [Sm-1]. However, specific conductivity values are often given in $\mu S\ cm^{-1}$ ($10^{-6}S \cdot 10^{2}m^{-1}$).

$$\kappa = \frac{1}{\rho}\;[\mathrm{Sm}^{-1}]$$

The conductance L of a solution between electrodes of a given surface area s distanced from each other by a distance l is therefore:

$$L = \frac{\kappa\, s}{l} = \frac{\kappa}{k} \;\; [\mathrm{S}]$$

where $k = \frac{l}{s}$ [m^{-1}] is the **cell constant** (it is a fixed value for a given instrument).

The electrical conductivity of electrolytes is in the range < 1 S/cm and is much lower than that of metals (< 104-106 S/cm). This is due to the smaller number of carriers (ions) and their lower mobility in the medium compared to electrons, which are the charge carriers in metallic conductors.

The conductivity κ depends on the type of electrolyte, its concentration, temperature. The factors influencing conductivity are briefly discussed below:

- **Concentration:** For low concentrations, an increase in ion concentration leads to higher electrical conductivity and is approximately linear. This is due to an increase in the number of charge carriers per unit of solution. However, for high electrolyte concentrations, as the concentration increases, due to interactions between ions and a decrease in their mobility and degree of dissociation, the conductivity after the initial increase decreases (Fig. 2).

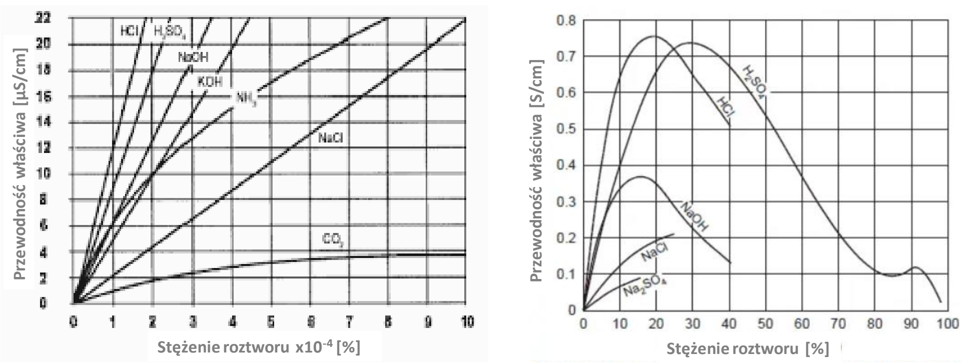


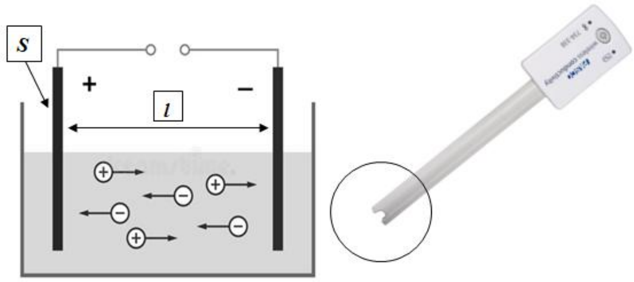
Fig. 2. Concentration dependence of conductivity at low and high concentrations of solutions of selected electrolytes.

- **Temperature:** temperature affects the degree of dissociation, ion mobility and viscosity of the solvent. As the temperature increases, the electrical conductivity of the solution increases.
- **Ion mobility:** The mobility of an ion depends on its size, charge and solvent viscosity. In general, a larger ion size and higher solvent viscosity reduce conductivity.
- **Ion charge:** Ions with higher charge move faster in solution and contribute to higher conductivity.

For small concentrations of strong electrolytes, the conductivity increases almost linear with increasing concentration. In the case of NaCl solution, which is a strong electrolyte, the research data indicates that the conductivity-concentration dependence can be assumed with a good approximation to be linear up to concentrations of 3-5%.

Construction of the conductivity meter

Conductometry is a method that measures the ionic conductivity of a solution between two electrodes. The measurement is made using a **conductivity cell or sensor**. The cell/sensor consists of two metallic surfaces (electrodes) with a given surface area **S**, which are placed at a specific distance from each other **l** (Fig. 3). The device applies a potential difference between the electrodes and measures the electric current that flows in the circuit due to the movement of ions. For a given conductivity cell or sensor, the surface area of the electrodes and the distance between them are fixed (the constant of conductivity cell/sensor).



Rys. 3. Conductivity meter operating scheme.

Direct conductometry

Conductometry enables the determination of **concentrations** on the basis of the relationship between the conductivity and the ion concentration of solutions. The method only works for simple electrolytes where a linear relationship exists between conductivity and concentration. It involves plotting a **calibration curve** (straight line) based on the determined conductivity values for increasing concentrations of the electrolyte. Then, by measuring the conductivity of an electrolyte solution of unknown concentration, it is possible to determine its concentration from the calibration curve. This is a non-selective method, which means that the concentration of a specific electrolyte in a mixture cannot be determined using this method. This method has been applied, among others, in the industrial analysis of solutions. It is often used for process control, including water purification technology. The values of conductivity for water are shown in Fig. 4. Ultrapure water has a very low conductivity; which increases rapidly when acids, bases or salts are dissolved in it.

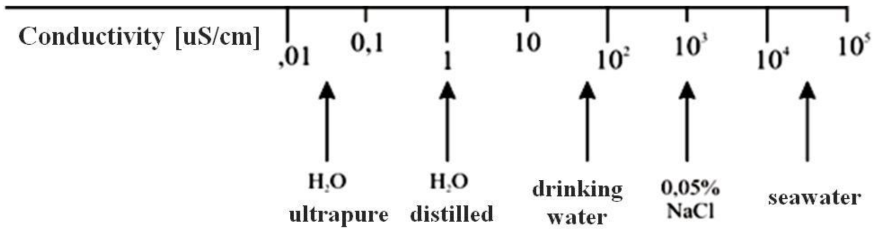


Fig. 4. Electrical conductivity for different aqueous solutions.

EXCERCISE MANUAL

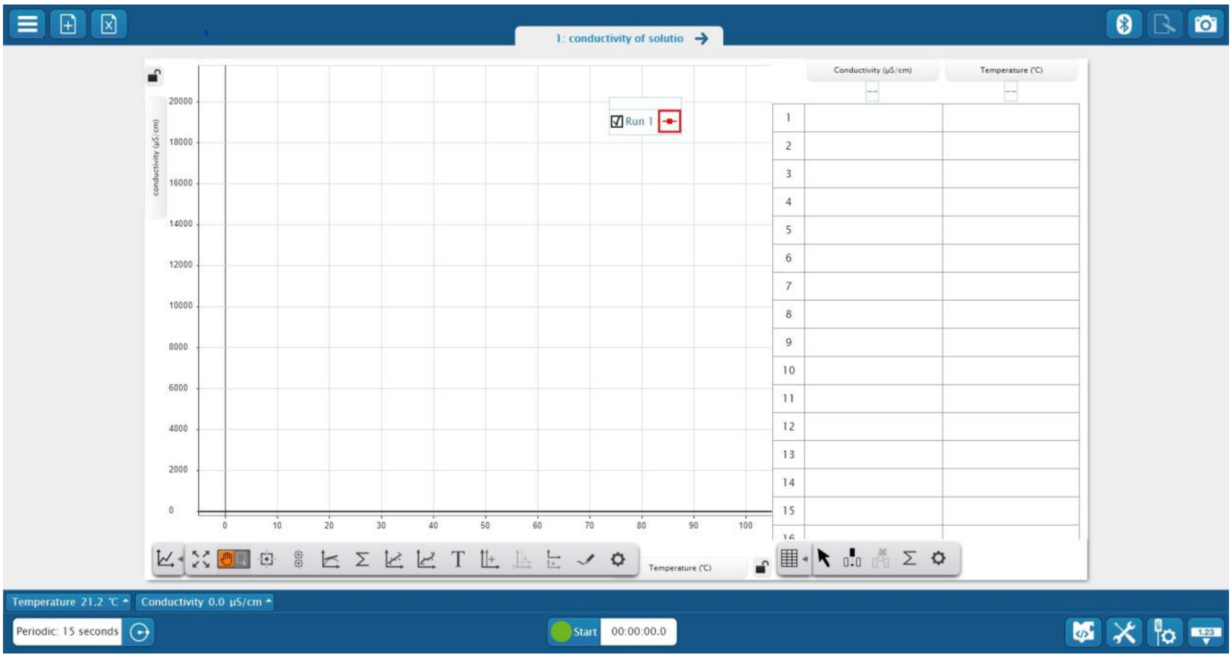
EQUIPMENT NEEDED (Photo 1)	• Beaker
• PASCO universal interface	• Mixer with thermostat and thermocouple
• Conductivity meter	• Stirrer magnet bar
• Thermocouple	• Measuring cylinder
MATERIALS NEEDED	• 1% NaCl, distilled water

In the experiment carried out, a conductivity meter will measure the conductivity of the solution and a thermocouple will measure the temperature of the solution. The PASCO program will simultaneously record the conductivity and temperature values of the electrolyte and plot the dependence of the specific conductivity on the temperature and on the concentrations of the tested solutions.

SETTING UP THE MEASURING SYSTEM

1. Turn on the power of the table (see the dashboard of the table - by your left leg when sitting in front of the computer) - turn the red "knob" in the direction of the arrows (it should pop out), turn the key as in a car and let go.

2. Turn on in the following order: (1) PASCO universal interface, and then (2) computer.
3. The measuring thermocouple should be connected to the PASCO universal interface, to analogue channel B (Photo beside).
4. Switch on the conductivity meter. If it is in operation mode the red LED flashes.
5. To start the program, select profile **B19** on the computer, and next desktop icon **b19**. A window shown in Photo below will open. Use the arrows next to the tab name to navigate between the sections.
6. If the program does not automatically connect to the conductivity meter, press the **Bluetooth button** and in the "*Wireless Devices*" window select **468-999 Conductivity**. In the case of thermocouple, after pressing "**Sensor Properties**" button, select "**Sensors**" and in the tab for "**Analogue channel B**" select "**Temperature**" (Photo below).
7. The sampling period (Periodic) should be set to 15 seconds.



8. Place a 200ml beaker on the magnetic stirrer table, gently place the magnet stirrer bar on the bottom of the beaker,
9. Check tripod arm with the thermocouples. One thermocouple (silver) is connected to the stirrer and allows you to thermostat the solution (maintain a constant set temperature). The other thermocouple (greenish) records the temperature in the solution and transmits the measurement data to a computer
10. The measuring system is ready for the measurements.

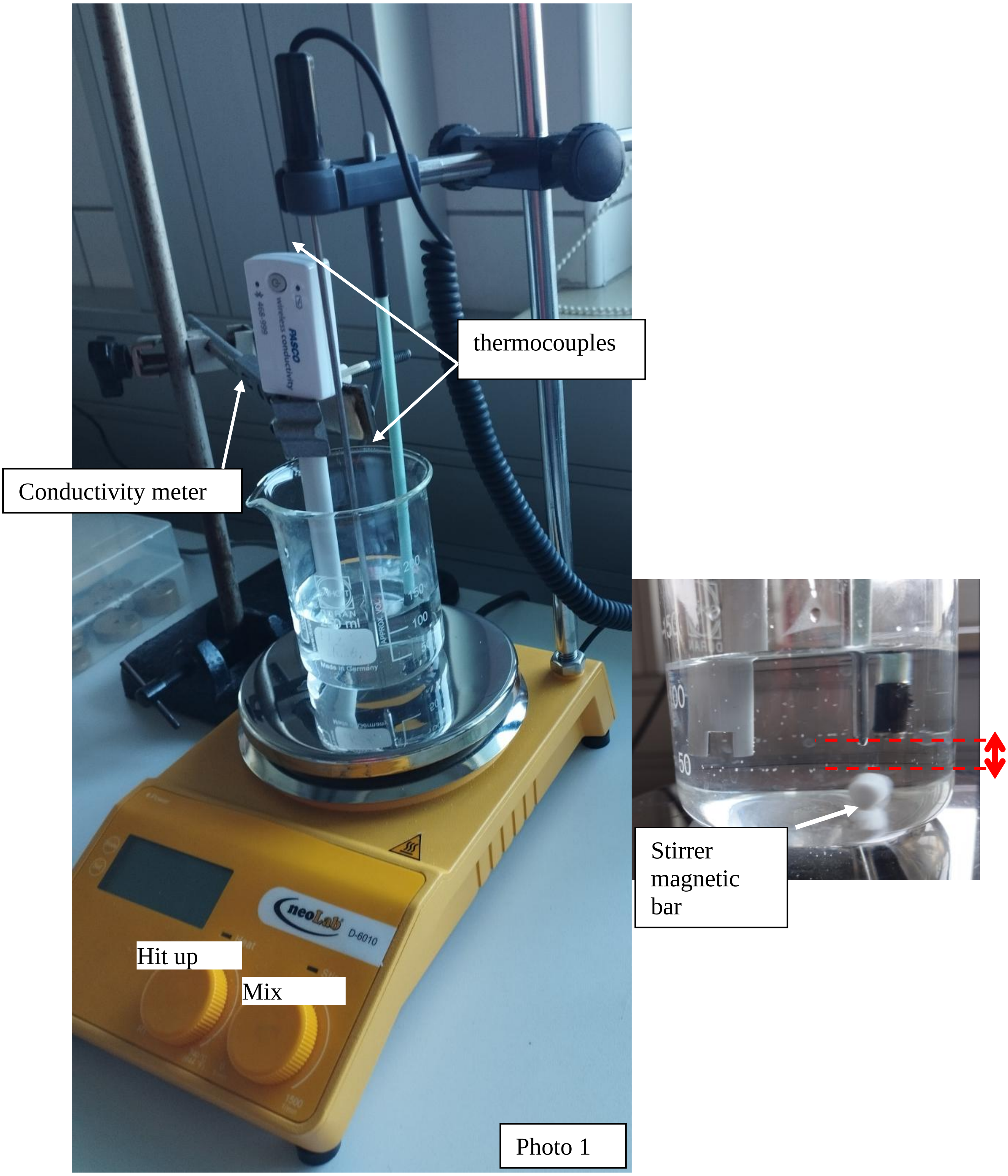


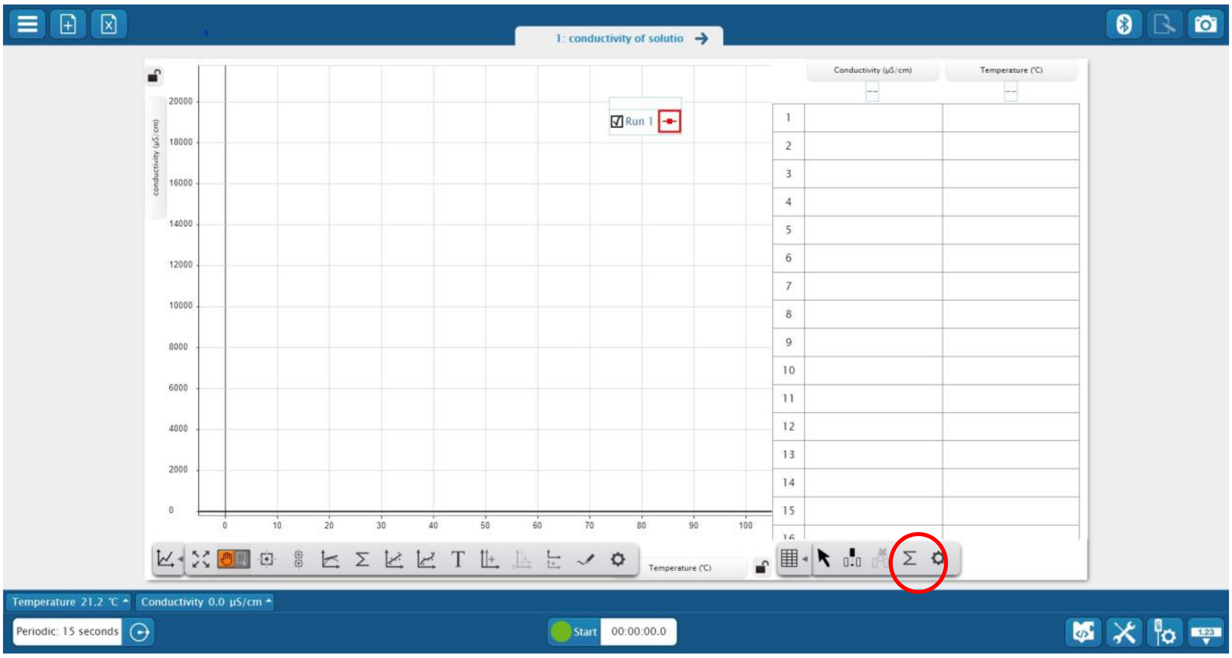
Photo 1

MEASUREMENTS MANUAL

I. RELATIONSHIP BETWEEN CONCENTRATION AND CONDUCTIVITY

1. Set up tab1: *conductivity of solution* in the software:.
2. Pour 70 ml of distilled water into a 200 ml glass beaker. Measure the appropriate volume of water with a measuring cylinder.

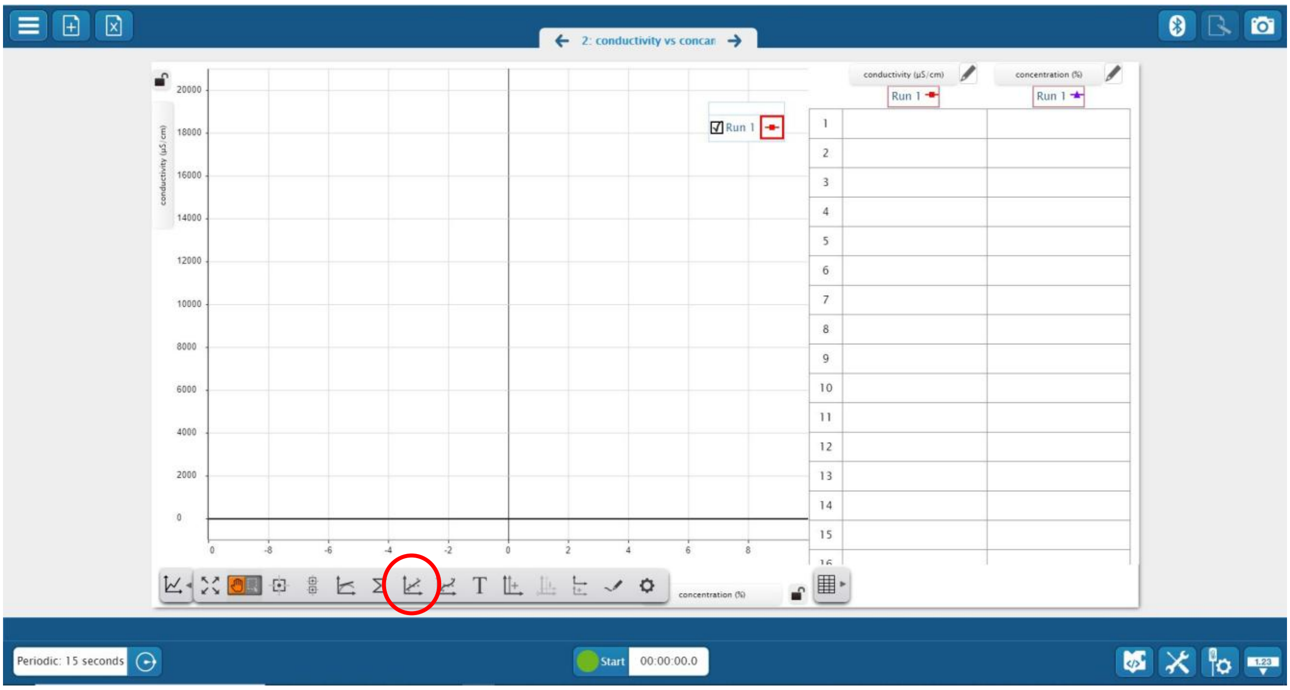
3. Insert the conductivity meter into the holder. Carefully adjust the tripod holder so that the thermocouple tips and electrodes of conductivity meter are fully dipped (about 1 cm in the water). Ensure that the measuring devices do not touch the walls of the beaker and each other, and (IMPORTANT!) that there is space between them and the stirrer (Photo 1).
4. Turn on the stirrer. Set the speed frequency value to **400**. Do not switch on the heating!
5. Press **Start** button. The program will take measurements of **conductivity and temperature** every 15 seconds, the results will be displayed in a graph and in a table on the screen (Photo below). Press **Stop** button after **3** measurements are recorded. Calculate the mean of the measurements including the standard deviation: tick **Σ** under the table and select **Mean** and **Standard Deviation,** respectively. Note the result.



6. Pour the water out of the beaker and add 70 ml of 1%NaCl to the beaker using a cylinder. Repeat **step 5**. Note the results.
7. Pour 70 ml of distilled water into the beaker using the cylinder. Calculate the concentration of the solution and repeat **step 5**. Note the results.
8. Pour another 70 ml of distilled water into the beaker. Calculate the concentration of the solution and proceed as described in **step 5**. Note the results.
9. Switch off the stirrer.
10. Remove the stirrer magnetic bar. Pour the solution from the beaker into the sink, rinse the beaker with tap water 2 times - rinse a third time with about 50 ml of distilled water. Wash the measuring devices: magnetic stirrer rod and tips of thermocouples and conductivity meter with distilled water by immersing them in 100 ml of distilled water for 1 minute (plastic beaker).
11. After washing, you can measure the conductivity of, for example, mineral water you have brought, tap water, or, for example, a sugar solution. (repeat steps **2, 3, 5**). Note the results. Rinse the beaker and measuring equipment each time as described in **step 10**.
12. Switch to tab2: *conductivity vs concentration* and perform Data Analysis.

DATA ANALYSIS – PART I

1. In this part of the exercise, use the calculated mean values of conductivities of distilled water and NaCl solutions. Enter the data into the table in tab 2 as `Run1` (Photo below). Before you enter data, select **New** in the Run window. The corresponding points will automatically appear on the graph.



2. Check whether the conductivity-concentration relationship is linear over the concentration range tested. To do this, fit a line to the experimental data:
   - Select the "**linear fit**" button in the program (Photo above).
   - Read off from the graph the **determined equation** of the line together with the correlation coefficient **r**. r range from -1 to 1. The further away r is from zero, the stronger the linear relationship between the two variables. If r is positive, then as one variable increases, the other also increases. If r is negative, then as one variable increases, the other decreases.
   - If, for the fitted line with the equation **y=mx+b**, a result of the coefficient r >0.95 is obtained, we can state linear (direct proportional) dependence of the conductivity on the concentration.
3. Knowing the equation for the fitted straight line, we can calculate the conductivity of any NaCl solution of a known concentration (provided that its concentration is within the range of the measured earlier concentrations):
   - Find the concentration of saline (scientific tables, internet), check if its concentration is in the range of studied concentrations.
   - Calculate the value of the conductivity of the saline using the determined equation.
   - Compare the result obtained with the "true" value - reported in scientific sources[1]. Calculate the absolute error and relative error of the saline conductivity measurement:

Absolute error (Δx) - difference between the true value (x) of quantity and the measured value (x_i).

$$\Delta x = |\mathbf{x} - \mathbf{x_i}|$$

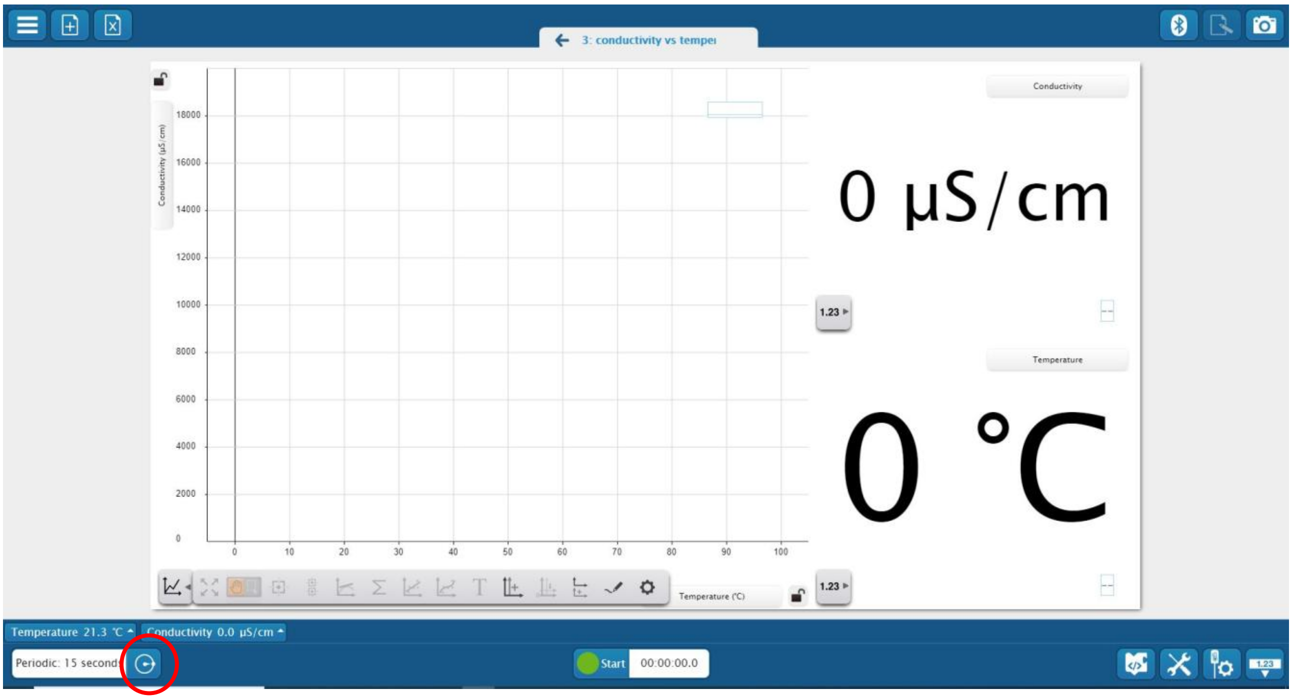
Relative error (Δx rel), expresses the ratio of the magnitude of the absolute error (Δx) to the true value (x). It does not have units. Expressed as a percentage, makes it easier to compare error magnitudes with each other.

$$\Delta x_{rel} = \frac{\Delta x}{x} \cdot 100\%$$

II. RELATIONSHIP BETWEEN TEMPERATURE AND CONDUCTIVITY

1. Go to tab 3: *conductivity vs temperature* (Photo below).

[1] Conductivity of salinel κ=14.5 mS/cm (22°C)



1. Pour 50 ml of 1%NaCl and 50 ml of distilled water into a beaker, carefully insert a stirring rod, insert thermocouples and conductivity meter.
2. In the Periodic window (picture above), change the **Stop Condition** setting from **Time Based** to **None**. This will allow you to manually stop the measurement when the final temperature is reached.
3. Switch on stirrer - set speed to **400**, switch on heating - set the temperature to **35ºC** and at the same time press the **Start** button in the program.
4. The program will automatically record the temperature and conductivity every 15 seconds (measured values are visible on the right side of the screen and on the graph). Continue measuring until the temperature reaches **35ºC**.
5. Finish the measurements by pressing the **Stop** button, **switch off the heating**.
6. Perform Data Analysis.
7. Wash the beaker and measuring equipment as described in **point 10 of part 1 of the exercise**.
8. Perform steps **2-7** for another (chosen by you) concentration of NaCl solution.
9. Switch off stirrer, conductivity meter.
10. Switch off the interface and the computer, press the red button on the table control panel.

DATA ANALYSIS – PART II

1. Evaluate the type of relationship between conductivity and temperature. Proceed as described in DATA ANALYSIS – PART I, point **1**. Carry out an analysis for both measurements. Note the results.

QEUSTIONS FOR DISCUSSION:

1. What is the relationship between the conductivity of a NaCl solution and its concentration? Justify your answer.
2. Was it possible to determine saline conductivity with satisfactory accuracy?
3. How does conductivity depend on temperature? What implications can this phenomenon have in practice? Does the electrolyte concentration have impact on this relationship – what was the difference between the slopes (m) of the fitted lines?