6.5. RESEARCH ON THE CONDUCTIVITY OF VARIOUS WATER SAMPLES

Purpose of experiment

Determine the conductivity of various water samples.

Tasks of experiment:

- Determine the average conductivity of tap water, mineral water, river water and other water samples
- Analyze the results and explain the different conductivity values.

Theoretical topics

- Electric current. Ohm's law.
- Electrical conductivity and the parameters that determine it.
- Energy band structure in crystals.
- Electrical conductivity and its dependence on temperature.

Equipment and materials

Cobra3 Basic-Unit measurement system, electric conductivity measurement probe, various water samples, beaker for water samples, stand with holder, PC with software,

Theoretical part

One of the defining characteristics of a solid is that its atoms are packed extremely close together, and therefore it is not possible for the nuclei to move very far from their equilibrium positions. As a result, only electrons carry current in solids and not ions. Electrons are extremely small, and can easily move among the atoms without creating holes or fractures in the atomic framework therefore wires can carry current for a long period without incurring damage. The best conductors are on the left side of the periodic table, since those are the elements with the weakest hold on their outermost electrons.

Gas molecules are normally widely separated from each other and therefore cannot conduct electricity by passing electrons from atom to atom as solids do. Not surprisingly, gases are therefore good insulators. Lightning is a good example: opposite charges gradually build up in a stormcloud and on the ground below, creating a stronger and stronger voltage difference. However, there is almost no current flow until finally the voltage attains a certain threshold and triggers an impressive example of what is known as a spark or electrical discharge. The lightning phenomenon occurs because, at some point, the electrical forces on the air electrons and nuclei of the air molecules become so strong that electrons are ripped away from some of the molecules. These free electrons then accelerate toward either the cloud or the ground, whichever is positively charged, and the positive ions accelerate the opposite way. As these charge carriers accelerate, they strike and ionize other molecules, producing a chain reaction.
In a liquid, the situation is again different. The molecules in this case can slide past each other, so both ions and electrons can carry currents. Pure water is a poor conductor because the water molecules tend to keep a strong hold on their electrons, and few electrons or ions are available to move. However, with the addition of even a small amount of certain substances called electrolytes, typically salts or bases, water can become quite a good conductor. When table salt, NaCl, for example, is added to water, the NaCl molecules dissolve into Na\(^+\) and Cl\(^-\) ions, which can then move and create currents. This explains why electric currents flow through the cells in our body: cellular as well as extracellular fluids are quite salty. When we sweat, however, not just water but also electrolytes are lost, with the result that dehydration strongly impacts on our cells’ electrical systems. For this reason, electrolytes are included in sports drinks and formulas for rehydrating infants who have diarrhea. Since current flow in liquids involves entire ions, physical signs of its occurrence can frequently be seen. For example, the H\(_2\)SO\(_4\) battery acid in a heavily used car battery gradually loses hydrogen ions that are the main charge carriers completing the circuit inside the battery. The surplus SO\(_4\) is then deposited as a blue crust on the battery posts.

Natural waters contain dissolved substances as well as undissolved solids and particles. These are mostly dissolved salts, i.e. electrolytes. The conductivity of the course of rivers subject to waste water effluents, for example, is therefore regularly monitored. High conductivities can result from in-washes after heavy downpours because of the geography, or may indicate contamination by inorganic salts or, in flowing water, the transport of salts from distant regions.

Many resistors and conductors have a uniform cross section with a uniform flow of electric current, and are made of one material. In this case, the electrical resistivity \(\rho\) is defined as:

\[
\rho = R \frac{A}{l},
\]

where \(R\) – the electrical resistance of a uniform specimen of the material, \(l\) – the length of the piece of material and \(A\) – the cross-sectional area of the specimen.

Conductivity \(\sigma\) is defined as the inverse of resistivity:

\[
\sigma = \frac{1}{\rho}.
\]

Conductivity has SI units of siemens per meter (S/m).

Besides the amount and composition of ionic species, electric conductivity is strongly dependent on temperature. Therefore, electric conductivity of water samples measured at various temperatures need to be ‘corrected’ to values corresponding to a standard temperature for meaningful data interpretation. In geophysical investigation, verification of resistivity images may require laboratory measurements of core samples at a common room temperature, which need to be adjusted to the subsurface temperature at sampling locations, which may have seasonal variability. The electric conductivity-temperature relation of natural waters is generally nonlinear. However, the degree of nonlinearity is relatively small in a temperature range of environmental monitoring (0–30 °C), and a linear equation is commonly used to represent the relation:

\[
\sigma_t = \sigma_{25}(1 + \alpha(t - 25));
\]

where \(\sigma_t\) is electrical conductivity at temperature \(t\), \(\sigma_{25}\) is electrical conductivity at 25 °C, and \(\alpha\) is a temperature compensation factor. Several values of \(\alpha\) are commonly cited in the standard literature: \(\alpha = 0.0191\), \(\alpha = 0.02\), \(\alpha = 0.025\).

As temperature increases, molecules' velocity also increases. Kinetic energy of molecules is in square law proportional to the velocity of the molecules \(E_k = \frac{mv^2}{2}\). So, when temperature...
increases, more molecules will have higher kinetic energy, thus the fraction of molecules that have high enough kinetic energy to exceed the activation energy also increases. Therefore, more molecules will dissolve into ions.

**Methodology**

The conductivity of various water samples are measured using Cobra3 Basic Unit connected with conductivity measurement module and conductivity probe (Fig. 6.5.1). Conductivity probe consists of two platinum plated electrodes and solution conducts electric current between those two electrodes. The Conductivity Probe is actually measuring conductance, defined as the reciprocal of resistance. When resistance is measured in ohms, conductance is measured using the SI unit siemens. Even though the Conductivity Probe is measuring conductance, we are often interested in finding conductivity of a solution. Conductivity is found multiplying conductance by the distance between two electrodes and dividing it by area of electrode surface.

In order to measure exact value of water sample conductivity the standard calibration solution is used which conductivity is 1.423 mS/cm at 25 °C.

**Procedures**

*Various water samples should be brought to the laboratory (tap water from home, mineral water etc.).*

1. Prepare the electrical conductivity measurement setup (Fig. 6.5.1): connect the conductivity measuring module to the Cobra3 BASIC-UNIT measurement system ports 1 and 3 (Fig. 6.5.4); connect the conductivity electrode to the conductivity measuring module and the temperature sensor to the input S2 of the Basic-Unit (5, Fig. 6.5.4).
2. Run the “measure Cobra3” software.

3. Run the new experiment in the software: on the menu bar choose “File” ⇒ “New measurement”. In the newly opened window set the measurement parameters as shown in Fig. 6.5.2: In the “Display” menu, set both Digital display 1 and Diagram 1 to conductivity (range 0 to 3000 mS/cm), In the “Temperature compensation” set “natural water”.
4. Calibrate the conductivity probe using a calibration solution. In the “New measurement” window (Fig. 6.5.2) press the “Calibrate” button and in the newly opened window (Fig. 6.5.3) in the
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5. In the “New measurement” window press the “Continue” button.
6. Fill a half beaker with the distilled (demineralized) water and place it near the stand.
7. Use the universal clamp to adjust the position of the conductivity and temperature probes so that they are completely immersed in the water.
8. Measure several (5-10) conductivity values by repeatedly pressing the “Save value” button.
9. Press the “Close” button.
10. Calculate the average value of the water conductivity: in the software on the menu bar choose “Analysis” – “Show average value”.
11. Repeat the measurement (procedures 3, 5-10) for the other types of water samples (tap water, mineral water, river water…).
12. Compare the results with the standard values (Table 1).

Table 1. Typical electric conductivity of various water samples.

<table>
<thead>
<tr>
<th>Water sample</th>
<th>Conductivity (mS/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distilled, deionized water</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>Rainwater, snow-water</td>
<td>10-100</td>
</tr>
<tr>
<td>Weakly mineralized surface water</td>
<td>50-200</td>
</tr>
<tr>
<td>Heavily mineralized surface or spring water</td>
<td>500-2000</td>
</tr>
<tr>
<td>Mineral water</td>
<td>&gt; 1000</td>
</tr>
<tr>
<td>Guidelines for drinking water</td>
<td>&lt; 2000</td>
</tr>
</tbody>
</table>

References
**Cobra3 BASIC-UNIT measure system**

**Fig. 6.5.4.** Cobra3 BASIC-UNIT measure system front panel.

1. **Module port.** Collecting connector (25 pin SUB-D socket) for measuring modules.
2. **Extension connector for Units.** 48 pin plug in the side wall for docking a further Unit.
3. **Analog input 1.** Earth related analog input (4 mm safety sockets) with measuring ranges of ±10 V and ±30 V.
4. **Sensor port S1.** On connection of sensors, measuring modules or special instruments to this socket, not only the analog input 1, but also the analog output, three supply voltages and three digital control leads are led out.
5. **Sensor port S2.** On connection of sensors, measuring modules or special instruments to this socket, both the analog input 2 (but only earth related), as well as three supply voltages and three digital control leads are led out.
6. **Analog input 2.** Earth free, potential separated difference input (4 mm safety sockets) with 6-step measuring range: ±30 V / ±10 V / ±3 V / ±1 V / ±0.3 V / ±0.1 V
7. **TIMER/COUNTER 1.** Three 4 mm sockets with the functions „START“, „STOP“ and a common earth socket. Controlled by TTL impulses or by contact opening or contact closing. This input can be used as a timer, as a counter and as a TTL input.
8. **TIMER/COUNTER 2.** As input 7 and additionally with the function “counter with gate time”.
9. **USB connection.** Type B Socket, situated in the side wall, for the connection of a USB interface via a data cable.
10. **Extension connector for Units.** 48 pin SUB-D socket, situated in the side wall, for docking a further Unit.
11. **Connecting elements and positioning foot.** The movable holding bar which is situated in the side wall gives a tight hold to an additional Unit docked on the side. The foot can be swung-out to enable the Unit to be held at an inclined position. The yellow colour of the foot indicates the movability of the holding bar.
12. **Voltage supply.** A low voltage socket in the side wall for connection of the Cobra3 power supply 12 V- /> 6 W.
13. **Control lamp.** Green light emitting diode which shows that the instrument is turned on. Further to this, the diode can be used as a signal during experiments, e.g. as a flashing light (see 17).
14. **Fixed voltage output.** Pair of 4 mm safety sockets for drawing off a direct voltage of 5 V / max. 0.2 A, e.g. for a light barrier.

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15. Threaded connector for stand clamp. With a stand clamp fitted to the back, the Basic-Unit can be held on a stand so that it can easily be seen by everybody.
16. Dovetail joint. For fastening several Units, one to another (has no electrical connection).
17. Indicator lamp. This yellow light emitting diode serves for user guidance, and is also usable as an indicator lamp during experiments (see 13).
18. Connecting elements and positioning foot. The immovable holding bar which is situated in the side wall gives a tight hold to an additional Unit docked on the side. The foot can be swung-out to enable the Unit to be held at an inclined position. The gray colour of the foot indicates the immovability of the holding bar.