

3B SCIENTIFIC[®] PHYSICS



**ELECTROCHEMISTRY
1002719**

ALF 06/18

**Practical experiments
for secondary levels I and II**

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Preface

The electrochemistry case is a teaching aid exclusively designed for chemistry and physics experiments in schools.

The fact that students can perform experiments themselves deepens their understanding of the subjects being treated. The experiments should be performed in small groups of not more than two or three students. Thus the teacher is only required to supervise and may also give suitable advice on specific questions that students are unable to answer themselves. Careful organization of workgroups can therefore add to the achievement, understanding and enjoyment of all students.

The accompanying literature reduces to a minimum the teacher's preparation time, which may for school experiments in particular be quite lengthy. With each experiment there are instructions for both teacher and students. The teacher's instructions include descriptions of all the facts required for the conduct of the experiment. The expected results for each experiment can be found in the teacher's instructions. (These may differ slightly from the theoretical results given in text books.) The teacher is also given instructions on how to prepare suitable electrolyte solutions.

The student instructions can be copied by the teacher and distributed to the students. This means that there is no need to go to the extra lengths of writing down an experiment procedure, freeing the student to concentrate on the essentials of the experiments themselves.

To ensure safety, German R (Risk) and S (Safety) phrases and hazard symbols are included for all chemicals used.

At the end of the instructions, notes can be found on the disposal of chemicals. In order to prevent wastage on chemicals, we recommend that once an experiment is finished, the electrolyte solutions that have been used should be removed from the chambers of the trough using the supplied pipette and stored in a labelled container for use in subsequent experiments. This also makes a contribution to the environment.

We would be grateful for comments and modifications (or notification of any errors) pertaining to the experiments. Please contact your supplier for the Electrochemistry case.

We wish you success in carrying out the experiments.

Contents of the Electrochemistry case



- 1 Meter for electrochemical and pH experiments, powered by battery or mains power supply.
- 1 3V adapter for electrolyzing platinum gauze electrode
- 1 Mains power supply prim: **115..240VAC** , **50-60Hz** sec: **12V-500mA**
- 1 Combined probe for measuring pH, electrode in storage vessel
- 2 Plastic beakers 25 ml
- 2 Pipettes
- 1 Storage box with:
 - 2 silver electrodes, 4 zinc electrodes, 2 iron electrodes, 2 carbon electrodes,
 - 2 aluminum electrodes, 2 nickel electrodes, 4 copper electrodes, 1 magnesium electrode (magnesium strip to wrap around a plastic plate), 1 platinum gauze electrode
 - 2 half cells for 4 electrodes each, 1 set of filter paper strips,
 - 1 set of cables for electrochemistry (consisting of: 3 cables with crocodile clips, red, each 20 cm long,
 - 1 cable with crocodile clip and plug, red, 30 cm long, 3 cables with crocodile clips, blue, each 20 cm long, 1 cable with crocodile clip and plug, blue, 30 cm long),
 - 1 emery stone
- 1 set of instructions for experiments

Assembly and cleaning of the battery block



The battery block is supplied fully assembled and can be used for experiments immediately. It is stored in the storage box inside the case.

If the battery block is used, it must be disassembled after the experiment is finished by undoing the knurled screws to completely separate the two half cells so that the electrolyte can be sucked out and the electrolytes removed. After removing the filter paper, the two half cells should be rinsed out with water and then thoroughly dried.

Reassemble the battery block for use in subsequent experiments. This involves placing one of the supplied filter paper strips flush between the two half cells. When this is done, first one and then the second knurled screw should be poked through the filter paper and the two half cells should then be screwed firmly together. (Note: The four openings on the inside must all face the filter paper (as in the illustration).

The 8 chambers are electrically connected via the filter paper, which becomes wet when the chambers are filled with electrolyte.

Please take care:

After the set is used, all the components employed must be thoroughly cleaned and dried.

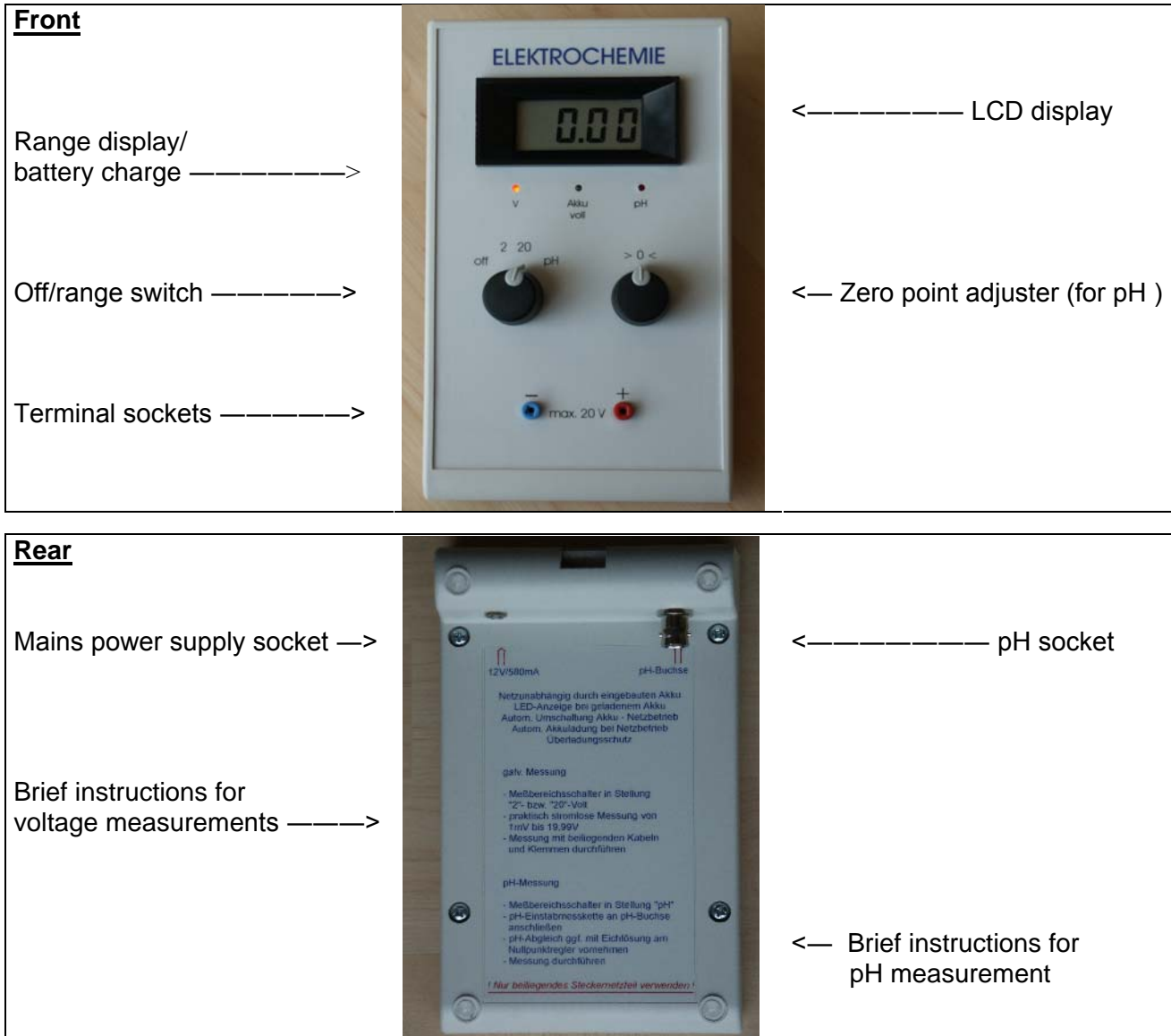
Remove the filter paper between the battery blocks and dry both the knurled screws.

The electrodes used should be cleaned under running water and dried in order to avoid corrosion.

It is recommended that the electrodes be rubbed with the emery stone after use in order to thoroughly remove any chemical residues that may have been deposited.

If you follow these instructions, you should get plenty of enjoyment from your case.

Meter



The meter is battery powered but can also be used with the power supply unit provided. The battery is recharged completely when the device is used with the power supply and overcharging is impossible. The power supply is plugged in to the bottom of the instrument.

In addition to voltage measurement, pH can also be measured with the meter.

1. Voltage measurement

To perform voltage measurement, the meter is turned on via the range switch and is then initially configured for the range 0 - 2V. If higher voltages are to be measured, the instrument can be reconfigured for 20 V by using the range switch again. Electrodes are connected to the meter via 2 mm sockets (red/blue) in order to take measurements.

2. pH measurement

If pH is to be measured, the supplied combined pH electrode is connected to the pH socket at the bottom. Set the range switch to "pH". To calibrate the combined pH electrode, a buffer solution is employed (either pH 4 or pH 9). This is a single-point calibration. After the pH electrode is immersed in the relevant buffer solution, the zero point adjuster is altered until the displayed pH value matches that of the buffer solution. It is now possible to conduct pH measurements. However, no further changes should be made to the adjustment knobs.

Measuring the voltage of galvanic cells - teacher's instructions

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	Electrodes: 1 Cu, 1 Zn, 1 Ag, 1 Fe, 1 Ni
Silver nitrate		34-50/53	26-45-60-61	2 Experiment cables
Iron (II)-sulfate-(7 H ₂ O)		22-36/38	24/25	2 Pipettes
Nickel sulfate-(6H ₂ O)		22-40-42/43-50/53	22-36/37-60-61	
Distilled water		---	---	

Warning: Please take care: **Salts of heavy metals are poisonous!**

Experiment procedure:

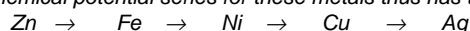
- The prepared 1.0 and 0.1 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Fill the chambers with electrolyte using the pipette (included in the case) and insert the appropriate electrodes. Clean the pipette thoroughly before using it add the next electrolyte.
- After the chambers (at least 2, at most 8) have been prepared for the experiment as described, start measuring voltages. In this experiment, each of 5 chambers is filled with a separate electrolyte and the corresponding electrode is inserted to make up a galvanic cell:
Cu / CuSO₄ , Zn / ZnSO₄ , Ag / AgNO₃ , Fe / FeSO₄ , Ni / NiSO₄
- To measure voltage, two experiment cables (red/blue with 2mm plugs - included in case) should be connected to the voltmeter. The connection between the two electrodes and the meter is made by means of crocodile clips.
- The voltage produced by the galvanic cell can be read off the meter. If a negative voltage is displayed, reverse the polarity of the two electrodes.

Observation and evaluation:

In galvanic cells, the less electropositive metal always forms the negative pole.

Electrons always flow from negative to positive poles, i.e. for a zinc/copper combination, they flow from the zinc to the copper and in a copper/silver combination, they flow from copper to silver.

The combinations involving zinc always have zinc as the negative pole and those involving silver always have silver as the positive pole of the galvanic element. An electrochemical potential series for these metals thus has the following order:



Which of the electrodes forms the negative pole can be determined by reversing the polarity.

Galvanic cell	Voltage (V) Electrolyte 1.0 mol/l	Voltage (V) Electrolyte 0.1 mol/l
Cu / Zn	1.086 approx.	1.086 approx.
Cu / Ag	0.383 approx.	0.383 approx.
Cu / Fe	0.670 approx.	0.670 approx.
Cu / Ni	0.044 approx.	0.044 approx.
Zn / Ag	1.416 approx.	1.416 approx.
Zn / Fe	0.378 approx.	0.378 approx.
Zn / Ni	1.095 approx.	1.095 approx.
Fe / Ag	1.089 approx.	1.089 approx.
Fe / Ni	0.700 approx.	0.700 approx.
Ag / Ni	0.290 approx.	0.290 approx.

Calculation of masses required to prepare a 0.1 molar solution:

The electrolyte solutions should be made up by the teacher in sufficient quantities (usually 1 liter suffices) in advance of the lesson.

- 1 liter of 1.0 molar CuSO₄ solution: Add water to 249.50 g CuSO₄ (5 H₂O) up to 1 liter in a measuring flask.
- 1 liter of 1.0 molar ZnSO₄ solution: Add water to 287.40 g ZnSO₄ (7 H₂O) up to 1 liter in a measuring flask.
- 1 liter of 1.0 molar AgNO₃ solution: Add water to 169.88 g AgNO₃ up to 1 liter in a measuring flask.
- 1 liter of 1.0 molar FeSO₄ solution: Add water to 277.90 g FeSO₄ (7 H₂O) up to 1 liter in a measuring flask.
- 1 liter of 1.0 molar NiSO₄ solution: Add water to 262.70 g NiSO₄ (6 H₂O) up to 1 liter in a measuring flask.

To make up a 0.1 molar solution, simply use 1/10 of the quantities given above (for making a 1.0 molar solution) and add water up to 1 liter in a measuring flask.

Measuring the voltage of galvanic cells

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	Electrodes:
Silver nitrate		34-50/53	26-45-60-61	1 Cu, 1 Zn, 1 Ag, 1 Fe, 1 Ni 2 Experiment cables
Iron (II)-sulfate-(7 H ₂ O)		22-36/38	24/25	2 Pipettes
Nickel sulfate-(6H ₂ O)		22-40-42/43-50/53	22-36/37-60-61	
Distilled water		---	---	

Warning: Please take care: **Salts of heavy metals are poisonous!**

Experiment procedure:

- The prepared 1.0 and 0.1 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Fill the chambers with electrolyte using the pipette (included in the case) and insert the appropriate electrodes. Clean the pipette thoroughly before using it add the next electrolyte.
- After the chambers (at least 2, at most 8) have been prepared for the experiment as described, start measuring voltages.

In this experiment, each of 5 chambers is filled with a separate electrolyte and the relevant electrodes are added to form a galvanic cell

Cu / CuSO₄ , Zn / ZnSO₄ , Ag / AgNO₃ , Fe / FeSO₄ , Ni / NiSO₄

- To measure voltage, two experiment cables (red/blue with 2mm plugs - included in case) should be connected to the voltmeter. The connection between the two electrodes and the meter is made by means of crocodile clips.
- The voltage produced by the galvanic cell can be read off the meter. If a negative voltage is displayed, reverse the polarity of the two electrodes.

Observation and evaluation:

Enter the results of the experiment in the following table and evaluate them.

Galvanic cell	Voltage (V)	
	Electrolyte 1.0 mol/l	Electrolyte 0.1 mol/l
Cu / Zn		
Cu / Ag		
Cu / Fe		
Cu / Ni		
Zn / Ag		
Zn / Fe		
Zn / Ni		
Fe / Ag		
Fe / Ni		
Ag / Ni		

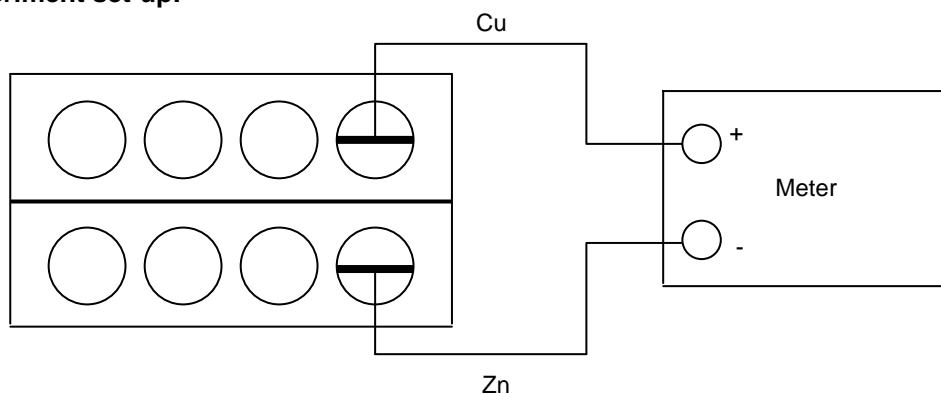
Measuring the voltage of a Daniell cell

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	Electrodes: 1 Cu, 1 Zn
Distilled water		---	---	2 Experiment cables 2 Pipettes

Warning: Please take care: Salts of heavy metals are poisonous!

Experiment procedure:

- The prepared 0.1 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Fill one chamber each with electrolyte using the pipette (included in the case). Clean the pipette thoroughly before using it add the next electrolyte.
- Insert the appropriate electrodes into the electrolyte solutions, CuSO₄ / Cu and ZnSO₄ / Zn.
- After the chambers have been prepared for the experiment as described, connect the experiment cables to the meter and start measuring voltages. If a negative voltage is displayed, reverse the polarity of the two electrode connections.
- The experiment can also be repeated using 1.0 molar copper sulfate and zinc sulfate solutions.

Observation and evaluation:**Sketch of experiment set-up:**

The electrolyte solutions should be made up by the teacher in sufficient quantities (usually 1 liter suffices) in advance of the lesson.

Calculation of masses required to prepare a 0.1 molar solution:

- 1 liter of 0.1 molar CuSO₄ solution: Add water to 24.95 g CuSO₄ (5 H₂O) up to 1 liter in a measuring flask.
- 1 liter of 0.1 molar ZnSO₄ solution: Add water to 28.74 g ZnSO₄ (7 H₂O) up to 1 liter in a measuring flask.

Calculation of masses required to prepare a 1.0 molar solution:

- 1 liter of 1.0 molar CuSO₄ solution: Add water to 249.50 g CuSO₄ (5 H₂O) up to 1 liter in a measuring flask.
- 1 liter of 1.0 molar ZnSO₄ solution: Add water to 287.40 g ZnSO₄ (7 H₂O) up to 1 liter in a measuring flask.

When the meter is connected to the Daniell cell with Cu / CuSO₄ or Zn / ZnSO₄ the measured voltage should theoretically be 1.08 V for an electrolyte concentration of 0.1 mol/l. The result of the actual measurement is usually slightly less than the theoretical value at 1.06 V.

If a 1.0 molar solution is used in the Daniell cell, the measured voltage should still be 1.06 V.

Measuring the voltage of a Daniell cell

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	Electrodes: 1 Cu, 1 Zn
Distilled water		---	---	2 Experiment cables 2 Pipettes

Warning: *Please take care:* Salts of heavy metals are poisonous!

Experiment procedure:

- The prepared 0.1 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Fill one chamber each with electrolyte using the pipette (included in the case). Clean the pipette thoroughly before using it add the next electrolyte.
- Insert the appropriate electrodes into the electrolyte solutions, CuSO₄ / Cu and ZnSO₄ / Zn.
- After the chambers have been prepared for the experiment as described, connect the experiment cables to the meter and start measuring voltages. If a negative voltage is displayed, reverse the polarity of the two electrode connections.
- The experiment can also be repeated using 1.0 molar copper sulfate and zinc sulfate solutions.

Observation and evaluation:**Sketch of experiment set-up:****Results of voltage measurement:**

- Daniell cell with 1.0 molar solutions** CuSO₄ / Cu and ZnSO₄ / Zn:

V

- Daniell cell with 0.1 molar solutions** CuSO₄ / Cu and ZnSO₄ / Zn:

V

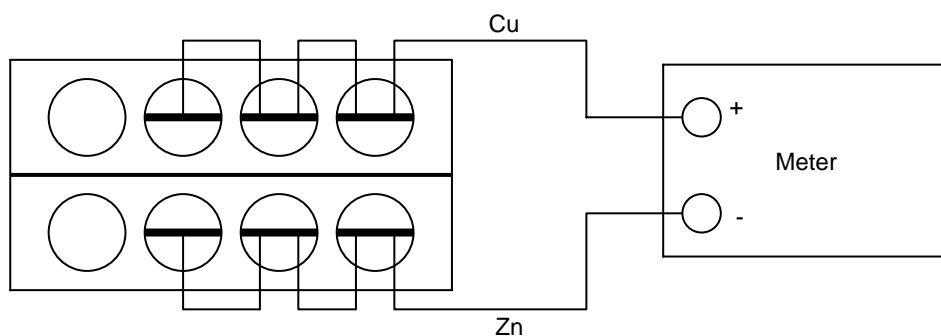
Measuring the voltage of three Daniell cells connected in parallel

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	Electrodes: 3 Cu, 3 Zn
Distilled water		---	---	6 Experiment cables 2 Pipettes

Warning: Please take care: Salts of heavy metals are poisonous!

Experiment procedure:

- The prepared 0.1 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Fill three chambers on one side of the battery block with 0.1 molar CuSO₄ solution then insert the copper electrodes.
- Now fill three chambers on the other side of the battery block with 0.1 molar ZnSO₄ solution then insert the zinc electrodes.
- Connect the copper electrodes together using experiment cables with crocodile clips and then connect the last one to the meter.
- As described in step 5, connect the zinc electrodes together then connect them to the meter.
- Read off the voltage from the meter.
(If a negative value is displayed on the meter, reverse the polarities of the cables to the meter.)

Observation and evaluation:**Sketch of experiment set-up:**

In the parallel circuit, the measured voltage with three electrodes connected together should be $V = 1.06$ V approx. It can be seen that connecting the electrodes in parallel does not lead to any increase in the voltage. What does increase in this case is the current as can be measured using a multimeter.

The electrolyte solutions should be made up by the teacher in sufficient quantities (usually 1 liter suffices) in advance of the lesson.

Calculation of masses required to prepare a 0.1 molar solution:

- 1 liter of 0.1 molar CuSO₄ solution: Add water to 24.95 g CuSO₄ (5 H₂O) up to 1 liter in a measuring flask.
- 1 liter of 0.1 molar ZnSO₄ solution: Add water to 28.74 g ZnSO₄ (7 H₂O) up to 1 liter in a measuring flask.

Measuring the voltage of three Daniell cells connected in parallel

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	Electrodes: 3 Cu, 3 Zn
Distilled water		---	---	6 Experiment cables 2 Pipettes

Warning: *Please take care:* Salts of heavy metals are poisonous!

Experiment procedure:

1. The prepared 0.1 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
2. Assemble the battery block as described.
3. Fill three chambers on one side of the battery block with 0.1 molar CuSO₄ solution then insert the copper electrodes.
4. Now fill three chambers on the other side of the battery block with 0.1 molar ZnSO₄ solution then insert the zinc electrodes.
5. Connect the copper electrodes together using experiment cables with crocodile clips and then connect the last one to the meter.
6. As described in step 5, connect the zinc electrodes together then connect them to the meter.
7. Read off the voltage from the meter.
(If a negative value is displayed on the meter, reverse the polarities of the cables to the meter.)

Observation and evaluation:**Sketch of experiment set-up:****Results of voltage measurement:**

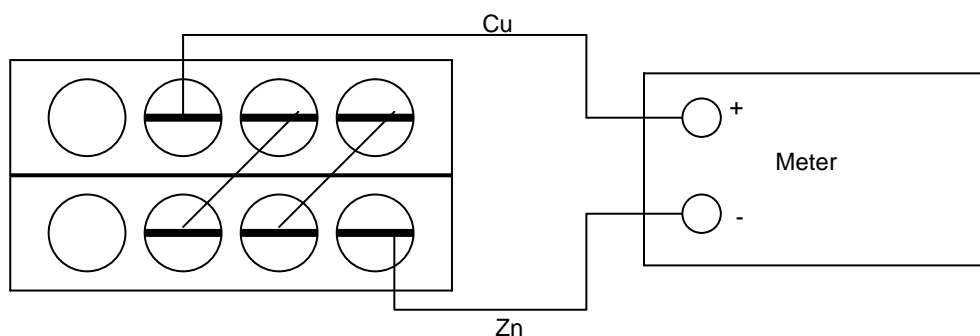
Measuring the voltage of three Daniell cells connected in series

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	Electrodes: 3 Cu, 3 Zn
Distilled water		---	---	4 Experiment cables
				2 Pipettes

Warning: Please take care: Salts of heavy metals are poisonous!

Experiment procedure:

- The prepared 0.1 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Fill three chambers on one side of the battery block with 0.1 molar CuSO₄ solution then insert the copper electrodes.
- Now fill three chambers on the other side of the battery block with 0.1 molar ZnSO₄ solution then insert the zinc electrodes.
- Connect two copper electrodes to two zinc electrodes using experiment cables with crocodile clips and then connect the last copper and the last zinc electrode to the meter.
- Read off the voltage from the meter.
(If a negative value is displayed on the meter, reverse the polarities of the cables to the meter.)

Observation and evaluation:**Sketch of experiment set-up:**

In the series circuit, the measured voltage with three electrodes connected together should be $V = 3.18$ V approx. It can be seen that connecting the electrodes in series leads to an increase in voltage proportional to the number of cells connected. The current that flows in this case is no higher than for the basic arrangement.

If a higher voltage is required, this can only be achieved by connecting cells in series.

The electrolyte solutions should be made up by the teacher in sufficient quantities (usually 1 liter suffices) in advance of the lesson.

Calculation of masses required to prepare a 0.1 molar solution:

- 1 liter of 0.1 molar CuSO₄ solution: Add water to 24.95 g CuSO₄ (5 H₂O) up to 1 liter in a measuring flask.
- 1 liter of 0.1 molar ZnSO₄ solution: Add water to 28.74 g ZnSO₄ (7 H₂O) up to 1 liter in a measuring flask.

Measuring the voltage of three Daniell cells connected in series

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	Electrodes: 3 Cu, 3 Zn
Distilled water		---	---	4 Experiment cables 2 Pipettes

Warning: *Please take care:* Salts of heavy metals are poisonous!

Experiment procedure:

1. The prepared 0.1 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
2. Assemble the battery block as described.
3. Fill three chambers on one side of the battery block with 0.1 molar CuSO₄ solution then insert the copper electrodes.
4. Now fill three chambers on the other side of the battery block with 0.1 molar ZnSO₄ solution then insert the zinc electrodes.
5. Connect two copper electrodes to two zinc electrodes using experiment cables with crocodile clips and then connect the last copper and the last zinc electrode to the meter.
6. Read off the voltage from the meter.
(If a negative value is displayed on the meter, reverse the polarities of the cables to the meter.)

Observation and evaluation:**Sketch of experiment set-up:****Results of voltage measurement:**

Measuring the standard potential of various metals

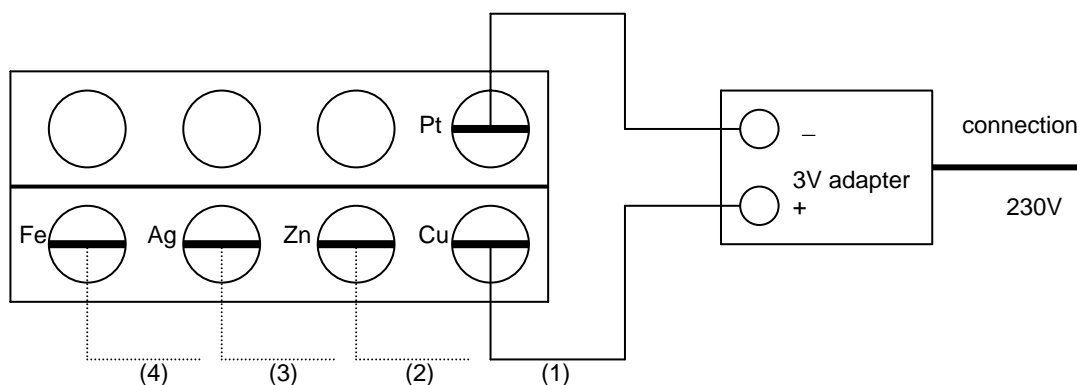
Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter Electrodes: 1 Cu, 1 Zn, 1 Ag, 1 Fe, 1 platinum gauze
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	2 Experiment cables
Silver nitrate		34-50/53	26-45-60-61	1 Mains power supply
Iron (II)-sulfate-(7 H ₂ O)		22-36/38	24/25	2 Pipettes
Hydrochloric acid 1 mol/l		36/37/38	26	1 3V adapter
Distilled water		---	---	

Warning: Please take care: Salts of heavy metals are poisonous! Hydrochloric acid is corrosive!

Experiment procedure:

- The prepared 1.0 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Add the 1 molar hydrochloric acid to one chamber of the battery block using the pipette and insert the platinum gauze electrode into this cell.
- Add a 1 molar CuSO₄ solution to a second chamber (opposite the platinum gauze electrode) and insert a copper electrode.
- To form a normalized hydrogen electrode, a 3V adapter is connected to the power supply. Connect the negative pole of the 3V adapter to the platinum gauze electrode and the positive pole to the copper electrode using experiment cables. Connect the power supply to the 230 V mains and electrolyze the platinum gauze for about 30 seconds. Hydrogen forms at the platinum gauze and completely surrounds the gauze.
- The 3V adapter is then replaced by the meter and the voltage can then be read off.
- Proceed as in steps 4 to 6 with each of the other metals using the corresponding electrolyte for each metal (AgNO₃ / Ag, ZnSO₄ / Zn and FeSO₄ / Fe).

Observation and evaluation:



For each redox pair, the standard electrochemical potentials as measured should be:

(1) $\text{Cu} / \text{Cu}^{2+} = +0.34 \text{ V}$, (2) $\text{Zn} / \text{Zn}^{2+} = -0.76 \text{ V}$, (3) $\text{Ag} / \text{Ag}^+ = +0.80 \text{ V}$, (4) $\text{Fe} / \text{Fe}^{2+} = -0.44 \text{ V}$

Calculation of masses required to prepare 1 liter of a 1 molar solution:

- For a CuSO₄ solution 249.50 g of CuSO₄ · 5 H₂O is needed.
- For a ZnSO₄ solution 287.40 g of ZnSO₄ · 7 H₂O is needed.
- For a AgNO₃ solution 169.88 g of AgNO₃ is needed.
- For an FeSO₄ solution 277.91 g of FeSO₄ · 7 H₂O is needed.

Measuring the standard potential of various metals

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Copper (II)-sulfate-(5 H ₂ O)		22-36/38-50/53	22-60-61	Meter Electrodes: 1 Cu, 1 Zn, 1 Ag, 1 Fe, 1 platinum gauze
Zinc sulfate-(7H ₂ O)		36/38-50/53	22-25-60-61	2 Experiment cables
Silver nitrate		34-50/53	26-45-60-61	1 Mains power supply
Iron (II)-sulfate-(7 H ₂ O)		22-36/38	24/25	2 Pipettes
Hydrochloric acid 1 mol/l		36/37/38	26	1 3V adapter
Distilled water		---	---	

Warning: Please take care: Salts of heavy metals are poisonous! Hydrochloric acid is corrosive!


Experiment procedure:

- The prepared 1.0 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Add the 1 molar hydrochloric acid to one chamber of the battery block using the pipette and insert the platinum gauze electrode into this cell.
- Add a 1 molar CuSO₄ solution to a second chamber (opposite the platinum gauze electrode) and insert a copper electrode.
- To form a normalized hydrogen electrode, a 3V adapter is connected to the power supply. Connect the negative pole of the 3V adapter to the platinum gauze electrode and the positive pole to the copper electrode using experiment cables. Connect the power supply to the 230 V mains and electrolyze the platinum gauze for about 30 seconds. Hydrogen forms at the platinum gauze and completely surrounds the gauze.
- The 3V adapter is then replaced by the meter and the voltage can then be read off.
- Proceed as in steps 4 to 6 with each of the other metals using the corresponding electrolyte for each metal (AgNO₃ / Ag, ZnSO₄ / Zn and FeSO₄ / Fe).

Observation and evaluation:**Sketch of experiment set-up:****Result of voltage measurement:**

Cu / Cu²⁺ _____ V
 Zn / Zn²⁺ _____ V
 Ag / Ag⁺ _____ V
 Fe / Fe²⁺ _____ V

Measuring the standard electrochemical potentials of various non-metals

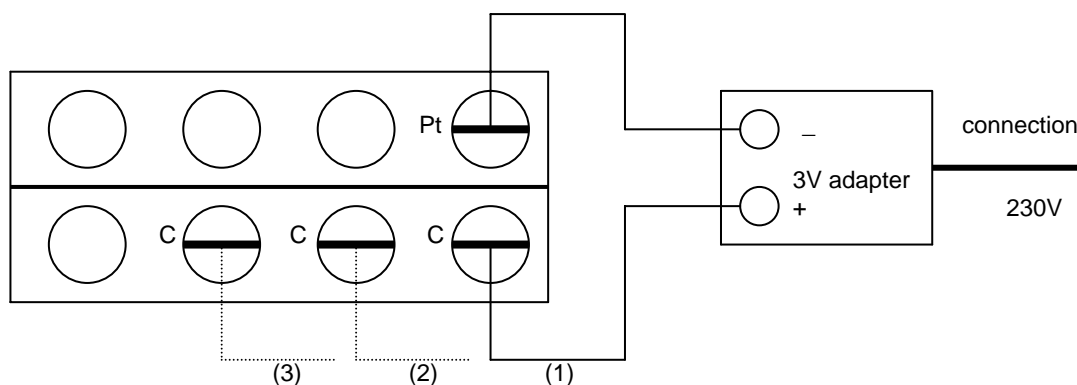
Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Sodium chloride		---	---	Meter Electrodes: 2 C, 1 Pt gauze
Potassium bromide		---	---	2 Experiment cables
Sodium iodide		---	---	1 Mains power supply
Hydrochloric acid 1 mol/l		36/37/38	26	2 Pipettes
Distilled water		---	---	1 3V adapter

Warning: Please take care: Hydrochloric acid is corrosive!

Experiment procedure:

- The prepared 1.0 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Add the 1 molar hydrochloric acid to one chamber of the battery block using the pipette and insert the platinum gauze electrode into this cell.
- Add a 1 molar NaCl solution to a second chamber (opposite the platinum gauze electrode) and insert a carbon electrode.
- To form a normalized hydrogen electrode, a 3V adapter is connected to the power supply. Connect the negative pole of the 3V adapter to the platinum gauze electrode and the positive pole to the carbon electrode using experiment cables. Connect the power supply to the 230 V mains and electrolyze the platinum gauze for about 30 seconds. Hydrogen forms at the platinum gauze and completely surrounds the gauze.
- The 3V adapter is then replaced by the meter and the $\text{Cl}^- / \text{Cl}_2$ voltage can then be read off.
- Proceed as in steps 4 to 6 with each of the other non metals dipping the carbon electrode into potassium bromide and potassium iodide solutions one after the other to determine the electrochemical potentials of $\text{Br}^- / \text{Br}_2$ and I^- / I_2 .

Observation and evaluation:




For each redox pair, the standard electrochemical potentials as measured should be:

- (1) $\text{Cl}^- / \text{Cl}_2 = + 1.35 \text{ V}$, (2) $\text{Br}^- / \text{Br}_2 = + 1.06 \text{ V}$, (3) $\text{I}^- / \text{I}_2 = + 0.54 \text{ V}$

Calculation of masses required to prepare 1 liter of a 1 molar solution:

- For an NaCl solution 58.44 g of NaCl is needed.
- For a KBr solution 119.01 g of KBr is needed.
- For a KI solution 166.00 g of KI is needed.

Measuring the standard electrochemical potentials of various non-metals

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Sodium chloride		---	---	Meter
Potassium bromide		---	---	Electrodes: 2 C, 1 Pt gauze
Sodium iodide		---	---	2 Experiment cables
Hydrochloric acid 1 mol/l		36/37/38	26	1 Mains power supply
Distilled water		---	---	2 Pipettes
				1 3V adapter

Warning: *Please take care:* Hydrochloric acid is corrosive!



Experiment procedure:

- The prepared 1.0 molar electrolyte solutions should be given to the students. Students require no more than 10 ml of the relevant solution each.
- Assemble the battery block as described.
- Add the 1 molar hydrochloric acid to one chamber of the battery block using the pipette and insert the platinum gauze electrode into this cell.
- Add a 1 molar NaCl solution to a second chamber (opposite the platinum gauze electrode) and insert a carbon electrode.
- To form a normalized hydrogen electrode, a 3V adapter is connected to the power supply. Connect the negative pole of the 3V adapter to the platinum gauze electrode and the positive pole to the carbon electrode using experiment cables. Connect the power supply to the 230 V mains and electrolyze the platinum gauze for about 30 seconds. Hydrogen forms at the platinum gauze and completely surrounds the gauze.
- The 3V adapter is then replaced by the meter and the $\text{Cl}^- / \text{Cl}_2$ voltage can then be read off.
- Proceed as in steps 4 to 6 with each of the other non metals dipping the carbon electrode into potassium bromide and potassium iodide one after the other to determine the electrochemical potentials of $\text{Br}^- / \text{Br}_2$ and I^- / I_2 .

Observation and evaluation:**Sketch of experiment set-up:****Result of voltage measurement:**

$\text{Cl}^- / \text{Cl}_2$ _____ V
 $\text{Br}^- / \text{Br}_2$ _____ V
 I^- / I_2 _____ V

Measuring the voltage of a zinc-carbon (Leclanché) cell

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Graphite powder		---	---	Meter Electrodes: 1 C, 1 Zn
Manganese (IV) oxide		20/22	25	2 Experiment cables
Ammonium chloride		22-36	22	1 Plastic beaker
Distilled water		---	---	2 Pipettes

Warning: Be careful when handling chemicals!

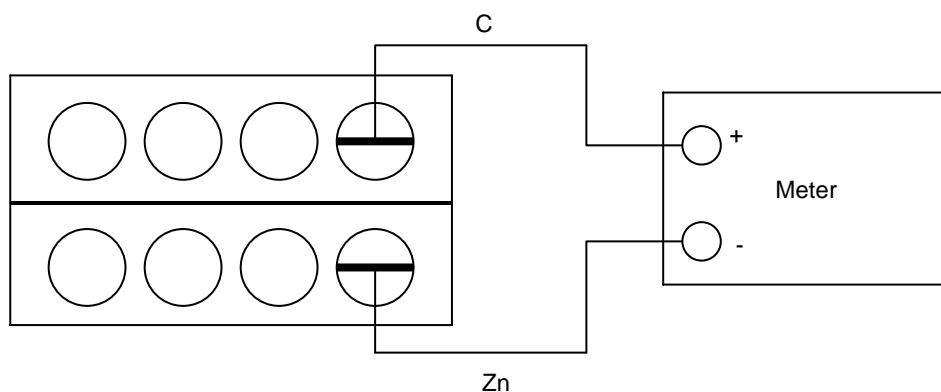
Experiment procedure:

1. To assemble a zinc-carbon or Leclanché cell a 20% ammonium chloride solution and some depolarizing paste are required. These should be given to the students.
2. Assemble the battery block as described.
3. Fill one chamber each with 20% ammonium chloride solution and insert the zinc electrode. Fill the chamber opposite with a depolarizing paste consisting of graphite powder, manganese (IV) oxide (battery manganese) and ammonium chloride solution and insert the carbon electrode. The depolarizing paste is there to prevent hydrogen forming at the carbon electrode.
4. Connect the two electrodes to the meter using 2 experiment cables with crocodile clips and measure the voltage generated by the Leclanché cell.

Observation and evaluation:

Batteries are important where there is no electric current. Batteries are galvanic cells that can convert chemical energy directly into electrical energy.

The dry cell (Leclanché cell) is an economically important type of galvanic cell. It supplies a voltage of between 1.3 and 1.4 V, as can be read from the meter.



Calculation of the mass of NH_4Cl required to prepare 1 liter of a 20% solution:



Put the beaker on a set of scales and adjust the scales to show 0.0 g. Fill the beaker with 200 g of NH_4Cl then add water until the scales display a mass 1000 g . This makes up a 20% solution.

To make depolarizing paste for about 30 students:

45g of graphite powder should be well mixed with 225 g of manganese (IV) oxide and 225 ml of 20% ammonium chloride solution. The resulting paste should not be stored for more than 1 day.

After use, the paste should be disposed of in the container for inorganic substances.

Measuring the voltage of a zinc-carbon (Leclanché) cell

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Graphite powder		---	---	Meter
Manganese (IV) oxide		20/22	25	Electrodes: 1 C, 1 Zn
Ammonium chloride		22-36	22	2 Experiment cables
Distilled water		---	---	1 Plastic beaker
				2 Pipettes

Warning: Be careful when handling chemicals!

Experiment procedure:

1. To assemble a zinc-carbon or Leclanché cell a 20% ammonium chloride solution and some depolarizing paste are required. These should be given to the students.
2. Assemble the battery block as described.
3. Fill one chamber each with 20% ammonium chloride solution and insert the zinc electrode. Fill the chamber opposite with a depolarizing paste consisting of graphite powder, manganese (IV) oxide (battery manganese) and ammonium chloride solution and insert the carbon electrode. The depolarizing paste is there to prevent hydrogen forming at the carbon electrode.
4. Connect the two electrodes to the meter using 2 experiment cables with crocodile clips and measure the voltage generated by the Leclanché cell.

Observation and evaluation:**Sketch of experiment set-up:****Results of voltage measurement:**

The Leclanché cell supplies a voltage of _____ V.

Measuring the voltage for various electrolyte concentrations

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Silver nitrate		34-50/53	26-45-60-61	Meter Electrodes: 2 Ag
Distilled water		---	---	2 Experiment cables 2 Pipettes

Warning: Be careful when handling silver nitrate! Silver nitrate is corrosive!

Experiment procedure:

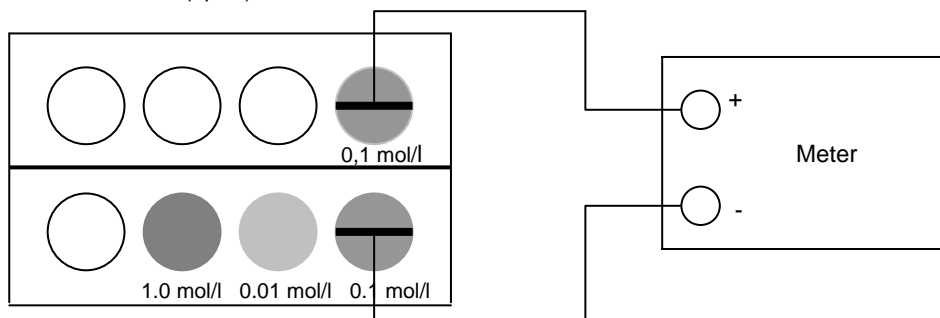
- Silver nitrate solutions of various concentrations should be given to the students.
- Assemble the battery block as described.
- Fill two chambers located opposite one another in the battery block with 0.1 molar silver nitrate solution and insert a silver electrode into both of them.
- Fill two more chambers with 1 molar and 0.01 molar silver nitrate solution.
- First measure the voltage for the Ag / AgNO₃ (0.1 mol/l) // Ag / AgNO₃ (0.1 mol/l) cell. Both silver electrodes should be connected to the meter.
- Remove one silver electrode from the 0.1 molar silver nitrate solution, rinse thoroughly with water and insert into the 1 molar silver nitrate solution. The voltage produced by the Ag / AgNO₃ (0.1 mol/l) // Ag / AgNO₃ (1.0 mol/l) cell can now be read off from the meter.
- Next remove the silver electrode from the 1 molar silver nitrate solution, rinse thoroughly with water again and insert into the 0.01 molar silver nitrate solution. The voltage from the Ag / AgNO₃ (0.1 mol/l) // Ag / AgNO₃ (0.01 mol/l) cell can now be read off from the meter.
- For the next experiment remove the silver electrode from the 0.1 molar silver nitrate solution, rinse thoroughly with water and insert into the 1.0 molar silver nitrate solution. The voltage from the Ag / AgNO₃ (1.0 mol/l) // Ag / AgNO₃ (0.01 mol/l) cell can now be read off from the meter.

Observation and evaluation:

Galvanic cell	Measured voltage (V)
Ag / AgNO ₃ (0,1 mol/l) // Ag / AgNO ₃ (0,1 mol/l)	--
Ag / AgNO ₃ (0,1 mol/l) // Ag / AgNO ₃ (1,0 mol/l)	0.058 V
Ag / AgNO ₃ (0,1 mol/l) // Ag / AgNO ₃ (0,01 mol/l)	0.058 V
Ag / AgNO ₃ (1,0 mol/l) // Ag / AgNO ₃ (0,01 mol/l)	0.116 V

Measuring a voltage from chains of electrolyte of equal concentration is impossible. To measure a voltage the electrolyte concentrations have to be different. If the electrolyte concentrations differ by a factor of 10, the voltage measured is 0.058 V, regardless of whether measurement is made between 1.0 mol/l and 0.1 mol/l or 0.1 mol/l and 0.01 mol/l concentrations. Each further increase by a factor of 10 increases the measured voltage by another 0.058 V. Due to the diffusion of the more concentrated electrolyte solution through the paper diaphragm, the concentrations in the two half cells tend to become more equal so that the potential difference decreases over time.


In the more concentrated silver nitrate solution, silver ions are reduced to silver and in the more dilute solution the silver goes into solution creating silver ions.. This means that the silver electrode in the more concentrated solution is the cathode (+ pole) and the one in the more dilute solution is the anode (- pole).



To make 1 liter of the required solutions:

- To make a 1 molar solution of AgNO₃ solution, 169.8 g of AgNO₃ should be dissolved in a liter of water.
- To make a 0.1 molar solution of AgNO₃ solution, 16.98 g of AgNO₃ should be dissolved in a liter of water.
- To make a 0.01 molar solution of AgNO₃ solution, 1.69 g of AgNO₃ should be dissolved in a liter of water.

Measuring the voltage for various electrolyte concentrations

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Silver nitrate		34-50/53	26-45-60-61	Meter
Distilled water		---	---	Electrodes: 2 Ag 2 Experiment cables 2 Pipettes

Warning: Be careful when handling silver nitrate! Silver nitrate is corrosive!


Experiment procedure:

- Silver nitrate solutions of various concentrations should be given to the students.
- Assemble the battery block as described.
- Fill two chambers located opposite one another in the battery block with 0.1 molar silver nitrate solution and insert a silver electrode into both of them.
- Fill two more chambers with 1 molar and 0.01 molar silver nitrate solution.
- First measure the voltage for the $\text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l}) // \text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l})$ cell. Both silver electrodes should be connected to the meter.
- Remove one silver electrode from the 0.1 molar silver nitrate solution, rinse thoroughly with water and insert into the 1 molar silver nitrate solution. The voltage produced by the $\text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l}) // \text{Ag} / \text{AgNO}_3 (1.0 \text{ mol/l})$ cell can now be read off from the meter.
- Next remove the silver electrode from the 1 molar silver nitrate solution, rinse thoroughly with water again and insert into the 0.01 molar silver nitrate solution. The voltage produced by the $\text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l}) // \text{Ag} / \text{AgNO}_3 (0.01 \text{ mol/l})$ cell can now be read off from the meter.
- For the next experiment remove the silver electrode from the 0.1 molar silver nitrate solution, rinse thoroughly with water and insert into the 1.0 molar silver nitrate solution. The voltage from the $\text{Ag} / \text{AgNO}_3 (1.0 \text{ mol/l}) // \text{Ag} / \text{AgNO}_3 (0.01 \text{ mol/l})$ cell can now be read off from the meter.

Observation and evaluation:**Sketch of experiment set-up:****Result of voltage measurement:**

Galvanic cell	Measured voltage (V)
$\text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l}) // \text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l})$	
$\text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l}) // \text{Ag} / \text{AgNO}_3 (1.0 \text{ mol/l})$	
$\text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l}) // \text{Ag} / \text{AgNO}_3 (0.01 \text{ mol/l})$	
$\text{Ag} / \text{AgNO}_3 (0.1 \text{ mol/l}) // \text{Ag} / \text{AgNO}_3 (1.0 \text{ mol/l})$	

Measuring the voltage for various electrolyte temperatures

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Silver nitrate		34-50/53	26-45-60-61	Meter Electrodes: 2 Ag
Distilled water		---	---	2 Experiment cables 1 Beaker 1 Bunsen burner 1 Thermometer 2 Pipettes

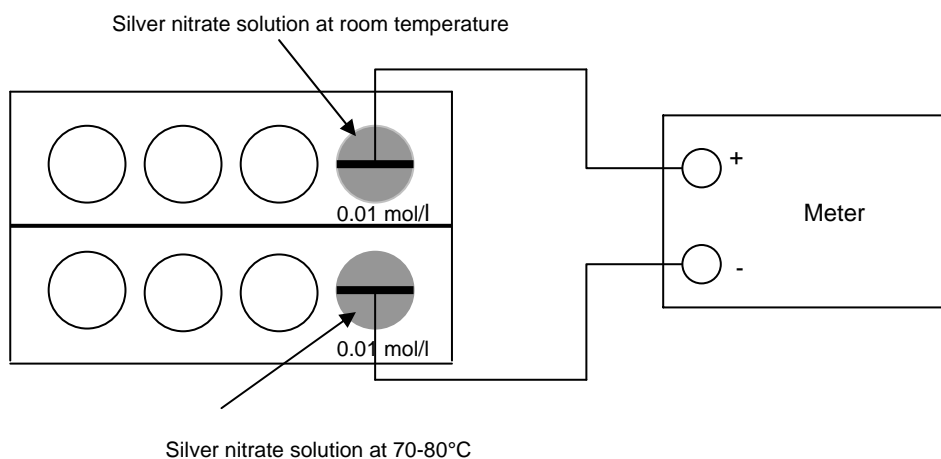
Warning: Be careful when handling silver nitrate! Silver nitrate is corrosive!

Experiment procedure:

1. The 0.01 molar silver nitrate solution should be given to the students.
2. Assemble the battery block as described.
3. Put about 15 ml of 0.01 molar silver nitrate solution in a beaker and heat it to about 70-80°C .
4. Fill one chamber of the battery block with 0.01 molar silver nitrate at room temperature and put the hot 0.01 molar silver nitrate solution into the chamber opposite.
5. Insert one silver electrode into both electrolyte solutions, connect the electrodes to the meter and read off the voltage.

Observation and evaluation:


By contrast with the previous observation that no voltage can be measured between electrolytes of the same concentration, it can be observed here that a voltage is indeed measured if the equally concentrated electrolytes are at different temperatures. This means that differences in temperature between electrolyte solutions can have an effect on the resulting potential (theoretically about 2 mV/10K). In the experiment a voltage of about 20 mV is measured. This gradually decreases as the temperatures of the two electrolyte solutions converge. When the temperatures are equal, the measured voltage is 0 V.



To make 1 liter of the electrolyte solution:

To make a 0.01 molar solution of AgNO_3 , 1.69 g of AgNO_3 should be dissolved in a liter of water.

Measuring the voltage for various electrolyte temperatures

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Silver nitrate		34-50/53	26-45-60-61	Meter Electrodes: 2 Ag
Distilled water		---	---	2 Experiment cables 1 Beaker 1 Bunsen burner 1 Thermometer 2 Pipettes

Warning: Be careful when handling silver nitrate! Silver nitrate is corrosive!

Experiment procedure:

1. The 0.1 molar silver nitrate solution should be given to the students.
2. Assemble the battery block as described.
3. Put about 15 ml of 0.1 molar silver nitrate solution in a beaker and heat it to about 70-80° .
4. Fill one chamber of the battery block with 0.1 molar silver nitrate at room temperature and put the hot 0.01 molar silver nitrate solution into the chamber opposite.
5. Insert one silver electrode into both electrolyte solutions, connect the electrodes to the meter and read off the voltage.

Observation and evaluation:**Sketch of experiment set-up:****Observation during the experiment:**

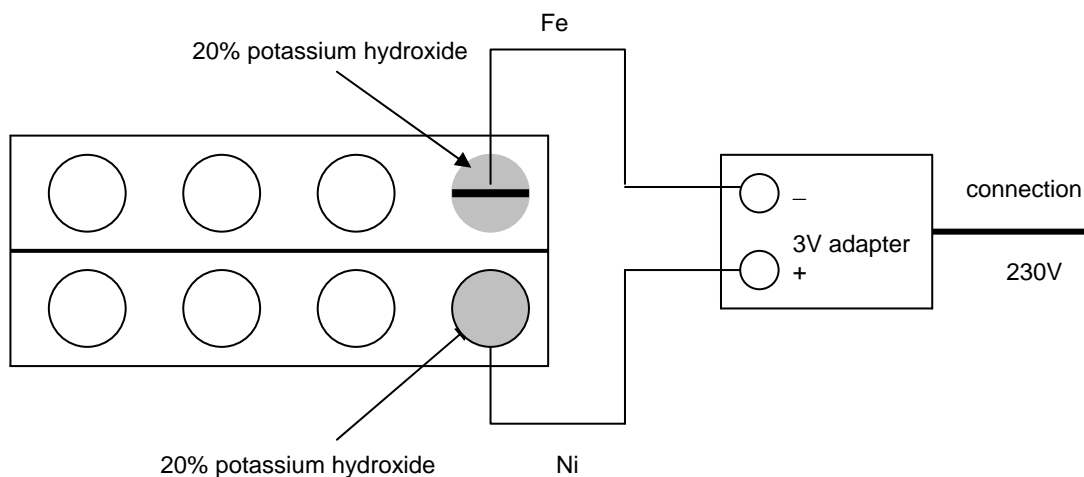
Assembly, charging and discharging of a steel accumulator

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Potassium hydroxide 20% approx. (\approx 4 molar) Distilled water		22-35 ---	26-36/37/39-45 ---	Meter Electrodes: 1 Ni, 1 Fe 2 Experiment cables 2 Pipettes

Warning: Be careful when handling potassium hydroxide! Wear protective glasses!

Experiment procedure:

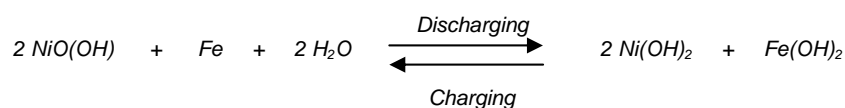
1. The suitably concentrated potassium hydroxide (20%) required for the experiment should be given to the students.
 2. Assemble the battery block as described.
 3. Fill two opposing half cell chambers with 20% potassium hydroxide.
 4. Insert an iron electrode into one chamber and a nickel electrode into the other.
 5. To charge up the cell, connect the 3V adapter so that the nickel electrode is connected to the + pole and the iron electrode is connected to the - pole.
 6. After connecting the 3V adapter to the mains power supply and plugging the latter into the 230V mains, allow the accumulator to charge up for about 10 minutes.
 7. The 3V adapter is then replaced by the meter and the voltage produced by the accumulator can then be measured.
-

Observation and evaluation:

The voltage displayed on the meter should be read off and written down. The no-load voltage at the terminals is 1.3 V approx.

If the meter is connected for a longer period of time, it can be observed that the voltage decreases rapidly because the capacitance of this co-called Edison accumulator is very low.

The following chemical processes take place within the Edison accumulator:



Assembly, charging and discharging of a steel accumulator

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Potassium hydroxide 20% approx. (\approx 4 molar)		22-35	26-36/37/39-45	Meter Electrodes: 1 Ni, 1 Fe
Distilled water		---	---	2 Experiment cables 2 Pipettes

Warning: Be careful when handling potassium hydroxide! Wear protective glasses!



Experiment procedure:

1. The suitably concentrated potassium hydroxide (20%) required for the experiment should be given to the students.
 2. Assemble the battery block as described.
 3. Fill two opposing half cell chambers with 20% potassium hydroxide.
 4. Insert an iron electrode into one chamber and a nickel electrode into the other.
 5. To charge up the cell, connect the 3V adapter so that the nickel electrode is connected to the + pole and the iron electrode is connected to the - pole.
 6. After connecting the 3V adapter to the mains power supply and plugging the latter into the 230V mains, allow the accumulator to charge up for about 10 minutes.
 7. The 3V adapter is then replaced by the meter and the voltage produced by the accumulator can then be measured.
-

Observation and evaluation:**Sketch of experiment set-up:****Observation for the experiment:**

Experiment 11 - measuring pH

Teacher's instructions

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Buffer solution pH 4 or 7		---	---	Meter
Hydrochloric acid		36/37/38	26	Electrodes: Combined pH probe
Sodium hydroxide		34	26-36/37/39-45	
Sodium chloride solution		---	---	
Sodium acetate solution		---	---	

Warning: Be careful when handling acids and alkalis! Wear protective glasses!

The Electrochemistry case contains a combined pH probe electrode for measuring pH. The meter displays highly accurate measurements with a single point calibration. Since the meter is battery powered, it can also be used to make pH measurements outside the classroom, e.g. in lakes and rivers.

Experiment procedure:

1. Take the combined pH probe out of the case and plug it into the pH connection on the underside of the meter.
2. Change the range switch on the front of the meter from voltage measurement to pH measurement.
3. Now take the pH probe out of its storage flask and rinse it with distilled water.
4. Immerse the pH probe in the buffer solution, wait for a moment and then adjust the zero point until it shows the correct value for the buffer solution. Make no more adjustments to the rotary knob thereafter.
5. Immerse the probe in the prepared solutions one after the other and read off the corresponding pH values. After each measurement, thoroughly clean the probe. Take care when doing this not to damage the probe's glass head.

Observation and evaluation:

In order to determine the degree of acidity or alkalinity of fluids, one determines their pH value. The pH value can either be determined with the help of indicators, which change their color depending on whether they are in an acid or alkaline solution, or with a combined pH probe, which displays the pH highly accurately on the digital display of a meter. The pH value measured with the probe is much more accurate as it can also measure fractional values. The pH value is dependent on the concentration of H_3O^+ ions in a solution.

The scale runs from pH 0 to pH 14.

*pH 0 – 6 = acid
pH 7 = neutral
pH 8 -14 = alkali*



Experimental result:

A variety of pH values are found depending on the concentrations of the solutions under investigation Therefore no specific results for the pH can be given. Use the table to record the pH values measured by the students for the various tested solutions.

Tested solution	Measured pH value
Hydrochloric acid	
Sodium hydroxide	
Sodium chloride solution	
Sodium acetate solution	

Experiment 11 - measuring pH

Student instructions

Chemicals	Hazard symbols	R phrases	S phrases	Equipment
Buffer solution pH 4 or 7		---	---	Meter
Hydrochloric acid		36/37/38	26	Electrodes: Single probe pH measuring equipment
Sodium hydroxide		34	26-36/37/39-45	
Sodium chloride solution		---	---	
Sodium acetate solution		---	---	

Warning: Be careful when handling acids and alkalis! Wear protective glasses!

The Electrochemistry case contains a combined pH probe electrode for measuring pH. The meter displays highly accurate measurements with a single point calibration. Since the meter is battery powered, it can also be used to make pH measurements outside the classroom, e.g. in lakes and rivers.

Experiment procedure:

1. Take the pH probe out of the case and plug it into the pH connection on the underside of the meter.
2. Change the range switch on the front of the meter from voltage measurement to pH measurement.
3. Now take the pH probe out of its storage flask and rinse it with distilled water.
4. Immerse the pH probe in the buffer solution, wait for a moment and then adjust the zero point until it shows the correct value for the buffer solution. Make no more adjustments to the rotary knob thereafter.
5. Immerse the probe in the prepared solutions one after the other and read off the corresponding pH values. After each measurement, thoroughly clean the probe. Take care when doing this not to damage the probe's glass head.

Observation and evaluation:

<i>Tested solution</i>	<i>Measured pH value</i>
<i>Hydrochloric acid</i>	
<i>Sodium hydroxide</i>	
<i>Sodium chloride solution</i>	
<i>Sodium acetate solution</i>	

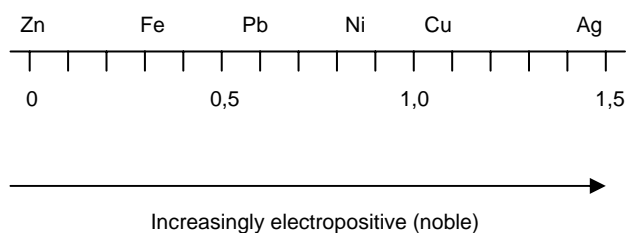
Standard electrochemical potential series

Summary of some important theoretical standard electrochemical potentials:

Reducing agent	⇌	Oxidizing agent	+ n e ⁻	Standard potential (in V)
Au	⇌	Au ⁺	+ e ⁻	+ 1.70
Au	⇌	Au ³⁺	+ 3 e ⁻	+ 1.42
Pt	⇌	Pt ²⁺	+2 e ⁻	+ 1.20
Ag	⇌	Ag ⁺	+ e ⁻	+ 0.81
Fe	⇌	Fe ³⁺	+ e ⁻	+ 0.77
Cu	⇌	Cu ²⁺	+2 e ⁻	+ 0.34
Cu ⁺	⇌	Cu ²⁺	+ e ⁻	+ 0.15
H ₂	⇌	2 H ⁺	+2 e ⁻	0.00
Cu	⇌	Cu ⁺	+ 3 e ⁻	- 0.036
Pb	⇌	Pb ²⁺	+2 e ⁻	- 0.12
Ni	⇌	Ni ²⁺	+2 e ⁻	- 0.23
Fe	⇌	Fe ²⁺	+2 e ⁻	- 0.44
Zn	⇌	Zn ²⁺	+2 e ⁻	- 0.76
Al	⇌	Al ³⁺	+ 3 e ⁻	- 1.66
Mg	⇌	Mg ²⁺	+2 e ⁻	- 2.37
K	⇌	K ⁺	+ e ⁻	- 2.92
Li	⇌	Li ⁺	+ e ⁻	- 3.02

Increasing concentration of Oxidizing agent
Increasing concentration of Reducing agent

Noble metals can be distinguished from less noble metals on the basis of the difference in voltage that is measured. Noble metals have positive potentials and ignoble metals have negative potentials. If zinc, not a noble metal, is assigned the potential 0, then the electropositivity of metals towards the most noble metals can be shown in an overview such as the following, based on the differences in voltage:



Notes on performing experiments

The teacher is responsible in all aspects for ensuring that pupils conduct the experiments in an orderly and proper fashion. The teacher must become thoroughly familiar with the experimental procedure and the handling of the appropriate equipment before the experiment is performed. Students should be warned of possible dangers and be advised on the prevention of accidents. All chemistry teachers should be informed concerning all aspects of safety regulations, accident avoidance and prevention and are obliged to abide by these.

Safety regulations and regulations for the handling of chemicals are specified in the laws concerning chemicals, hazardous materials and in the technical regulations for hazardous materials. Further byelaws and guidelines for local regions are legally binding upon the school.

Instructions for disposal:

All equipment and electrodes should be cleaned and dried as thoroughly as possible after experiments are completed in order to ensure their continued functionality.

Please dispose of residues and waste with due regard to the environment.

Those chemicals that have been used, which cannot be recycled for further use and need to be destroyed, should be stored in special containers and disposed of in an appropriate manner.

Types of waste:

1. Inorganic acids
Disposal: *container for acids and alkalis!*
2. Alkalis
Disposal: *container for acids and alkalis*
3. Inorganic salts
Disposal: *container for inorganic salts*
4. Salts of heavy metals
Disposal: *to be agreed with the party responsible for their disposal.*

Disposal of substances should always be agreed with the party responsible for disposal. If so agreed, substances may be dissolved in water in order to stabilize them.