THE ANSWER IS

BLOWING IN THE WIND

TASK SHEET

Challenge 1

28th of April 2015

Country:
Team:

- Lab coats and safety goggles must be worn all times in the laboratory.
- Eating and drinking is strictly prohibited in the laboratory.
- Disposable gloves are provided and should be worn while working with chemicals.

- On completion of your work all papers including scribbling paper must be handed in. NOTHING must be taken from the laboratory.
- All results must be entered into the answer sheet (coloured paper).
- Graphs must be handed in together with the answer sheet.

Only the final answer sheet (coloured paper) and the supplemented graphs will be assessed.

Challenge 1 consists of five parts, which can be worked on individually or as a team.

Task A: 90 Marks
Task B: 92 Marks
Task C: 92 Marks
Task D: 06 Marks
Task E: 24 Marks

You have **4 hours** to complete Challenge 1

The Story

KLEIN - VIRTULIEN

The region Klein-Virtulien is situated in the South Rim of the Alps, 800-1300 meters above sea level. 60% of the region's electrical power demand is supplied by hydroelectric power, and the remaining 40% is imported. In order to meet the increasing energy demand and to reduce the dependency on electricity imports, a new renewable energy generating plant will be built. This plant will not only produce energy but will also have the capacity to store electric energy.

The mountainous terrain in the region ideally suits the construction of a wind power plant with the possibility of two energy storage alternatives:

1. **A classical pump station**
2. **A modern electrolysis plant (Power-to-Gas, P2G)**

Prior to the actual power plant construction in Klein-Virtulien several objections have been raised:

- The Virtu creek that will feed the pump station is one of Klein-Virtulien's most biodiverse running waters. According to a local environmental initiative the creek is home to *Astacus astacus subsp. virtuliensis,* an endangered crayfish. Members of this local enviromental initiative are concerned that the new power station will significantly alter the natural habitat of the crayfish and therefore lead to its extinction. The new power station proponents deny the presence of *Astacus astacus subsp. virtuliensis* in the region and maintain it closely resembles another non-protected species of crayfish.
- Another local environmental initiative promotes the following argument against the construction of the pumped storage hydro power station: Near the planned storage reservoir lies landfill from an abandoned leather factory. In the event of a flood in the area there are concerns that toxic waste could be leached, especially hexavalent chromium. In order to test this possibility, landfill samples will have to be investigated for the determination of possible Cr(VI) contamination.
- A further local environmental initiative opposes the electrolysis plant in Klein-Virtulien, because from their point of view the combination of wind power and Power-to-Gas does not provide the required efficiency.

In order to raise community awareness regarding the power station concerns, especially of the youth, an international competition will take place in Klein-Virtulien.

You, as a competing team, are asked to take on the role of evaluators and issue a joint recommendation for the future power station. In order to do so, you will have to conduct several investigations and experiments.

Task A

Take care of the order in which the tasks are completed.
Before starting section 3.2 and 4 you have to solve 3.1 and hand over the **crayfish handout** 3.1 to the laboratory assistant. ➔ Only then you will receive further material to continue, table “Function”, a diagram showing the morphology of a crayfish as well as a crayfish for identification.

Material:

- crayfish extremities (left or right half of a crayfish)
- Crayfish handout with the shape of a crayfish
- Glue
- Forceps
- Polystyrene-box
- Magnifying glass
- Millimeter paper
- Ruler

- 1 Crayfish
- Diagram showing the morphology of a crayfish
- Table “Function”

1. The ecology of *Astacus astacus subsp. virtuliensis*

Ecological concepts: Biotope, habitat, ecological niche

In nature, organisms are not randomly distributed; they prefer species-specific distinct subareas. In order to describe their non-random spatial use, terms such as biotope, habitat and ecological niche are used.

Biotope: Is a topographical area with more or less uniform environmental conditions and is characterised by a biocenosis.

Habitat: The area of the biotope occupied by a distinct kind of organism.

Ecological niche: Represents the interaction between

- the habitat’s spatial description
- the used resources (nutrition, light, water, salinity, etc.) and
- the species’ reaction to environmental factors

(Adapted from: Sinsch, U. (2004). Studienbrief 1: Konzepte der Autökologie.) Universität Koblenz-Landau.

***Scientific information*:**

The ecological demands of Astacus astacus subsp. virtuliensis correspond with those of Astacus astacus. Both live exclusively in fresh water, colonize rivers and streams and warm lakes and ponds with steep banks in Summer. However, Astacus astacus subsp. virtuliensis prefers a minimum water depth of 40 cm. The water temperature in Summer must be at least 11°C, the optimum temperature range is between 19°C and 21°C. The upper pessimum (= opposite of optimum) starts at 24°C, at 25°C the crayfish die. The temperature drop in Autumn marks the start of the mating season.

The optimum oxygen content of the water is between 6 and 12 mg/L, 3.5 mg/L is the absolute minimum.

A prerequisite for the colonization by this crayfish is a strong structuring of the benthic zone; Sufficient hiding places and resting places must be present (large stones, banks with tree roots, caves dug in the banks). As many crayfish species, Astacus astacus subsp. virtuliensis is crepuscular and nocturnal.

During the day it withdraws in the resting areas. The young can be seen in shallow water, where they can hide in between plants. Astacus astacus subsp. virtuliensis is an omnivore. Its diet comprises algae, water plants, insect larvae, mussels, slugs and carrion. It "collects" its food actively.

1.1. Match the characteristics (left column) that correspond with the correct ecological concepts (biotope, habitat, ecological niche) through ticking the correct box.

⇨ *Answer sheet*

1.2. Astacus performance in response to water temperature in summertime

In Summer (beginning of June until mid September) the water temperature is an essential factor for the species performance, and thus for the occurrence of *Astacus astacus subsp. virtuliensis.*

1.2.1 Draw a graph (bell-shaped curve) demonstrating the relationship between the stated water temperatures (minimum, optimum, maximum) versus species performance.

⇨ *graph paper*

Note: The species performance is the number of animals using this biotope without increasing or decreasing the population: It can take values from 0 (no individual survives) to 100 (optimal habitat use).

1.2.2 Label the graph of 1.2.1 with the characteristic temperature range and temperature points/temperature ranges (minimum, maximum, optimum, pessimum). Annotate the graph and add a legend. ⇨ *graph*

2. Possible effects of a pump station on *Astacus astacus subsp. virtuliensis*

Scientists found that the erection of a pump station may change some ecological factors for *Astacus astacus subsp. virtuliensis*. Examine, if the construction of a pump station will influence the population of *Astacus astacus subsp. virtuliensis*, using the given two graphs on the answer sheet “Average oxygen content in the river per month” and “Average temperature in the river per month”

2.1. Identify areas in the graphs representing ecological factors that can lead to extinction of the crayfish population under the given conditions in Summer. Shade the area/s you identified.

2.2. Shade optimal area/s for temperature and oxygen content in Summer within the graphs.

3. Functional morphology of crayfish

Reminder: Take care of the order in which the tasks are completed.
Before starting section 3.2 and 4 you have to solve 3.1 and hand over the crayfish handout 3.1 to the laboratory assistant.

3.1 On the provided crayfish handout, arrange the crayfish extremities from the glass container in the correct order. Select the appropriate handout, left or right!

⇨ *crayfish handout*

<u>All extremities must be glued onto the crayfish handout!!</u>

Hint: The picture in the handout is taken from the ventral side. Some limbs are hard to distinguish. If you cannot determine their exact order, position them as a group. The very exact positioning of limbs yields only 2 marks in total. Once you are satisfied with your layout hand over the crayfish handout to the laboratory assistant who will now take a picture.

3.2 Match each extremity to its main function (multiple assignments are possible, but maximally three assignments per extremity are allowed).→The table "Function"

⇨ *Answer sheet*

Each box must show either a cross or a zero: "X" for correct, "0" for incorrect!!

Function:

- A= Grasping objects/food and used for defence/attack
- B= Processing/manipulation (breaking, chewing, handling) of food
- C= Reproduction/brood care
- D= Sensory perception
    - D1 = chemical sense
    - D2 = tactile sense
    - D3 = balance (equilibrium)
- E= Movement
    - E1 = pacing
    - E2 = swimming

4. Crayfish identification

- **This task can only be solved once you have completed task 3.1 and handed in *crayfish handout* 3.1 to the laboratory assistant.** Only then you will receive the **crayfish for identification** and **the Diagram showing the morphology of a crayfish** from the laboratory assistant!

Using the key in the answer sheet to verify if the present crayfish is *Astacus astacus subsp. virtuliensis*.

Legend for crayfish identification:

A	Cephalothorax	**7**	Joint of the cheliped
B	Tail	**8**	Rostrum
1	Antenna	**9**	Postorbital ridge
2	Anterior carapacae	**10**	Spines
3	Posterior carapacae	**11**	Cervical groove
4	Abdomen	**12**	Areola
5	Telson	**13**	Transverse bands across abdominal segments
6	Cheliped		

4.1 Tick the statements on the key in the grey column that lead to the identification of the presented crayfish! ⇨ *Answer sheet*

5. Theoretical questions

5.1. Which of the statements are correct, which are incorrect? Tick your choice!

⇨ *Answer sheet*

6. Evaluate the situation of constructing a pump station in Klein-Virtulien

With regard to the suspected *Astacus astacus subsp. virtuliensis* population, evaluate whether the concerns of the citizen’s initiatives are justified.
Use the information from **“The ecology of *Astacus astacus subsp. virtuliensis*“ (1),** your insights from **“The possible effects of a pump station on *Astacus astacus subsp. virtuliensis*” (2),** as well as your results from **“Crayfish identification” (4)**. Assess the effects of the alternative power plant station on the crayfish population.

Summarise your assessment by ticking yes or no in the table.

⇨ *Answer sheet!*

TASK B

Introduction

In close proximity to the proposed reservoir lies landfill from an abandoned leather factory. The opponents have raised some concerns due to possible leaching of hexavalent chromium (Cr(VI)), if the area was to flood. The project managers are looking into these allegations and will acquire landfill samples to conduct an investigation of the contamination with Cr(VI).
As a chemistry expert you have been asked to extract Cr(VI) from these samples according to the norm DIN S4 and to determine the Cr(VI) concentration spectrophotometrically. Calculate the expected pollution from chromium and assess possible environmental consequences.
Cr(III) is an essential trace element, whereas Cr(VI) is carcinogenic. In compounds chromium mainly appears with the oxidation states +3 and +6. Cr(VI) is far more toxic than Cr(III) due to its ability to penetrate cell membranes. Once in the cell it acts as a strong oxidising agent, thus causing oxidative damage in the body.
One method to analyse Cr(VI) spectrophotometrically is based on its reaction with 1,5-diphenylcarbazide (DPC) in acid solution.

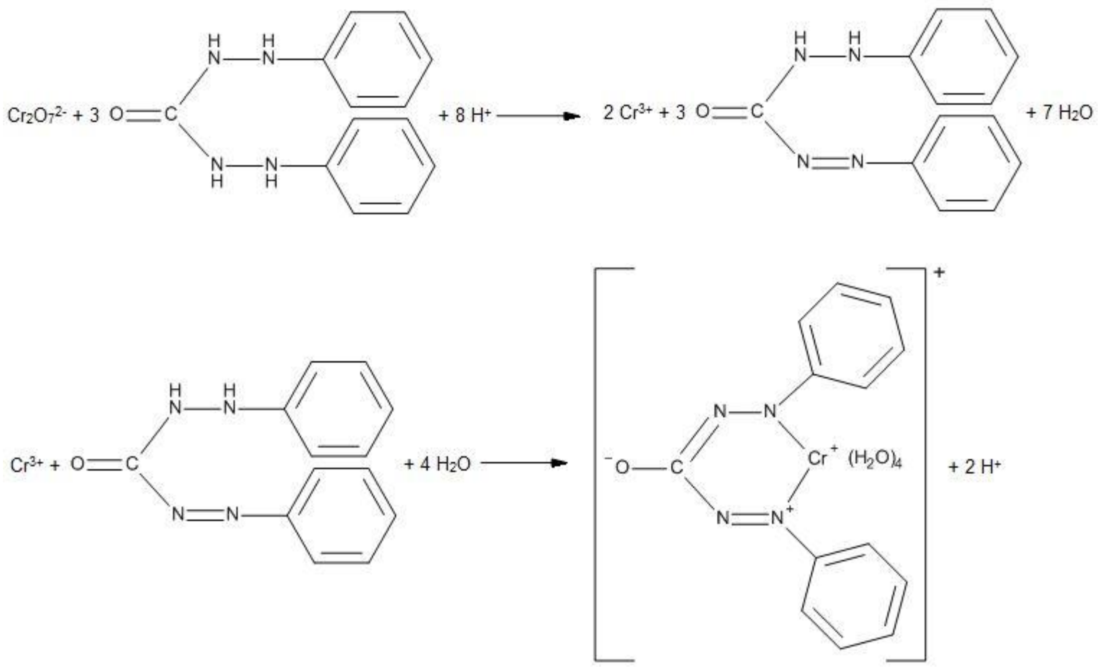


Fig.1: Reaction of dichromate with DPC in acid solution

This reaction is very sensitive, thus even slight traces of Cr(VI) can be detected. The reaction results in the formation of a purple complex (see Fig.1), the colour intensity of which is directly proportional to the concentration of Cr(VI). With this colouration the Cr(VI) concentration can be

measured at 550 nm. The absorbance is a function of the wavelength of the light and the concentration of the sample.
Within a certain concentration range, the relation between concentration and absorption is linear. This relation is described with Lambert-Beer's law:

$A = a*c*d$

A = the absorbance, measured by the spectrophotometer

a = the molar absorption coefficient of the substance (also known as ε)

c = the molar concentration (mol/L)

d = the distance the light travels through the sample (pathlength, simplified: the thickness of the cuvette)

In this task, ***A*** will be measured, ***d*** can be found in the list of materials, ***a*** can be calculated from the calibration curve and with this information ***c*** can be calculated.

Design and function of the spectrophotometer used for this task is shown in Fig. 2 and Fig. 3

Fig. 2: Spectrophotometer UV-1600 PC

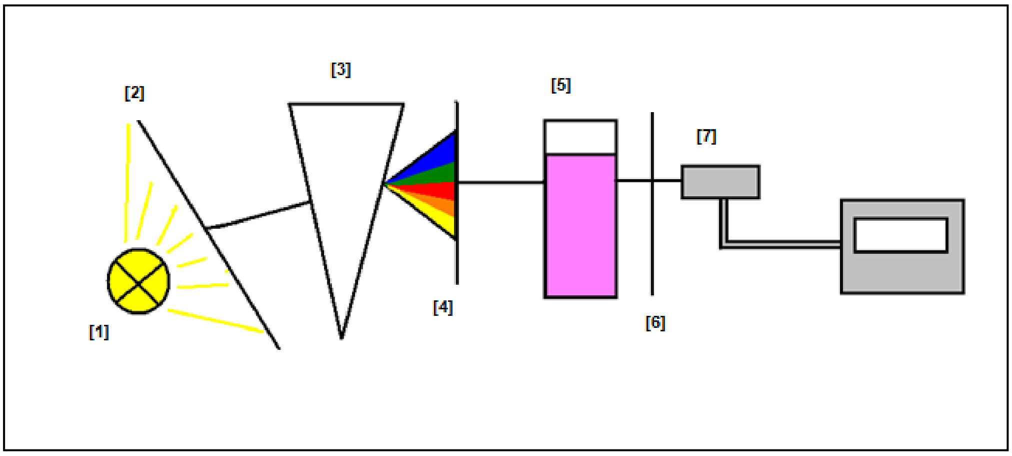


Fig. 3**:** Schematic drawing of a spectrophotometer (courtesy of Michaela De Rouw)

[1] Light source
[2] Entrance slit
[3] Prisma
[4] Exit slit
[5] Cuvette with sample
[6] Entrance slit
[7] Detector with displaying device

In the spectrophotometer at hand, light with a wavelength of 550 nm passes through a cuvette with a pathlength of 1 cm. The wavelength corresponds to the maximum absorption of **the Cr(VI) solution, which has been determined based on an absorption spectrum (see Fig.4).**

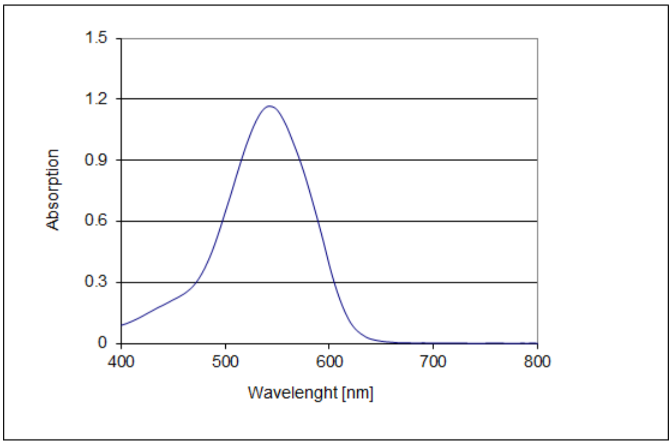


Fig. 4: Absorption spectrum of the complex from Cr(VI) and DPC

The cuvette contains the solution that should be investigated. The light passing through the cuvette is partially absorbed and a detector records the intensity of the light that reaches the opposite side.

List of materials	List of chemicals
• Paper, graph paper, ruler, rubber • Calculator • Periodic table • Permanent marker, pencil, sharpener • Piston pipette 100 µL (adjustable) • Piston pipette 1000 µL (adjustable) • Pipette tips (blue and yellow) • Container for used tips • Test tubes 15 mL (Falcon) • Test tube rack • 1 cm cuvettes for the spectrophotometer • Paper towels • 1 spectrophotometer (for 3 groups)	• Ultrapure water • Cr(VI) stock solution for calibration (28.29 mg/L dipotassium dichromate $K_2Cr_2O_7$), labelled “Cr(VI)“ • Sulfuric acid 0.5 M, labelled “0.5 M H_2SO_4“ • Reagent solution (120 mg 1,5-diphenylcarbazide in 50 mL acetone), labelled “DPC“ • 5 solutions (eluates from soil samples) with unknown Cr(VI) concentrations, labelled “E1“, “E2“, “E3“, “E4“ and “E5“ • Reference solution is quality control solution with a known Cr(VI)-concentration (4.00 mg/L), labelled “Ref“

Instructions:

Soil samples, from the former landfill site, have been acquired from five different locations. Due to lack of sufficient time, the extraction has already been completed for you: a 100 g soil sample and one litre ultrapure water were shaken upside down for 24 hours.
On your place you can find the soil samples as eluates (E1-E5), of which the Cr(VI) concentration has to be determined.
In order to determine the concentrations of each of the five samples, you must first plot a calibration curve. Therefore, you need the absorption values of the solutions with known concentrations. These solutions must be prepared from the stock solution (labelled "Cr(VI)") by appropriately diluting it.

1. Calculate the concentration of Cr(VI) in the stock solution in mg/L.

⇨ *Answer sheet*

Before you continue, the accuracy of the result has to be confirmed by a lab assistant on the answer sheet!

2. Determination of a calibration curve and spectrophotometric measurement

In order to determine a calibration curve, five diluted solutions with a concentration ranging from 25-250 µg/L have to be prepared from the stock solution. You will find the concentrations needed for the five solutions in Table 1 on your answer sheet.

2.1. Calculate the volume of stock solution required to prepare 10 mL of the respective solutions.
Record the values in Table 1! ⇨ *Answer sheet*

2.2. Preparation of calibration solutions

a. Mark six 15 mL test tubes with 1-6
b. Add 2 mL sulfuric acid (marked "0.5 M H_2SO_4") in each test tube with a piston pipette.
c. Add 0.2 mL of the reagent solution (marked "DPC") in each test tube with a piston pipette.
d. Using your calculation from Table 1 on the answer sheet, measure and add the appropriate volume of stock solution to test tubes 2-6, respectively.
e. Fill each test tube up to the 10 mL mark with ultrapure water.
f. Close test tubes and mix thoroughly.

2.3. Preparation of samples and reference solution

a. Mark the next six test tubes with 7-12
b. Add 2 mL sulfuric acid (marked “0.5 M H_2SO_4”) in each test tube with a piston pipette.
c. Add 0.2 mL of the reagent solution (marked “DPC”) in each test tube with a piston pipette.
d. Pipette 250 µL of eluate E1 into test tube 7, 250 µL of eluate E2 into test tube 8, and continue this procedure to test tube 11, and of reference solution into test tube 12. See Table 2 on the answer sheet.
e. Fill each test tube up to the 10 mL mark with ultrapure water.
f. Close test tubes and mix thoroughly.

2.3.1. Calculate the dilution factor for the eluates.

The result of this calculation has to be confirmed before you continue with the spectrophotometer measurements (lab assistant’s signature on answer sheet).

⇨ *Answer sheet*

2.4. Spectrophotometer measurement

a. Transfer the prepared solutions (test tubes 1-12) into the cuvettes (use at least ¾ of the total cuvette volume). Do not forget to label the cuvettes appropriately.
b. Inform the lab assistant that you are ready to use the spectrophotometer. Since three teams share one spectrophotometer, you may have to wait a few minutes for your turn. In the meantime, you could study the function of the spectrophotometer or answer “7. Concluding Questions”!
c. Complete the spectrophotometer measurements within 10 minutes.

Instructions for the spectrophotometer: Put cuvette 1 (blank) into the spectrophotometer. The smooth side must face the light source. Close the lid and then press “Zero”. Then, place cuvette 2 into the spectrophotometer, close the lid, and record the absorption (in Table 2). Repeat with cuvettes 3-12.

2.4.1. Record the measured absorptions in Table 2. ⇨ *Answer sheet*

3. Plotting a graph

3.1. Plot the recorded absorbance values using a coordinate system. ⇨*Graph paper!*

- The abscissa should show the concentration in µg/L and the ordinate should show the corresponding absorbance.
- Plot the regression line.
- From this plot, calculate the slope and determine the intercept. Show graphically how you obtained your values.
- Enter the absorption values of the eluates into the coordinate system and mark the corresponding concentrations on the abscissa.
- Make all your calculations on the graph paper.

Hand in your graph paper to the lab assistant.

For all further calculations you will receive values for the slope and intercept.

4. Calculate the concentration (µg/L) of eluates 1-5 and the reference solution.

Record the values in Table 3. ⇨ *Answer sheet*

5. Calculation of Cr(VI) content in soil samples

5.1 Calculate the original content (mg Cr(VI)/kg) in the soil samples.
Use the concentration values from 4.

Take the dilutions into account (see confirmed results of section 2.3.). ⇨ *Answer sheet*

6. Cr (VI) pollution in the soil and the reservoir

If the area of the former landfill gets flooded, all Cr(VI) present in the soil will be dissolved and therefore found in the reservoir water.

Answer 6.1. to 6.4. ⇨ *Answer sheet*

6.1 Calculate the average Cr(VI) content in the soil (mg Cr(VI)/kg).

6.2 Use the average concentration to calculate how much Cr(VI) (kg) is present, if the landfill contains 2000 t waste.

6.3 What is the concentration of Cr(VI) (µg/L) that can be expected in the reservoir if the landfill is flooded with 80 million m^3 water and all the Cr(VI) is leached?

6.4 From an ecological point of view, should the reservoir be built? (limit of Cr(VI) in drinking water: 50 µg/L)

7. Concluding questions

On the Answer sheet tick **yes** or **no in the corresponding columns.** ⇨ *Answer sheet*

TASK C

1. Measurements on a wind machine

Investigate some of the physical properties of a wind machine.

1.1. Measurement of air speed

Determine the speed of the air generated by the wind machine.

Materials:

- Wind machine mounted on a stand (Fig. 1.1.)
- Windmaster (anemometer) mounted on a stand
- Ruler
- Tape measure

Fig. 1.1 Wind machine

Procedure

Mount the wind machine and the Windmaster at a distance of 0.4 m from each other. The center of the air outlet and of the rotating cups of the anemometer should be at the same height and the wind machine should point exactly in direction of the Windmaster (Fig. 1.2).

The distance is measured from the edge of the air outlet to the rotation axis of the anemometer.

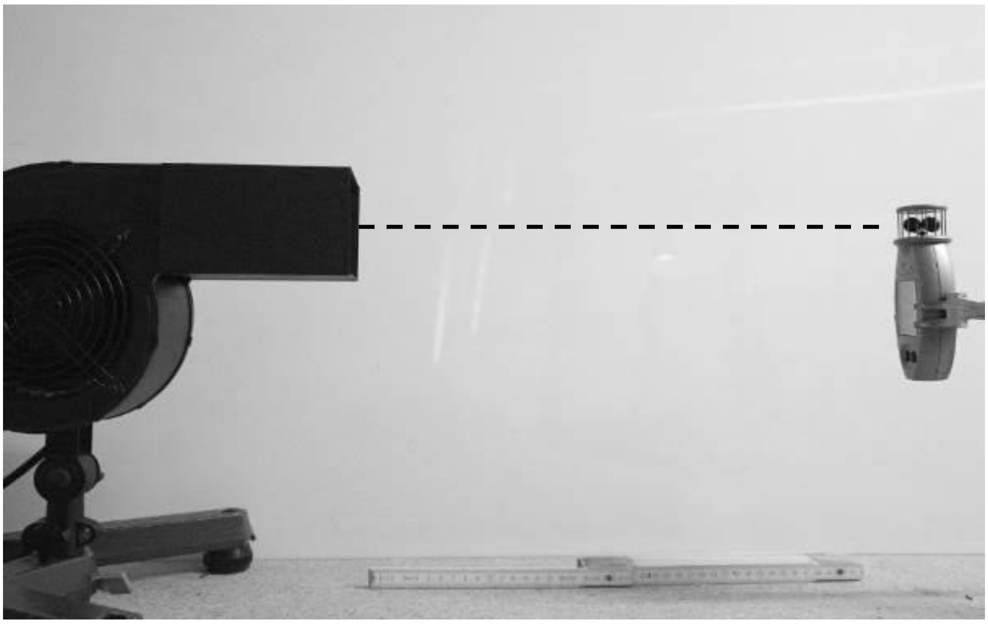


Fig. 1.2: Set Up

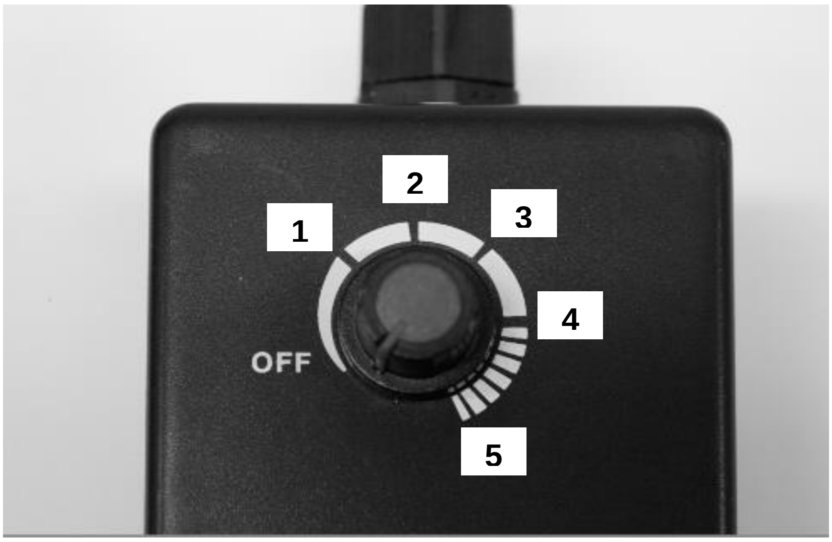


Fig. 1.3: Rotary switch for different speeds of air

The air speed can be controlled by the rotary switch (see Fig. 1.3). Caution: The different levels are not marked by numbers on the actual device!

Switch on the wind machine at the lowest level, level 1. Let it run for 15 seconds. Switch on the Windmaster and let it run for about 1 minute. Observe the display and make a note of the average value (AV) and of the maximum value (MX), see Fig. 1.4.

Fig. 1.4 Windmaster.

Shown on the display from top down: current value, maximum value (MX), average value (AV). All values are measured in m/s.

Write the average value (AV) and maximum value (MX) on the answer sheet (Table 1.1.1). Switch off the Windmaster.

Change the wind machine to level 2 and switch on the Windmaster after 15 seconds. Make the same measurements as before and write the values on the answer sheet. Switch off the Windmaster after the measurement. Continue the same procedure for levels 3-5 of the wind machine.

1.1.1. Complete Table 1.1.1 with the corresponding values! ⇨ *Answer sheet*

1.1.2. Drawing the diagram "Levels of the wind machine (x-axis) versus air speed (y-axis)"

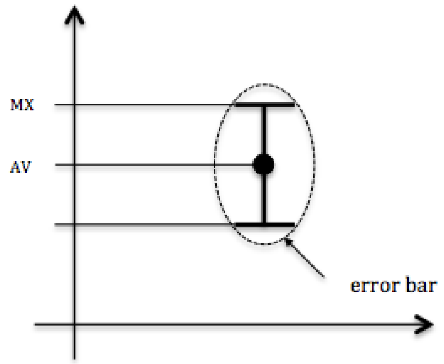
Draw a diagram using the measured values from Table 1.1.1 ⇨ *millimeter paper*

Make an appropriate scale for the y-axis (air speed in m/s). Draw points for the average speeds. The maximum values should be the upper limits of the error bars. Assume that the error bars are symmetrical around the average value. Draw the error bars.

Be sure to use the provided millimeter paper and paste your diagram on the answer sheet!

Information:

Error bars are a graphical representation of the variability of data and are used on graphs.



1.2. Measurements of the open circuit voltages with various rotor blades

A characteristic parameter of the power generated by windmills is the respective open circuit voltage. It is defined as the voltage that is generated without any load on the generator. Measure this voltage for different rotor blades in order to find the most efficient blade.

Materials:

- Propeller – 16 cm diameter
- Propeller – 18 cm diameter
- Propeller – 20 cm diameter
  (see Fig. 1.5)
- Two crossed propellers – 16 cm diameter
- Inverted propeller – 16 cm diameter
  (see Fig. 1.6)
- Multimeter
- Cables
- Wind machine
- Generator
- Stand for the generator

Fig. 1.5: Propellers 16 cm, 18 cm, 20 cm. (Inscription on the blade should be directed toward the generator)

Fig. 1.6: Two crossed propellers, 16 cm (inscription is directed toward the generator), and inverted propeller (inscription is directed toward the wind machine).

Procedure

The distance between wind machine and propeller is again 0.4 m throughout all measurements in this part (Fig. 1.7).

Fig. 1.7: Wind machine (left) and propeller (right).

The propeller is mounted on the generator using the white piece of plastic (Fig. 1.8). The multimeter is connected to the generator by crocodile clips.

Fig. 1.8: Propeller mounted on the generator.

Measure the off-load voltages U_0 for all propellers and for all levels of the wind machine. Start each measurement with one type of propeller at level 1, and the wind machine should run for at least 15 seconds on each level. Since the voltage values displayed may fluctuate throughout your measurements you will have to carefully observe and make a decision on the average value.

Insert the voltage values recorded into Table 1.2 ⇨ *Answer sheet*

1.3. Output power of various propellers

The voltage alone is not a definitive characteristic of a wind generator. More importantly, the power that can be produced when a load is attached to the generator must be taken into consideration. The power can be calculated using values of the current passing through a resistor and the corresponding voltage.

Materials:

- Wind machine
- Generator with different propellers: 16, 18, 20, 16/16, 16 (inverted)
- Two connection cables (black, red) from the generator
- Multimeter with cables
- Calculator
- Tape measure

The distance between the wind machine and the propeller is again 0.4 m. The generator should be connected to the multimeter as shown in figure 1.9.

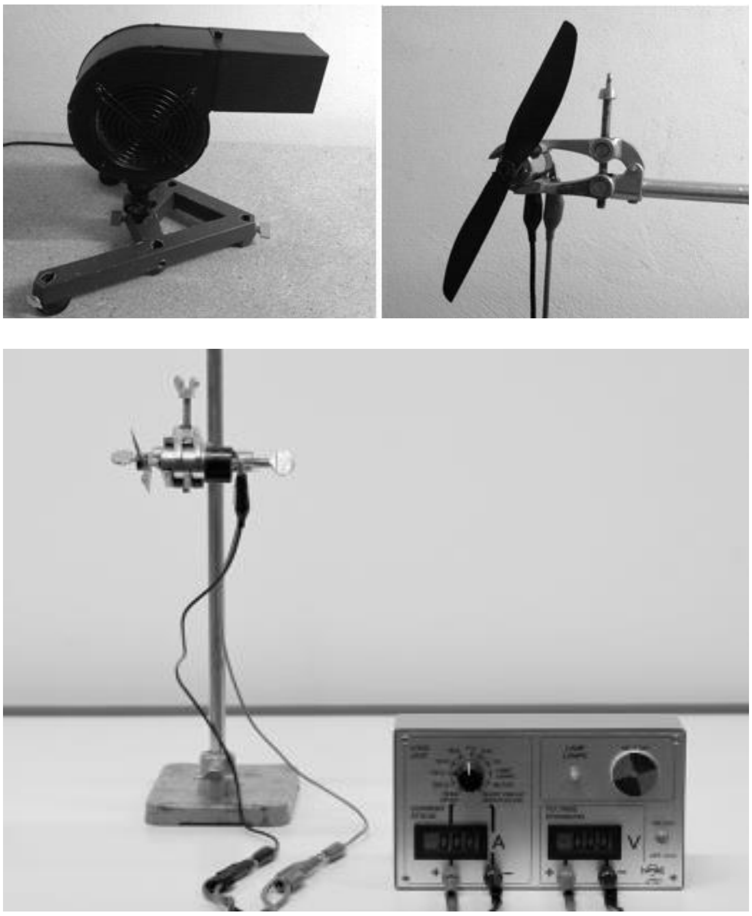


Fig. 1.9: Wind machine, propeller and connections to the multimeter.

Switch the wind machine to level 5.

The resistance ("Load Last" on the box), should be varied from 1 Ω to 200 Ω (seven levels).

- **Insert the measured values of voltage and current into Tables 1.3.** ⇨ *Answer sheet*
- **Calculate the corresponding power and insert these values into the table.**

⇨ *Answer sheet*

If needed ask the laboratory assistant for the formula of power. 5 marks will be deducted.

Caution: The values may not be strictly constant – use average values.

- **Draw the values for the power in the diagrams.** ⇨ *Answer sheet!*

2. Measurements on a model of a PowerToGas facility

The conversion of electric power to gas is a possibility for storing energy. Water is split into hydrogen and oxygen through electrolysis and electrical energy is transferred to chemical energy. Later on, a fuel cell may enable the inverse process, the transfer from chemical to electrical energy.

2.1. Electrolysis

Investigate the process of electrolysis. How much electrical energy is needed to produce a certain amount of hydrogen? How high is the efficiency of this model?

Material

- Wind machine
- Generator
- Propeller – 16 cm diameter (not inverted)
- Multimeter (measure the voltage and the current at the electrolyser). Rotary switch (electric load): Short Circuit
- Electrolyser: Fill it with distilled water
- Cables
- Stopwatch

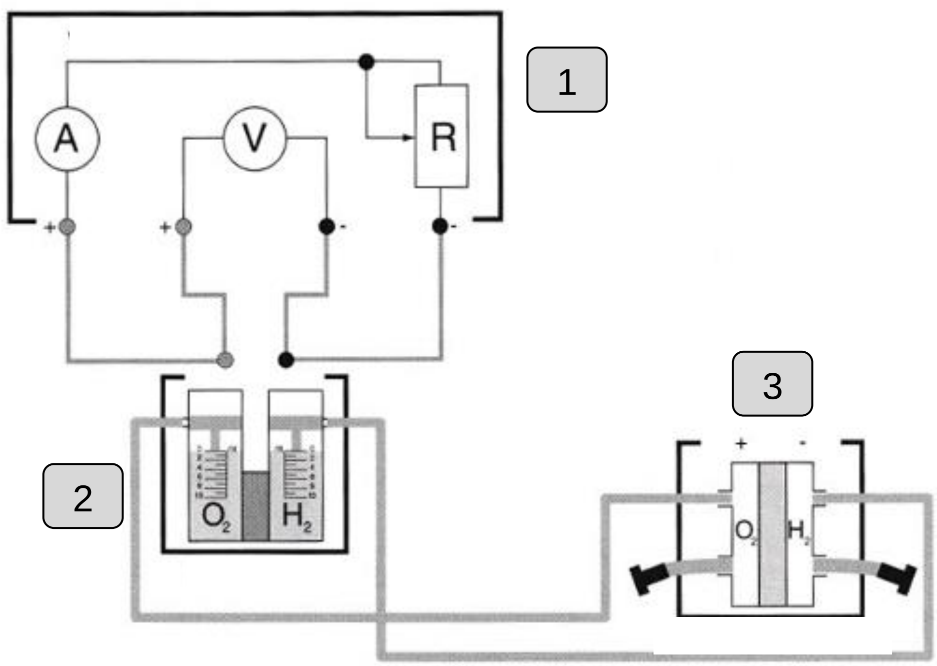


Fig. 2.1: Circuit diagram: V, A, and R are part of the multimeter (1); electrolyser (2); fuel cell (3). The cables to the generator are not shown. They should be connected to the poles of the electrolyser (see text).

Procedure

Assemble the model according to Fig. 2.1.

The fuel cell is already connected to the electrolyser (hoses with shut-off valves), it will be used later (2.2).

Hint: Connect first the circuit generator – electrolyser – multimeter (measurement of the current). Then establish the measurement of the voltage. Pay attention to the correct polarity (+ of the generator has to be connected to + of the electrolyser).

Before you continue, the circuit has to be confirmed by a lab assistant on the answer sheet.

2.1.1. Measurement of the power at the electrolyser with different air speeds

The wind machine should be mounted 0.2 m (half of the usual distance!!) in front of the propeller.

Measure the voltage and current for each of the five levels of the wind machine ⇨ *Answer sheet*
(It should run for about 1 minute, take average values).

Calculate the power at the electrolyser. Insert the values into Table 2.1.1 ⇨ *Answer sheet*

2.1.2. Production of hydrogen

Use the same equipment as before (level 5) and determine how much energy is needed to produce 10 ml of hydrogen gas.

Procedure

Pay only attention to the column of hydrogen gas. Start at zero value (if the value is too high, then release some gas). Once the production of gas starts be sure to also start the stopwatch. Stop the stopwatch once 10 ml of hydrogen gas has been collected.

Measure the voltage and current (average values) and the time needed for the production of 10 ml of hydrogen. Record the values on the answer sheet**.** ⇨ *Answer sheet*
Calculate the electrical energy that is needed by the electrolyser to produce 10 ml of hydrogen, using the power and the time. Insert your result into table 2.1.2 ⇨ *Answer sheet*

If needed ask the laboratory assistant for the formula of electric energy. 1 mark will be deducted.

2.1.3. Efficiency of the electrolysis procedure

The calorific value of hydrogen is 10.7 MJ/m^3 (at experimental conditions)

Calculate the efficiency of the apparatus using the result from 2.1.2! Insert your result
⇨ *Answer sheet*

2.2 Fuel cell

A fuel cell produces electrical energy from chemical energy (hydrogen).

Material:

- Electrolyser with hoses and shut-off valve
- Fuel cell
- Multimeter
- Cables

Procedure

There should still be available 10 ml hydrogen gas and at least 5 ml oxygen gas in the electrolyser from the last experiment. If not, you will have to use the wind machine-propeller-generator system to produce the required amount of gas.

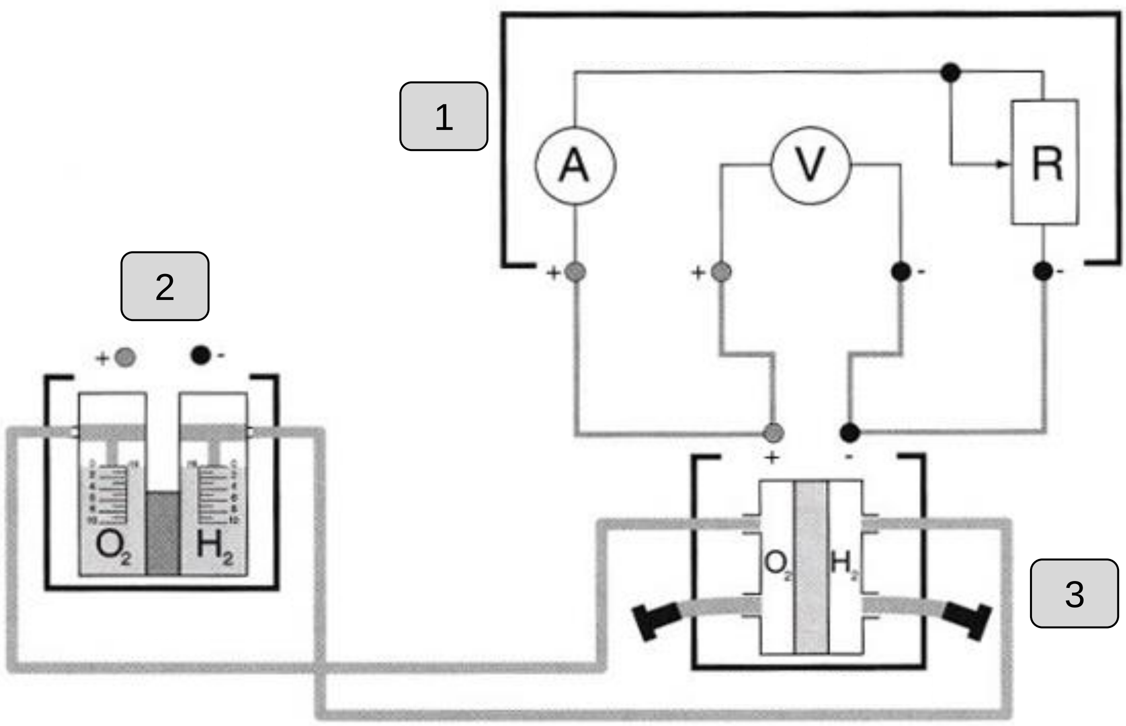


Fig. 2.2: Circuit diagram: V, A, and R are part of the multimeter (1); electrolyser (2); fuel cell (3). The multimeter should now be connected to the fuel cell.

Close a circuit with the fuel cell, 3-Ohm resistor and Amperemeter of the multimeter (Fig. 2.2).

2.2.1. Released electrical energy of a fuel cell

Determine the time it takes to transfer 10 ml hydrogen back into electric energy. Calculate the amount of electrical energy with the measured values of voltage, current, and time.
Insert these values ⇨ *Answer sheet*

2.2.2. Efficiency of the fuel cell

Determine the efficiency of the fuel cell by comparing the caloric energy of 10 ml hydrogen and the released electrical energy. ⇨ *Answer sheet*

3. Comparison of realistic facilities

The following calculations should give an answer whether a planned pump storage facility or a PowertoGas facility are best suited for storing electric energy. Can the energy produced by a wind power plant be stored by each facility? Which facility has better efficiency?

3.1. Power of a planned wind power plant

The power, which can be taken out of a wind of speed *v* by a modern wind turbine, can be calculated by the following formula:

$$P = c_{Betz} \cdot \frac{\rho}{2} \cdot v^3 \cdot A$$

P: power in Watt
c_{Betz}: power coefficient, modern facilities have approximately $c_{Betz} \approx 0.5$
ρ: density of air (ρ = 1,19 kg/m³ at 20°C)
v: speed of wind (m/s)
A: area covered by the rotating rotor blades (m²)

The wind power plant should consist of 10 wind turbines with rotor blades of 35 m length.

3.1.1. Calculate the power of this wind power plant assuming a wind speed of 40 km/h.
Give the result in units of Megawatt (MW). ⇨ *Answer sheet*

3.1.2. Calculate the energy which is produced in one day (MWh) under these conditions.
⇨ *Answer sheet*

3.2. Power of a planned pump storage facility

The planned construction has a drop height of water of 250 m. The maximum flow rate is 50 m³ per second. The power can be calculated from the gravitational potential energy of the water.

The same flow rate (50 m³/s) is also manageable in pumping water up to a height of 250 m. The efficiency of this procedure is 60 %, i.e. 60 % of the incoming energy can be stored in the water.

3.2.1. Power of the facility

Calculate the potential energy of the water pumped up in 1 s.
⇨ *Answer sheet*

If needed ask the laboratory assistant for the formula of potential energy. 1 mark will be deducted.

- #### 3.2.2 Energy in the system

Calculate: How much water can be transported up each day, assuming maximum power of the wind power plant? ⇨ *Answer sheet*

- #### 3.2.3 Total efficiency

If the water is released and flows through the turbine, the efficiency of generating electrical energy is 80 %.

Calculate the total efficiency of the pump storage facility
⇨ *Answer sheet*

3.3. Dimensions and efficiency of a planned PowertoGas facility

3.3.1. Electrolysis

The planned facility can produce hydrogen gas from electrical energy with an efficiency of 70%.

Calculate the amount of hydrogen gas that can be produced each hour, if the wind power plant runs at full power. ⇨ *Answer sheet*

Hint: Use the results of 3.1.

3.3.2. Total efficiency of the PowertoGas facility

A modern fuel cell has an efficiency of 50 %.

Calculate the total efficiency of the electrolysis-fuel cell facility. ⇨ *Answer sheet*

3.4. Comparison of both facilities

You, as an evaluator, now have to compare and judge the two facilities. As constraints, you have to consider:

The capacity of the upper reservoir of the pump storage facility is 80 million m³ at most.

The gas storage of the electrolysis facility has a flow rate of 2000 m³ hydrogen per hour, at most.

Which of these two facilities do you recommend for construction?

Insert your results and decision in Table 3.4! ⇨ *Answer sheet*

Task D

Recommendation of the science team for the power station construction in Klein Virtulien

1. **Summarize your results as a team in the table "Findings" to help you come to a common statement in table "Recommendation"!** ⇨ *Answer sheet*

2. **Indicate your team recommendation in the table "Recommendation"!** ⇨ *Answer sheet*

Task E

Facts about....

Evaluate the statements in the table "Facts about…."! ⇨ *Answer sheet*