14th INTERNATIONAL JUNIOR SCIENCE OLYMPIAD

THE NETHERLANDS 2017

Water and sustainability

Multiple Choice Test

December, 5th 2017

Carefully read the “EXAMINATION RULES” and “EXAM INSTRUCTIONS”

Radboud Universiteit

Hogeschool van Arnhem en Nijmegen

QUADRAAM GELDERSE ONDERWIJS GROEP

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EXAMINATION RULES

1. You are NOT allowed to bring any personal items into the examination room, except for the water bottle, personal medicine or approved personal medical equipment.
2. You must sit at your designated desk.
3. Check the stationery items (pen, calculator, and scrap paper) provided by the organizers.
4. Do NOT start answering the questions before the **“START”** signal.
5. You are NOT allowed to leave the examination room during the examination except in an emergency in which case you will be accompanied by a supervisor/volunteer/invigilator.
6. If you need to visit the bathroom, please raise your hand.
7. Do NOT disturb other competitors. If you need any assistance, raise your hand and wait for a supervisor to come.
8. Do NOT discuss the examination questions. You must stay at your desk until the end of the examination time, even if you have finished the exam.
9. At the end of the examination time you will hear the **“STOP”** signal. Do NOT write anything more on the answer sheet after this stop signal. Arrange the exam, answer sheets, and the stationary items (pen, calculator, and scrap paper) neatly on your desk. Do NOT leave the room before all the answer sheets have been collected.

EXAM INSTRUCTIONS

1. After the "START" signal, you will have 3 hours to complete the exam.
2. ONLY use the pen and pencil provided by the organizers.
3. Check that your name, code and country are on your answer sheet and sign your answer sheet. Raise your hand, if you do not have the answer sheet.
4. Read each problem carefully and indicate your answer on the answer sheet using a cross (as shown below). There is only one correct answer for each question.

   Example: *(A) is your answer*.

1	~~A~~	B	C	D

5. If you want to change your answer, circle your first answer and then indicate your new answer using a cross (as shown below). You can only make ONE correction per question.

   Example: *(A) is your first answer and (D) is your final answer*.

1	~~A~~	B	C	~~D~~

6. Only the answer sheet will be evaluated. Before writing your answers on the answer sheet, use the scrap paper provided.
7. Point rules

   Correct answer : + 1 point
   Wrong answer : − 0.25 point
   No answer : no point

8. The total number of questions is 30. Check that you have a complete set of the test questions (15 pages, page 5 – page 19) after the "START" signal is given. Raise your hand, if you find any missing sheets.
9. Useful information for answering the questions (atomic masses, constants and formulas) is provided on page 4.

GENERAL INFORMATION

The first twenty elements of the Periodic System with their standard atomic weights							
H 1.008							**He** 4.003
Li 6.941	**Be** 9.012	**B** 10.81	**C** 12.01	**N** 14.01	**O** 16.00	**F** 19.00	**Ne** 20.18
Na 22.99	**Mg** 24.31	**Al** 26.98	**Si** 28.09	**P** 30.97	**S** 32.06	**Cl** 35.45	**Ar** 39.95
K 39.10	**Ca** 40.08						

Constants

acceleration due to gravity: g = 9.81 m/s^2

gas constant R = 8.3145 J/(mol K)

Formulas

area of a circle: $A = \pi r^2$

circumference of a circle: $C = 2\pi r$

volume: $V = Ah$

density: $\rho = \frac{m}{V}$

pressure: $p = \frac{F}{A}$

heat: $Q = mc\Delta T$

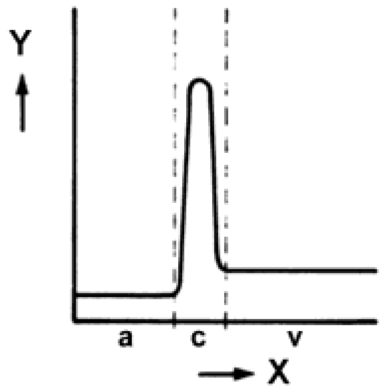
power: $P = \frac{E}{t}$

gravitational potential energy: $E_p = mgh$

Ohm's law: $V = IR$

Biology questions – Corrected version

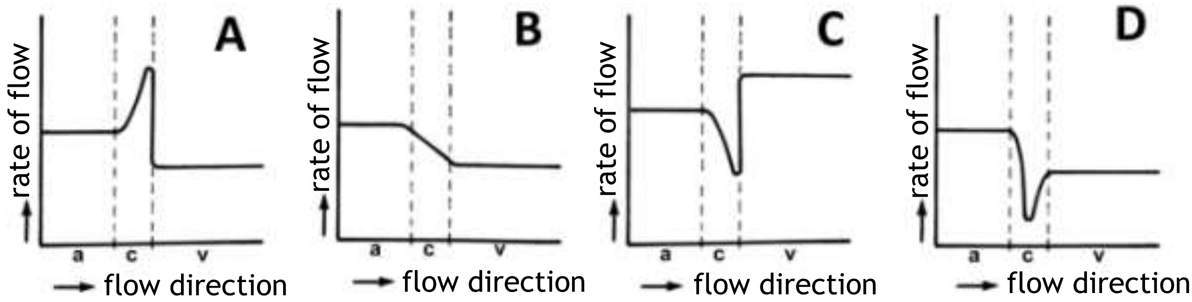
Rate of flow of blood



In a muscle in the upper arm of a human, blood runs through arteries, capillary vessels and veins. The picture shows the total area of a cross section of one of these arteries (a), the subsequent capillary vessels (c) and the corresponding returning veins (v).

X = direction of the blood flow
Y = total area of cross section

1. Which of the following pictures correctly shows the rate of flow (velocity) of the blood through an artery, a capillary vessel and a vein concerned?



Fermentation and Respiratory Quotient RQ

Floris investigates the conversion of glucose by yeast. The glucose is converted anaerobically as well as aerobically. Consider the reaction equations:

Aerobic: $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$
Anaerobic: $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$

Floris starts off with a solution containing 0.50 mol of glucose and some yeast. By measuring the loss of mass he is able to determine the amount of CO_2 generated.

When all the glucose is converted, the total loss in mass due to the generation of CO_2 is 79.2 g (= 1.8 mol CO_2). Floris assumes that no carbon dioxide remains in the solution. Now Floris is able to calculate the Respiratory Quotient of the process.

The Respiratory Quotient is defined as:

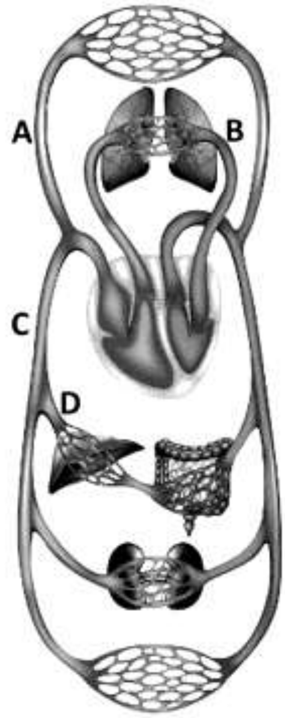
$$RQ = \frac{\text{moles of CO}_2\ \text{(produced)}}{\text{moles of O}_2\ \text{(used)}}$$

2. What is the correct Respiratory Quotient?

A $RQ = 0.67$
B $RQ = 1.2$
C $RQ = 1.5$
D $RQ = 1.8$

Glucose concentration in blood

The picture shows blood circulation in a mammal.
Four locations are indicated by A, B, C and D.

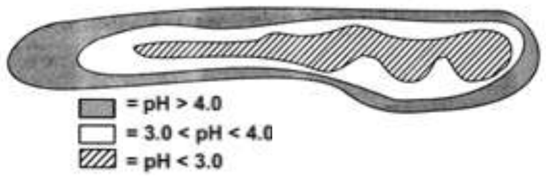


3. Which location has the lowest glucose concentration?

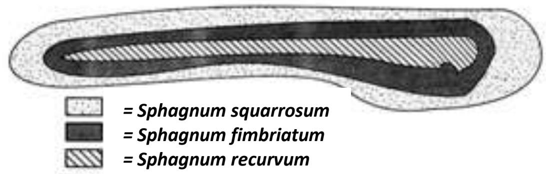
Sphagnum

The distribution of *Sphagnum* (moss) species is influenced by pH, but not by other abiotic factors.
After a long period of stable weather conditions Tom investigates the distribution of three different *Sphagnum* species on a small island surrounded by brackish water. The results are shown below.

pH distribution



moss distribution



Three conclusions are:

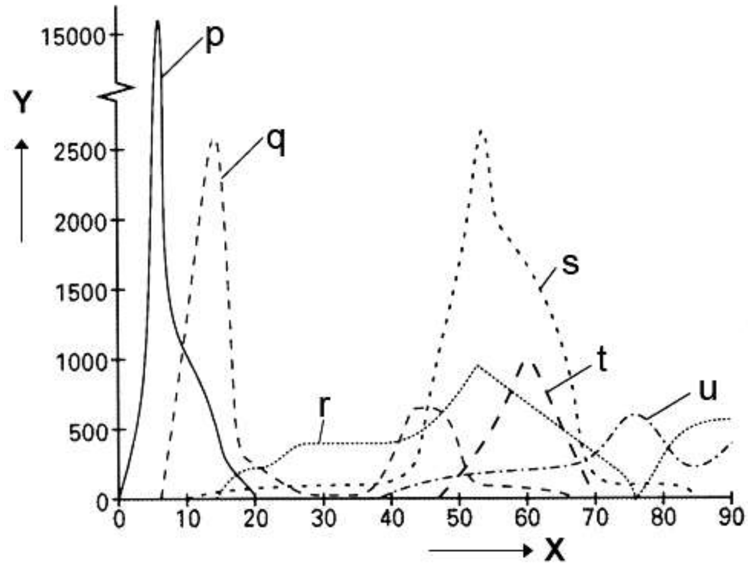
I *Sphagnum squarrosum* can only survive if pH > 4.0.
II Competition occurs between *Sphagnum recurvum* and *Sphagnum fimbriatum*.
III *Sphagnum recurvum* and *Sphagnum squarrosum* have overlapping habitats.

4. Which conclusion(s) are correct?

A only II
B only I and III
C only II and III
D I, II and III

Hay water

Mary boiled water and dried grass in a beaker for some time, and left it uncovered for several days. During that period only heterotrophic bacteria were found in the beaker. After ten days, she added a few drops of water from a ditch and covered it with a lid. The water from the ditch only contained heterotrophic unicellular organisms, but no bacteria or fungi. Mary regularly determined the population size of the different species present in the beaker over three months. Alltogether six different species (p - u) were found. The diagram shows the number of individuals per mL in the beaker.



X = Time (days); Y = number of individuals per mL

Looking at the results Mary considers two conclusions.

I Eventually the number of dividing bacteria will decrease to zero.

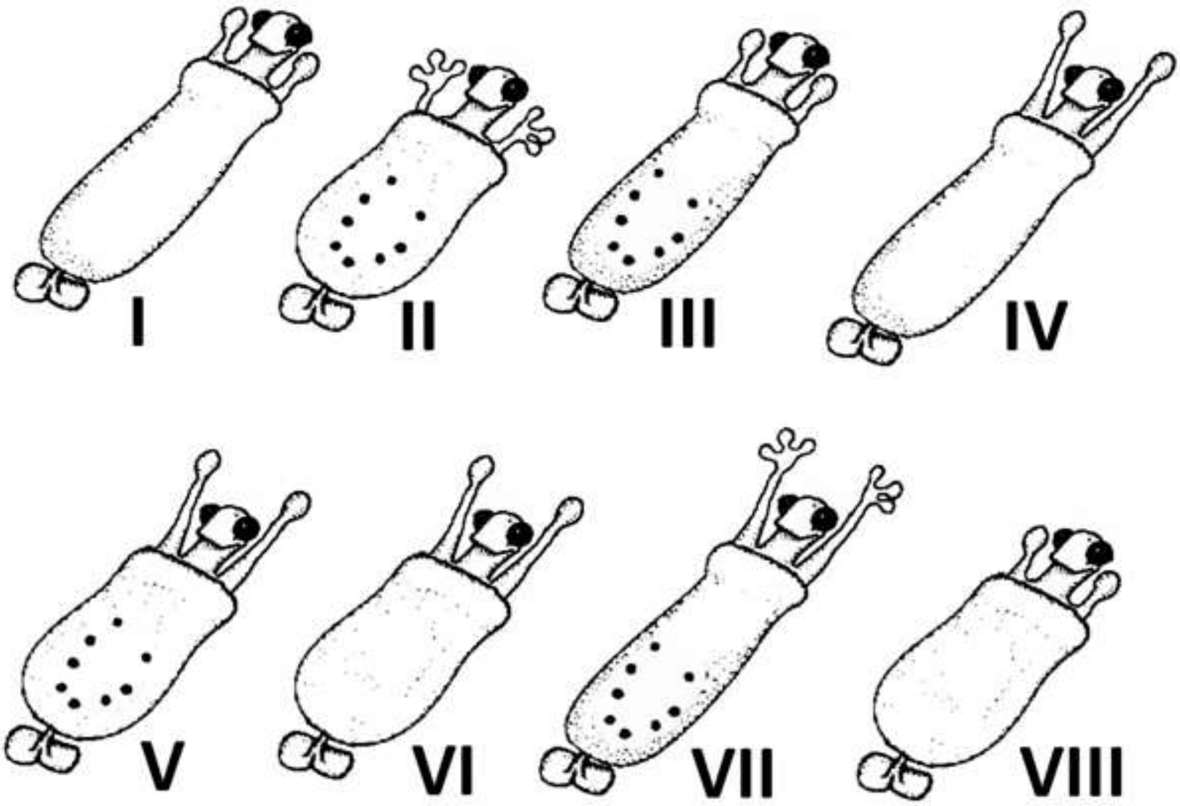
II Eventually a climax stage will develop, comprising bacteria and other heterotrophic unicellular organisms, in a stable natural equilibrium.

5. Which conclusion(s) is/are correct?

A only I
B only II
C both I and II
D neither I nor II

Identification of Caminalcules

In modern biology DNA plays an important role in distinguishing different species. In the past this was done primarily by considering external characteristics. The picture below shows *Caminalcules*: non-existent creatures invented by Joseph Camin to demonstrate to his students how to distinguish species and set up evolutionary trees.



The eight *Caminalcules* shown can be distinguised with just three of the following four features:
Long arms, long body, presence of belly spots, and presence of fingers.

6. Which of the following four features is **NOT** needed?

A long arms
B long body
C presence of belly spots
D presence of fingers

Water loss

In a pilot study the daily water loss of a group of subjects is monitored under different conditions. Three processes are monitored: diffusion (not sweating) of water through skin, lung ventilation, and urine production.
The table shows the results in a random order.

	Average daily loss of water in mL/day		
	mild exercise at 20 °C	mild exercise at 30 °C	strenuous exercise at 20 °C
Process I	350	250	650
Process II	50	50	50
Process III	1400	1300	600

7. Which processes correspond to lung ventilation and urine production?

	lung ventilation	urine production
A	process I	process II
B	process I	process III
C	process II	process III
D	process III	process I

Temperature-sensitive alleles

Some fly species have alleles that are temperature sensitive. Fertilized eggs only develop below a specific temperature, see the table below.

Genotype	Temperature necessary for development
EE	< 18 °C
Ee	< 20 °C
ee	< 28 °C

Two flies, both with genotype Ee, mate. Their fertilized eggs (F1) are allowed to develop at 19 °C. The F1 flies mate randomly and the eggs produced are again allowed to develop at 19 °C.

8. What fraction of eggs produced in the F1 crossing will **not** develop?

A 1/9
B 2/9
C 4/9
D 6/9

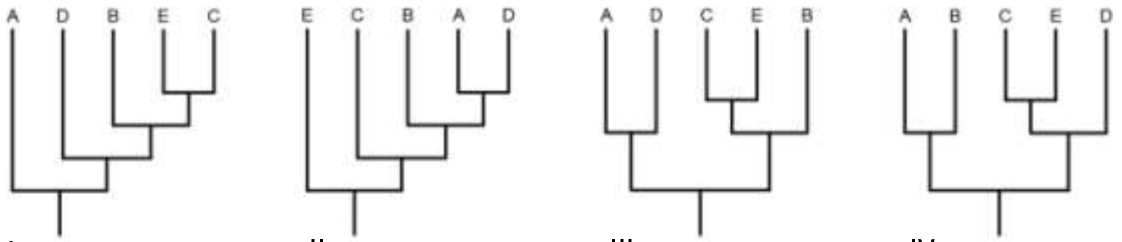
DNA and evolutionary relation

Several people (A - E) in the same city contract Legionnaires' disease. It is important to identify how many sources are causing this outbreak, and what those sources are, to prevent the disease from spreading. The pathogens' DNA is extracted, and the alleles of seven of its genes are determined to identify the number of sources. Then, for each pair of patients, we count how often the alleles for those seven genes are different, known as the 'distance' between the patient's pathogens. If the two pathogens of two patients are identical on all seven genes, then the distance is 0, whereas if the pathogens have different alleles for all seven genes, the distance is 7. The distances for all pairs of patients A - E are given below in the 'Distance matrix'.

Distance matrix					
Patient A	Patient B	Patient C	Patient D	Patient E	
	5	5	1	4	Patient A
		2	5	2	Patient B
			6	1	Patient C
				6	Patient D
					Patient E

The data in the table can be used to depict the relation of the pathogens in patients A - E as a dendrogram (tree structure).

9. Which of the dendrograms below corresponds to the distance matrix?



I II III IV

A I
B II
C III
D IV

Legionella

Strains of *Legionella* (the bacterium responsible for Legionnaires' disease) can be identified by means of the allele for the gene *flaA*. This gene codes for a protein that is part of the bacterium's flagellum.

The bases 670 to 700 of the <u>coding strand</u> (the complement of the template strand) of the DNA of an allele of *Legionella*'s *flaA* gene are represented below. Bases 197 to 199 make up the start codon.

	670---700	
5'	T T T C A G T A T C G G C A G C A C A A A A G C T T C T T C T	3'

10. What is the correct order of the amino acids in the part of the protein that is coded for by the DNA fragment above? Use the table below, in which the genetic code is depicted.

standard genetic code									
1st base (5'-end)	**2nd base**								**3rd base (3'-end)**
	U		**C**		**A**		**G**		
U	UUU	Phe (F)	UCU	Ser (S)	UAU	Tyr (Y)	UGU	Cys (C)	**U**
	UUC		UCC		UAC		UGC		**C**
	UUA	Leu (L)	UCA		UAA	Stop	UGA	Stop	**A**
	UUG		UCG		UAG	Stop	UGG	Trp (W)	**G**
C	CUU		CCU	Pro (P)	CAU	His (H)	CGU	Arg (R)	**U**
	CUC		CCC		CAC		CGC		**C**
	CUA		CCA		CAA	Gln (Q)	CGA		**A**
	CUG		CCG		CAG		CGG		**G**
A	AUU	Ile (I)	ACU	Thr (T)	AAU	Asn (N)	AGU	Ser (S)	**U**
	AUC		ACC		AAC		AGC		**C**
	AUA		ACA		AAA	Lys (K)	AGA	Arg (R)	**A**
	AUG	Met (M)	ACG		AAG		AGG		**G**
G	GUU	Val (V)	GCU	Ala (A)	GAU	Asp (D)	GGU	Gly (G)	**U**
	GUC		GCC		GAC		GGC		**C**
	GUA		GCA		GAA	Glu (E)	GGA		**A**
	GUG		GCG		GAG		GGG		**G**

A Phe - Ser - Ile - Gly - Ser - Thr - Lys - Ala - Ser - Ser
B Phe - Gln - Tyr - Trp - Gln - His - Lys - Ser - Phe - Phe
C Ser - Val - Ser - Ala - Ala - Gln - Lys - Leu - Leu
D Lys - Ser - *Stop*

Chemistry questions

Photosynthesis by algae

Surface water can contain organic and inorganic matter. In many surface water most of the organic matter is formed by photosynthesis. Phytoplankton, such as algae, are one of the major producers of organic matter. In this organic matter carbon atoms, nitrogen atoms and phosphorous atoms often occur in the following ratio: C : N : P = 106 : 16 : 1. Organic matter produced during photosynthesis by algae can be described by the formula $C_{106}H_{263}O_{110}N_{16}P$.

The following incomplete equation summarizes phytoplankton photosynthesis:

$$\_\ NO_3^{-} + \_\ HPO_4^{2-} + \_\ H^{+} + \ldots \rightarrow C_{106}H_{263}O_{110}N_{16}P + \ldots \qquad \text{(equation 1)}$$

In this equation some coefficients are missing as well as the formulas of some molecules.

11. Which molecules are missing in this incomplete equation?

	on the left	on the right
A	CO_2	H_2O and O_2
B	CO_2 and H_2O	O_2
C	CO_2 and O_2	H_2O
D	O_2	CO_2 and H_2O

12. What should the coefficient of H^+ be when equation 1 is balanced?

A 3
B 16
C 17
D 18

Green chemistry

Green chemistry is an area of chemistry and chemical engineering that deals with the development of sustainable production processes.
Two important concepts in green chemistry are atom economy and the E – factor. The formulas for these concepts are:

$$\text{atom economy} = \frac{\text{mass of the desired product}}{\text{mass of the starting materials}} \times 100\%$$

and

$$E - \text{factor} = \frac{\text{mass of the starting materials} - \text{mass of the obtained product}}{\text{mass of the obtained product}}$$

13. Which words have to be filled in for I and for II in the sentence below?

A green process has a ..I.. atom economy and a ..II.. E – factor.

	I	II
A	high	high
B	high	low
C	low	high
D	low	low

Determination of oxygen

Dissolved oxygen (O_2) is important for underwater life. The concentration of oxygen in polluted surface water can decrease dangerously. Therefore this concentration is determined regularly.
The concentration of dissolved oxygen can be determined with a titration. A sample of 10.00 mL is taken from the surface water. The sample is treated with an acidic solution of potassium iodide after which the following reaction takes place:

$O_2 + 4\,H^+ + 4\,I^- \rightarrow 2\,I_2 + 2\,H_2O$

An excess of an acidic solution of potassium iodide is added to make sure that all oxygen reacts.
Next the iodine is titrated with a 0.0100 M solution of sodium thiosulfate ($Na_2S_2O_3$). The following reaction takes place:

$I_2 + 2\,S_2O_3^{2-} \rightarrow 2\,I^- + S_4O_6^{2-}$

Starch is used to indicate the endpoint of the titration.

A student performed the determination. At the end of the titration the solution turned colorless when the last drop of the solution of sodium thiosulfate was added, as it should. Nevertheless it turned out that the calculated concentration of dissolved oxygen higher than expected.

14. Which of the following errors could be responsible for this result?

I After rinsing the burette with distilled water the burette was immediately filled with the solution of sodium thiosulfate.
II At the start of the titration the nozzle through which the titrant should leave the burette was filled with air, not with the solution of sodium thiosulfate.

A only I
B only II
C both I and II
D neither I nor II

The numerical value of the concentration of dissolved oxygen in mg per liter is given by the relation $K \times V_{\text{thio}}$.

In which V_{thio} is the volume, in mL, of the sodium thiosulfate solution that was used in the titration.

15. What is the value of K?

A 4.00
B 8.00
C 16.0
D 32.0

Fertilizer from urine

In some open air rock festivals in The Netherlands, the urine that those attending produce is collected. This urine is first treated in such a way that the urea in it is converted into ammonium salts. Then the pH of the solution is adjusted and a solution of magnesium chloride is added, to give an insoluble compound called struvite. The formula of struvite is $MgNH_4PO_4.6H_2O$. In this way phosphate is recovered, which contributes to slowing the depletion of natural sources of phosphorous. Also a useful fertilizer is obtained.

The pH of the solution is important, as both phosphate and ammonium are involved in pH dependent equilibria. In Figure 1 the percentage occurrence of H_3PO_4, $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-} as a function of pH is given. In Figure 2 the percentage occurrence of NH_4^+ and NH_3 as a function of pH is given.

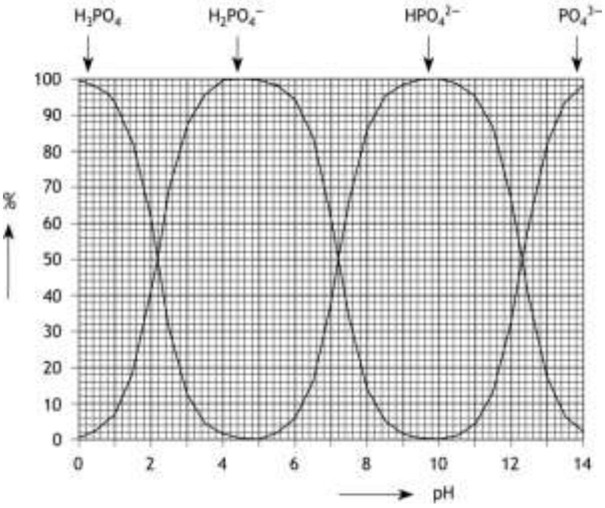


Figure 1

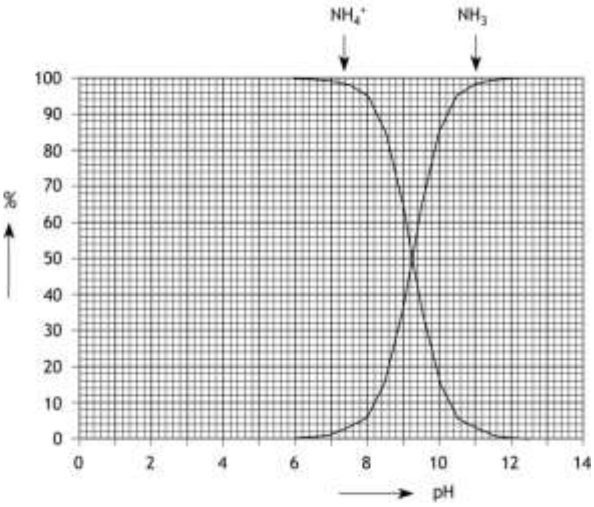


Figure 2

The reaction wherein struvite is formed, is carried out at a pH of about 8.
The reaction equation shows the main species that are present in the solution.

16. Which equation describes the formation of struvite at pH = 8?

A $Mg^{2+} + NH_3 + 7\ H_2O + PO_4^{3-} \rightarrow MgNH_4PO_4.6H_2O + OH^-$
B $Mg^{2+} + NH_4^+ + PO_4^{3-} + 6\ H_2O \rightarrow MgNH_4PO_4.6H_2O$
C $Mg^{2+} + NH_3 + HPO_4^{2-} + 6\ H_2O \rightarrow MgNH_4PO_4.6H_2O$
D $Mg^{2+} + NH_4^+ + HPO_4^{2-} + 5\ H_2O + OH^- \rightarrow MgNH_4PO_4.6H_2O$

Hydrogen fuel cell

Hydrogen is regarded as a fuel of the future, because there is no emission of CO_2.
Hydrogen can be used in fuel cells.

17. Which reaction takes place at which electrode in a hydrogen powered fuel cell during use?

	positive electrode	negative electrode
A	$H_2 \rightarrow 2\ H^+ + 2\ e^-$	$O_2 + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O$
B	$H_2 + 2\ e^- \rightarrow 2\ H^+$	$O_2 + 4\ H^+ \rightarrow 2\ H_2O + 4\ e^-$
C	$O_2 + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O$	$H_2 \rightarrow 2\ H^+ + 2\ e^-$
D	$O_2 + 4\ H^+ \rightarrow 2\ H_2O + 4\ e^-$	$H_2 + 2\ e^- \rightarrow 2\ H^+$

Elimination of CO_2

Carbon dioxide is a greenhouse gas. During the combustion of fossil fuels, large amounts of carbon dioxide are formed. To prevent this from entering the atmosphere, one might consider to remove it using the so called water-gas shift reaction. In this reaction carbon dioxide reacts with hydrogen to form carbon monoxide and water:

$$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g)$$

The enthalpy of formation of CO_2, CO, and H_2O are as follows:
$CO_2(g)$: – 394 kJ/mol, CO(g): – 111 kJ/mol and $H_2O(g)$: – 242 kJ/mol.

18. What is the reaction enthalpy ($\Delta_r H$) of the forward reaction; is this reaction endothermic or exothermic?

	$\Delta_r H$	endothermic/exothermic
A	– 41 kJ/mol	endothermic
B	– 41 kJ/mol	exothermic
C	+ 41 kJ/mol	endothermic
D	+ 41 kJ/mol	exothermic

Using the water-gas shift reaction to prevent carbon dioxide from entering the atmosphere has the drawback that the highly toxic gas carbon monoxide is formed. Carbon monoxide can be converted into methanol by adding extra hydrogen gas. The formation of methanol from carbon monoxide and hydrogen is an equilibrium reaction:

$$CO(g) + 2\ H_2(g) \rightleftharpoons CH_3OH(g)$$

The forward reaction is exothermic.

19. Which of the following conditions favors the formation of methanol in this equilibrium reaction?

I high pressure
II high temperature

A only I
B only II
C both I and II
D neither I nor II

Fertilizers

The quality of surface water in the Netherlands is influenced by the use of fertilizers in agriculture. Many fertilizers contain nitrogen (N). It is important to reduce the use of nitrogen in fertilizer to minimize the nitrogen load of surface water.
Three nitrogen containing fertilizers are:
$(NH_4)_2SO_4$ (ammonium sulfate), $CaCN_2$ (calcium cyanamide), and $CO(NH_2)_2$ (urea).

20. Which of these fertilizers has the highest mass percentage of nitrogen?

A ammonium sulfate
B calcium cyanamide
C urea
D all three have the same mass percentage of nitrogen

Physics questions

Solar shower

You can use solar power to have a warm shower while camping. The Solar Camp Shower bag (see Figure 1), contains 15 kg of water with a temperature of 18 °C. On a sunny day, the water absorbs 200 W of solar power.

Figure 1: Solar Camp Shower.

21. How long does it take for the water to reach a temperature of 35 °C? (The specific heat of water is c = 4.2x10^3 J/(kg K).)

A 0.4 h
B 0.8 h
C 1.5 h
D 3.0 h

Liquid and vapor

Boiling transforms 1 liter of liquid into 1000 liters of vapor at a certain pressure.

Consider the following statements.

I The density of the vapor is 1/1000th times the density of the liquid.
II The average distance between the molecules in the vapor phase is 10 times the average distance between the molecules in the liquid phase.

22. Which of these statements is true?

A only I
B only II
C both I and II
D neither I nor II

Hydro pneumatic suspension

The hydro pneumatic suspension of some cars is equipped with spring bulbs. Such a metal bulb is filled with nitrogen gas. The purpose of the gas is to lift about ¼ of the weight of the car that rests on the suspensions, via a piston, oil and a rubber membrane (see Figure 2). The area of the rubber membrane is 200 cm^2. The weight of the car that rests on the suspensions is 16 000 N. Neglect the weight of the oil and the piston. The whole system is in rest. The pressure of the outer air is $1.0 \cdot 10^5$ Pa.

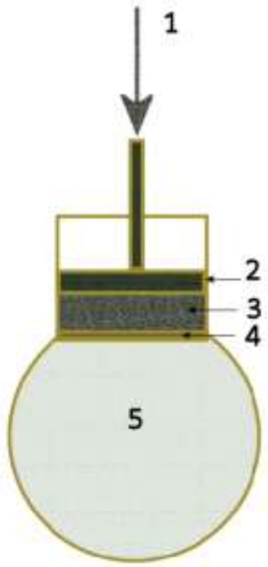


Figure 2: Spring bulb.
1 = ¼ weight of the car
2 = piston
3 = oil
4 = rubber membrane
5 = nitrogen gas

23. What is the pressure of the enclosed nitrogen gas?

A $2.0 \cdot 10^5$ Pa
B $3.0 \cdot 10^5$ Pa
C $8.0 \cdot 10^5$ Pa
D $12 \cdot 10^5$ Pa

Heating paraffin

A constant amount of heat is added per second to a certain amount of solid paraffin (see Figure 3).

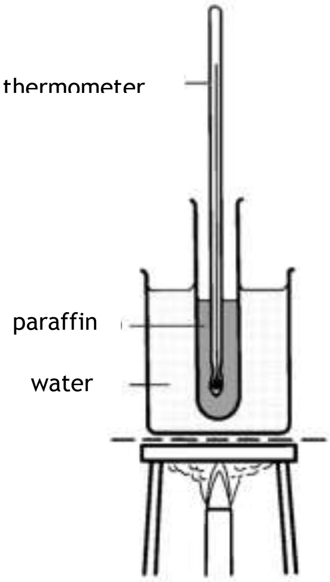


Figure 3: Experimental setup

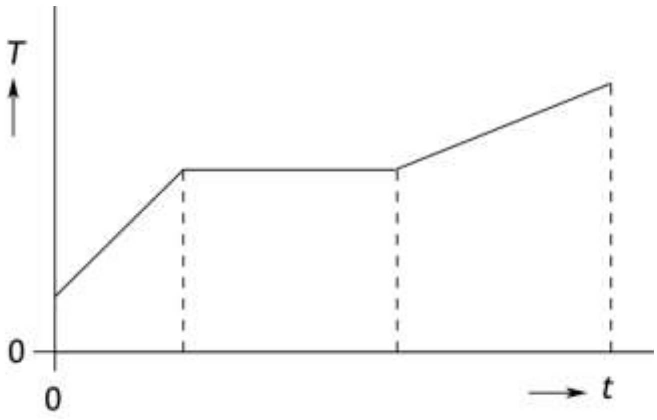


Figure 4: *T* - *t* diagram

The graph in Figure 4 displays the temperature (T) of the paraffin as a function of time (t).

Consider the following two statements regarding the change in the temperature of the paraffin.

I The specific heat capacity of liquid paraffin is smaller than that of solid paraffin.
II During melting, the potential energy of the molecules increases.

24. Which of these statement(s) is true?

A only I
B only II
C both I and II
D neither I nor II

A little boat and a bottle in a river

On a windless day, someone throws an empty sealed bottle in the river Waal, and the bottle floats downstream. At the same time, and at the same place, a powerboat sails upstream. After 10 minutes, the boat turns quickly around and travels downstream with the same power as before. After a while, the boat overtakes the bottle. At that time, the bottle and the boat are 3 km downstream from the initial starting point.

25. How fast does the river Waal flow on a windless day?

A 3 km/h
B 9 km/h
C 12 km/h
D 15 km/h

Electric circuit

In the circuit depicted in Figure 5, slide S is displaced along variable resistor R towards point X.

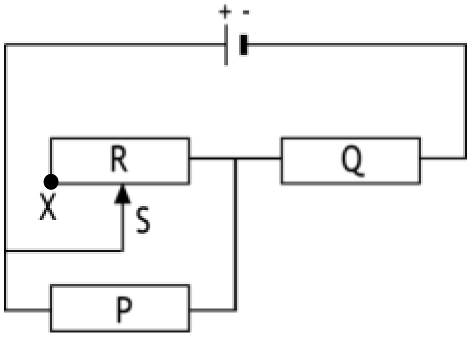


Figure 5: Electric circuit

26. How does the current passing resistors P and Q change?

	in P	in Q
A	increases	increases
B	increases	decreases
C	decreases	increases
D	decreases	decreases

Supertanker

A supertanker sails from the North Sea, via a river, to the port of Rotterdam.


Figure 6: Supertanker

27. Which statement about the draft (i.e. how deep a ship lies in the water) is true when the ship sails from the sea into the river?

A The tanker will have a deeper draft in the river.
B The tanker will have a shallower draft in the river.
C The draft will remain the same.
D The draft depends on the air pressure.

Electricity storage

In California, storage systems will be installed to improve regulation of the production of electricity by wind turbines. When there is an energy surplus, the wind turbine drives a flywheel. The cylindrical flywheel has a diameter of 0.90 m, a length of 1.5 m and a mass of 1 350 kg. The maximum frequency of the flywheel is 20 000 revolutions per minute. When the storage system has to supply electricity, the flywheel drives the generator. The rotational energy of a spinning object equals $E_{\text{rot}} = \frac{1}{2}I\omega^2$, with the moment of inertia $I = \frac{1}{2}mR^2$ for a cylinder with mass m and radius R that turns with angular velocity ω (in rad/s).

28. Taking these data into account, how much energy can maximally be stored by the flywheel?

A $7.6 \cdot 10^6$ J
B $1.5 \cdot 10^8$ J
C $3.0 \cdot 10^8$ J
D $1.2 \cdot 10^9$ J

Sky crane

A sky crane was used for the landing of the Mars explorer 'Curiosity'.
The four exhausts expel combustion gases that hold the crane at a constant height before landing. The four exhausts are arranged in an oblique arrangement. In Figure 7 you can see the thrust exerted on the crane by the gas from exhaust A. The thrust of the gas ejected from the other exhausts have the same magnitude and operate at the same angle.

Compare the thrust (F_{thrust}) at A to the gravitational force (F_g) on the whole system.

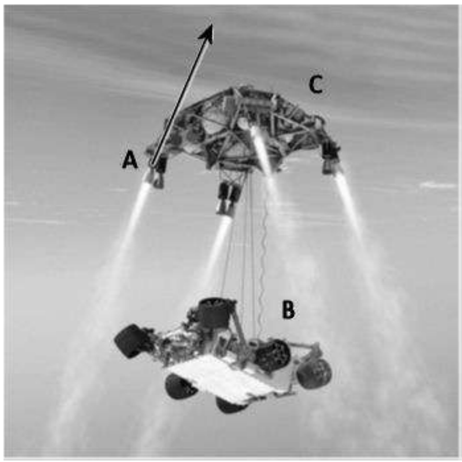


Figure 7: The landing system
A = One of the four exhausts
B = Mars explorer 'Curiosity'
C = Flying crane

29. Which statement is true?

A $F_{thrust} = F_g$
B $F_{thrust} = \frac{1}{4}F_g$
C $F_{thrust} < \frac{1}{4}F_g$
D $F_{thrust} > \frac{1}{4}F_g$

Properties of water

Two specific properties of water are highlighted below.

Property 1
The heat capacity of water is large compared to other common substances.

Property 2
The density of water behaves differently between 0 °C and 4 °C compared to other substances (see Figure 8).

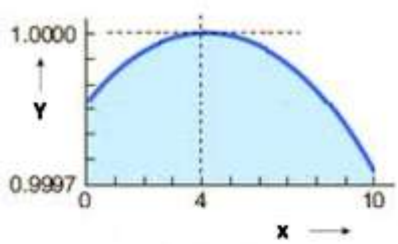


Figure 8:
Y = density of water in kg/dm^3
X = temperature in °C

Consider the following statements:

I Property 1 has a stabilizing effect on the average temperature on earth.
II Property 2 causes that liquid water with a temperature of + 4 °C will be located on the bottom of a ditch, when there is a thin layer of ice on top of the water.

30. Which of these statements is true?

A only I
B only II
C both I and II
D neither I nor II

Water and sustainability

Theoretical Test

December, 7th 2017

Carefully read the “EXAMINATION RULES” and “EXAM INSTRUCTIONS”

EXAMINATION RULES

1. You are NOT allowed to bring any personal items into the examination room, except for the water bottle, personal medicine or approved personal medical equipment.
2. You must sit at your designated desk.
3. Check the stationery items (pen, calculator, ruler, and scrap paper) provided by the organizers.
4. Do NOT start answering the questions before the **"START"** signal.
5. You are NOT allowed to leave the examination room during the examination except in an emergency in which case you will be accompanied by a supervisor/volunteer/invigilator.
6. If you need to visit the bathroom, please raise your hand.
7. Do NOT disturb other competitors. If you need any assistance, raise your hand and wait for a supervisor to come.
8. Do NOT discuss the examination questions. You must stay at your desk until the end of the examination time, even if you have finished the exam.
9. At the end of the examination time you will hear the **"STOP"** signal. Do NOT write anything more on the answer sheet after this stop signal. Arrange the exam, answer sheets, and the stationary items (pen, calculator, and scrap paper) neatly on your desk. Do NOT leave the room before all the answer sheets have been collected.

EXAM INSTRUCTIONS

1. After the "START" signal, you will have 3 hours to complete the exam.
2. ONLY use the pen and pencil provided by the organizers.
3. Check if your name, code and country name are filled in on your answer sheets and sign every page of the answer sheets. Raise your hand, if you do not have the answer sheets.
4. You have 18 pages of answer sheets - including the front page. Raise your hand, if you find any sheets missing.
5. Read the problems carefully and write the correct answers in the corresponding boxes of the answer sheets.
6. Only the answer sheets will be evaluated. Before writing your answers on the answer sheets you may use the scrap paper provided to avoid errors on your answer sheets.
7. The number of points that can be obtained is indicated for each question.
8. The total number of questions is 27. Check if you have a complete set of the test questions sheets (13 pages, page 6 - page 18) after the **"START"** signal is given. Raise your hand, if you find any sheets missing.
9. Useful information for answering the questions (atomic masses, constants and formulas) is provided on page 4.
10. Always show your calculations. If you do not show your calculations, no points are awarded for the question.
11. You should write your final answers down in the appropriate number of digits.

GENERAL INFORMATION

The first twenty elements of the Periodic System with their standard atomic masses							
H 1.008							**He** 4.003
Li 6.941	**Be** 9.012	**B** 10.81	**C** 12.01	**N** 14.01	**O** 16.00	**F** 19.00	**Ne** 20.18
Na 22.99	**Mg** 24.31	**Al** 26.98	**Si** 28.09	**P** 30.97	**S** 32.06	**Cl** 35.45	**Ar** 39.95
K 39.10	**Ca** 40.08						

Constants

acceleration due to gravity: $g = 9.81\ \mathrm{m/s^2}$

gas constant $R = 8.3145\ \mathrm{J/(mol\ K)}$

Formulas

area of a circle: $A = \pi r^2$

circumference of a circle: $C = 2\pi r$

volume: $V = Ah$

density: $\rho = \dfrac{m}{V}$

pressure: $p = \dfrac{F}{A}$

heat: $Q = mc\Delta T$

power: $P = \dfrac{E}{t}$

gravitational potential energy: $E_p = mgh$

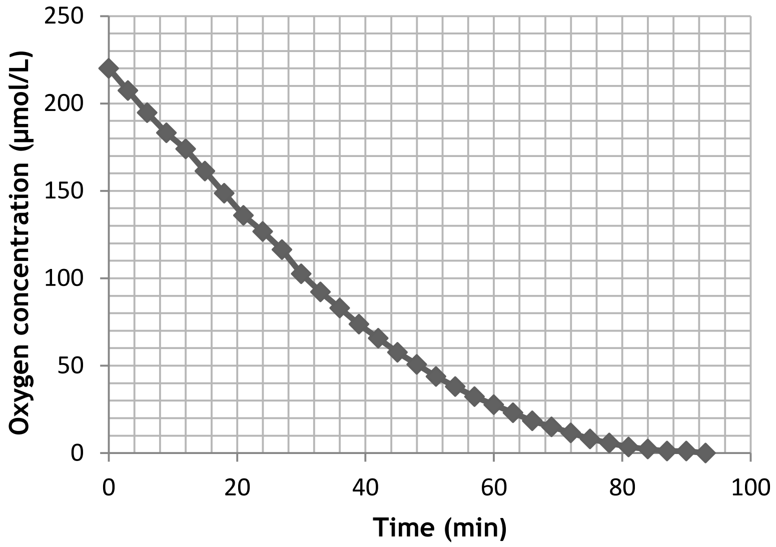
Ohm's law: $V = IR$

Biology questions

Plants in floodplains

The plants growing on the flood plains of the large rivers of the Netherlands are flooded regularly. Submerged plants can take up oxygen (for aerobic respiration) from the water around them, but since oxygen diffuses 10^4 times more slowly in water than in air, the plants are expected to suffer from oxygen deficiency.

This is measured by placing the plant in a closed box filled with water in the dark, and measuring the decrease in oxygen concentration in the box while stirring vigorously. The graph below shows the decrease in oxygen concentration with time in such a box. The graph is also given on your answer sheet.



1. (**1.2 points**) Use the graph on your answer sheet to determine the maximum (aerobic) respiration rate of this submerged plant (in µmol/min), given that the volume of the box is 1.2 L. Indicate in the graph how you obtained your answer. Give your answer in two significant figures.

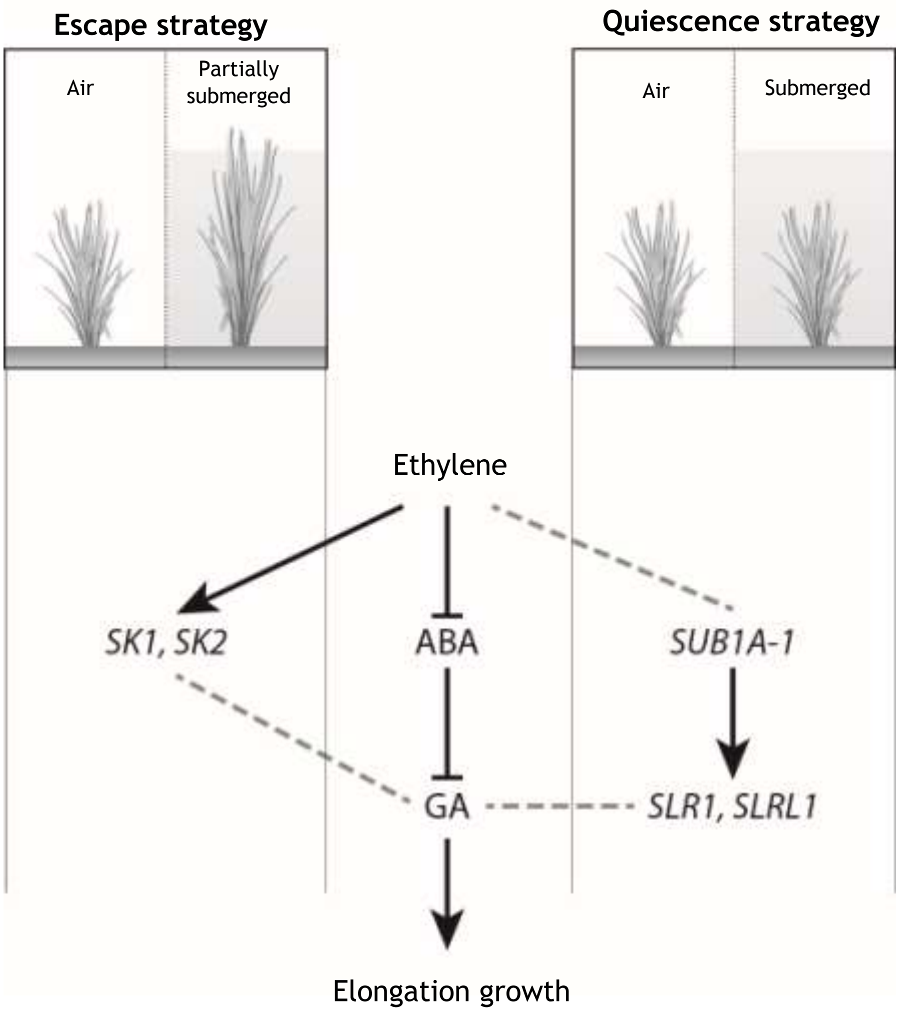
   If the plant in this box is submerged in fresh water under a bright lamp instead of being kept in the dark, the oxygen concentration does not change over time. This is due to underwater photosynthesis.

2. (**0.4 points**) What is the rate of oxygen production by underwater photosynthesis by the whole plant?

   Some plants, for example rice (*Oryza sativa*), can adapt quickly to flooding by adjusting their growth rate. Two strategies used by rice are illustrated in the figure on the next page: either by elongating rapidly, until it is partially above water ('Escape strategy'); or by halting its growth, preserving energy and oxygen until the water levels go down ('Quiescence strategy'). The figure is also given on your answer sheet.

Growth is regulated by the plant hormones gibberellic acid (GA), abscisic acid (ABA), and ethylene (see figure). Ethylene is a gaseous hormone, that diffuses poorly in water, but is highly volatile in air. Some genes that are involved in the regulation of plant growth are *SK1* and *SK2*, *SUB1A-1* and *SLR1* and *SLRL1*. Overexpression of *SLR1* under normal conditions is known to result in a dwarf phenotype.

3. (**1.2 points**) Complete the missing interactions for the two strategies by adding a notation to the end of each of the three dashed lines. Use an arrowhead (→) for enhancing interactions, or a perpendicular line (⊣) for inhibiting interactions.

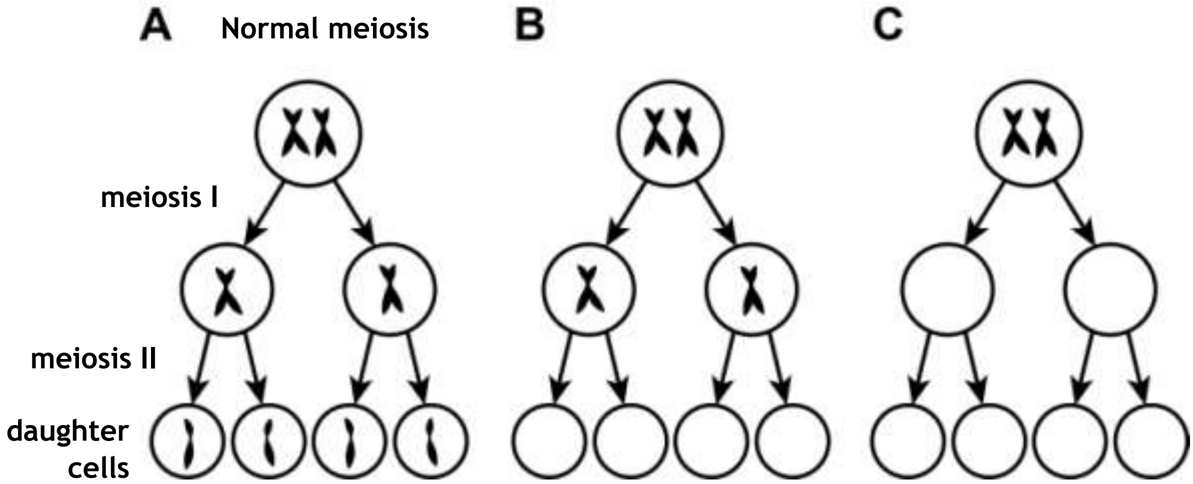


Oysters

The flat oyster (*Ostrea edulis*) is indigenous to the Dutch coast. The oysters are harvested for consumption, but the oyster population – and harvests – have been suffering from infections with the protist *Bonamia ostreae*. A solution to the decline is the use of triploid oysters, which grow and mature faster and are more resistant to this infection.

Triploid oysters have three sets of chromosomes in their cells. They are bred in the lab, but can also occur naturally through faulty meiosis: instead of gametes with one chromosome set, gametes with two chromosome sets can be formed. When these gametes are fertilized by normal gametes, triploid individuals are formed.

In column A of the figure below normal meiosis is depicted for one chromosome pair. There are two principally different ways in which faulty meiosis could lead to triploidy.



4. (**1.2 points**) Indicate the two fundamentally different forms of faulty meiosis in columns B and C, by drawing chromosomes/chromatids or by leaving cells empty. Meiosis I for column B is already given.

   The protist *B. ostreae* lives inside the haemocytes (cells of the immune system) of the oyster, causing the cells to die, which eventually kills the oyster. *B. ostreae* can survive, but not reproduce, outside of the oyster.

5. (**0.8 points**) How can the interaction between the oyster and *B. ostreae* be characterized? Choose the role of each of the two species from the words given below.

I.	commensal	IV.	parasite
II.	endosymbiont	V.	predator
III.	host	VI.	prey

An oyster farmer suffering from a *B. ostreae* infection in his breeding zone wants to know how much his harvest would improve from switching to triploid oysters. To study this, he makes a model of the interaction between *Ostrea edulis* and *B. ostreae* in his breeding zone, which is connected to the sea.

The change in the oyster population size per day is:

$$\frac{\Delta N_O}{\Delta \mathrm{t}} = aN_O - bN_O - cN_O N_B$$

The change in the *B. ostreae* population size per day is:

$$\frac{\Delta N_B}{\Delta \mathrm{t}} = pN_O N_B - qN_B$$

Here, N_O is the number of oysters *O. edulis*, N_B is the number of *B. ostreae* and t is the time in days. The letters *a, b, c, p* and *q* are positive parameters, with unit 'per day' (d^{-1}).

6. (**0.8 points**) What do the parameters *p* and *q* signify? Choose from the following descriptions:

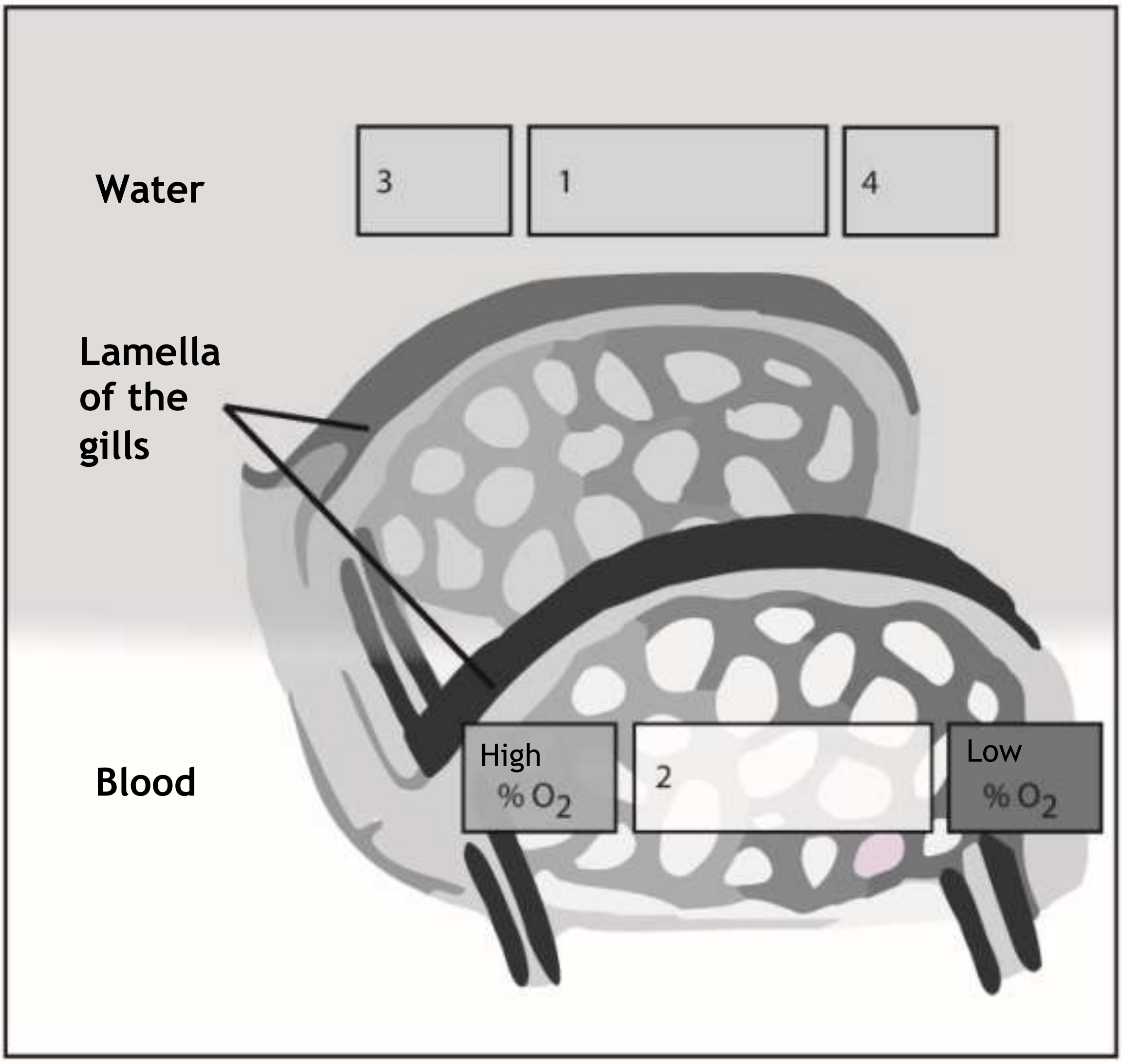
   I. Birth rate of oyster *O. edulis*
   II. Immigration rate of oyster *O. edulis*
   III. Death rate of oyster *O. edulis*
   IV. Birth rate of protist *B. ostreae*
   V. Immigration rate of protist *B. ostreae*
   VI. Death rate of protist *B. ostreae*

7. (**1.2 points**) Which of the parameters *a, b* and *c* are different for triploid oysters compared to diploid oysters, based on the information provided? Fill out the table on your answer sheet, using '+' if the parameter is bigger for triploid oysters, '-' if the parameter is smaller for triploid oysters and 'o' if there is no difference or if no information was given.

Osmosis in fish

Fish use their gills for gas and ion exchange, i.e. they 'breathe' with their gills. To allow for enough exchange, gills use counter current exchange and the fish actively move water through their gill system. The epithelial cells of lamella of the gills are in direct contact with the surrounding water.

8. (**1.2 points**) The figure below shows a schematic representation of the capillary blood vessels in the lamella of the gills of a fish. Indicate in the figure on your answer sheet:
   - at **location 1**: the direction of water flow, by drawing a **horizontal arrow**;
   - at **location 2**: the direction of blood flow through the capillaries, by drawing a **horizontal arrow**;
   - at **location 3 and 4**: the concentration of O_2 in the water, use **H** for high % O_2 and **L** for low % O_2.



9. (**0.8 points**) What would the consequences be for the freshwater fish if it were **NOT** able to regulate water intake and excretion? Complete the following sentence by making the correct choices for I, II, III and IV. Tick the right boxes on your answer sheet.

   If a freshwater fish swimming in a river were not able to regulate its water intake, the fish's cells would ….(I)….. Instead, freshwater fish regulate their water content by drinking ….(II)…., and by producing ….(III)…. amounts of very ….(IV)…. urine.

   The choices for I, II, III and IV are:

I	'swell up'	or	'shrink'
II	'a lot'	or	'very little'
III	'large'	or	'small'
IV	'concentrated'	or	'diluted'

Anammox

The antibiotic penicillin can be used to target pathogenic bacterial infections. It targets cell wall biosynthesis, more specifically, it inhibits the biosynthesis of peptidoglycan. So far it was thought that anaerobic ammonium oxidizing (anammox) bacteria did not contain any peptidoglycan in the cell wall. However, when a bioreactor with a co-culture of anammox bacteria and other bacteria was fed with medium containing penicillin, the numbers of living anammox bacteria dropped. Anammox bacteria are dependent upon other bacteria in the co-culture for essential nutrients.

Three possible hypotheses for this finding are considered:

I Anammox bacteria have peptidoglycan in their cell walls.
II Penicillin affects other bacteria in the co-culture.
III Anammox bacteria have membrane structures that resemble the target of penicillin and those are inhibited/blocked by penicillin.

10. **(1.2 points)** Match each of these hypotheses (I-III) to the experimental design (A-C) that could study its validity and the prediction (1 or 2) that follows when the hypothesis is **true**. Encircle on your answer sheet one letter and one digit per hypothesis.
    Experimental design:
    A. Grow anammox in pure culture supplemented with all essential nutrients and apply penicillin again
       Prediction 1: Growth in the culture
       Prediction 2: No growth in the culture
    B. Test the cell wall of anammox for peptidoglycan
       Prediction 1: The cell wall contains peptidoglycan
       Prediction 2: The cell wall contains no peptidoglycan
    C. Use fluorescent penicillin and test whether it binds to anammox cell walls using microscopy
       Prediction 1: Fluorescent penicillin binds the cell walls
       Prediction 2: Fluorescent penicillin does not bind the cell walls

Chemistry questions

Water and the fight against *Legionella*

In March 1999 more than 200 people developed Legionnaires' disease after visiting a flower exhibition in the village of Bovenkarspel in the Netherlands. These people had inhaled small drops of water spread by fountains that were contaminated with Legionella bacteria. Over 30 people died from the outbreak.

Legionella bacteria are often present in the tap water systems of large institutions.

The activity of *Legionella* bacteria is expressed in cfu (colony forming units). Water with less than 100 cfu/L is regarded as safe. The impact of outbreaks, such as the one in Bovenkarspel, means that a lot of attention is paid to fight Legionella. We discuss three methods here.

Heating

The tap water is heated for a period of time above 60 °C. To express how fast the bacteria die, the concept of the D-value is often used. The D-value is the time in which 90% of the bacterial population dies at a given temperature. The rate at which the bacteria die is exponential. For example, the D-value for *Legionella* at 60 °C is 5 min.

11. (**1.2 points**) Calculate the minimum time that water with 1 200 cfu/L needs to be heated at 60 °C to reduce the level to that regarded as safe. Give your answer in minutes; round your answer to one decimal place.

Chlorination

In this method hypochloric acid, $HClO$, is added to the tap water. Hypochloric acid is a weak acid, with $K_a = 4.0 \cdot 10^{-8}$. The pH of the water when using this method is important, because the antibacterial action of $HClO$ is better than that of ClO^-. So the pH must be such that $[HClO] > [ClO^-]$.

12. (**1.6 points**) Calculate what the pH should be in order to achieve $[HClO] > [ClO^-]$. Indicate if this is the maximum or the minimum pH value.

A drawback of this method is that the hypochloric acid can act as an oxidant to oxidize the copper water pipes.

The unbalanced equation of the reaction of hypochloric acid with the copper that the water pipes are made of is:

$$Cu(s) + HClO(aq) + H^+(aq) \rightarrow Cu^{2+}(aq) + H_2O(l) + Cl_2(aq)$$

This reaction is a redox-reaction.

13. (**1.2 points**) Write down balanced the equations of the half-reactions and the balanced overall reaction equation.

Copper – silver ionization

A relatively new method to fight *Legionella* is the so called copper - silver ionization. In this process copper ions (Cu^{2+}) and silver ions (Ag^{+}) are generated into the water system by electrolysis. Both types of ions are released at the same electrode.

14. (**0.8 points**) A sketch of an electrolysis cell is given on your answer sheet.
    In this sketch, circle the electrode where the copper ions and silver ions are formed
    Also draw with arrows to indicate in what direction the electrons flow in this cell.

Inside the bacterium the silver ions can react with ~ S — H groups in proteins. A possible reaction of silver ions with ~ S — H groups is the formation of disulfide links, ~ S — S ~. Such a reaction induces denaturation of the proteins and the death of the bacteria.

The unbalanced equation for the formation of the disulfide links by the action of Ag^{+} is:

$\sim S-H \ + \ Ag^{+} \ \rightarrow \ \sim S-S \sim \ + \ Ag \ + \ H^{+}$

15. (**0.8 points**) Write down the balanced equation.

Silver ions can react with ~ S — H groups in the same protein chain, or with ~ S — H groups in different protein chains.
In proteins we make a distinction between the primary, the secondary, the tertiary, and the quaternary structure.

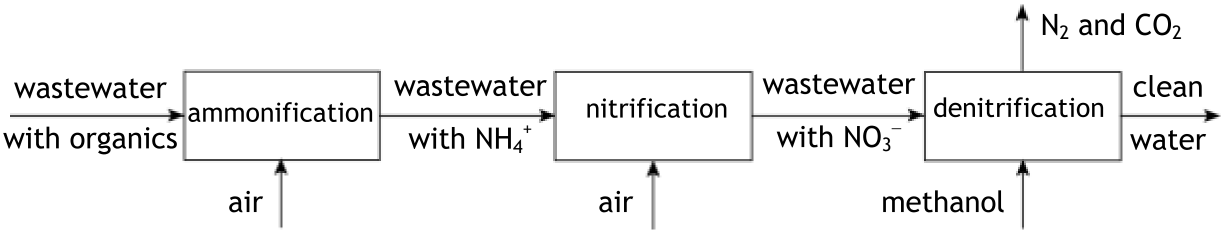
16. (**0.4 points**) At which of these levels of structure does a change take place when silver ions react with ~ S — H groups in the same protein chain? Tick the correct box on your answer sheet.

Wastewater treatment

Over the last decades agricultural, industrial and domestic activities have increased the release of nitrogen compounds in the environment. One of the effects of this excessive nitrogen release is eutrophication of surface water. To prevent nitrogen pollution, wastewater needs to be treated before it can be discharged.

Figure 1 shows a representation of conventional wastewater treatment.

Figure 1



Ammonification is the process in which organic matter is oxidized. The nitrogen containing compounds are converted into ammonium (NH_4^+).

In the nitrification the ammonium is converted by nitrifying bacteria, via nitrite (NO_2^-) into nitrate (NO_3^-). The reactions are:

$2\ NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 4\ H^+$, followed by:
$2\ NO_2^- + O_2 \rightarrow 2\ NO_3^-$

Denitrification is the conversion of nitrate into the harmless gas nitrogen (N_2). Methanol is needed as a reducing agent. Denitrification is also a bacterial process. The reaction is:

$6\ NO_3^- + 5\ CH_3OH + 6\ H^+ \rightarrow 3\ N_2 + 5\ CO_2 + 13\ H_2O$

Aeration (passing air through the water) is the most energy consuming operation in wastewater treatment. On average it costs 3 kWh for pumping of one kg of oxygen through wastewater. The price for electricity in the Netherlands is € 0.19 per kWh.

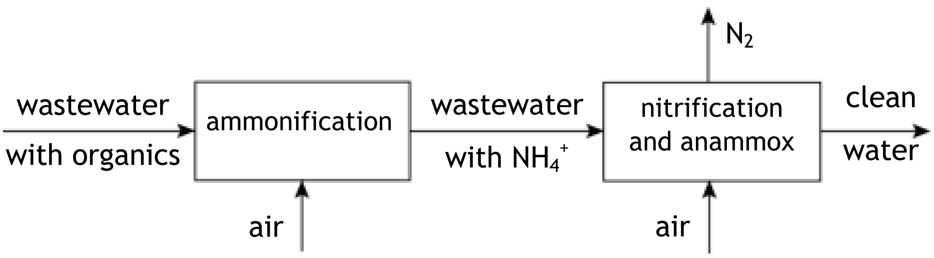
17. (**1.2 points**) Calculate the costs for aeration in the nitrification reactor, in euros, on a yearly basis in the conventional wastewater treatment for the city of Nijmegen. Nijmegen has 175 000 inhabitants producing, after ammonification, 11.4 grams (= 0.632 mol) of ammonium ions per person per day. Assume that all the oxygen reacts in the nitrification process.

Running conventional wastewater treatment systems will become increasingly uneconomic and does not meet our sustainability policies in the future as a result of the high energy consumption, greenhouse gas emissions and operational costs.

The anammox process is a new treatment system to remove nitrogen from wastewater. This process is carried out by <u>an</u>aerobic <u>amm</u>onium <u>ox</u>idizing (anammox) bacteria, that convert ammonium ions and nitrite ions into nitrogen molecules. The anammox bacteria work together in a reactor with nitrifying bacteria that oxidize ammonium into nitrite. The anammox process is an innovative and sustainable system that is increasingly used for wastewater treatment worldwide.

Figure 2 describes wastewater treatment using the anammox process.

Figure 2



The reactions are:

nitrification: $2\ NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 4\ H^+$
anammox: $NH_4^+ + NO_2^- \rightarrow N_2 + 2\ H_2O$

Compared to the conventional process, oxygen consumption in wastewater treatment using the anammox process is considerably less.

18. (**1.6 points**) Calculate the percent decrease in oxygen required per mole of ammonium in the anammox system relative to the conventional process. Round the answer to a whole number.

All processes mentioned in this problem are part of the natural nitrogen cycle. One can imagine that the cycle starts with the fixation of nitrogen (N_2) in organic matter. An incomplete diagram of the nitrogen cycle is given on the answer sheet. In this diagram, ammonification is already indicated by 'Amf' and fixation of nitrogen by 'Fix'.

19. (**1.2 points**) Complete the diagram of the nitrogen cycle on the answer sheet.
    - Include and label any missing arrows
    - Write NO_2^- and NO_3^- in the correct place
    - Include all mentioned processes as follows:
      anammox by 'Amx'
      denitrification by 'Den'
      nitrification by 'Nit'

Physics questions

Wind energy

In a wind turbine, kinetic energy from the passing air is transformed into electrical energy. The kinetic energy of the air, passing per second (power) along the sails of the rotor, is given by:

$P = \frac{1}{2} A\rho v^3$

In which (see Figure 1):

- P is the power of the air passing through area A (in W);
- A is the area of the plane covered by the sails, perpendicular to the direction of the wind (in m^2);
- ρ is the density of the air (in kg/m^3);
- v is the wind speed (in m/s).

At one particular moment the wind speed $v = v_0$ and $P = P_0$.

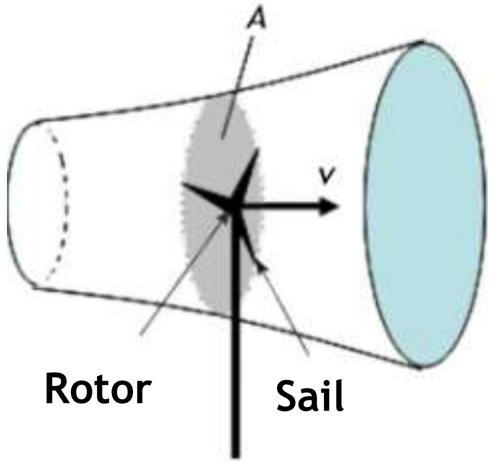


Figure 1: Schematic overview of a wind turbine.

20. (**0.4 points**) What will be P when the wind speed is $2v_0$? Express your answer using P_0.

In a wind turbine, only a fraction of the kinetic energy of the air can be transformed into the kinetic energy of the rotor. According to Betz's theorem, this transformation has a maximum efficiency of 59%.
In addition, there are energy losses during the transformation of the kinetic energy of the rotor into electrical energy. The efficiency of this conversion is 70% for a certain type of wind turbine.
The sails of these particular wind turbines describe a circular surface with a diameter of 80 m. The density of the air is 1.2 kg/m^3. The wind speed is 36 km/h.

21. (**1.6 points**) Calculate the maximum electric power, in W, generated by one of those wind turbines.

The Dutch government has made plans to build an artificial offshore reservoir in the sea (see Figure 2). This plan is known as the plan-Lievense.

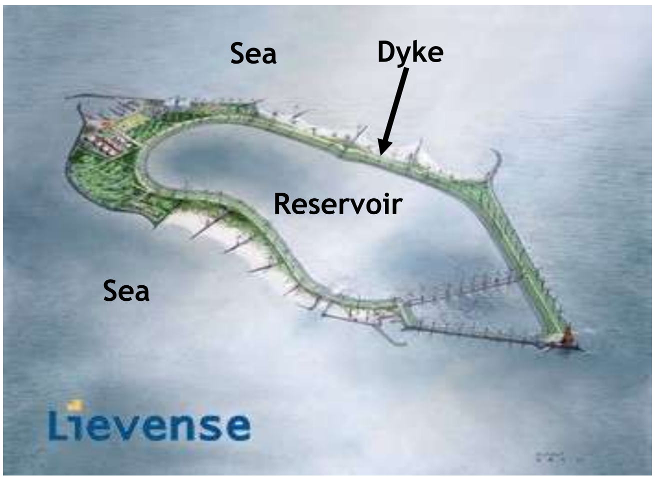


Figure 2: Artificial offshore reservoir.

The water level of the reservoir enclosed by the surrounding dyke is much lower than the water level of the sea. Wind turbines are built along the top of the dyke. At sufficiently high wind speeds, these wind turbines pump water from the reservoir into the sea. On the other hand, at low wind speeds, the system is designed in such a way that water is drained from the sea, through the turbines embedded in the dyke, into the reservoir. The turbines drive generators thereby generating electric energy.
An overview is given in Figure 3.

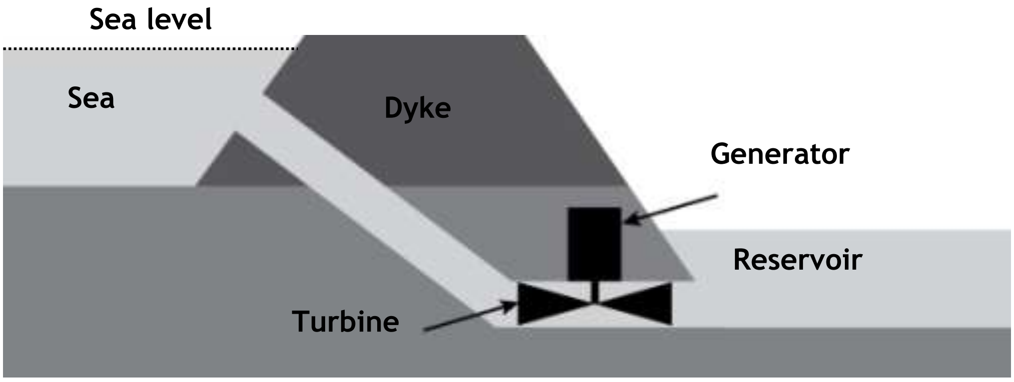


Figure 3: Overview of the mode of action of the artificial reservoir.

The water level in the reservoir can vary between 32.0 m and 40.0 m below sea level. In order to decrease the water level in the reservoir from its highest to its lowest level, the wind turbines need to pump $3.3 \cdot 10^{11}$ kg water from the reservoir to the sea. Assume that the shores of the reservoir are vertical and the sea level remains constant.

22. (**1.2 points**) Calculate the area of the reservoir in m^2. The density of seawater is $1.03 \cdot 10^3$ kg/m^3.

In another design 75 wind turbines will be placed on the dyke, all of which have an average electrical power of 5.0 MW.

23. (**2.0 points**) Calculate how many hours it will take the full set of wind turbines to decrease the water level in the reservoir from its highest to its lowest level.

Now, you may wonder what the purpose of such a power plant is. After all, the electrical energy generated by the wind turbines could be directly transferred to the power grid. Nevertheless, despite this argument and the tremendous costs of this project, there are many advocates of this power plant. On the answer sheet, there are several arguments.

24. (**1.2 points**) For each of the arguments on the answer sheet indicate whether they do (YES) or do not (NO) <u>specifically</u> support the building of this type of power plant, as opposed to a power plant of only wind turbines in the same place, that transfer the electricity directly to the power grid. You will lose marks for wrong answers but may leave it blank if you don't know (no loss of marks). The minimum score for this question is 0.

Room for the river

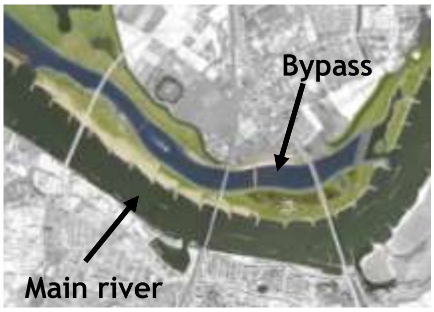


Figure 1: Aerial overview of the bypass and main river.

The Waal river takes a sharp bend near Nijmegen. During extreme high water levels the location acts as a bottleneck, making it difficult for water to drain away. A bypass parallel to the main river was dug to overcome this problem (see Figure 1).

For reasons of simplicity, we assume that the bypass is a drain with a rectangular profile. *W* is the width of the drain in meters, and *D* is the depth of the water in meters (see Figure 2). In the case that the depth is much less than the width the amount of water that flows per second through a rectangular drain is given by the following formula:

$Q = \frac{A}{n} D^{2/3} S^{1/2}$ formula 1

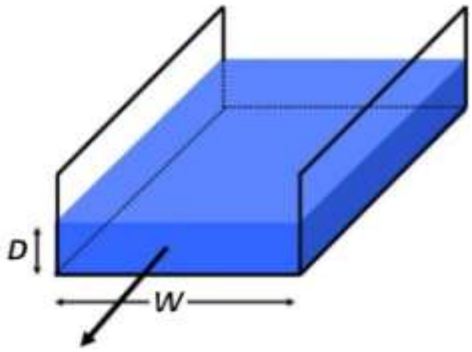


Figure 2: Schematic overview of the drain.

In which:
- Q is the volume of water that flows per second through the drain (in m^3/s);
- $A = W \times D$, the cross-sectional area of the drain up to the level of the water (in m^2);
- n is a parameter describing the resistance to the flow of water;
- S is the gradient of the river (in m/m).

25. (**0.8 points**) Use formula 1 to derive the units of n.

In the case of the Nijmegen bypass: S = 0.50 m/km = $5.0 \cdot 10^{-4}$ m/m, and W = 200 m. Just after completion, the magnitude of n equaled 0.018. At the highest water level reached by the Waal near Nijmegen, $Q_{Waal} = 1.4 \cdot 10^4\ m^3/s$.

26. (**1.2 points**) Calculate the minimum depth of the bypass, in m, needed to drain at least 10% of the Waal's water, when the water level is at its maximum.

After a while, the bottom of the bypass becomes slightly overgrown. As a result, the value of the depth *D* decreases by about 1%. Furthermore, as a result of the vegetation the value of *n* changes from 0.018 to 0.022. Consequently, when the water level in the river Waal is at its maximum, the bypass is no longer capable of draining 10% of the water.

27. (**1.6 points**) Calculate the new drain capacity of the bypass, in % of the Waal's water.

Water and sustainability

Practical Test

Paramecium **– Fajans titration – Blue energy**

December, 9th 2017

Carefully read the “EXAMINATION RULES” and “EXPERIMENT INSTRUCTIONS”

EXAMINATION RULES

1. You are NOT allowed to bring any personal items into the examination room, except for personal medicine or approved personal medical equipment.
2. You must sit at your designated table.
3. Check the stationery items (pen, calculator, ruler, and scrap paper) provided by the organizers.
4. Do NOT start your experiments before the **"START"** signal.
5. You are NOT allowed to leave the examination room during the experiment, except in an emergency in which case you will be accompanied by a supervisor/volunteer/invigilator.
6. Do NOT disturb other competitors. If you need assistance, raise your hand and wait for a supervisor to come.
7. You can ONLY ask questions and discuss the experiments with your own team members. You must STAY at your table until the end of the time allocated for the experiments, even if you have finished the experiments or do not wish to continue.
8. At the end of the experiment time you will hear the **"STOP"** signal. Do NOT write anything more on the answer sheet after this stop signal. Arrange the exam, answer sheets, and the stationary items (pen, calculator, ruler, and scrap paper) neatly on your desk. Do NOT leave the room before all the answer sheets have been collected.

EXPERIMENT INSTRUCTIONS

1. After the “START” signal, you will have 15 minutes to read the experiments. In this time, it is NOT allowed to conduct the experiment yet, or answer the questions.
2. After the first 15 minutes, another whistleblow will indicate that you can start the experiment and start answering question. From this moment you have three hours to complete the test.
3. Use only the pen and pencil provided by the organizers.
4. The total number of experiments is 3. Check if you have a complete set of the exam sheets (16 pages, page 4 – page 19) and answer sheets (28 pages - including the front page). Raise your hand, if you find any sheets missing.
5. Check that your name, code and country are filled in on your answer sheets and sign every page of the answer sheets. Raise your hand, if you find any sheets missing.
6. Read the experimental procedures and questions carefully and write your answers in the corresponding boxes of the answer sheets.
7. When units are provided in the answer sheets, you have to write the answers correctly for the units.
8. Always show your calculations if room for this is provided. If you do not show your calculations, no points are awarded for the question.
9. You should write your final answers down in the appropriate number of digits.
10. You MUST wear a **Lab Coat** and **Safety Glasses** during the experiments.
11. You will be provided with two sets of translated answer sheets. Only the YELLOW answer sheets will be evaluated. You can split up the white answer sheets among your team and use them as scrap paper, but they will NOT be evaluated.
12. The YELLOW answer sheets should be kept behind the cardboard shield.
13. The number of points that can be obtained is indicated for each question.
14. Use of micropipette (Gilson pipette):
    a) Set the volume with the thumb wheel. Maximum volume for P1000 is 1000 μL (indicated by a red one (1) and two black zeros (0), the bars on the last wheel indicate the third decimal); for P20 the maximum is 20 μL. (Black two (2), black zero (0) and red zero (0)). **Do not exceed the maximum volume!**
    b) Fit the pipette tip to the pipette.
    c) Push the pushbutton until the first stop.
    d) For liquid take up: insert tip under liquid level and slowly release the pushbutton.
    e) For liquid dispensing: place tip in another container and push the pushbutton until the second stop.
    f) Remove the tip.

Biology - The contractile vacuole of *Paramecium*

Introduction

Paramecia are one of the best known and most studied types of unicellular organism. The shape of a *Paramecium* cell somewhat resembles a slipper, although the front is located at the 'heel' and the back at the 'toes' of the slipper (Figure 1).

Paramecia are mostly cultivated in 'hay infusion' (water in which hay has been boiled for about ten minutes). Bacteria feed on the degradation products of the hay and readily grow in this medium. *Paramecia* in turn consume the bacteria, allowing them to thrive in the medium as well.

Paramecia contain some interesting cell organelles named 'contractile vacuoles'. These vacuoles are used to pump water out of the cell.

In this experiment, you will investigate the contraction frequency of the anterior (= 'at the front') contractile vacuole of *Paramecium caudatum* for two salt concentrations of the surroundings.

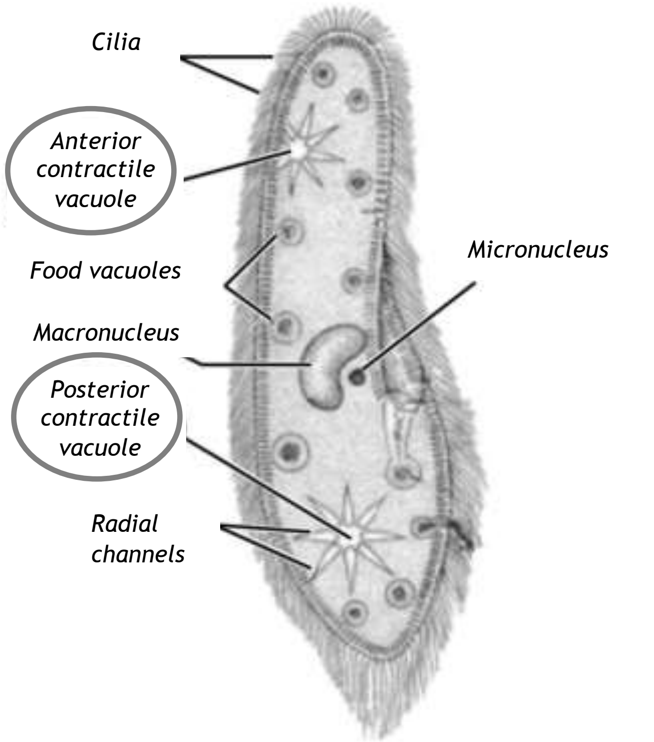


Figure 1 *– Schematic drawing of a Paramecium cell with contractile vacuoles and some other cell organelles indicated.*

➢ **Read the protocol and answer question 1 on the answer sheet.**

Protocol

Investigation of the contraction frequency of the anterior contractile vacuole

To be able to investigate the contraction frequency of *Paramecium's* anterior contractile vacuole, you must study live *Paramecia* under the microscope. For this, you will prepare your own microscopy samples following these steps: First, you will concentrate the *Paramecia* from the hay infusion (section **A**). Then, you will prepare a microscopy sample of the concentrated *Paramecium* culture (sections **B** and **C**). Finally, you will analyse the *Paramecia* under the microscope (section **D**).

ATTENTION! It is important that the *Paramecia* in the microscopy samples are as fresh as possible when you analyse them. Therefore, perform all sections (A, B, C and D) for one salt concentration before moving on to the other salt concentration.

ATTENTION! It is possible that some *Paramecia* do not survive the preparation of the microscopy sample. Do not analyse *Paramecia* that are not healthy (swollen or shrunken or with protruding vesicles), that do not show any movement at all or whose vacuoles contract less than once per minute. If your sample does not contain enough healthy *Paramecia*, you have to make a new sample. You are allowed to use more than one droplet for your observations.

Materials

- A 50 mL Erlenmeyer flask with water
- A plastic 15 mL tube labelled ‘**P—**’, containing a *Paramecium* culture in hay infusion *without any additions*
- A plastic 15 mL tube labelled ‘**P+**’, containing a *Paramecium* culture *with extra sodium chloride added to increase the salt concentration by 0.03 mol/L*
- A 15 mL tube rack
- An empty 1.5 mL microcentrifuge tube labelled with ‘**P—**’ and your group number
- An empty 1.5 mL microcentrifuge tube labelled with ‘**P+**’ and your group number
- An empty 1.5 mL microcentrifuge tube labelled ‘**•**’
- Three spare microcentrifuge tubes
- A P1000 micropipette with blue pipette tips
- A P20 micropipette with yellow pipette tips
- A microcentrifuge, at one side of the lab, managed by a supervisor
- A plastic 15 mL tube labelled ‘**G—**’, containing methylcellulose gel *without any additions*
- A plastic 15 mL tube labelled ‘**G+**’, containing methylcellulose gel *with added sodium chloride to a concentration of 0.03 mol/L*
- A microcentrifuge rack
- Microscopy slides
- Cover slips
- A microscope
- A stopwatch
- A small waste bin
- Dissection needle

Experimental Procedure

A. Concentrating *Paramecia*

1. Use a P1000 micropipette to transfer 1.5 mL water to the microcentrifuge tube labelled '•'. Tightly close the tube with the attached cap.
2. Use a P1000 micropipette to transfer 1.5 mL *Paramecium* culture from the 15 mL tube labelled '**P—**' to the 1.5 mL microcentrifuge tube with the same label. Tightly close the tube with the attached cap.
3. Have a supervisor centrifuge the microcentrifuge tube labelled with '**P—**' and your group number, and the tube labeled '•' for 3 minutes at 3000 rpm. The tube labelled with '•' is used as counterbalance.
4. Obtain the centrifuged tubes. The *Paramecia* are now collected in a so-called 'pellet', at the bottom of the tube with your group number, a little to the side of the tube where the cap attaches (see Figure 2).

Figure 2 *– Schematic drawing of a micro-centrifuge tube with a pellet (grey area).*

5. Set the P1000 micropipette to 1 mL and, *immediately* after centrifugation, extract 1 mL of the supernatant (the liquid above the pellet) from the microcentrifuge tube. Take care NOT to take up the pellet, so do NOT put the pipette tip at the bottom of the tube! Dispose of the 1 mL of supernatant in a sink.
6. Close the tube and firmly tap the bottom of the tube a couple of times with your finger to resuspend the *Paramecia*. After that, make sure all liquid is collected at the bottom of the tube again.
7. You now have 0.5 mL concentrated *Paramecium* suspension. Every time when using this suspension for preparing a microscopy sample, **first tap it with your finger to homogenise.**

B Preparing a microscopy sample for inspection by a supervisor

1. Set your P20 micropipette to 5 µL and leave it at this setting. Use this micropipette to place 4 droplets of 5 µL of the concentrated *Paramecium* suspension on a microscopy slide, as shown in Figure 3.
2. Place the microscopy slide with the droplets on the stage of the microscope.
3. Use the correct procedure to magnify the sample 40x (10x ocular lens and 4x objective) and make sure a *Paramecium* is in focus.
4. *Raise your finger to attract the attention of a supervisor. He or she will inspect your sample and award points in* ***question 2*** *depending on your preparations.*

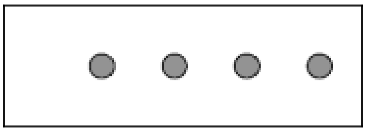


Figure 3 *– schematic drawing of a microscopy slide with 4 droplets.*

5. After your sample has been inspected, **read question 3 on the answer sheet**, but do not answer it yet until after performing section D. Magnify the sample 100x and observe the *Paramecia*.

C. Preparing a microscopy sample for analysis

1. Use the P20 micropipette to place a total of 25 µL of the methylcellulose gel from the tube labelled '**G—**' in the middle of a microscopy slide. ATTENTION: move the plunger of the pipette in a *slow* manner to avoid air bubbles in the tip.
2. Now, again use the P20 micropipette to take up 5 µL of the *Paramecium* suspension and carefully deliver it into the gel droplet on the microscopy slide.
3. Use a dissection needle to carefully but thoroughly mix the *Paramecia* with the gel. Try to prevent the droplet from spreading over the slide and try to prevent the formation of air bubbles.
4. Carefully place a coverslip on the gel droplet, but *do NOT press it*! Your microscopy sample is now ready for use.

D Observing Paramecia

1. Place the microscopy slide with the sample on the stage of the microscope.
2. Use the correct procedure to magnify the sample 100x.
3. Take a good look at the *Paramecia*.

➢ **Answer question 3**.

The *Paramecia* have two contractile vacuoles, one at the front (the anterior contractile vacuole) and one at the back (the posterior one) of the cells (see Figure 1). During the entire experiment, observe the **anterior** contractile vacuoles.

4. Observe six consecutive contractions of the anterior vacuole of a *Paramecium*. Note down the total time between contraction 1 and contraction 6 in **Table A2 in question 4** on your answer sheet. Repeat this for eight more *Paramecia*.

Repeat the procedures in sections **A**, **C** and **D** for the *Paramecium* culture with the higher concentration labelled '**P+**'. You do NOT have to get your sample checked, i.e. you should skip section **B** completely. In section **C**, use the methylcellulose gel from the tube labelled '**G+**' instead of the '**G—**' gel.

➢ **Answer questions 5-12**.

Chemistry - Determining the concentration of a sodium chloride solution using the Fajans titration procedure

Introduction

Sea water contains about 35 g of salts per liter, most of which is sodium chloride. From the difference in salt concentrations between sea water and fresh water, electrical energy can be generated using so-called ‘blue energy’ techniques.

Weighing titration

To determine the chloride concentration of water, a technique that is called *weighing titration* can be employed.

In a ‘normal’ (volumetric) titration, a solution of a substance X with an unknown concentration is pipetted into an Erlenmeyer flask. An indicator is added and the solution of X in the Erlenmeyer flask is *titrated* with a second solution with a known concentration of reagent by slowly adding this solution from a burette. When the indicator changes colour, the end point of the titration is reached and the concentration of substance X can be calculated from the volume of the solution of X, the volume of the reagent solution that was added, the concentration of the reagent solution, and the ratio in which the substances react with each other.

In a *weighing titration* both the solution of X and the reagent solution are contained in syringes. Both syringes are weighed before the titration is started. Then, a certain amount of the solution of X is transferred from its syringe into an Erlenmeyer flask. An indicator is added and the solution of X in the Erlenmeyer flask is *titrated* with the second solution with a known concentration of reagent by slowly adding this solution from the second syringe. When the indicator changes colour, the end point of the titration is reached and both syringes are weighed again. The concentration of substance X can be calculated from the densities of both solutions, the masses of the solutions that were transferred to the Erlenmeyer flask, the concentration of the reagent solution, and the ratio in which the substances react with each other.

Importantly, in a weighing titration, it is very easy to correct for adding too much reagent solution (‘overshooting the end point’) by adding a bit of the solution of X again until the indicator has regained its original colour and then titrating the solution again with the reagent solution. Both syringes are only weighed when the end point has been reached exactly.

The experiment

In this experiment, you will use the so-called Fajans titration to determine the concentration of a solution of sodium chloride (NaCl). The Fajans titration involves titrating the sodium chloride solution with a solution of silver nitrate ($AgNO_3$), resulting in a white precipitate according to the following reaction:

$$Ag^{+}(aq) + Cl^{-}(aq) \longrightarrow AgCl(s)$$

Some dextrin (a kind of starch) is added to prevent the precipitate from coagulating too much. Dichlorofluorescein functions as the indicator. It changes from yellow to pink when the end point of the titration is reached.

Materials

ATTENTION! The amounts of provided materials, detailed in the list below, are more than sufficient to carry out the experiments in full. In case you inadvertently spill, break or use too much of something, replacement / replenishment is available, but it will cost you and your team **one full mark** out of the thirteen you can earn for this experiment. The only exception is demineralized water, which you can obtain at no cost in marks by handing in your empty bottle to a supervisor. You will receive a full bottle in return.

- A 250 mL or 300 mL Erlenmeyer flask
- Two 50 mL beakers
- Two 20 mL plastic syringes
- Two blunt needles
- A small spatula
- A P1000 micropipette
- A pipette stand
- Two blue micropipette tips
- Paper towels
- A waste canister, labelled 'Waste'
- A permanent marker pen
- Disposable gloves (available from boxes at a central point in the lab)
- A cardboard cover for the table
- A plastic bottle, labelled 'NaCl', containing 100 mL of a sodium chloride solution of unknown concentration
- A black plastic bottle, labelled '$AgNO_3$', containing 75 mL of a **20.00 g/L** silver nitrate solution
- A 15 mL centrifuge tube, labelled 'DCF', containing a 1 mg/mL solution of dichlorofluorescein in 96% ethanol
- A centrifuge tube rack
- A wash bottle with demineralized water
- A capped glass vial, labelled 'Dextrin', filled with dextrin
- Two 10 mL glass vials
- An accurate scale (shared by two teams)
- A 1.0 mL disposable plastic pipette with scale marks (see Figure 1 below)

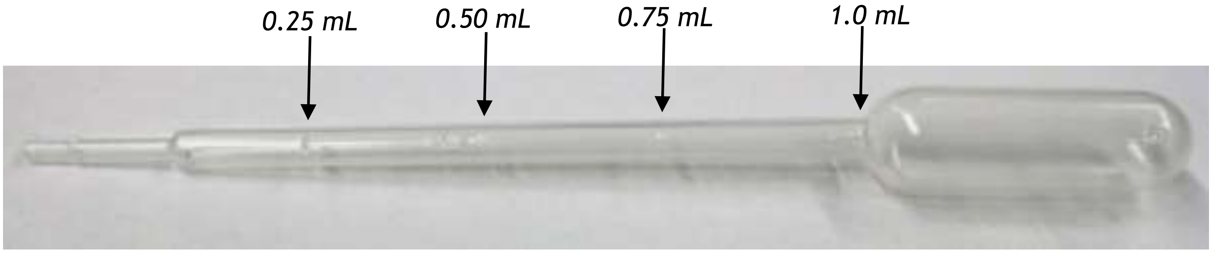


Figure 1 *– A disposable plastic pipette with scale marks indicated by arrows.*

Data

In table 1 below, you can find the standard atomic weights of some elements:

Table 1 – *Standard atomic weights of some elements*

Element	**Standard atomic weight**
N	14.01
O	16.00
Na	22.99
Cl	35.45
Ag	107.87

Safety precautions

ATTENTION! You are required to wear gloves during the entire experiment. Although the solutions used are quite harmless, spilled silver nitrate solution can lead to ugly brown spots on your skin. The same holds for your clothes, the table and the floor, so try to prevent spilling the solution and, if you accidentally spill something, clean up any droplets immediately with a paper towel.

- Before using the solutions of NaCl and $AgNO_3$ pour them in a beaker.
- Do not attempt to remove any air bubbles out of the syringes.

A. Determining the densities of the solutions

Use the scale, the micropipette (**and tips!**) and the glass vials to determine the densities of the solutions of sodium chloride and silver nitrate. Make sure that you obtain highly accurate values for the densities of the solutions! **Write your measurements, calculations and answers on the answer sheet.**

B. A trial titration

Goals

The trial titration has two goals:

- estimating the approximate volume of silver nitrate solution that needs to be added to a certain amount of the sodium chloride solution to reach the end point.
- observing the colour change of the indicator at the end point. Note that the colour of the yellow solution gradually becomes somewhat orange; this is NOT the end point of the titration. The end point is reached when the yellow-orange colour of the suspension has **just** (i.e. with the addition of a single droplet) clearly changed to pink and remains pink also after you thoroughly swirled the contents of the Erlenmeyer flask.

Procedure

1. Equip one of the syringes with a blunt needle.
2. Fill the syringe up to the **15** mL mark with the sodium chloride solution.
3. Dry off any liquid on the outside of the syringe and the needle, also from the needle tip. Do not worry about the air bubble in the syringe.
4. Carefully empty the syringe into the 250 mL Erlenmeyer flask.
5. Add about 85 mL of demineralized water to the solution in the Erlenmeyer flask.
6. Add three spatulas full of dextrin to the Erlenmeyer flask. Swirl the flask to suspend the dextrin.
7. Use the disposable pipette to add about 0.5 mL of dichlorofluorescein solution to the Erlenmeyer flask.
8. Equip the other syringe with the second blunt needle.
9. Fill the syringe up to the **20** mL mark with silver nitrate solution.
10. Dry off any liquid on the outside of the syringe and the needle, also from the needle tip.
11. Now, titrate the sodium chloride solution with the silver nitrate solution by adding silver nitrate solution to the sodium chloride solution in the Erlenmeyer flask while constantly or intermittently swirling the contents of the flask. Keep adding silver nitrate solution until you have reached the end point
12. Read off the remaining volume of silver nitrate solution in the syringe and calculate the volume of silver nitrate solution that you have added.
13. If you like, you may experiment a little by adding a few droplets of sodium chloride solution again, followed by some droplets of silver nitrate solution, so you get an idea of the principle of weighing titration.
14. When you are finished, pour the suspension from the Erlenmeyer flask into the waste canister. Thoroughly rinse the Erlenmeyer flask three times with demineralized water. Also pour the rinsings into the waste canister.

C. Accurate titrations

ATTENTION! To accurately titrate the sodium chloride solution, it is important that you add the indicator solution only **just before** the end point of the titration is reached.

Procedure

1. Fill the first syringe up to the **20** mL mark with the sodium chloride solution.
2. Dry off any liquid on the outside of the syringe and the needle, also from the needle tip.
3. Weigh the syringe in the upright position with the solution. **Write the initial mass on the answer sheet.**
4. Carefully empty the syringe **down to the 5 mL mark** into the 250 mL Erlenmeyer flask. So, only expel about 15 mL from the syringe; it is important that some sodium chloride solution remains in the syringe!
5. Add about 85 mL of demineralized water to the Erlenmeyer flask.
6. Add three spatulas full of dextrin to the Erlenmeyer flask. Swirl the flask to suspend the dextrin.
7. Fill the second syringe up to the **20** mL mark with silver nitrate solution.
8. Dry off any liquid on the outside of the syringe, also from the tip.
9. Weigh the syringe with the solution. **Write the initial mass on the answer sheet.**
10. Now, titrate the sodium chloride solution with the silver nitrate solution until you are about 1 mL away from the end point.
11. Use the disposable pipette to add 0.5 mL of dichlorofluorescein solution to the Erlenmeyer flask.
12. Complete the titration.
13. When you are satisfied that you have exactly reached the end point, weigh both syringes and **write down their final masses on the answer sheet.**
14. When you are finished, pour the suspension from the Erlenmeyer into the waste canister. Thoroughly rinse the Erlenmeyer flask three times with demineralized water. Also pour the rinsings into the waste canister.

Repeat the accurate titration two times (so three accurate titrations in total). **Then work out the questions on the answer sheets.**

Physics - Blue energy

Introduction

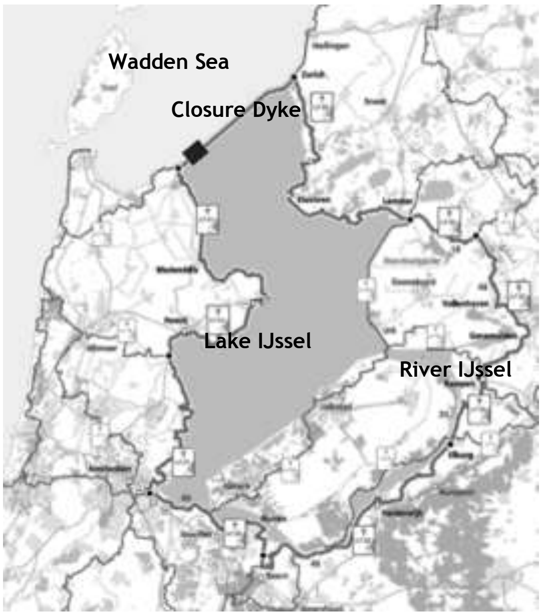


Figure 1 *– The Lake IJssel with the Closure Dyke in the North. The contours of the former* Southern Sea *are indicated by the bold line.*

In 1932, in the Netherlands, a dyke was built that dammed off the former Southern Sea from the Wadden Sea (Figure 1). That dyke, called the Closure Dyke, caused the former salty Southern Sea to become the fresh-water Lake IJssel, named after the river IJssel that feeds it. To regulate the water level in the lake, water is drained through the Closure Dyke into the Wadden Sea at low tide.
From the difference in salt concentrations between sea water and fresh water, electrical energy can be generated. The general name for electrical energy generated from differences in salt concentration is 'Blue energy'. One of the ways to generate electrical energy in an energy power plant is called 'Reverse ElectroDialysis' (RED). In such a plant, salt and fresh water are physically separated by membranes that allow either positively charged ions or negatively charged ions to pass through. Due to the concentration difference, ions from the salt water migrate to the fresh water. This charge transport can be used to generate electricity. Blue energy is a renewable source of energy that does not result in the production of greenhouse gases such as CO_2, NO_x and SO_x.

Goals and experimental setup.

You will use two experimental setups to generate results that you can use to estimate how much energy can maximally be generated from the difference in salt concentrations between using a Blue Energy power plant. The complete experiment consists of three parts:

A. **Setup A: The concentration cell**
   You will use this setup to measure the voltage (= the electric potential difference) between salt solutions of different concentrations.
B. **Setup B: Conductivity**
   You will use this setup to measure the electrical conductivity of the different salt solutions.
C. Carrying out a number of calculations.

Equation sheet

Ohm’s law: $\Delta V = I \cdot R$

Electrical conductance: $G = \frac{1}{R}$; unit is siemens: $[G] = \mathrm{S} = \Omega^{-1}$

Specific electrical conductivity: $\sigma = G\,\frac{l}{A}$

Electrical power $P = \Delta V \cdot I$

Circumference of a circle: $2\pi r$

Area of a circle: πr^2

A. Measuring potential differences using the concentration cell

Goals of the experiment

1. Measuring the potential differences between solution **X0** and solutions **X1** – **X4.**
2. Determining the concentration of solution **X0**.

The experiment

Setup

A photograph of the experimental setup is provided in Figure 2 (start situation).

Materials

- Two beakers of 100 mL (indicated by A in Figure 2)
- A stand with clamps
- A salt bridge (B)
- Two silver/silver chloride electrodes (C)
- A plastic holder for the salt bridge and the electrodes (D)
- A digital multimeter
- A red electrical wire
- A black electrical wire
- One 250 mL flask labeled **X0**, containing a salt solution of unknown concentration
- Four 250 mL flasks labeled **X1** to **X4**, containing salt solutions of different known concentrations. (Note: you also need these flasks in experiment B)
- A list of concentrations is provided with the setup.
- Paper towels

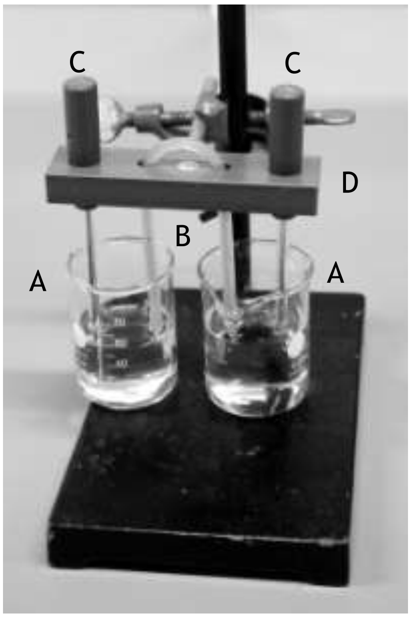


Figure 2 *– Experimental setup, start situation*

ATTENTION!
Be careful using the electrodes! Always store them with their wires in a salt solution except while changing solutions. Do not rinse them with demineralized water.
Do NOT use the Ω-position of the multimeter switch, the silver chloride electrodes will be severely damaged and thereafter useless.
If the multimeter beeps, press the RANGE button to prevent it from switching off. If it switched off, turn the dial to OFF and then back to mV ≂
If you have any other problems regarding the multimeters, please contact the lab assistants.

Performing the experiment

At the start of the experiment the setup is as depicted in Figure 2. The salt bridge and electrodes are both submerged in salt solution **X0**. During the experiment the content of the left beaker is replaced by solutions **X1** to **X4**, the right beaker stays filled with the **X0** solution.

1. Set the dial of the multimeter to mV ⎓ and press the blue button to select direct current (DC).
2. Connect carefully the right electrode with the red electrical wire to the $V\Omega$ port of the multimeter and the left electrode with the black electrical wire to the COM port of the multimeter.
3. Wait until the multimeter indicates a reasonably stable voltage. Write down the voltage in table A1 on the answer sheet (Note: the voltage can have a positive or negative value). *If the voltage is larger than 3 mV (or less than -3 mV), ask the lab assistant for a new set of electrodes!*
4. Raise the clamp with holder such that the salt bridge and electrodes are removed from the solutions. Empty the *left* beaker in the sink. Dry the inside of the beaker thoroughly with a paper towel.
5. Pour approximately 80 mL of solution **X1** in the beaker and place it back on the stand base.
6. Lower the clamp with the holder such that the salt bridge and electrodes properly hang in the solutions again.
7. Wait for the voltage to stabilize (max 5 minutes), you can gently shake the beakers during this period. Write down the voltage in table A1 on the answer sheet.
8. Repeat steps 4 to 7 for solutions **X2**, **X3** and **X4**.
9. When you are finished, leave the setup with the electrodes and salt bridge hanging in the solutions, disconnect the electrical wires and switch off the multimeter. Ask the lab assistant to pick up the electrodes and salt bridge for safe storage. If you need the electrodes later again, you can ask for them.

➢ **Answer questions 1 to 5 on the answer sheets.**

B. Measuring the electrical conductance of the solutions

Goals of the experiment

- Measuring the electrical conductance of solutions **X0** and **X1**–**X4**.
- Determining the concentration of **X0**.
- Determining the specific electrical conductivity of **X0** and **X1**–**X4**.

The experiment

Materials

- Two beakers of 100 mL
- A set of two gold-plated electrodes (part A in Figure 3)
- AC power supply box (B) (without cable)
- Two digital multimeters (C)
- Four 250 mL flasks labeled **X1** to **X4**, containing salt solutions of different concentrations (the same flasks as in part A)
- One 250 mL flask labeled **X0**, containing a salt solution of unknown concentration
- Paper towels
- One set square (in your pencil case)
- Four electricity wires (red, black, 2x blue) (D) and two wires of a multimeter (red, black) (E)
- A stand with clamps

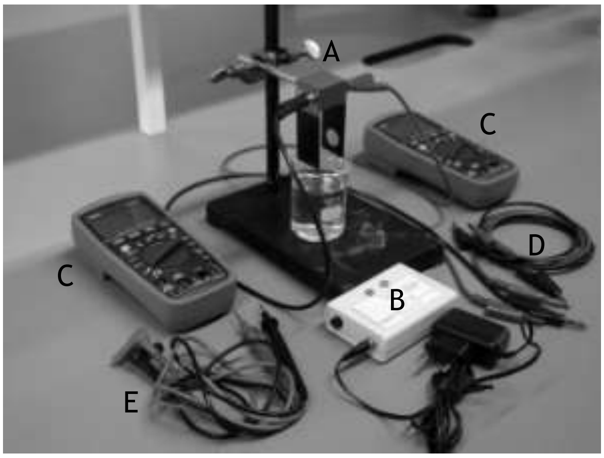


Figure 3 *- Materials for the setup of the experiment*

Setup

In this experiment the electrical conductance of the salt solutions will be determined with the materials depicted in Figure 3. A set of gold plated electrodes is submerged in a beaker containing the salt solution. The electrodes must be connected to a power supply, which delivers an alternating voltage with a high frequency (1 kHz) and a low voltage. This is needed to prevent electrolysis of the salt solution. From the measurement of voltage across and current through the electrodes the electrical conductance can be determined.
In Figure 4 a schematic of the power supply is shown, with the AC voltage supply depicted as the box with the triangle shaped symbol. During the experiment we will connect the ports on the right side with the electrodes for the conductance measurements.
In order to measure the current, the box contains a resistor $R_1 = 10\ \Omega$ and an amplifier to amplify the voltage across the resistor 10 times. The output is measured between the two upper ports.

Performing the experiment

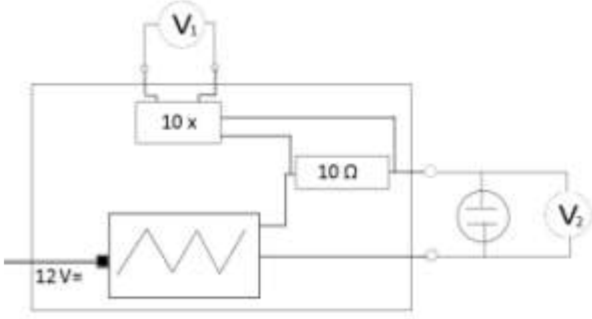


Figure 4 - *Schematic of the power supply box. The symbol* ⊣|⊢ *is used for the electrodes.*

1. Pour 80 mL of solution **X0** in both beakers. Beaker 1 will be used for measurements, beaker 2 for rinsing with **X0** in between measurements.
2. Submerge the set of electrodes in beaker 1 such that the circular gold plated surfaces are fully submerged in the solution.
3. Build the electrical circuit using the schematic from Figure 4. Make sure the multimeters are in the mV ≂ AC setting (using the blue button so that 'AC' appears in the display) for alternating current, and connected to the appropriate sockets.
   Ask a lab assistant to check your circuit and to connect your power supply.
   Let the lab assistant sign the answer sheet before proceeding with the experiment!
4. Now plug the power supply in the wall socket and wait a moment until both multimeters show a more or less constant value. If the reading of a multimeter is "OL" (out of limit), change the range with the RANGE button, or turn the dial to V~. Write the values in Table B1 at question 7 on the answer sheets, and complete the symbols of the measuring quantities with the correct units in the top row.
5. Lift the electrodes out of beaker 1, and lower them in beaker 2 for rinsing.
6. Pour the contents of beaker 1 down the drain and dry the inside of the beaker.
7. Fill beaker 1 with solution **X1**.
8. Take the electrodes out of the clamp, shake them gently and put them back in beaker 1 in the same way as at step 2. Take the readings from the multimeters and write them down in Table B1 at question 7 on the answer sheets.
9. Repeat the measurements (steps 5 – 8) for the remaining solutions **X2**, **X3**, and **X4**. Write down the readings on the answer sheet.
10. Finally, remove the power supply from the wall socket. Clean the beakers and electrodes.

➢ **Answer questions 8 to 10 on the answer sheets**

The conductance you measured is dependent on the distance between the electrodes and the area of the conducting surface. The *specific conductivity*, however, is a property of the solution and does not depend on the setup used. The relationship between conductance and specific conductivity σ is:

$$\sigma = G \cdot \frac{l}{A} \quad \text{in S/m.}$$

In this equation l is the distance between the electrodes and A the conductive area of the electrodes. In the cell you used this is the area of the gold plated circle.

➢ **Answer questions 11 and 12 on your answer sheets.**

C. Calculating the theoretical maximum electrical power

Goal

- Calculating the theoretical maximum power produced by a RED Blue Energy cell.

In the previous sections we have obtained information on the obtainable voltage from a concentration cell, and the electrical conductivity of salt solutions. Using these data we will now calculate how much electrical power a Blue Energy power plant could produce in theory.

In Figure 5 the schematic of a RED Blue Energy cell is depicted. It consists of two large flat electrodes and a membrane in between. This membrane has the same functionality as the salt bridge in setup A. Salt water flows on one side of the membrane, and fresh water on the other side. This creates a potential difference between the electrodes in the same way as measured in setup A. The electrodes can be connected to an external resistor R_{ext} to generate current and power.

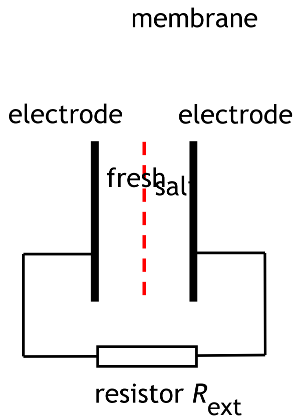


Figure 5 *-Schematic RED Blue Energy cell*

In the following part of this exercise you are going to calculate the maximum power a Blue Energy cell could deliver, on basis of your own measurements.

➢ **Answer question 13 on your answer sheets.**

For the RED cell the distance between the electrodes and membrane is equal to $l = 2.0\ \text{mm}$ and the total area of the electrodes is $A = 1.0 \times 10^2\ \text{m}^2$.
The internal resistance of the RED cell can be calculated as follows:

$$R_{\text{int}} = \frac{1}{G_{\text{fresh}}} + \frac{1}{G_{\text{salt}}}$$

➢ **Answer questions 14 and 15 on your answer sheets.**

To obtain the maximum power from the RED cell, connect it to an external resistor with an equal resistance as the internal resistance:

$$R_{\text{ext}} = R_{\text{int}}$$

➢ **Answer questions 16 to 18 on your answer sheets.**

Water and sustainability

Multiple Choice Test

Answer key

December, 5th 2017

Answer key

Biology questions

Rate of flow of blood

1. **D**
   On average the total amount of blood running should stay the same (in fact slightly less in capillary vessels and vein due to run off of lymph through lymph vessels, but this influence can be neglected). So roughly the rate of flow will be a flipped version of the cross section area ⇒ D is correct.

Fermentation and Respiratory Quotient RQ

2. **C**
   Assume *a* mol is converted aerobically, so (0.5 – *a*) mol glucose is converted anaerobically.
   This means that 6*a* mol CO_2 (aerobically) plus 2×(0.5 - *a*) mol CO_2 (anaerobically) is generated while 6*a* mol O_2 is used.
   Total amount generated mol CO_2 = 6*a* + 2×(0.5 - *a*) = 4*a* + 1 and this equals 1.8,
   so *a* = 0.2.
   In other words: 1.8 mol CO_2 is generated and 6×0.2=1.2 mol O_2 is used.
   $RQ = \frac{\text{moles of CO2 (produced)}}{\text{moles of O2 (used)}} = \frac{1.8}{1.2} = 1.5$

Glucose concentration in blood

3. **A**
   Liver is essential as it releases glucose. So D is highest.
   From liver vein the blood flows into posterior (inferior) vena cava (C). There it is mixed with lower glucose containing blood stream coming from lower body parts. After right atrium and ventricle of the heart blood flows to lungs where some glucose is consumed. After that it flows back through pulmonary artery (B) to the heart. Next blood leaves the heart by aorta and flows partly to the brains (again some glucose consumption) and other body parts. From upper body finally blood returns to the heart by anterior (superior) vena cava (A).

Sphagnum

4. **C**
   At some places (especially East part) *Sphagnum squarrosum* exist while pH<4.0, so conclusion I is wrong. *Sphagnum recurvum* and *Sphagnum fibriatum* are neighbors and do not mix. The boundary is sharp, but does not overlap with the pH boundaries. So competition must exist. Conclusion II is correct.
   The picture shows that *S. squarrosum* and *S. recurvum* exist in different pH ranges:
   S. squarrosum doesn't occur where pH<3, while *S. recurvum* doesn't exist where pH>4.
   So III is correct.

Hay water

5. **A**

I The beaker only contains heterotrophic organisms which are dissimilating and consuming organic materials. No organic compounds are produced by something like photosynthesis. So mass must decrease.

II The heterotrophic organisms are continuously using organic compounds, which will run out. Their number will gradually decrease to zero. A climax stadium will not be established.

Determination of Caminalcules

6. **D**

See table. Features present are indicated with √ for I up to VIII.
With focusing only on long arms, long body and belly spots it is possible to identify all eight creatures. Fingers, only present in II and VII, are not needed.

Feature	I	II	III	IV	V	VI	VII	VIII
Long arms				√	√	√	√	
Long body	√		√	√			√	
Belly spots		√	√		√		√	
Fingers		√					√	

Water loss

7. **B**

Diffusion of water through skin (do not mix up with sweating) is not influenced by body activity and must be constant. So this is II → A and C are incorrect. Strenuous activity will result in extra air inhalation (breathing), causing extra water loss by lung ventilation. This must be process I. Meanwhile this extra water loss will result in reduction of urine production (process III).

Temperature-sensitive alleles

8. **A**

Genotype F1 is: ¼ EE + ½ Ee + ¼ ee, but EE will not develop at 19 °C, so F1 offspring is ⅔ Ee and ⅓ ee.
The combination EE again will not develop. The fraction of genotype EE in F2 will be:
½ × ⅔ (Ee) × ½ × ⅔ (Ee) = 1/9.

DNA and evolutionary relationship

9. **C**

A & D and C & E are most related (short distance) and must be close together in the dendogram.
D & E and D & C must be far from each other in the dendogram as they are least related (i.e. largest distance). The only dendogram matching with these statements is C.

Legionella

10. **A**

(670 – 199)/3 = 157, an integer result, so the T at position 671 is the first base of a new codon. This codon is T T C on the coding strand, which is transcribed into RNA as U U C, which is translated into Phe. The next codon is A G T, which is transcribed into A G U and translated into Ser, so answer A is correct.

Chemistry questions

Photosynthesis by algae

11. **B**

In photosynthesis carbon dioxide and water are converted and oxygen is formed.

12. **D**

On the right side only neutral molecules are written.
1 HPO_4^{2-} and 16 NO_3^- are needed to supply the P and N atoms in $C_{106}H_{263}O_{110}N_{16}P$.
1 HPO_4^{2-} and 16 NO_3^- have 18 negative charges, so 18 positive charges at the left side are needed to obtain neutrality.

Green chemistry

13. **B**

The atom economy represents how much of the starting materials gets into the products. The higher the better.
The *E*-factor represents how much waste is obtained. The lower the better.

Determination of oxygen

14. **C**

If the burette is not rinsed with the solution of sodium thiosulfate, this solution is diluted with the water from the inside of the burette. Because of this V_{thio} will be too high and consequently the result.
If there is air in the tap aperture of the burette, in the beginning of the titration the level of the solution in the burette goes down while no solution leaves the burette. Because of this V_{thio} will be too high and consequently the result.

15. **B**

V_{thio} mL 0,0100 M sodium thiosulphate solution contains $V_{thio} \times 0.0100$ mmol $S_2O_3^{2-}$; this has reacted with $\frac{1}{2} \times V_{thio} \times 0.0100$ mmol I_2 and to form this amount of I_2, in the first reaction $\frac{1}{2} \times \frac{1}{2} \times V_{thio} \times 0.0100$ mmol O_2 has reacted with iodide.
$\frac{1}{2} \times \frac{1}{2} \times V_{thio} \times 0.0100$ mmol O_2 is $\frac{1}{2} \times \frac{1}{2} \times V_{thio} \times 0.0100 \times 32.00$ mg.
This was dissolved in 10.00 mL surface water. So the O_2 concentration in the surface water is $\frac{1}{2} \times \frac{1}{2} \times V_{thio} \times 0.0100 \times 32.00 \times \frac{10^3}{10.00} = 8.00 \times V_{thio}$ mg/L.

Fertilizer from urine

16. **D**

From figure 1 it can be seen that at pH = 8 the predominant phosphate species is HPO_4^{2-} and from figure 2 it can be seen that at pH = 8 the predominant ammonium species is NH_4^+.

Hydrogen fuel cell

17. **C**

In an electrochemical cell, the electrode where the oxidator, in this case oxygen, reacts is the positive electrode . The other electrode is the negative electrode.

No CO_2

18. **C**

$\Delta_r H = -\Delta_f H_{CO_2} + \Delta_f H_{CO} + \Delta_f H_{H_2O}$ = –(–394) + (–111) + (–242) = +41 kJ/mol.

The reaction enthalpy is positive, so the reaction is endothermic.

19. **A**

According to Le Chatelier's principle an increase in pressure leads to a decrease in the number of gas molecules.
And an increase in temperature favors the endothermic reaction.

Fertilizers

20. **C**

All three fertilizers have the same amount of N atoms per mol. So the one with the least molar mass has the highest mass percentage of N.
The molar masses are:

$(NH_4)_2SO_4$:	132.14 g/mol
$CaCN_2$:	66.02 g/mol
$CO(NH_2)_2$:	60.06 g/mol.

Physics

Solar Shower

21. **C**

The amount of heat the water takes up is:
$Q = mc\Delta T = 15 \times 4.2 \cdot 10^3 \times (35 - 18) = 1.07 \cdot 10^6$ J.

The heating time can be calculated as: $t = \frac{Q}{P} = \frac{1.07 \cdot 10^6}{200} = 5.33 \cdot 10^3$ s and that is $\frac{5.33 \cdot 10^3}{3600} = 1.5$ h.

Liquid and vapor

22. **C**

Because $\rho = m/V$, the density of the vapor becomes 1000 times lower than the density of the liquid. It is easy to see that statement II is also correct.

Hydro pneumatic suspension

23. **B**

$p = 1.0 \cdot 10^5 + \frac{4000}{200 \cdot 10^{-4}} = 3.0 \cdot 10^5$ Pa

Heating paraffin

24. **B**

The specific heat capacity of the solid and liquid paraffin is indicated by the *slopes* of the first and the last part of the graph, respectively. If the slope is steeper, the heat capacity is lower, so the heat capacity of liquid paraffin is higher than the heat capacity of solid paraffin, so statement I is false.
During melting, the temperature is constant, so the kinetic energy of the molecules is constant, so only the potential energy of the molecules increases. N.B. The work done on the environment is neglected here.

A little boat and a bottle in the river

25. **B**

Because we are considering relative motions here, we can omit the motion of the river for the time being. In that case, the boat travels for 10 minutes in one direction followed by 10 minutes in the opposite direction after which it overtakes the bottle. In truth, the bottle has covered a distance of 3 km in 20 minutes, so the speed of the river is 3 km per 1/3 hour, so 9 km/h.

Electric circuit

26. **B**

When the slide is displaced towards X, the total resistance in the circuit increases. As a result, both the current in, and the voltage over Q decrease. The voltage across P must increase, because the sum of the voltages is equal to the voltage of the source. This means that the current in P will also increase.

Super tanker

27. **A**

The density of salt water is higher than the density of fresh water, so the buoyancy of a volume of salt water is higher than the buoyancy of the same volume of fresh water. Hence, the tanker will displace a larger volume of fresh water and will have a deeper draft in the river, which contains fresh water.

Electricity storage

28. **C**

$E_{rot} = \frac{1}{2}I\omega^2$, with $I = \frac{1}{2}mR^2$

Thus $E = \frac{1}{4}mR^2\omega^2 = \frac{1}{4} \times 1\,350 \times 0.45^2 \times \left(\frac{20\,000 \times 2\pi}{60}\right)^2 = 3.0\cdot 10^8$ J.

Sky crane

29. **D**

The thrust force is pointed diagonally upwards and is larger than its vertical component. Together, the vertical components must equal the gravitational force F_g. So $F_{thrust} > \frac{1}{4}F_g$

Properties of water

30. **C**

Because of its high heat capacity, a lot of heat is needed to increase the temperature of a volume of water and, the other way round, a lot of heat is emitted when it cools down. Thus, water limits temperature changes in its surroundings: statement I is correct.
Because the density of water of + 4 ^{0}C is greater than the density of water between 0 ^{0}C and 4 ^{0}C, the bottom of the ditch will contain water of + 4 ^{0}C: statement 2 is also correct.

IJSO

14th INTERNATIONAL JUNIOR SCIENCE OLYMPIAD

THE NETHERLANDS 2017

Water and sustainability

Theoretical Test

Marking scheme

December, 7th 2017

Radboud Universiteit

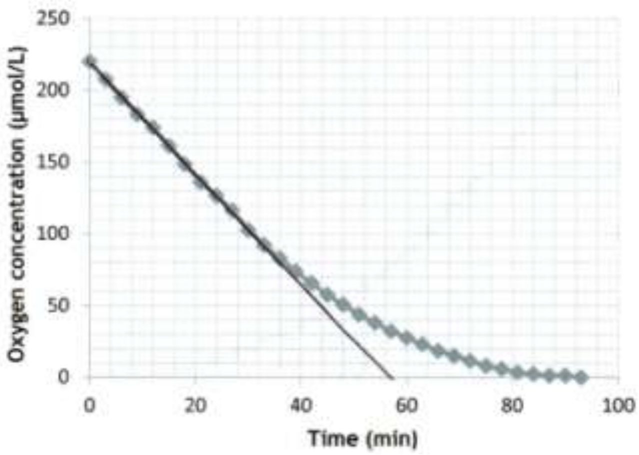
Hogeschool van Arnhem en Nijmegen

slo

Biology questions

Plants in floodplains

1. Maximum score 1.2
An example of a correct calculation is:
The slope of the initial decline of the curve describes the maximum respiration rate per liter per minute. This slope is $\frac{220}{56}$ μmol/(L min) (see figure).



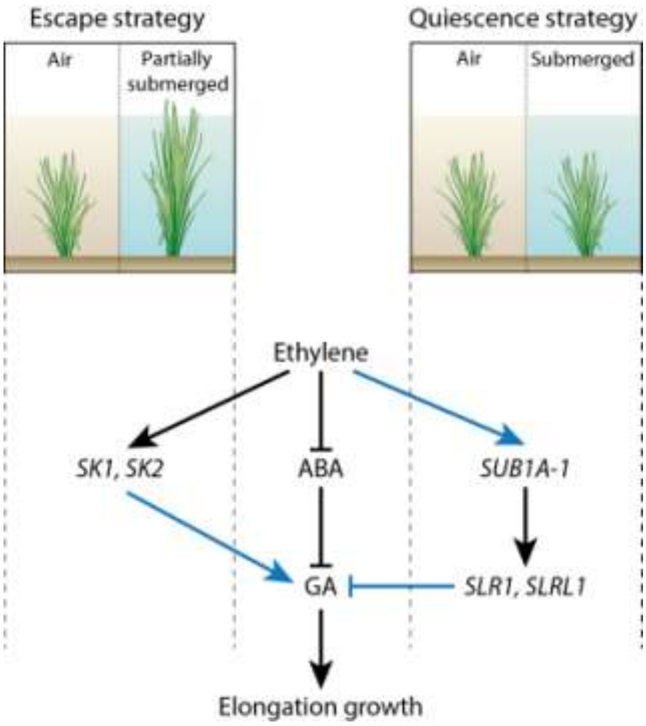
The volume of the box is 1.2 L, so the maximum respiration rate of the submerged plant is $\frac{220}{56} \times 1.2 = 4.7$ μmol/min (range: ± 0.2 μmol/min).

- notion that the slope of the initial decline of the curve describes the maximum respiration rate per liter per minute 0.4
- calculation of the slope 0.4
- multiplying the slope by 1.2 (L) 0.4

2. Maximum score 0.4
4.7 μmol/min

Remark
The answer should be the same as the result of the calculation of question 1.

3. Maximum score 1.2

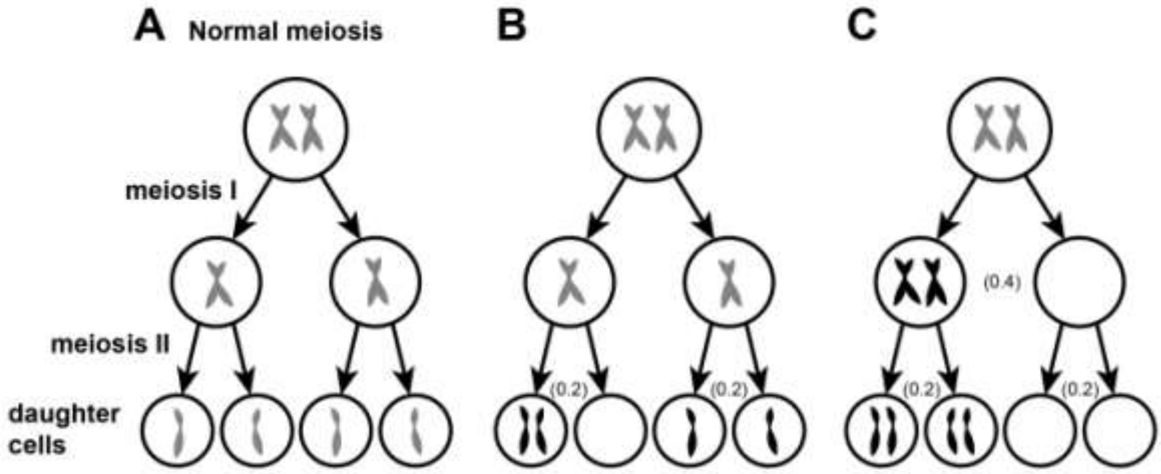


per correct interaction 0.4

Oysters

4. Maximum score 1.2

A correct answer may look as follows:



correct meiosis I step (from first to second row of C) 0.4
per correct meiosis II step (second to third row of B and C) 0.2
scores are also indicated in the figure above (in brackets).

Remark
Cells derived from the same cell can be permuted.
If in B the student gives a faulty meiosis II for all four daughter cells, he/she also receives full points.
If nothing is filled in on the second row of C, the student does not receive points for the empty cells on the third row.

5. Maximum score 0.8

Species	*O. edulis* (oyster)	*B. ostreae* (protist)
Role	III	IV

per correct answer 0.4

6. Maximum score 0.8

Parameter	*p*	*q*
Description	IV	VI

per correct answer 0.4

7. Maximum score 1.2

Parameter	a	b	c
Triploid vs. diploid	+	o	–

Explanation:
a: birth/growth rate of oyster: '[triploid oysters] grow and mature faster'.
b: death rate of oyster: no info provided
c: infection parameter: '[triploid oysters] are more resistant to infections'.

per correct cell 0.4

Remark
No points for empty cells.

Osmosis in fish

8. Maximum score 1.2

at location 1: → (arrow to the right)
at location 2: ← (arrow to the left)
at location 3: H (low % O_2)
at location 4: L (high % O_2)

· directions of both arrows at locations 1 and 2 are opposite	0.4
· if arrows are opposite and direction at locations 1 and 2 correct	0.4
· both indications at locations 3 and 4 correct	0.4

9. Maximum score 0.8

I swell up
II very little
III large
IV diluted

per correct answer	0.2

Anammox

10. Maximum score 1.2

Hypothesis	Experiment			Prediction		
I	A	B	C	1		2
II	A	B	C	1		2
III	A	B	C	1	OR	2

· all pairings of I – III with A – C are correct	0.8
if two pairing of I – III with A – C are correct	0.4
if two pairing of I – III with A – C are correct	0.2
· all predictions correct	0.4
if one or two pairing(s) of I – III with A – C is/are correct and the corresponding prediction correct	0.4
if all pairings correct, but one prediction incorrect	0.2
if no pairing is correct or no prediction is correct	0

Chemistry questions

Water and the fight against *Legionella*

11. Maximum score 1.2

An example of a correct answer is:
After x D-values the concentration is decreased to $0.10^x \times 1\,200$ cfu/L. So to reach a level of 100 cfu/L: $0.10^x \times 1\,200 = 100$. This gives $x = 1.08$.
So after heating during $1.08 \times 5 = 5.4$ min the concentration of *Legionella* in the water is below the level that is regarded as safe.

- after x D-values the concentration is decreased to $0.10^x \times 1\,200$ cfu/L — 0.4
- calculation of x — 0.4
- rest of the calculation — 0.4

12. Maximum score 1.6

An example of a correct answer is:
The equilibrium is: $HClO + H_2O \rightleftharpoons H_3O^+ + ClO^-$

$$K_a = \frac{[H_3O^+][ClO^-]}{[HClO]} \text{ or } [H_3O^+] = K_a \frac{[HClO]}{[ClO^-]}$$

So when $[H_3O^+] > K_a$ then $[HClO] > [ClO^-]$ or pH < pK_a. pK_a = $-\log 4.0 \cdot 10^{-8} = 7.40$.
In the pH region below 7.40 $[HClO] > [ClO^-]$.

- correct expression for K_a — 0.4
- when $[H_3O^+] > K_a$ then $[HClO] > [ClO^-]$ — 0.4
- calculation of the pH value — 0.4
- this is a maximum pH — 0.4

Remark
If the student gives the wrong number of significant figures, no points will be subtracted.

13. Maximum score 1.2

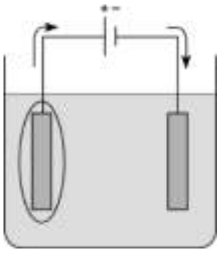
- half-reaction of the reducing agent: $Cu(s) \rightarrow Cu^{2+}(aq) + 2\,e^-$ — 0.4
- half-reaction of the oxidizing agent: $2\,HClO + 2\,H^+(aq) + 2\,e^- \rightarrow Cl_2(aq) + 2\,H_2O$ — 0.4
- overall reaction equation: $Cu(s) + 2\,HClO(aq) + 2\,H^+(aq) \rightarrow Cu^{2+}(aq) + 2\,H_2O(l) + Cl_2(aq)$ — 0.4

If the following answer is given: — 0.8
half-reaction of the reducing agent: $2\,HClO + 2\,H^+(aq) + 2\,e^- \rightarrow Cl_2(aq) + 2\,H_2O$
half-reaction of the oxidizing agent: $Cu(s) \rightarrow Cu^{2+}(aq) + 2\,e^-$
overall reaction equation: $Cu(s) + 2\,HClO(aq) + 2\,H^+(aq) \rightarrow Cu^{2+}(aq) + 2\,H_2O(l) + Cl_2(aq)$

Remarks:
- *When the student gives an equation like*
  $Cu(s) - 2\,e^- \rightarrow Cu^{2+}(aq)$
  no points will be subtracted.
- *No points will be subtracted for missing or incorrect state indications.*

14. Maximum score 0.8

A correct answer may look as follows:



· correct electrode indicated 0.4

· flow of the electrons correct in relation to indicated electrode 0.4

15. Maximum score 0.8

$2\ \sim S-H\ +\ 2\ Ag^{+}\ \rightarrow\ \sim S-S\sim\ +\ 2\ Ag\ +\ 2\ H^{+}$

· 2 ~S—H left and 2 H^{+} right 0.4

· 2 Ag^{+} left and 2 Ag right 0.4

16. Maximum score 0.4

The reaction of silver ions with ~S—H groups in one protein chain results in a change of the tertiary structure of the protein.

Wastewater treatment

17. Maximum score 1.2

An example of a correct answer is:

$0.632 \times 2 \times 32.00 \times 10^{-3} \times 175\,000 \times 365 \times 3 \times 0.19 = 1.5 \cdot 10^6$ euros

- calculating the number of moles of oxygen needed per inhabitant per day: multiplying 0.632 (moles) by 2 — 0.4
- converting the number of moles of oxygen needed into kg oxygen needed per inhabitant per day: multiplying by the molar mass of oxygen (= 32.00 g/mol) and by 10^{-3} (kg/g) — 0.4
- converting the amount of kg oxygen needed per inhabitant per day into kg oxygen per year for the population of Nijmegen: multiplying by 175 000 (inhabitants) and by 365 (days per year) — 0.2
- converting the amount of kg oxygen per year for the population of Nijmegen into the costs per year: multiplying by 3 (kWh per kg oxygen) and by 0.19 (€ per kWh) and the answer lies in between $1.47 \cdot 10^6$ euros and $1.5 \cdot 10^6$ euros — 0.2

Remark

If the answer is given as 1 470 000 euros or 1 500 000 euros no points are subtracted.

18. Maximum score 1.6

An example of a correct answer is:

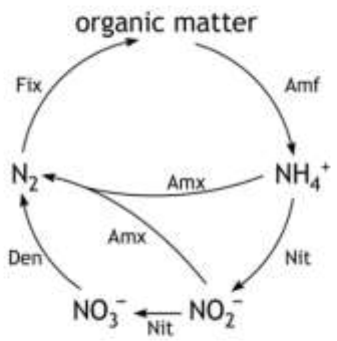
$\frac{2-0.75}{2} \times 100\% = 63\%.$

- oxidizing one mole of NH_4^+ to NO_3^- in the conventional process requires 2 moles of oxygen — 0.4
- oxidizing one mole of NH_4^+ to NO_2^- in the anammox process requires 1.5 moles of oxygen — 0.4
- only half of the amount of NH_4^+ has to be oxidized — 0.4
- calculation of the percentage reduction — 0.4

If the answer $\frac{2-1.5}{2} \times 100\% = 25\%$ is given:	1.2
If the answer $\frac{3-1}{3} \times 100\% = 67\%$ is given	0.8
If the answer $\frac{3-2}{3} \times 100\% = 33\%$ is given	0.4

19. Maximum score 1.2

A correct answer may look as follows:



- NH_4^+ connected with N_2 via NO_2^- and NO_3^- — 0.4
- ‘Nit’ and ‘Den’ in the right place — 0.4
- shortcut ‘Amx’ from NH_4^+ to N_2 and shortcut ‘Amx’ from NO_2^- to N_2 — 0.4

Physics questions

Wind energy

20. Maximum score 0.4

$P = 8P_0$ (W)

21. Maximum score 1.6

An example of a correct answer is:

$P = \frac{1}{2} \times \pi \times \left(\frac{80}{2}\right)^2 \times 1.2 \times \left(\frac{36\times10^3}{3600}\right)^3 \times 0.70 \times 0.59 = 1.2\cdot10^6$ W

- calculation of the area that is covered by the sails: $\pi \times \left(\frac{80}{2}\right)^2$ 0.4
- calculation of the wind speed in m/s: multiplying 36 (km/h) by 10^3 (m/km) and dividing by 3600 (s/h) 0.4
- applying the factor 0.70 × 0.59 0.4
- completion of the calculation 0.2
- answer in 2 or 3 significant figures 0.2

22. Maximum score 1.2

An example of a correct answer is:

The volume of water that has to be pumped is $V = \frac{m}{\rho} = \frac{3.3\cdot10^{11}}{1.03\cdot10^3} = 3.2\cdot10^8$ m^3.

The height difference is $h = 40.0 - 32.0 = 8.0$ m.

So the area of the reservoir is $A = \frac{V}{h} = \frac{3.2\cdot10^8}{8.0} = 4.0\cdot10^7$ m^2.

- use of $A = \frac{V}{h}$ 0.4
- use of $V = \frac{m}{\rho}$ 0.4
- completion of the calculation 0.2
- answer in 2 or 3 significant figures 0.2

23. Maximum score 2.0

An example of a correct answer is:

The increase in potential energy is: $\Delta E_p = mg\Delta h = 3.3\cdot10^{11} \times 9.81 \times \frac{1}{2} \times (40.0 + 32.0) = 1.17\cdot10^{14}$ J.

The total average power of the wind turbines is $75 \times 5.0\cdot10^6 = 375\cdot10^6$ W.

Since $E = Pt$, and $E = \Delta E_p$, it follows that $t = \frac{\Delta E_p}{P} = \frac{1.17\cdot10^{14}}{375\cdot10^6} = 3.11\cdot10^5$ s or $\frac{3.11\cdot10^5}{3600} = 86$ h.

- insight that $\Delta E_p = mg\Delta h$ 0.4
- insight that $\Delta h = \frac{1}{2} \times (40.0 + 32.0)$ m 0.4
- calculation of ΔE_p 0.4
- use of $E = Pt$ 0.4
- completion of the calculation 0.2
- answer in 2 or 3 significant figures 0.2

24. Maximum score 1.2

Yes	No	Question
	√	Because of its location at sea, nobody is annoyed by this plant.
√		In this plant, energy can be stored and subsequently be used in the absence of wind.
√		In this plant, energy can be stored and subsequently be used whenever necessary.
	√	This plant is a cheap way of generating electricity.
√		This plant can supply a constant power.
√		The power supply of this plant can be adapted to the demand.
	√	This plant can replace a number of coal-fired power stations.
	√	This plant does not expel CO_2.

Per correct answer 0.15

Remark:
For every wrong argument 0.15 points deduction. The total score for this question cannot be less than 0 points.

Room for the river

25. Maximum score 0.8

An example of a correct derivation is:

For n holds: $n = \frac{A}{Q} D^{2/3} S^{1/2}$

So the unit of n is: $\frac{\mathrm{m}^2}{\mathrm{m}^3/\mathrm{s}} \mathrm{m}^{2/3}$ or $\mathrm{s/m}^{1/3}$.

· all units correctly used	0.4
· rest of the derivation	0.4

26. Maximum score 1.2

An example of a correct calculation is:

$D = \left(\frac{0.10 \times 1.4 \cdot 10^4 \times 0.018}{200 \times (5.0 \cdot 10^{-4})^{1/2}}\right)^{3/5} = 2.8$ m.

· multiplying $1.4 \cdot 10^4$ ($\mathrm{m^3/s}$) by 0.10	0.4
· use of the correct values of D, W and S	0.4
· completion of the calculation	0.2
· answer in 2 or 3 significant figures	0.2

27. Maximum score 1.6

An example of a correct calculation is:

$0.99 \times 0.99^{2/3} \times \frac{0.018}{0.022} \times 10\% = 8.0\%$.

· insight that A decreases by 1%	0.4
· insight that because of the decrease in D of 1%, the drain decreases by a factor $0.99 \times 0.99^{2/3}$	0.4
· insight that when n increases by a factor $\frac{0.022}{0.018}$, the drain decreases by a factor $\frac{0.018}{0.022}$	0.4
· completion of the calculation	0.2
· answer in 2 or 3 significant figures	0.2

Remark
If D of previous question is used, correct calculation gives the same answer and same amount of marks.

IJSO

14th INTERNATIONAL JUNIOR SCIENCE OLYMPIAD

THE NETHERLANDS 2017

Water and sustainability

Practical Test

Answer sheets

December, 9th 2017

Signature:	

The contractile vacuole of *Paramecium*

1. **(1 point)** Below, five possible statements about the experiment are given. (Note that the statements are not necessarily correct!). Indicate in **Table A1** which statements represent hypotheses and which statements represent predictions, while making sure to match corresponding hypotheses and their predictions if the hypotheses were true. You have to use one statement twice.
   a. The contraction frequency of the anterior vacuole is the same for both salt concentrations.
   b. *Paramecium* regulates water outflow by changing the contraction frequency of the vacuole when the osmotic value of the surroundings changes.
   c. Salt concentration does not affect *Paramecium*.
   d. Paramecium counterbalances water inflow in different environments by changing only the volume that is pumped out per contraction of the vacuole.
   e. The anterior vacuole contracts more often for the lower salt concentration than for the higher salt concentration.

***Table A1** – Hypothesis and prediction*

	Hypothesis	Prediction
1		
2		
3		

Signature:	

2. **(2.1 points)** One of your supervisors will note down the scores you obtained for your microscopy sample on his/her own sheet. He/she will tick one of the boxes below when he/she has scored your work. DO NOT fill anything in these boxes.

3. **(0.7 points)** Compare the *Paramecia* in the samples with and without the methylcellulose gel. What is the **most appropriate** reason to use a gel to make the samples? Tick the correct answer.

☐ A The gel provides a constant 'base level' osmotic value, so the difference in salt concentrations between the two cultures is better defined.

☐ B The gel inhibits the movements of the *Paramecia*, so it is easier to observe them, and their contractile vacuoles, under the microscope.

☐ C The gel prevents the water in the sample from evaporating, so the salt concentration stays constant over time.

☐ D The gel provides an abundant food source for the *Paramecia*, so they do not have to move around anymore to collect food. As a result, it is easier to observe them, and their contractile vacuoles, under the microscope.

☐ E The gel prevents the cover slip from crushing the *Paramecia*.

Signature:	

4. **(3.9 points)** Observe six consecutive contractions of the anterior vacuole of a *Paramecium*. Note down the total time between contraction 1 and contraction 6 in the correct column of **Table A2** below.

Table A2.*–The total time between six consecutive contractions of the anterior contractile vacuoles of nine* Paramecia *at two different salt concentrations.*

	$t_{6\text{ contractions}}$ (s)	
Culture → / ***Paramecium* no. ↓**	**'P—'**	**'P+'**
1		
2		
3		
4		
5		
6		
7		
8		
9		

Signature:	

5. **(0.9 points)** From the measured times in **Table A2**, calculate the corresponding contraction frequencies $f_{\text{contraction}}$, and write these in **Table A3**. Write down the calculation for the first *Paramecium* in culture **P—** (*i.e.* corresponding to the bold cell in **Table A3**) in the box below. Fill out the correct unit between the brackets in the top cell of **Table A3**.

calculation

$f_{\text{contraction}}$ =

Table A3*–The contraction frequencies of the anterior contractile vacuoles of nine* Paramecia *at two different salt concentrations.*

	$f_{\text{contraction}}$ (… … … … …)	
Culture -> / ***Paramecium* no. ↓**	**'P—'**	**'P+'**
1		
2		
3		
4		
5		
6		
7		
8		
9		

Signature:	

6. **(0.8 points)** From the numbers in **Table A3**, calculate the average contraction frequencies of the anterior contractile vacuoles for each culture and write them in **Table A4**. Write down your calculation for the '**P—**' culture (*i.e.* corresponding to the bold cell in **Table A4**) in the box below.

calculation

$f_{\text{contraction, average, 'P—'}} =$

Table A4 *– The average contraction frequencies of the anterior contractile vacuoles of nine* Paramecia *at two different salt concentrations.*

Culture →	'P—'	'P+'
$f_{\text{contraction, average}}$ (...)		

Instead of the average, scientists sometimes determine the so-called 'median' of a number of data points. The median can be found by arranging the data points from small to large (or the other way round); the median then is the middle number. If the number of data points is even, there is no middle number and the median is calculated as the average of the two middle numbers.

Signature:	

7. **(0.2 points)** *Per culture*, copy the contraction frequencies from **Table A3** to **Table A5**, but order them from small to large.

Table A5*—The contraction frequencies of the anterior contractile vacuoles of nine* Paramecia *at two different salt concentrations, ordered from small to large.*

	$f_{\text{contraction}}$ (...)	
Culture → / ***Paramecium* no. ↓**	**'P—'**	**'P+'**
1		
2		
3		
4		
5		
6		
7		
8		
9		

Signature:	

8. **(0.4 points)** For each culture, determine the median of the contraction frequencies of the anterior contractile vacuoles of nine *Paramecia* and write them in **Table A6**.

Table A6*–The median contraction frequencies of the anterior contractile vacuoles of nine* Paramecia *at two different salt concentrations.*

Culture →	**'P–'**	**'P+'**
$f_{\text{contraction, median}}$ $(\dots)$		

9. **(0.8 points)** What, in general, is the advantage of the using the median over the average? And what is the disadvantage? (N.B. 'extreme values' are either very large or very small values). Tick one correct advantage and one correct disadvantage.

Advantage:

☐ A The median is less sensitive to extreme values than the average.

☐ B If there are no extreme values, the median is a more accurate description of the data than the average.

☐ C The median is easier to calculate, since it is only based on one (for an odd number of values) or two (for an even number of values) values, whereas the average uses all values.

Disadvantage:

☐ A Since the median is based on only one or two values, it is a less accurate description of the data than the mean.

☐ B The median is more sensitive to extreme values.

☐ C If there are no extreme values, the median is a less accurate description of the data than the average.

Signature:	

10. **(0.8 points)** Can each of the following conclusions be drawn based on this experiment?

		YES	NO
I	The volume of water displaced by one contraction of the contractile vacuoles is constant across salt concentrations.	☐	☐
II	The iso-osmotic value of *Paramecium* is higher than the osmotic value of both '**P—**' and '**P+**'.	☐	☐
III	The contraction frequency of the contractile vacuoles is constant over time.	☐	☐
IV	A change in salt concentration of the environment does not affect *Paramecium*.	☐	☐

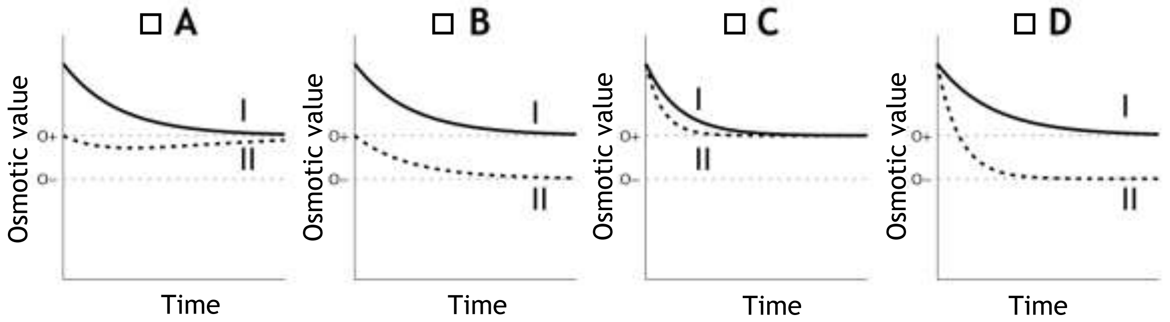
Signature:	

11. **(0.7 points)** *Paramecium* has the ability to adjust its internal osmotic value (**O**) to its surroundings over the course of several hours. Of course there is a limit to this ability. Assume that the minimum osmotic value *Paramecium* can achieve is equal to that of the surroundings in the '**P+**' culture. Call this osmotic value **O+.**

Four graphs are shown. Tick the graph that correctly depicts:

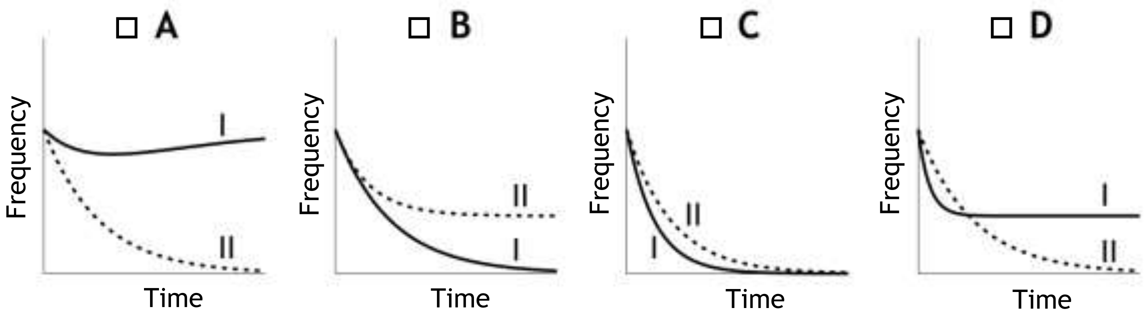
Case I: the osmotic value of a *Paramecium* cell over time when it is transferred from an iso-osmotic environment (where *Paramecium* had the same osmotic value as its environment) equal to 1.5×**O+** into an environment with an osmotic value of **O+**.

Case II: the osmotic value of a *Paramecium* cell over time when it is transferred from an iso-osmotic environment equal to 1.5×**O+** into an environment with an osmotic value **O—** equal to that of the '**P—**' culture.



Signature:	

12. **(0.7 points)** Similarly, tick the graph below that correctly depicts the contraction frequencies of the contractile vacuoles of the *Paramecia* in cases I and II over time.



Signature:	

Determining the chloride concentration of a sodium chloride solution using the Fajans titration

A. Determining the densities of the solutions

1. **(1.9 points – 0.6 points for the calculation and 1.3 points for accuracy of the result)**
   Calculate the density of the sodium chloride solution in g/mL. Only if you are unable to get a result, use the arbitrary value of 1.12 g/mL for subsequent questions.

measurements   calculation   answer: $\rho_{\text{NaCl sln}} =$ g/mL

Signature:	

2. **(1.9 points – 0.6 points for the calculation and 1.3 points for accuracy of the result)**
Calculate the density of the silver nitrate solution in g/mL. Only if you are unable to get a result, use the arbitrary value of 1.05 g/mL for subsequent questions.

measurements
calculation
answer: $\rho_{\text{AgNO}_3\text{ sln}} =$ g/mL

Signature:	

B. Trial titration

Write the results of the trial titration in this box (you will get no marks for this).

C. Accurate titrations

3. **(0.4 points)** For every accurate titration, write down the initial (i) and final (f) masses of the syringes containing the sodium chloride solution and the silver nitrate solution.

	$m_{\text{NaCl syringe, i}}$ (g)	$m_{\text{NaCl syringe, f}}$ (g)	$m_{\text{AgNO}_3\text{ syringe, i}}$ (g)	$m_{\text{AgNO}_3\text{ syringe, f}}$ (g)
Titration 1				
Titration 2				
Titration 3				

Signature:	

4. **(0.85 points)** Calculate the volumes of sodium chloride solution that you titrated. Show the calculation for titration 1 only. Complete the table.

calculation

	$V_{\mathrm{NaCl\ solution}}$
Titration 1	
Titration 2	
Titration 3	

5. **(0.85 points)** Calculate the volumes of silver nitrate solution that you used to titrate the sodium chloride solution. Show the calculation for titration 1 only. Complete the table.

calculation

	$V_{\mathrm{AgNO_3\ solution}}$
Titration 1	
Titration 2	
Titration 3	

Signature:	

6. **(0.4 points)** Calculate the molarity (*i.e.* the concentration in mol/L) of silver nitrate in the solution. Only if you are unable to calculate the molarity, use the arbitrary value of 0.440 mol/L for subsequent calculations.

calculation

molarity: mol/L

7. **(2.9 points – 0.9 points for calculation and 2.0 points for consistency of practical work)** Calculate the molarities of chloride in mol/L that follow from the three accurate titrations. Show the calculation for titration 1 only.

calculation

	C_{Cl^-} (mol/L)
Titration 1	
Titration 2	
Titration 3	

Signature:	

8. **(3.2 points - 0.2 points for calculation and 3.0 points for accuracy of practical work)** Calculate the average $\overline{C}_{\mathrm{Cl}^-}$ in mol/L of the three chloride concentrations that you calculated in question 7.

calculation   answer: $\overline{C}_{\mathrm{Cl}^-} =$ mol/L

9. **(0.6 points)** Calculate the sodium chloride concentration of the solution in g/L.

calculation   answer: $C_{\text{mass, NaCl sln}} =$ g/L

Do not write in the box below

Penalty for using extra materials	Signature of lab assistant

Signature:	

Blue energy

A. Measuring potential differences using the concentration cell

1. **(1.2 points)** Fill out the remaining columns of Table A1.

Table A1 *– Measurement results of the voltage for solutions* ***X0*** *to* ***X4****.*

Solution	C_{NaCl} (g/L)	$\log(C_{NaCl})$	V (mV)
X0			
X1			
X2			
X3			
X4			

Signature:	

2. **(1.4 points)** Plot the values of V against $\log(C)$. Draw the data points as clear dots. Draw the straight line of best fit through the data points using the set square.

Figure A1 – *Graph of the measurements: voltage as function of* $\log(C)$.

Signature:	

3. **(1.0 points)** The relationship between V and $\log(C)$ is linear and can be written as $V = a + b \cdot \log(C)$. Determine from Figure A1 the values of a and b, without uncertainties.

calculation
$a =$ mV
$b =$ mV

4. **(0.5 points)** Indicate in Figure A1 clearly which point corresponds to the unknown solution **X0** and write down the coordinates below (without units).

coordinates corresponding to solution **X0**:
horizontal:
vertical:

Signature:	

5. **(0.9 points)** Determine the concentration C_0 of solution **X0**.

calculation   answer: $C_0 =$ g/L

B. Measuring the electrical conductance of the solutions

6. **(0.4 points).** Let the lab assistant check your electrical circuit.
You may <u>not</u> write in the next box.

Correct circuit: ☐ yes ☐ no Signature lab assistant:	Remarks:

Signature:	

Use table B1 in questions 7 to 12 and use the information in your procedure sheets to complete this table.

Table B1 *– Measurement results for salt solutions* ***X1*** *to* ***X4*** *and* ***X0****. Also write down the missing units in the column headings.*

Solution	C_{NaCl} (g/L)	V_1(______)	V_2(______)	I (______)	G (______)	σ (______)
X0						
X1						
X2						
X3						
X4						

7. **(1.0 points)** Write the readings of the multimeters in Table B1, and complete the symbols of the measuring quantities with the correct units in the top row.

Signature:	

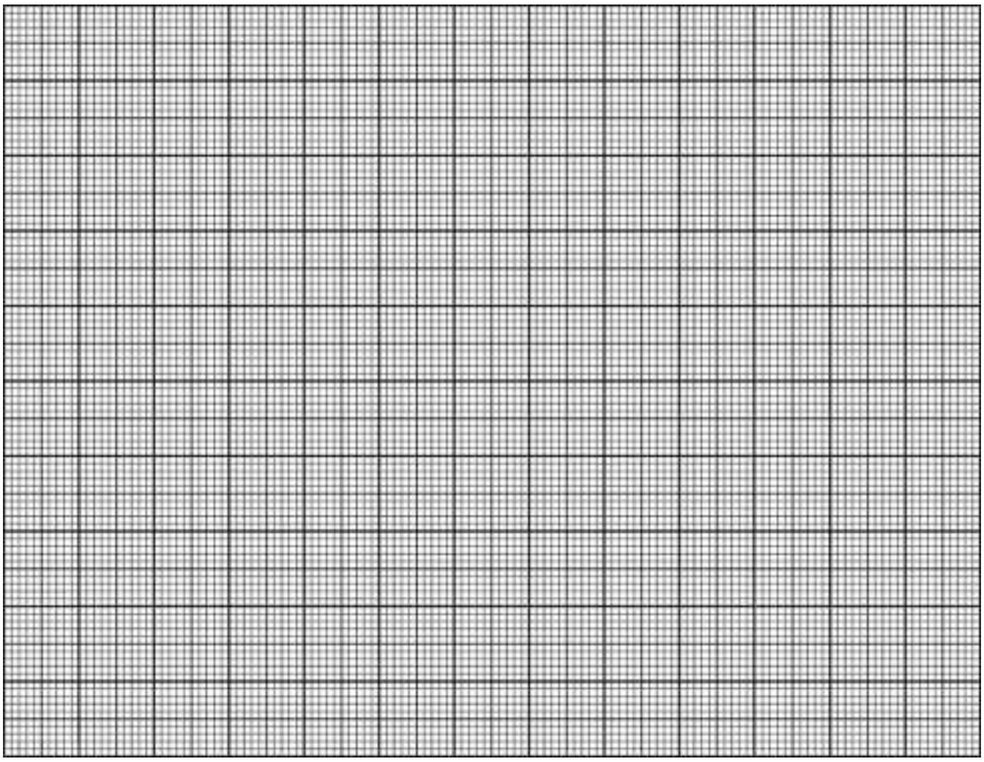
8. **(0.8 points)** Calculate from your measurements the current I which went through the setup, and calculate for each known salt concentration the conductance G. Enter your results in Table B1. Show in the box below the calculations for **X1** only.
The conductance is the reverse of the resistance and has as unit S (which stands for Siemens). See the equation sheet for more information, and enter the results in Table B1 .

calculation of the current I for **X1**
calculation of the conductance G for **X1**

Signature:	

9. **(1.4 points)** Plot the conductance G against concentration C in a graph (Figure B1). Clearly indicate your measurement data as dots on the graph. Based on your data points draw a smooth curve (best fit).

Figure B1 *– Graph of the measurements: conductance as function of concentration.*



10. **(0.8 points)** Determine from your graph the concentration of the solution labeled **X0**. Show clearly how you obtained your result.

answer: $C_0 =$ g/L

Signature:	

11. **(0.8 points)** Determine values for l and A of the pair of electrodes. Use SI units, so l in m and A in m^2.

calculation
answers: $l =$ m $A =$ m^2

12. **(0.4 points)** Calculate the specific conductivities of solutions **X0** and **X1** to **X4** and write down the results in Table B1. Show in the box below the calculation for **X0** only.

calculation
answer for X**0**: $\sigma =$ S/m

Signature:	

C. Calculating the theoretical maximum electrical power

13. Consider your graph in Figure A1 and answer the following questions.
    a) **(0.2 points)** If you want to obtain the maximum voltage from the RED cell, which of the solutions **X0** to **X4** should you use for the salt water?
    b) **(0.2 points)** Which of the solutions **X0** to **X4** should you use for the fresh water?
    c) **(0.5 points)** Read from Figure A1 how large the potential difference ΔV is across the cell when using the solutions you chose in questions 13a and 13b.

solution to be used for the salt water: solution to be used for the fresh water: $\Delta V =$ mV

Signature:	

14. **(0.5 points)** Calculate the conductance G_{fresh} of the fresh water side and G_{salt} of the salt water side of the RED cell. Use the specific conductivities from Table B1 on the answer sheet.
Note: if you don't have data for σ, use $\sigma_{\text{fresh}} = 0.99\ \text{S/m}$ and $\sigma_{\text{salt}} = 11.6\ \text{S/m}$ for your calculations.

calculations   answers: $G_{\text{fresh}} =$ $G_{\text{salt}} =$

15. **(0.5 points)** Calculate the internal resistance of the RED cell.

calculation $R_{\text{int}} =$

Signature:	

16. (0.8 points) Calculate the current I through the external resistor. Use the potential difference ΔV you found in question 13.
Note: if you don't have a value for ΔV, use $\Delta V = 55.0$ mV as a value for your calculation.

calculation $I =$ A

17. (0.4 points) Calculate the power P this RED cell delivers to the external resistor.

calculation $P =$ W

18. (0.3 points) How many of these RED cells you need for a power plant to generate 1.0 MW?

answer: