EUROPEAN UNION SCIENCE OLYMPIAD

TEST 1

Theme: Water

Gothenburg, Sweden

Tuesday 13th April, 2010

UNIVERSITY OF GOTHENBURG

General instructions

Wear the supplied plastic apron and safety spectacles at all times within the laboratory.

Eating and drinking is prohibited in the laboratory.

Disposable gloves are provided and must be worn when handling chemicals.

All paper used, including rough work paper, must be handed in at the end of the experiment.

All results must be entered into your answer book.

Your graph must be handed in along with the answer book.

Only the final answer book, and attached graph, will be marked.

The tasks may be carried out in which ever order you wish.

Task 1: 7 credit points

Task 2: 17 credit points

Task 3: 27 credit points

Task 4: 26 credit points

The scenario

In a galaxy many light years from the Milky Way, a planet similar to our own is populated by intelligent life. These “aliens” are not humans, but they look very much like us and their technology is far more advanced than ours. For example, they have the technology for inter-galactic travelling. The name of the planet is Rullet and the citizens of Rullet are called “rulers”.

Even though their technology is very advanced, they face immediate and severe problems. Their natural resources for energy production were used up many generations ago. However, they learned to produce solar power in such amounts that they have been able to sustain their energy-consuming civilization. Unfortunately, their sun is now dying and soon they will have no solar power either.

This has of course been known for quite some time, and ruler scientists have been working on a solution for this. They recently had a major breakthrough in cold fusion and they now know exactly how to produce all the energy they need from pure water in cold fusion plants. The only problem is that the water supply on Rullet is very limited. Water is so rare, rulers consider water to be a “noble liquid”.

According to ruler scientists, 10 m^3 of water would be enough to produce all the energy the planet needs for 100 years! Since water in such amounts is unheard of on planet Rullet they need to find water supplies elsewhere.

Rulernaut[1] Hon Sala is assigned the mission of exploring the universe and look for planets where water can be found in superabundance. Rulian astronomers suggest that she starts looking in the galaxy Silky Road[2], because their infra-red spectrometers have indicated that there might be large reservoirs of water molecules somewhere in that galaxy.

Using her WARP-powered spacecraft, she arrives at galaxy Silky Road in no-time (or perhaps we should say “no-space” since she is WARP-powered?). Once in the galaxy, she has no problem of locating planets housing water. The first planet she visited was Queso. There she found lakes which contained contaminated water. The organisms living in the lakes produced ethanol during their metabolism. Now she is heading for our own planet Earth. This is where our story begins: Hon Sala has just arrived at planet Earth. She leaves her spacecraft in order to look for water. At first she is very disappointed. There is no water in sight.

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[1] Name of astronauts on planet Rullet.
[2] Name of Milky Way on planet Rullet.

Task 1 - Relative humidity of air

Having looked for several hours and still not having found any water, she sits down to think. It is early in the morning local time and while she sits there trying to figure out her next step, a beetle appears from its nest in the sand.

“And how do you find water, my little friend?” Hon Sala asks the beetle. She observes the beetle for a while and she can see it running to the top of a pile of sand and turning its back to the sun and then it just sits there.

“What are you waiting for?” Hon Sala wonders. To her great surprise, after a while a drop of water appears on its back and she can see the little drop of water slide down its back and into its mouth.

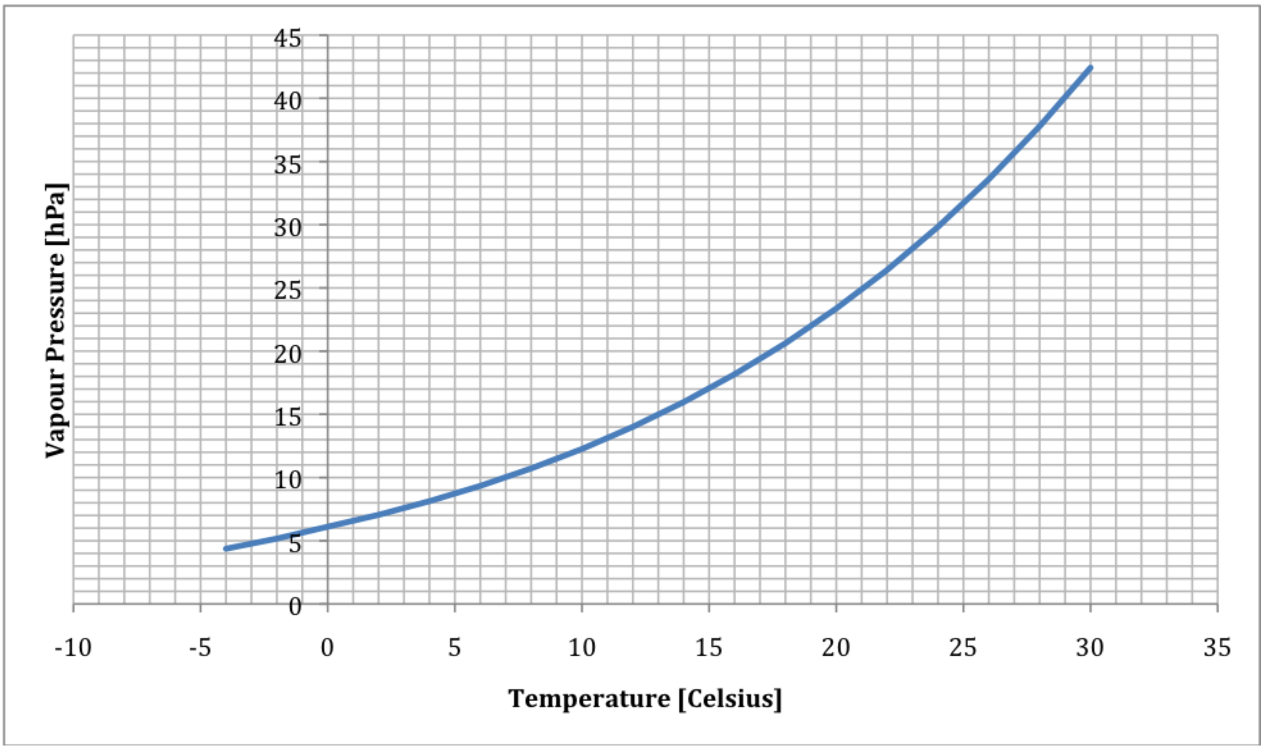
“Of course!”, she says out loud, ”now I know how to get water!”

She sits down and tries to recapitulate what she learned at Rullet School of Science. She remembers that liquids always produce a certain amount of vapour in the ambient. If there is any water around on the Earth there must also be some water vapour in the air. The vapour, of course, gives rise to a certain pressure in the atmosphere. It is called vapour pressure. If the vapour pressure becomes large enough, water may precipitate into liquid water. She can still remember her teacher’s final words:

“Remember this, students, the higher the temperature the higher the vapour pressure!”

Now she knows how to extract the water from the air! She only need to wait until night when the air temperature drops. If she is lucky, the air temperature will drop so much that the air no longer can hold all the water and hence water will appear on leaves where she can collect it!

The maximum partial pressure of water in air depends on the temperature according to the diagram below.



Change axes to Temperature/ °C and maximum vapour pressure/hPa.

The maximum vapour pressure in air vs temperature (1 hPa = 10^2 Pa= 10^2 N/m^2).

The *relative humidity* in air is defined as

$$\frac{\text{vapour pressure in air}}{\text{The maximum vapour pressure in air before water droplets percipitate}} \times 100\ \%$$

You should now help Hon Sala by determining the relative humidity in the room you are in, using only the equipment available.

Experiment

Hon Sala waited for the night to lower the temperature. You will have to be smarter than that, since you're in an air conditioned room and cannot cool the entire room! You can use the cooling spray to decrease the temperature of the piece of metal having a mirrorlike surface and thereby determine the actual vapour pressure in the room. (Hint: cool the metal slowly and measure the temperature frequently).

Determine the temperature when the dew point is reached. Enter your answer in **box 1.1** in the answer booklet together with the time of measurement. Now you can determine the vapour pressure for water in the room. Enter your answer in **box 1.2**. Finally calculate the relative humidity in the room. Enter your calculation in **box 1.3**.

Task 2 - Viscosity of water

After a busy night when Hon Sala collected condensed water from leaves and flowers, she is somewhat disappointed. Obviously the air on this planet doesn't contain enough water for her purposes. During the night, she has only been able to collect 0.7 liters of water not counting the 0.2 liters she has been drinking. Water is so rare on her home planet that almost no one can afford to drink it, but here, she just couldn't resist it.

Hon Sala is a real scientist and therefore starts to investigate more of the properties of water. On her planet she has studied many different liquids and she thinks that the water she accumulated during the night flows very easily. The property of a fluid which is related to the resistance to flow is called viscosity. She looks around in her spaceship to find suitable equipment for an experiment. She finds a long tube and a couple of small balls. She intends to fill the vertically aligned tube with water and then let a ball fall downwards through the water. The ball will quickly attain a constant velocity and that velocity can be related to the viscosity. Hon Sala now tries to remember the relation between viscosity and velocity. She needs your help. The friction force between the ball and water can be approximated by the following expression:

$F_R = 6 \pi \eta r v$

where η = viscosity, r = ball radius, v = speed of ball. Assume the density of water is 1000 kg/m^3.

(This formula is only valid if the velocity is small and the dimensions of the container are large.)

Question

There is one more force acting upwards. Write the expression for that force in **box 2.1** in the answer booklet.

Question

After a short time the sum of the forces acting upwards will equal the force acting downwards on the ball. Write the expression for the downward force in **box 2.2** in the answer booklet.

Question

Derive an expression for the viscosity, η, in terms of variables given in the questions above. Write the result in **box 2.3**.

Question

Hon Sala also wants to find the unit for viscosity. Derive the unit from your expression and write it in **box 2.4**.

Experiment

Now it is time to set up the experiment. Use the equipment that you have in the box on your lab desk. Fill the tube with water from the beaker labeled "H_2O - η". The tube has two marks. The distance between the arrows is 0.50 m. Do at least five measurements to get a good estimate of the viscosity. For each ball determine its mass (m_B) and radius (r). Use the scale provided in the lab and the vernier calliper on your desk. Determine the falling time for each ball and calculate the corresponding velocity. Now you can calculate the viscosity (g = 9.82 m/s^2). Fill in your data in **TABLE 2.A** in the answer booklet.

Due to the influence of the walls of the tube the ball is falling slightly slower than if there was no walls in the vicinity of the ball. The correction factor to the measured viscosity is given by

$$C = \frac{1}{1+2.4\frac{r}{R}}$$

where r = average radius of the balls used and R = inner radius of the tube.

Write the value of the correction factor in **box 2.6**.

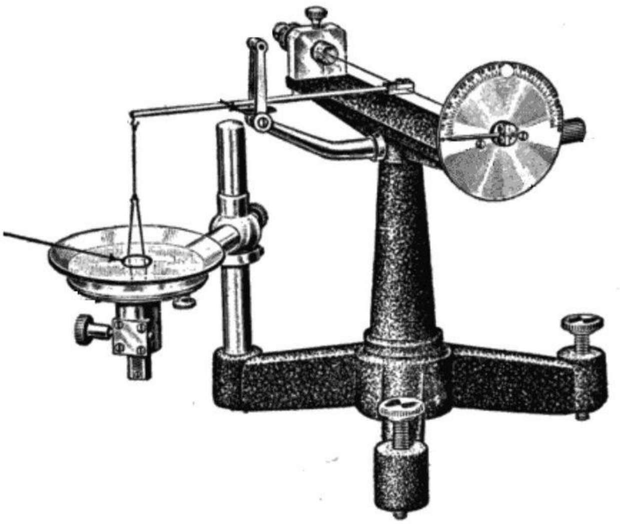
Now do the correction of the viscosity and write it in **box 2.7**.

Question

It is interesting to know what the radius of the tube would have to be for Hon Sala to be allowed to neglect the correction factor. Assume that she could neglect the correction factor if it equals 0.99 and calculate R. Fill in your answer in **box 2.8**.

Task 3 - Surface tension and biomechanics

Finally Hon Sala finds a lake. She walks down to the lake to take a sample of water for her experiments. Now she notices small animals that runs on the surface of the water. She is puzzled by this since she did not see any animals running on the surface of the water at the planet Qeuso. She can think of at least two explanations, either the animals differ in some way from the animals on Qeuso or the water from that planet has some peculiar property. Since she has a hard time capturing the small animals she looks for a method to test the water instead. She thinks that the surface tension of water may explain the puzzling observation. In her computer she finds a file related to surface tension measurements. She finds a method developed by French physicist Pierre Lecomte du Noüy. The methods is based on a ring tensiometer (see picture to the left). Unfortunately she does not have such a meter onboard the ship. But she is inventive and looks at the picture of the setup and realizes that she can at least construct a simplified version with things that she can find on the ship. Your task is now to reproduce the simple tensiometer that Hon Sala used for her measurements.

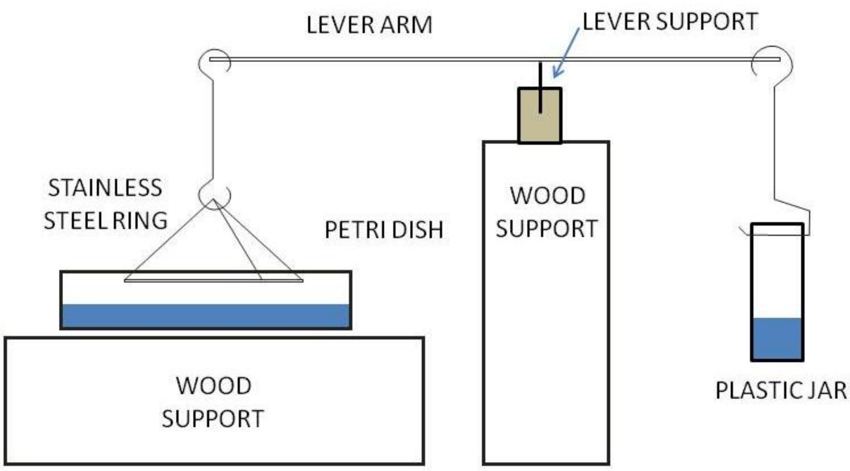


Experimental background

On the lab bench you will find all the things that Hon-Sala used and you can build a replica of the equipment she used.

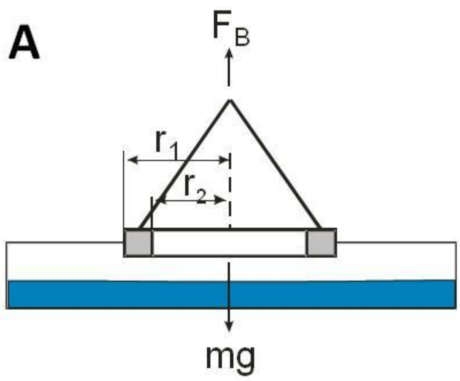
- A straight stainless steel lever arm with a hole at each end
- A small wood support with a slit in one end
- A small piece of stainless steel plate that fits in the wood support above
- A stainless steel ring
- Two stainless steel hooks
- A small plastic jar
- Two different pipettes
- One petri dish
- Two bottles with water samples
- Two larger wood supports, one for the lever arm and one for the petri dish and the stainless steel ring.

From this you can build a very simple balance and with this determine the surface tension (see below).

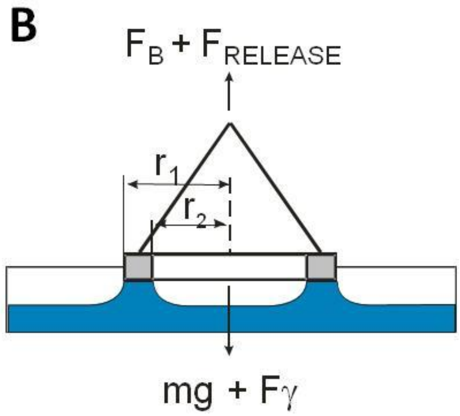


Hon Sala also found the description of how to calculate the surface tension and you can see her drawing and formula for calculating the surface tension to the right and below.

Note that the black side of the lever arm should be facing up and the notch on the other side marks where the lever support should be placed. Note also that when you have assembled your lever system the stainless steel ring should be resting on the wood support support by its own weight before you balance the system (the lever arm is not symmetrical around the balance point).



Before you can test the surface tension of the two water samples you need to balance the lever system. You do this by adding a small amount of water (around 600 µl) to the plastic jar until stainless steel ring raises from the wood support and the lever arm is horizontal. At this point the force pulling the ring up (balance force = F_B) match the mass of the ring multiplied with the gravitational constant (mg) (see Figure A to the right).



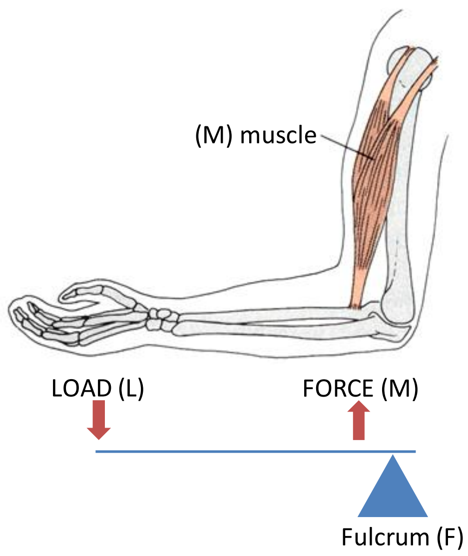
The Petri dish with the test water should then gently be positioned on the wood support centered under the stainless steel ring. Then gently lower the lever arm so that the stainless steel ring touches the water surface. To overcome the surface tension that is now acting on the ring ($F\gamma$) you have to add more water to the plastic jar. Finally $F_B + F_{RELEASE}$ reaches the point were it overcomes $mg + F\gamma$, and the ring separates from the water (se Figure B on the previous page). Be careful and keep track of the amount of water you add, when the ring is pulled from the water surface you should note down the amount of water you added (assuming a density of water of 1.0 g ml^{-1}) you can now calculate the force ($F_{RELEASE}$) and then calculate the surface tension using the

$$\gamma = \frac{F_{RELEASE}}{4 \cdot \pi \cdot r}$$

formula below. Note that you need to take into account that the lever arm is not symmetrically placed over the lever support.

where r is the mean value of r_1 and r_2 and $F_{RELEASE}$ is the force needed to pull the ring of the surface

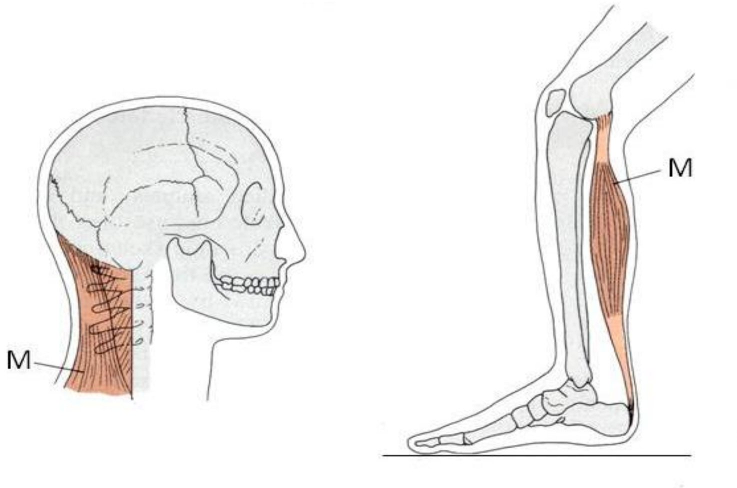
The setup is a simple balance and Hon Sala realizes that she needs to understand the concept of this balance before she can perform the surface tension tests. Later on you will do these experiments, yourself. She vaguely remembers that during her biology studies she read about lever systems in the body and how to calculate the forces. She opens a file which describes three different lever systems that can be found in the human body. She does not remember all the details so you have to help her.



To the right you can see one type exemplified by the human arm. When you lift something you hold the LOAD in your hand, the force that you use to lift or hold the object is generated by your muscles and the fulcrum is the elbow joint. In the schematic picture of the lever system to the right the two forces are marked FORCE (M), which is the muscle force, and LOAD (L), which is the load. The FULCRUM (F) is the balance point of the lever system, in this example the elbow. Two other types of lever systems are described in her file but unfortunately the schematic description of where the LOAD, FORCE and FULCRUM are missing.

(REMOVE THE M IN THE FIGURE... write muscle instead)

(Cut diagram below , above knees

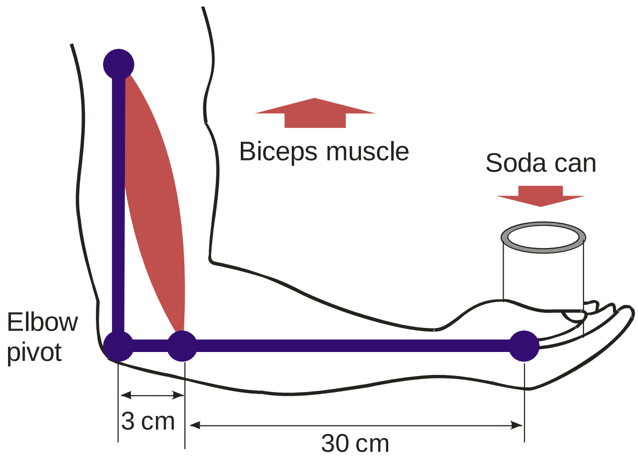


Question

In the picture above you see a schematic representation of the two other lever systems that Hon Sala found in the file. Mark where the LOAD, FORCE and FULCRUM (with the same signs as in the example) are acting in the two examples, use the figure in **box 3.1** in the answer booklet.

Question

The next question is about how to calculate the forces in a lever system. Look at the figure below. Calculate the muscle force needed to hold the soda can that weights 365 gram and fill in the answers in **box 3.2** in the answer booklet.



Experiment

Now assemble the lever balance so that you can perform the measurements of the surface tension (see above).

Hon Sala has brought with her a sample of the water from planet Queso and also collected a water sample from the lake on earth. You will help her to measure the surface tension of both water samples. Unfortunately she do not remember which of the two bottles that contain the water sample from Qeuso, the bottles are just marked 1 and 2 (you find two flasks with water samples that she left behind on the bench)

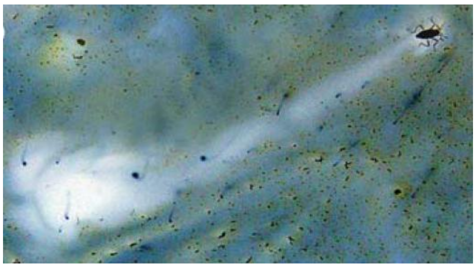
Measure the surface tension of both water samples. Repeat the measurement at least three times for each water sample and calculate the average value. Do not forget to fill in the proper units for the surface tension. Fill in **TABLE 3.A** in the answer booklet.

Similar to your finding (hopefully) Hon Sala found that there was a clear difference in surface tension between the two water samples. Assuming that there is no difference in the animals on the planet Qeuso she now knows why she did not see any animals running on the water surface and she marks the two bottles correctly. Fill in your answer in **TABLE 3.A** in the answer booklet.

Now she starts to look for an explanation for the difference in the ships library. One difference that she finds is that at Qeuso the water has an ethanol content of around 10% due to large number of fish species that produce ethanol as part of their normal metabolism. She also finds out that the oxygen content in the water is very low due to a combination of a lower oxygen content of the atmosphere and a high consumption of oxygen from all the fish living in the water.

Question

Hon Sala tries to tie this information together (ethanol production and low oxygen levels). You have to help her by striking out the wrong parts in the text in **box 3.3** in the answer booklet.



When she finished her measurements in the ships laboratory she returns to the lake. When she is sitting at the shoreline she spots a small insect that comes running towards the water, it walks straight out on the surface of the lake and then stops. Hon Sala picks up a fresh pine needle and tries to poke the little insect so that she can study how it moves its legs when walking on the surface. The animal shoots of over the surface with twice the speed that it had when walking on land. Hon Sala gets startled by this sudden activity and drops the pine needle in the water. To her surprise the pine needle floats and slowly starts to move over the water surface. The water is perfectly calm, there are no water currents or wind. She finds a reference to something that is called Marangoni propulsion in a scientific paper by Billard & Bruyant but the part of the paper that describes the mechanism is gone.

Question

You have to help her by striking out the wrong parts in the text in **box 3.4** in the answer booklet.

Task 4 - Water hardness

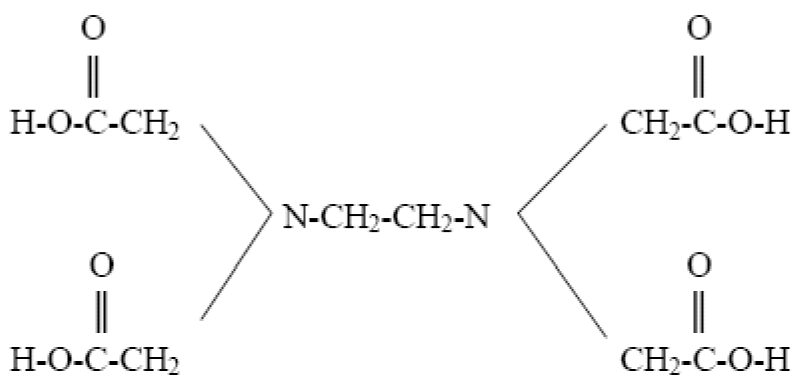
Now that she has all the water she needs, there is one more thing she would like to do before she returns home. She would like to test the quality of the water she got.

Hon Sala knows that one of the factors that establish the quality of a water supply is its degree of hardness. Since this was one of the things she was instructed to investigate, she studied this on her long voyage. The hardness of water is defined in terms of its content of calcium and magnesium ions. Since an analysis does not distinguish between Ca^{2+} and Mg^{2+}, and since most hardness is caused by carbonate deposits in the earth, hardness is usually reported as total parts per million calcium carbonate by weight. A water supply with a hardness of 100 parts per million would contain the equivalent of 100 grams of $CaCO_3$ in 1 million grams of water or 0.1 gram in one litre of water. How much Mg^{2+} and Ca^{2+} does the water contain? Is the water dangerous to Hon Sala seen from the value of the hardness factor?

Calcium and Magnesium Analysis by EDTA Titration

Chemical background

Hon Sala look into her file in chemistry which now came in handy and found that water hardness can be readily determined by titration with the chelating agent EDTA (ethylenediaminetetraacetic acid). This reagent is a weak acid that can lose four protons on complete neutralization; its structural formula is below.



The file says: ‘The four acid sites and the two nitrogen atoms all contain unshared electron pairs, so that a single EDTA ion can form a complex with up to six sites on a given cation. The complex is typically quite stable, and the conditions of its formation can ordinarily be controlled so that it contains EDTA and the metal ion in a 1:1 mole ratio. In a titration to establish the concentration of a metal ion, the EDTA that is added combines quantitatively with the cation to form the complex. The end point occurs when essentially all of the cation has reacted'.

In this experiment you will use EDTA solution with known concentration to determine the hardness of an unknown water sample. Since both EDTA and Ca^{2+} and Mg^{2+} are colourless, it is necessary to use a rather special indicator to detect the end point of the titration. The indicator you will employ is called Erichrome Black T, which forms a rather stable wine-red complex, $MgIn^{-}$, with the magnesium ion. As EDTA is added, it will complex free Ca^{2+} and Mg^{2+} ions leaving the $MgIn^{-}$ complex alone until essentially all of the calcium and magnesium has been converted to chelates. At this point the EDTA concentration will increase sufficiently to displace Mg^{2+} from the indicator complex; the indicator reverts to an acid form, which is sky blue, and this establishes the end point of the titration.

The titration is carried out at a pH of 10, in a borate buffer, which keeps the EDTA (H4Y) mainly in the half- neutralized form, H_2Y^{2-}, where it complexes the Group IIA ions very well but does not tend to react as readily with other cations as Fe^{3+} that might be present as impurities in the water. Taking H_4Y and H_3In as the formulas for EDTA and Eriochrome Black T respectively, the equations for the reactions that occur during the titration are as follows.

This experiment requires that you know the concepts of stoichiometry, concentration and dilutions.

Experimental procedure

First series of experiments - de-ionized reference solutions

(Please note that the filling of the burette will be demonstrated in the laboratory.)

- Pipette four 5.00 ml portions of de-ionized water into four clean but not necessarily dry 25 ml Erlenmeyer flasks.

- Then add 0.30, 0.50, 0.70 and 1.00 ml, respectively of your Mg^{2+} solution from the plastic bottles into the four Erlenmeyer flasks.

- To each flask add 1 ml of borate buffer (pH 10) and 1 drop of Erichrome Black T indicator.

- The initial colour should now be deep red and the end point colour at equilibrium purple. (Compare with reference bottle provided.)

- Fill the micro burette with the EDTA- solution, adjust it to zero, and titrate the first solution. Write down the amount of EDTA- solution used to the equivalence point.

- Then refill the micro burette again and repeat the procedure for the remaining three reference solutions.

- Be sure to read the micro burette to the highest precision available.

- If anything goes wrong, please repeat the procedure for that particular solution.

Fill in all your data in **TABLE 4.A** in the answer booklet.

Test samples for hardness determination of planet earths water

You have now been supplied with a sample of water for hardness analysis. The determination of the hardness will, to begin with, follow the analysis done on the de-ionized water.

Second series of experiments – planet earths water

- Pipette four 5.00 ml portions of earth water into four clean but not necessarily dry 25 ml Erlenmeyer flasks.
- Then add 0.30, 0.50, 0.70 and 1.00 ml, respectively of your Mg^{2+} solution from the volumetric flask into the four Erlenmeyer flasks.
- To each flask add 1 ml of borate buffer (pH 10) and 1 drop of Erichrome Black T indicator.
- The initial colour should now be deep red and the end point colour at equilibrium purple.
- Fill the micro burette with the EDTA- solution, adjust it to zero, and titrate the first solution. Write down the amount of EDTA- solution used to the equivalence point.
- Then refill the micro burette again and repeat the procedure for the remaining three reference solutions.
- Be sure to read the micro burette to the highest precision available.
- If anything goes wrong, please repeat the procedure for that particular solution

Fill in all your data in **TABLE 4.A** in the answer booklet.

Determination of hardness

Use the supplied mm paper to plot two set of lines.

Plot a graph of the dependence of the volume of EDTA (in ml) versus volume of Mg^{2+} solution added..

a) For de-ionized water

b) For ground water.

Both graphs plotted on the same axis

- Determine from the graphs in this figure (and Table 4A in the answer booklet) the difference (ΔEDTA) between the test solutions and the reference solutions.

- Since the concentration of the EDTA solution is known, 0.??? M, the hardness of the water from planet earth can now be established by using the result of ΔEDTA.

Now you can answer **questions 4.1 - 4.4** in the answer booklet.

Finally answer **questions 4.5 - 4.7** in the answer booklet.

Mission completed

Now Hon Sala has completed her mission. Before leaving she wants to get a nice view of the landscape. She starts climbing a mountain. It is a very high mountain and she can see that the top of it is all white.

"I wonder what all that white stuff is?" she thinks. "From here it looks like whipped cream." When she finally reaches the top of the mountain, she realizes that the white stuff is not whipped cream. When she puts it in her mouth it melts and she understands that it is frozen water. "Wow!" she says out loud. She is cold after the long walk and decides to make herself a hot cup of water using the small camping stove she brought with her.

Question

The boiling point of water is 100 ^{0}C at sea level. Hon Sala is now on a very high mountain. Will that have any influence on the temperature at which water boils?

a) No, the water will still boil at exactly 100 ^{0}C.

b) Yes, the water will boil at a temperature less than 100 ^{0}C.

c) Yes, the water will boil at a temperature higher than 100 ^oC.

d) It depends on the temperature on the mountain: If the temperature on the mountain is different from that at the sea level, then the boiling point will also differ with exactly that difference.

e) It depends on the humidity on the mountain: If the humidity on the mountain is different from that at the sea level, then the boiling point will also differ.

Enter your answer in **box 4.8** in the answer booklet.

SIGN THE BOOKLET AND GIVE IT TO THE CONTROLLER!

GOOD LUCK!