April 1st, 2014 – TASK A

All about Olive oil

- Task sheet -

Precautions

1. Wear a laboratory coat, safety glasses and sturdy footwear during the entire duration of your stay in the laboratory.

2. Disposable gloves must be worn when working with chemicals.

3. It is not permitted to eat or drink in the laboratory.

4. The lab assistant's directions are to be followed at all times

Instructions for the completion of tasks

1. You may complete the tasks in any order, individually or as a group. Due to time limitations, it is advisable to split the work load.
2. All results must be entered into the answer sheet.
   Only <u>one</u> signed answer sheet version can be handed up and assessed.
3. All used papers with data and graphs including rough work have to be handed in at the end of the experiment.
4. If you are requested to have one of your results recorded before continuing with the next stage of your work, points will only then be allocated if the results are in fact recorded by the lab assistant at the correct time

THE NAMING OF THE CITY OF ATHENS

A Dispute Between Two Gods

*Part of the representation of the **western pediment** of the **Parthenon***

The dispute between Athena and Poseidon

.... for

Olive oil

and

Salt Water

A myth… 1582 BC

… The Goddess Athena had a fight with the God Poseidon as to who would be the patron deity of the city of Kekropia and give their name to it. Kekropas, who was the king of the city and had named it after himself, proposed that the two Gods compete as to who would offer the city the most valuable of gifts. The competition took place on the Acropolis hill. The remaining ten Gods were the judges and Kekropas the witness.

First came Poseidon who struck the rock with his trident and immediately water sprang from it. A lake was formed which became known as the "Erehtheida Sea". The people were happy, but when they tasted the water, they found that it was salty. To make them happy, Poseidon struck the rock again and a magnificent white horse appeared.

Then it was Athena's turn. The Goddess of wisdom struck the rock with her spear and an olive tree appeared which grew and spread its branches, which were full of olives. All agreed that Athena's gift was the most valuable one, and for this reason, the city was named after her …

The city was called Athena.

«Apollodoros, Library C΄»

Apollodoros the ***Athenian*** *(*108 BC- *110 BC) was an ancient Greek historian and scholar*

So the olive tree became sacred for the Athenians.

Olive-tree was considered the fountain of health and life.

*Its fruit was blessed, becoming a symbol of knowledge, prosperity, health, strength and beauty. Olive branches became wreaths to crown the winners of the famous Olympic Games, and the invaluable olive extract, **olive oil,** was the prize given to the winners of the Panathenean Games which were held in honour of the Goddess Athena.*

The use of olive oil in Ancient Greece dates back to 3000 BC. Information about its use, both in the diet as well in the preparation of perfumes and body lotions, is found in the oldest recorded form of the Greek Language – Linear B. After the 6th century BC, it was increasingly used for lighting purposes.

Homer called olive oil the 'golden liquid' while Ippokratis called it the 'great healer'. There are over 60 pharmaceutical uses included in his Code.

*However, Ippokratis (450 BC), was the first to also knowledge the healing properties of **salt.** He used salt to cure infections, congestion and various other ailments.*

As salt inhibits the growth of microorganisms, it has been used as a food preservative and was considered the 'refrigerator' of antiquity.

The Greeks would offer salt to the Gods during sacrifices. It was a symbol of purity, refinement, grace and gaiety. The phrase, "salt of Attica", was known to denote the refined and witty Spirit of Attica.

In addition, in AD 1500, Parakelsos wrote that as humans we need salt and without it everything would decompose.

*Throughout the years, **olive oil** and **sea water have** never naturally mixed**,** so as to keep their secrets of superiority well hidden...*

Science however has managed to discover and reveal these...

TASK A1 – Biology Transpiration

Olive trees belong to a class of plants with a conductive tissue and the ability to regulate their internal osmotic environment, making them less dependent on water availability, especially during abnormal environmental conditions, such as excessive heat and strong winds.

Water movement from the soil to the plant's roots and leaves is achieved through osmosis, gravity, mechanical pressure, or matrix effects, such as capillary action. Approximately 1% of the water absorbed by plants is used in metabolic processes, such as photosynthesis. Of the rest, about 95% is excreted by transpiration via stomata (from the Greek word *στόμα*, "mouth"), which are small pores found on the epidermis of the leaves, and re-enters the water cycle. Stomata in olive trees lie on the underside surface of leaves and are covered by scale-like trichomes which prevent evaporative water loss during dry or windy conditions.

In actively growing plants, water continuously evaporates from the surface of leaf cells which are exposed to air. This loss of water is recovered by additional absorption of water from the soil. This is achieved by utilizing the hydrogen bonding between adjacent water molecules and because of its adhesion to capillary walls, which allow the column of water to be 'pulled' up through the plant as water molecules are released at the leaf surface. In most plants, transpiration is a passive process, largely controlled by the humidity of the atmosphere and the moisture content of the soil. Some dry environment plants have the ability to open and close their stomata. This adaptation limits water loss from plant tissues in order to cope with conditions of severe drought.

Transpiration offers multiple advantages to plants, such as evaporative cooling, gas exchange and nutrients assessment. During water conversion energy is released during the transition from liquid to gas at the interface between leaf cells and the atmosphere. This exothermic process produces highly energetic gas molecules, which are released into the atmosphere, thereby **cooling** the plant. In addition, transpiration allows for **gas exchange** though open stomata to occur between the atmosphere and the leaves. Carbon dioxide (CO_2), which is needed for photosynthesis to occur, enters the leaves during transpiration. **Accessing nutrients and water from the soil** is another advantage offered by the process of transpiration. Water and the nutrients dissolved in it are vital to the plant's growth. Even though less than 5% of the water taken up by roots remains in the plant, this amount of water is vital for the plant's structure (acts as a turgor so that the plant can stand without bones) and biochemical processes.

Parameters affecting the rate of transpiration include leaf structures, like stomata and cuticle. When **stomata** are open, transpiration rate increases. For transpiration to occur water vapor leaving the stomata must diffuse through a **boundary layer** of still air hugging the surface of the leaf and subsequently reaching the atmosphere, where water vapour will be removed by the moving air. The larger the boundary layer, the slower the rate of transpiration is.

Environmental conditions also affect the transpiration rate. **Relative humidity** describes the amount of water vapor (moisture) in the air compared to the amount of water vapour that air could "hold" at a certain temperature. Any differences in the humidity levels between leaves and the atmosphere, create a gradient for water to move from the leaf to the atmosphere and vice versa. Elevation of the atmospheric **temperature** increases the water holding capacity of the air. Concomitantly, cooler air holds less water than warmer air and as a result, a low temperature will lead to a decreased driving force for transpiration. The amount of **soil water** provided to the plant also affects transpiration rate. Plants with adequate soil moisture will normally transpire at high rates, while plants growing in dry soil cannot continue to transpire because the water in the xylem that moves out through the leaves cannot be recovered from the soil. This condition causes the leaf to lose turgor or firmness and the stomata to close. If this loss of turgor continues throughout the plant, the plant will wilt. Stomata are triggered to open in the presence of **light** so that CO_2 is available for photosynthesis and remain closed in the dark. Finally, **wind** can alter the rate of transpiration by modifying the boundary layer.

The problem we are dealing with in this task

How do olive trees survive in Mediterranean countries, where, compared to other areas, extended periods of sunshine with low water availability are encountered?

In this experiment, you will study the process of transpiration using olive tree branches in different environmental conditions. You will also study different morphological adjustments of the leaves on the macro and the microscopic level.

Short overview of TASKS

- Task A1 Study of transpiration rate
- Task A1.1 Assembly of the potometer- water uptake at room conditions (RC)
- Task A1.2 Calculation of total leaf surface (in m^2) at RC
- Task A1.3 Calculation of water uptake under light conditions (LC)
- Task A1.4 Calculation of the total leaf surface (in m^2) at LC
- Task A1.5 Draw a graph. Calculation of transpiration rate
- Task A1.6 Preparation of the microscopic slide

Experimental Procedure

Introduction

A potometer (from the Greek word *ποτό* = drink and *μέτρο* = measure), otherwise known as a transpirometer, is a device used for measuring the rate of water uptake by a leafy shoot. Photosynthesis and transpiration are the reasons why plants uptake water and the potometer is an instrument used to estimate the rate of transpiration. Despite many metabolic processes also changing water content, their effects are usually ignored when conducting potometer experiments. This is because the volume of water involved in these processes is insignificant compared to that constantly flowing (evaporating) through the plant in transpiration stream.

The following formula can be used to calculate water loss in an olive branch:

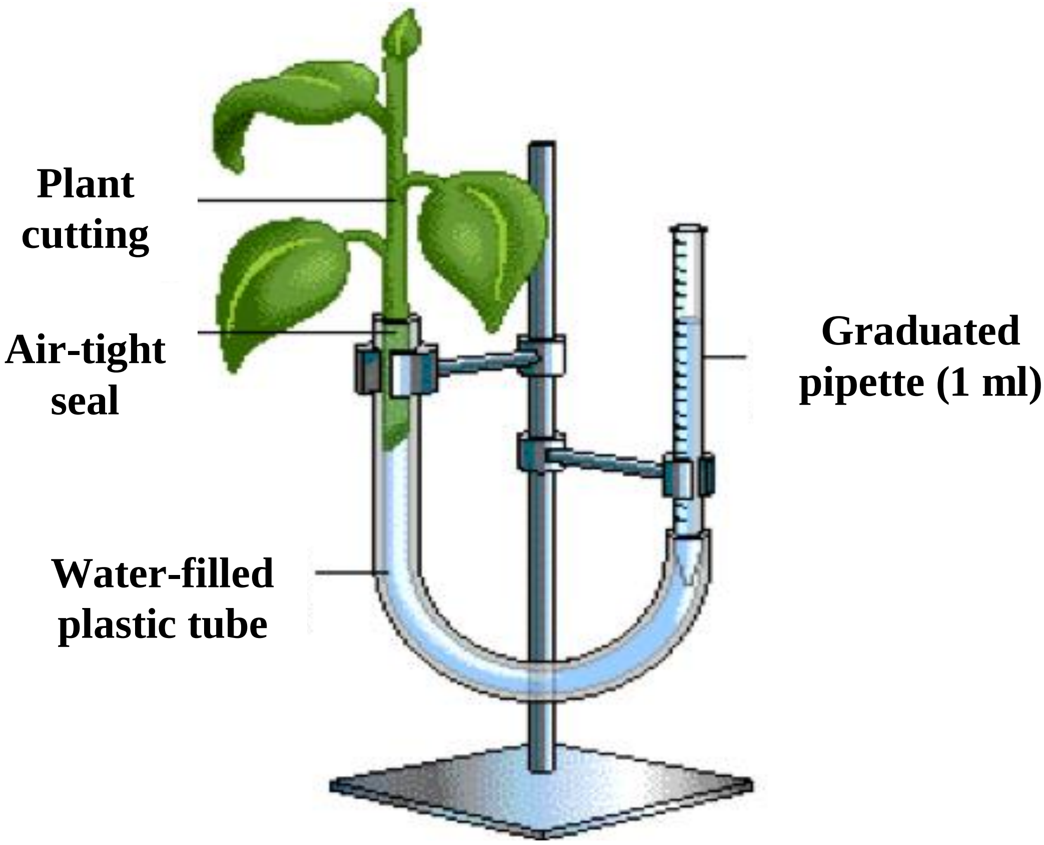
$$W = (Vt - Vo) / S$$

Where W is water loss (mL/m^2), Vt is volume reading at each time point (mL), Vo is the initial volume reading (mL) and S is the total leaf surface for each olive branch (m^2)

Task A1 Study of transpiration rate

Materials and equipment

- Glass pipette (1 mL)
- Pipette filler
- Weighing scale
- Silicone tube (2-4mm, 35 cm)
- Vaseline
- Retort stand with 3 clamps and 3 bosses
- Plug extension
- 1 Energy-saving lamp
- Glass bowl
- Beaker (100 mL)
- Watch
- Microscope and microscopy accessories
- Glass slides and cover slips
- Pruning hook
- Ruler, pencil, pen, rubber and graph paper
- Plastic pieces of $2cm^2$ and $1\ cm^2$
- Gloves
- Tissue
- Calculator



Potometer

Task A1.1

Assembly of the potometer

The following section outlines the steps required to set up the potometer for this task

1. Connect the pointy end of your glass pipette to one end of the elastic tube
2. Adjust the pipette filler on the other end of your glass pipette
3. Fill in the water bath with water from the adjacent water tap. Immerse the free end of the elastic tube into the water bath. Using the pipette filler, suck water in the glass pipette up to the 0.1-0.2 ml mark. Make sure the other end of the silicone tube is fully immersed in water in order to avoid generation of any bubbles in the glass pipette
    a. **Note 1:** Make sure you have no bubbles in your devices

b. **Note 2:** When in step 6, make sure there is not any water higher than the '0' mark on the glass pipette. If that is the case, remove H_2O from the pipette and repeat step 3

4. Choose a leafy shoot with approximately 30 leaves. The diameter of the stem needs to be approximately equal to the diameter of the tube
5. Position the shoot in the water-filled bowl. Carefully cut the shoot at 1–2 cm from its edge without removing it from water
6. Adjust the shoot on the free end of your plastic tube, without removing it from water. Make sure there are no bubbles at the bottom of the shoot

If you have any bubbles, follow the steps below:

- Remove the glass pipette/plastic tube/shoot arrangement in the water-filled bowl
- Remove the shoot
- Repeat step 6

7. Remove the pipette filler
8. Position your glass pipette/plastic tube/shoot arrangement on the retort stand
9. Use the top clamp to position the glass pipette vertically. Make sure you can read the graduation marks on your glass pipette. Appropriately support the shoot with the second clamp to control the connection between the branch and the silicone tube. Make sure that the water level in the pipette and the plastic tube is even
10. Wipe the glass pipette and the rubber tube with tissue and remove any water from the leaves and the shoot
11. Make sure there are no leaks where the glass pipette is connected with the rubber tube and the plant shoot. Use vaseline at the connections in case more waterproofing is required, in particular, where the plant shoot is connected to the rubber tube. Monitor your arrangement for at least 5 minutes to ensure there are no water leaks and that the water level in the glass pipette is constant.
12. The reading on your glass pipette is your initial volume (Vo)

Please make sure you follow the instructions carefully whilst assembly of the potometer, otherwise marks will be deducted

Note: It is important to check your device with the lab supervisor before you commence with your experiment.

Water uptake at room conditions (RC)

Record the water volume in the glass pipette every 5 minutes for a total of 30 minutes . Make a note of your readings in the respective field in your answersheet, column B in table 1 (RC control)

Note 1: If the water level in the pipette is in between two readings, take the third decimal place to be 5

When you finish recording your measurements:

1. Remove the pipette/plastic tube/shoot arrangement for the metallic stand, move to the water bowl and remove the shoot
2. Remove any water from the arrangement and clean the unattached end of the plastic tube from any Vaseline.
3. **Keep the branch for the next task**

Task A1.2

Calculation of total leaf surface (in m^2)

Room conditions (RC)

1. Remove all the leaves from the branch - Remove the stem from each leaf and wipe each leaf carefully to remove any vaseline (if any)
2. Weigh all the leaves together using the weighing scale. Input your measurement in the answer sheet at Task A1.2.a

3. Choose five (5) of the biggest leaves - Cut a 2 cm^2 piece from each leaf and weigh all of them using the scales provided. Input your answer in your answer sheet at b
4. Calculate the mass of 1 m^2 leaf
    - Fill in your answer in the answer sheet under c
5. Calculate the total leaf surface for branch S and add the value in the answer sheet under d
6. Calculate the water loss per m^2 of leaves for each respective point in time (e.g. 5 min, 10 min). Input your calculations in your answer sheet under column C, table 1

Task A1.3

Calculation of water uptake under light conditions (LC)

- Repeat steps 2-12 -in section A1.1
    - **Use a new branch**
- Position the lamp at a 5 cm distance from the top of the branch
- Plug and switch on the lamp
- Wait for 15 min before starting your measurements
- Complete column B in table 2 in your answer sheet
- Switch off the lamp

Task A1.4

Calculation of the total leaf surface (in m^2)

Light conditions (LC)

The following steps apply to the branch used in task A1.3

Repeat steps 1-6 in Task A1.2 and add your measurements in table 2 (under column C) in your answer sheet.

Before you proceed to the next step, ask your laboratory supervisor to approve of your progress so far

Task A1.5

Draw a graph-Calculation of transpiration rate

Use the graph paper provided to draw a graph using the data in tables 1 and 2 (water loss versus time). Determine a line of best fit from your data in table 1 for RC and table 2 for LC. Draw your graphs on the same sheet.

Calculate transpiration rate in the space provided in the answer sheet. :

a. At room conditions

b. At light conditions

Transpiration rate is: total water loss in mL/m^2 per hour.

Answer question BIO 1.

Task A1.6

Preparation of the microscopic slide

Trichomes

1. Choose one of the leaves
2. Use a blade to scrape off the fluff off of the underside of the leaf
3. Transfer what you scraped off of the leaf on the microscopy slide, having added one drop of water first – Observe
4. Add your observations in the respective field in your answer sheet

   Ask your laboratory supervisor to check the slide you have prepared
5. Answer the following question BIO 2 in the answer sheet

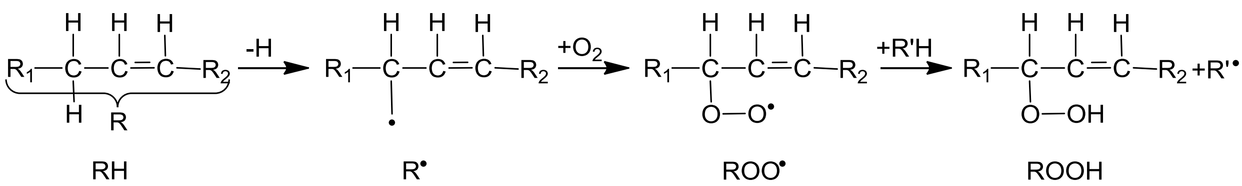
Answer the additional questions BIO 3 and BIO 4.

TASK A2 - Chemistry

Determination of the Peroxide Value (PV) in olive oils

The oxidation of lipids by atmospheric oxygen is an important factor in the development of rancidity and the formation of objectionable odours in edible oils; as a result, controlling it is of outmost importance for all industries which use them as raw materials.

Lipid oxidation initially leads to the formation of hydro-peroxides (ROOH) through a free radical mechanism as shown below:



This chain reaction can end when relatively unreactive compounds or relatively stable free radicals form. Hydro-peroxides (primary products of oxidation), are unstable and break down to produce volatile and usually foul smelling compounds (secondary products of oxidation) such as hydrocarbons, aldehydes, ketones, acids which can impact undesirable flavours and aromas to lipids, even when present in small amounts (ppm).

Factors which increase the rate of oxidation of fats and oils are: the presence of excess oxygen, light, humidity, increased temperature, the presence of pro-oxidants/catalysts, such as ions of transition metals (eg. Cr, Co, Zn, Cu, Fe), as well as the co-existence of various bacteria and enzymes (lipoxygenases).

Lipid oxidation occurs in two stages:

a) the first stage involves the formation of hydro-peroxides which occurs at a very slow rate, and

b) the second stage involves the formation of secondary products which actually catalyse and increase the rate of the overall oxidation process.

Oxidative rancidity of the lipid, which corresponds to the stage of formation of secondary products due to the decomposition of hydro-peroxides, affects the lipid as a whole, possibly making it inedible. This should be avoided, as once a lipid has gone rancid it cannot be treated in any way. The rate of oxidation can be decreased by keeping the lipid in a sealed container, away from light and high temperatures, or by using antioxidants, or by the removal of pro-oxidizing agents such as trace metals during the refining process.

Identification of the degree of lipid oxidation is mainly done through the determination of the Peroxide Value of the lipid. **Peroxide Value** determines the primary products of the oxidation (hydro-peroxides) of the lipid.

In the following experiment, the **peroxide value (PV)** of two samples of olive oil (sample A and sample B) will be determined.

Peroxide Value (PV) is defined as the mmol of peroxide per kg of the lipid.

The determination of the Peroxide Value is based on the oxidation of iodide ions (I^-) by the hydro-peroxides, in an acidic environment, at room temperature. The molecular iodine (I_2) released is titrated against a standardised sodium thiosulfate solution ($Na_2S_2O_{3(aq)}$).

The following reactions take place during the process:

$$ROOH + 2I^- + 2H^+ \longrightarrow ROH + H_2O + I_2$$

$$2Na_2S_2O_3 + I_2 \longrightarrow Na_2S_4O_6 + 2NaI$$

APPARATUS	MATERIALS
▪ Electronic balance (±0.1 g)	▪ Olive oil (sample A and sample B)

▪ 2 conical flasks with stoppers (250 mL) ▪ 2 volumetric cylinders (25 or 50 and 100 mL) ▪ Beaker (400 mL) ▪ Retort stand and clamp ▪ 50 mL burette ▪ 2 pipettes (5 and 10 mL) ▪ Pipette filler ▪ Small funnel ▪ 2 wash bottles ▪ Timer ▪ Dark Box to store the prepared samples	▪ $CHCl_3(l)$ ▪ $CH_3COOH(aq)$ (glacial) ▪ Saturated solution of KI(*aq*) ▪ Starch solution 1.0% ▪ 0.01 M $Na_2S_2O_3(aq)$ ▪ Distilled water ▪ Acetone for rinsing equipment

Experimental Procedure

Experiment 1a.

Steps 1.1 to 1.6 should be performed in the fume hood.

1.1 Weigh approximately 5 g of **olive oil sample A** in a 250 mL conical flask. Record your measurement on the Answer Sheet (Table 1).

1.2 Add 10.0 mL of chloroform ($CHCl_3$) to the same flask, put the stopper on and swirl until the sample is mixed with the chloroform.

Che 1. Answer the question on the Answer Sheet

1.3 Add 15 mL of glacial ethanoic acid (CH_3COOH glacial) to the same flask and swirl in a similar manner.

1.4 Add at least 1 mL of saturated potassium iodide solution ($KI_{(aq)}$), immediately stopper the flask and swirl vigorously for 1 minute.

1.5 Place the conical flask in a dark place for 5 minutes for the reaction to occur.

Che 2. Answer the question on the Answer Sheet

1.6 Remove the stopper and add 75 mL distilled water and approximately 10 - 15 drops of the starch solution (1.0% w/w) to the conical flask.

The titration will be carried out on the bench.

1.7 Titrate the solution in the conical flask with the standardized 0.01 M $Na_2S_2O_3$(*aq*) until the solution is decolourized.

Che 3. Answer the question on the Answer Sheet

1.8 Repeat the above steps two more times.

Che 4. Complete Table 1 on the Answer Sheet

Experiment 1b.

Repeat the above procedure for **olive oil sample B**.

Che 5. Complete Table 2 on the Answer Sheet

Complete the rest of the Answer Sheet (**Che 6** and **Che 7**)

Task A3 - Physics

Viscosity and Refractive Index of Olive-Oil

Many of olive-oil's physical properties were known to ancient Greeks and were used to check its quality: Aristotle described the process of cultivating olive trees and Hippocrates used olive-oil as an ingredient of his pharmaceutical preparations. Olive-oil is a liquid of extremely complex composition. Even so, we can determine a number of olive-oil's physical characteristics and compare them to the corresponding characteristics of other liquids.

During the experiments of task A3, we are going to measure the values of two physical characteristics of olive-oil: (a) the coefficient of viscosity and (b) the refractive index.

Task A3.1 - Measuring the olive-oil coefficient of viscosity

Ancient Greeks used to cover their bodies with olive-oil! They did so, because they believed that olive-oil was a source of strength and also because it decreased friction between their bodies when they wrestled in the palaestra. The latter choice is explained in nowadays science through the study of a property of the liquids, called "viscosity". In this part, we measure the viscosity coefficient of olive-oil.

Theoretical framework - Designing the experimental procedure

Motion of a small sphere inside a liquid-filled vertical tube:

A small plastic sphere is moving along the symmetry-axis of a vertical cylindrical tube containing a liquid (figure 1). According to Newton's 2nd law, we may write:

$$ma = F_{\mathrm{g}} - F_{\mathrm{b}} - F_{\mathrm{v}} \tag{1}$$

where m is the sphere's mass and a its acceleration.

The following forces are exerted on the sphere:

a) The gravitational force F_w:

$$F_w = mg = \rho_s V g \quad (2)$$

Where ρ_s is the sphere's density and V its volume. Assume $g = 9{,}81\ \text{ms}^{-2}$. If the radius of the sphere is denoted by r, then its volume is given by the relationship: $V = \frac{4}{3}\pi r^3$

b) The buoyant force F_b. According to Archimedes' principle, the direction of this force is vertical upwards and its magnitude is equal to:

$$F_b = \rho_L g V \quad (3)$$

where ρ_L is the liquid's density.

c) The frictional force F_v. This force is caused by the motion of the sphere inside the liquid and its direction is opposite to the direction of the sphere's velocity. Given that the sphere's speed is relatively small (as in our case), then the magnitude F_v of the frictional force is proportional to the sphere's speed υ and is given by Stokes's law for a spherical body of radius r:

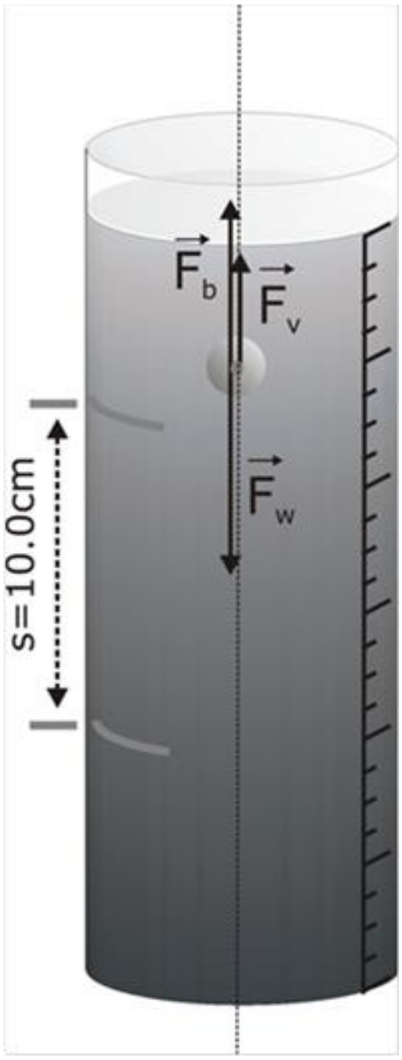


Figure 1

$$F_v = 6\pi r \eta \upsilon \quad (4)$$

(Note: We assume that the distance between the sphere and the wall of the cylindrical tube is large compared to the sphere's radius. So, in our calculations, we do not take into account the effect of the tube's walls in the sphere's motion.)

The coefficient η is named **viscosity coefficient of the liquid** and depends on the liquid and its temperature. Its measurement unit in SI is $1\,\mathrm{Pa \cdot s}$.

In this experiment, we are going to measure the viscosity coefficient of olive-oil by studying the motion of several plastic spheres along the axis of the cylindrical tube containing the liquid.

The sphere obtains its terminal velocity almost immediately. The magnitude of this velocity is given by the relationship:

$$\upsilon = \frac{2}{9}\frac{gr^2(\rho_\mathrm{s} - \rho_\mathrm{L})}{\eta} \qquad (5)$$

Prove the above relationship in the answer sheet.

In equation (5), quantities ρ_L, r, ρ_s and υ can be experimentally measured or calculated. The value of g is: g=9,81m/s^2. The only unknown factor is the viscosity coefficient η.

In experimental procedure A3.1, we will use equation (5) to determine experimentally the olive-oil coefficient of viscosity.

Equipment and materials

1. Plastic identical spheres (~20), inside a cylindrical plastic box
2. Vernier caliper [x1]
3. Electronic balance, of $0{,}1\ \mathrm{g}$ accuracy [x1]
4. Volumetric cylinder 250 mL [x1]
5. Electronic chronometer [x1]
6. Syringe 20 mL [x1]
7. Plumb [x1]
8. Cork that fits the mouth of the volumetric cylinder, with a tube of internal diameter 8 mm [x1]
9. Olive-oil (approximately $0.3\ \mathrm{L}$)
10. Marker [x1]
11. Kitchen paper [1 roll]

12. Scientific calculator

13. 30cm ruler

Experimental procedure

[All measurements and calculations should be shown in part A3.1 of the answer sheet]

A3.1a Measure the radius r of the plastic spheres. Determine the mass of a plastic sphere. Calculate the density ρ_s of the plastic spheres.

By using the syringe and the balance, determine the density (ρ_{ol}) of olive-oil.

Express the values of the calculated quantities with the correct number of significant figures.

A3.1b Use the marker to note on the volumetric cylinder two horizontal lines, at a distance of 10 cm from each other. Take care the upper line be approximately 6-7 cm under the free surface of the liquid. (see figure 1). Use the plumb to check if the cylinder is vertical. Place on the cylinder's mouth the cork with the tube. Carefully release one sphere through that tube, so that it will move along the cylinder's axis of symmetry.

Using the chronometer, measure the time interval in which the sphere travels the distance s ($s = 10\ \text{cm}$) between the two horizontal lines that you have marked on the cylinder. Repeat the same procedure for five spheres in total. Record your measurements in table B of the answer sheet. Calculate the average value of this time interval ($\overline{t}_{oil}$) and then the value of the terminal speed of the spheres inside the olive-oil. .

Using equation (5), calculate the value of the viscosity coefficient of olive-oil.

Task A3.2 - Measuring the refractive index of olive-oil

From Ptolemy's law to Snell's law

The strange deep-green color of olive-oil as well as the spectacle of light rays going through it, was mesmerizing to the ancient Greeks. In the Hellenistic period, during the 2nd AD century in Alexandria, Claudius Ptolemy studied light as it was moving from the air into liquids. He described the phenomenon of refraction and stated a law about this. Ptolemy's law differs from Snell's law, which is describing refraction in nowadays Physics. In this task, we are going to study refraction phenomenon for olive-oil according to both laws and compare them.

Theoretical framework – Experimental procedure layout

Figure 1 shows a thin light beam, which initially travels in the air and then meets the surface of a transparent body. A part of the incident ray is reflected, and the rest is coming into the transparent body, being refracted. Angles α and β formed by the incident and the refracted ray, respectively, with the line which is perpendicular to the body's surface at the point of incidence O, obey Snell's law:

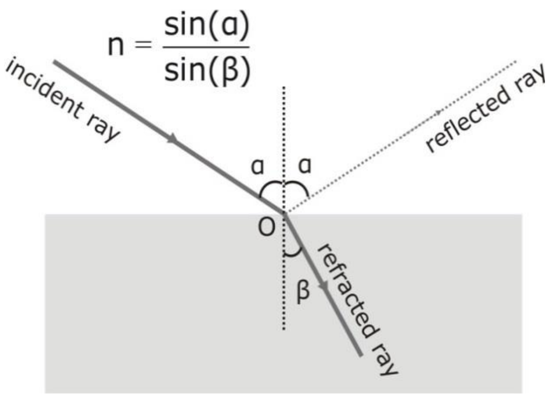


Figure 1

$$\frac{\sin\alpha}{\sin\beta} = n, \qquad (1)$$

where n is the refractive index of the body defined by the relationship:

$$n = \frac{c}{\upsilon}, \qquad (2)$$

c is the speed of light in the air and υ is the speed of light in the transparent body.

In task A3.2, we apply Snell's law to calculate the refractive index of olive-oil. To this end, we will use the experimental device shown schematically in figure 2. The light beam AO starting from pin A and going through the center O of the semi-cylindrical prism is refracted following the Ox direction. If we place a second pin at point B of the refracted ray and place your eye looking towards the BO direction, then points A, O and B will look like they are lying on a straight line. Thus, we are able to find the direction of the refracted ray Ox, coming from the incident ray AO (see figure 2). Using the polar paper, we can determine this line and measure the angle of incidence α and the angle of refraction β, which are formed respectively by AO and OB with the line perpendicular to the surface CD.

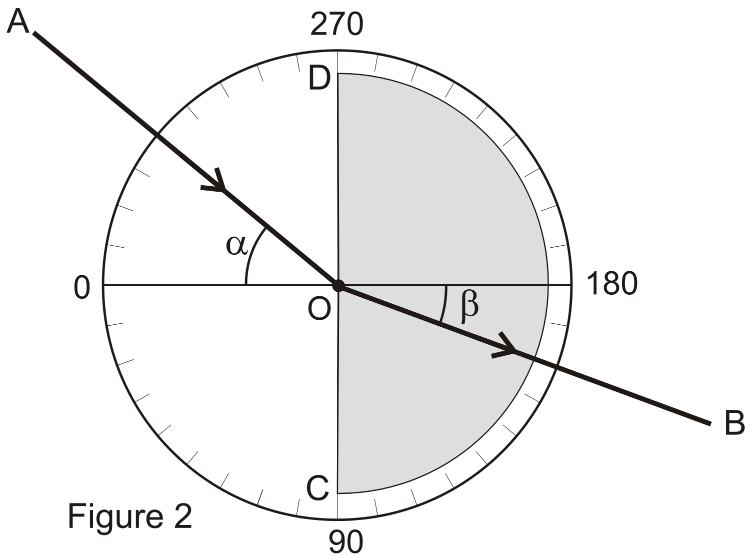


Figure 2

For several different positions of pin A, we can measure each time the angle of incidence and the angle of refraction. According to Snell's law (equation 1), the refractive index of the liquid can be determined as the slope of the line $y = nx$, where $y = \sin\alpha$ and $x = \sin\beta$.

Equipment and materials

1. Semi-cylindrical container [x1]
2. Polar paper (subdivisions every 2 degrees)
3. Olive-oil (~100 mL) in plastic cup
4. Piece of styrofoam 2,5 cm x 24 cm x 24 cm [x1]
5. Pins 3,5 cm [x3]
6. Kitchen paper
7. Graph paper [x2]
8. Scientific calculator

Experimental procedure

[All measurements and calculations should be shown in part A3.2 of the answer sheet]

A3.2a Fill the semi-cylindrical container with olive-oil. Using the procedure described before, find the refracted ray and measure the angle of refraction, for five different angles of incidence: **30, 40, 50, 60, and 70 degrees**.

A3.2b Fill in the 2nd and 4th column of table C1, in part A3.2 of the answer sheet. Plot a graph of sin*α* vs sin*β*. From your graph, determine the refractive index (n_{oil}) of olive-oil.

Record in part A3.2 of the answer sheet the value (n_{oil}) of the refractive index of olive-oil you determined.

A3.2c Snell's law: comparison of the theoretical predictions to the experimental data

How well do our measurements agree with Snell's law?

One quantitative way to judge if Snell's law agrees with our measurements is the calculation of the "mean relative deviation" of our measurements from the value of the refractive index we determined.

In detail:

Let n_{oil} be the refractive index of olive-oil experimentally determined in step A3.2b.

Let α_j be one of the values of the angles of incidence recorded in table C1 and β_j the corresponding value of the refraction angle. According to this measurement, the refractive index of olive-oil is equal to:

$$n_j = \frac{\sin \alpha_j}{\sin \beta_j}$$

The relative deviation A_j of this value from the value n_{oil} you determined is:

$$A_j = \left| \frac{n_j - n_{oil}}{n_{oil}} \right|$$

The mean relative deviation A_{Snell} of the A_j can be calculated using the formula:

$$A_{Snell} = \frac{1}{N} \cdot \sum_{j=1}^{N} A_j \quad (3)$$

Based on the experimental values you have recorded in table C1, calculate the mean average deviation A_{Snell} of the experimental data from Snell's law predictions for olive oil. Express your answer in % percentage.

Record your calculations in part A3.2 of the answer sheet.

A3.2d A recursion in history: the law of Claudius Ptolemy.

Long before **Snell**, **Claudius Ptolemy (2nd A.D. century, Alexandria)** suggested the following law of refraction:

$$\frac{\alpha}{\beta} = n' = \text{constant} \quad (4)$$

Let us determine the refractive index of olive-oil (n'_{oil}), using our previous measurements and according to Ptolemy's law.

Plot a graph of *α* vs *β. Note*: Draw the best-fit straight line going through (0, 0). From your graph, determine the refractive index (n'_{oil}) of olive-oil according to the "theory" of Claudius Ptolemy.

A comparison between Snell's and Ptolemy's law: *with which one do your experimental data fit better?*

Using the method followed in step A3.2c, calculate the mean relative deviation $A_{Ptol.}$ of the experimental data from the theoretical predictions of Ptolemy's law. Use the experimental data recorded in table C1.

The relative deviation of each measurement from the value of the refractive index you determined according to Ptolemy's law is:

$$A'_j = \left| \frac{n'_j - n'_{oil}}{n'_{oil}} \right|.$$

The mean relative deviation $A_{Ptol.}$ is calculated by using the formula:

$$A_{Ptol.} = \frac{1}{N} \cdot \sum_{j=1}^{N} A'_j \,. \quad (5)$$

Express your answer in % percentage.

Compare A_{Snell} to $A_{Ptol.}$ and decide which of the two theories s better.

Record your calculations and answers in part A3.2 of the answer sheet.