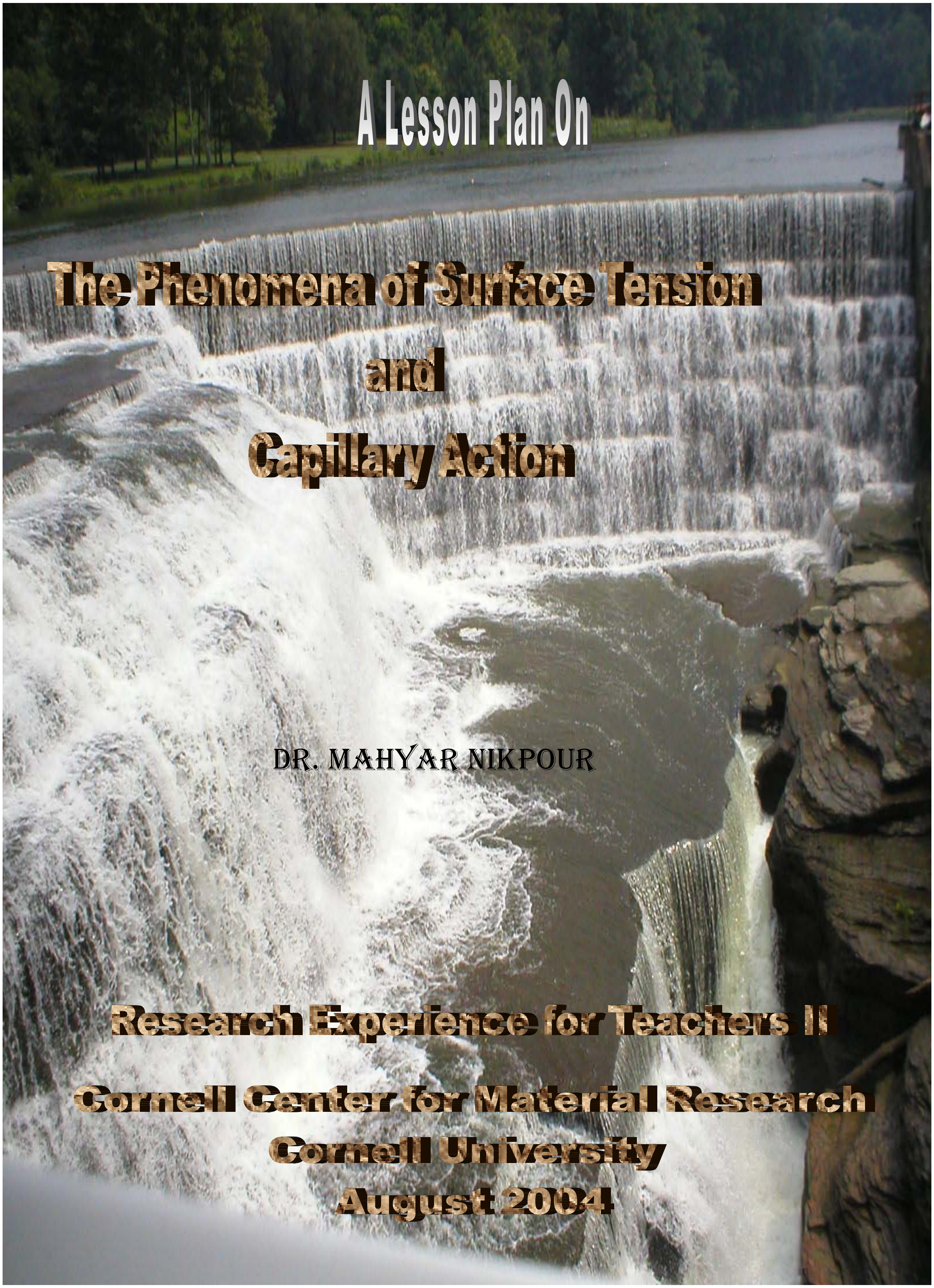

A Lesson Plan On

The Phenomena of Surface Tension and Capillary Action

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Research Experience for Teachers II

Cornell Center for Material Research
Cornell University
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INTRODUCTION

All physical and chemical processes have an interface associated with them. In many areas of the fields of chemical engineering, food science, medicine and physics and material sciences, surface chemical properties and processes are important. Many disciplines, like introductory chemistry and physics, are concerned with the study of interfacial phenomena and sometimes the degree of understanding displayed is too superficial.

This lesson plan attempts to describe and explore, as far as the limits of a high school science course allows, some fundamental of the subject, mainly surface tension and capillary action. Most part of it is appropriate for a Regents chemistry class. Some extensions may be more suitable for second year chemistry or a science research program.

At the beginning the State Education standards pertaining to this topic are listed, including the Performance Indicator and Major Understandings. The lesson plan is based on an inquiry system and guides the teacher through the introduction and the development of the subject.

The lesson starts by assessing and establishing or re-establishing students' prior knowledge of mass an, density and buoyancy concepts. It then continues by motivating them by some short films on basilisk lizard and water spider walking or running on the water surface. The discussion opened after watching the films, inspires students to asks questions about the nature of forces opposing the downward gravity force and will lead them to learn the concepts of surface tension

The theory of interfacial forces is explored through an inquiry system. Hydrogen bond is reviewed and different aspect of surface tension and capillary action are demonstrated by simple displays and activities.

To develop students understanding of the subject, a challenging question is asked as the students observe Tokar's demonstration. That will be followed by a novel lab activity that incorporates related theoretical conceptions and many laboratory skills: measuring the mass, reading the volume of a liquid in a graduated cylinder (meniscus). At the end of the lab there some questions to assess the progress in learning for different groups of students.

A further understanding can be offered (maybe for advanced groups of students or for the second year chemistry class) by introducing formal definitions of surface tension and related formulations and problem solving.

At the end sample Regents like questions are provided that can help teachers to design a proper assessment.

A research project which is based on the author's own research work at Cornell is offered and is attached to this lesson plan.

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Roosevelt administrators, particularly Mrs. C. Castillo have gracefully recommended and encouraged me to participate in the RET program and the ensuing summer research work, for which I am genuinely beholden. I would like also to acknowledge the facilities provided by the Cornell University Outreach Programs and particularly, I am thankful for all the support Nev Singhota, the Educational Programs director, and Kevin Dilley, Educational Programs Specialist and other RET program staff afforded me to start my research and obtain all materials necessary.. I am also indebted to Dr. Jonathan Shu for his assistance and guidance to use CCMR spin coating facility.
I was given the prodigious opportunity to work at the lab of Professor Mingming Wu who was my mentor and who endowed me with her constant and remarkable insights and comments throughout all my research and also provided me with useful reference materials. I am also deeply grateful to Mark Buckley, a graduate student and John Roberts an undergraduate Mechanical engineering student who assisted me in setting up the camera and data acquisition. John also made the protective encasing for the slides.

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Title of Unit: Physical Behavior of Matter

Key Idea 5:
Energy and matter interact through forces that result in changes in motion.

Performance Indicator 5.2:
Explain chemical bonding in terms of the behavior of electrons

Major understanding 5.2m:
Intermolecular forces created by the unequal distribution of charge result in varying degrees of attraction between molecules. Hydrogen bonding is an example of a strong intermolecular force.

Major understanding 5.3h:
Behavior and characteristics of matter, from the microscopic to the cosmic levels, are manifestations of its atomic structure. The macroscopic characteristics of matter, such as electrical and optical properties, are results of microscopic interactions.

Real World Connections:
Electrostatic, Meniscus (concave/convex), Capillary Action, Surface Tension, Sessile drop of water

Focus of the Lesson Plan:
Define and explore the phenomena of surface tension and capillary action.

Assessing Prior Knowledge

Through an inquiry system review the concepts of mass and density and buoyancy with students. Ask students to compare the density of common objects: wood, steel, paper, air …Encourage them to discuss which objects float on water and which one sinks and Why? Do human or insects float on water? Demonstrate this: For example a dead fly sinks in water.
Ask why a boat, though denser than water, floats. Correct them if required and explain that is because it is partially immersed in water and the buoyant force balances its weight.
Dead leaves are generally denser than water. Place a leave on the surface of water in a container. Put a small metal washer on the leave. Let students to observe and find out why dead leaves float on water. They are not immersed in water, so the weight of the leave is not balanced by a buoyant force.

Motivation

Continue the above activity by showing them short clips of films showing water spiders walking on the water surface. Show a picture or film of Basilisk lizard running on the surface of a pond:

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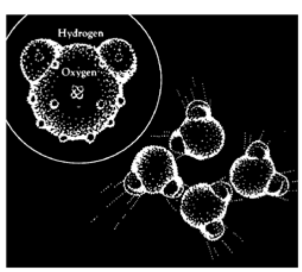
You can find easily many Internet sites with short clips of walking insects or Basilisk lizard. For example:
Basilisk lizard:
visionlearning.com/library/module viewer.php?mid=57
Water Spider:
http://www.fcps.k12.va.us/StratfordLandingES/Ecology/Insects/Common%20Water%20Strider/water%20strider%202.mov

Introduction to Understanding

At this time the minds are set for the introduction of the topics of surface tension and capillary action. Teach the topic by illustrations, demonstrations and real world connections. Use an inquiry system. At the end of the lesson students should be familiar with following concepts and ideas:

The hydrogen bond is a special case of dipole forces. A hydrogen bond is the attractive force between the hydrogen attached to an electronegative atom of one molecule and an electronegative atom of a different molecule. Usually the electronegative atom is oxygen, nitrogen, or fluorine, which has a large partial negative charge. The hydrogen then has the partial positive charge.



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1. Water is an example of a liquid with hydrogen bonds

2. Hydrogen bonds are effective between the molecules of water over a very short range. The intermolecular forces between molecules of water are considerably stronger than interaction between these molecules and those of gases above the surface.

3. Another name for attractive forces of molecules of water to each other is cohesion - in the case of water this is caused by hydrogen bonding. In liquid water each molecule of water is attracted in all directions to perhaps as many as four other water molecules through hydrogen bonding.

4. This leads to the situation illustrated in the Figure 1. Equally strong hydrogen bonds act on the molecules within the water in all direction and neutralize one another. However, within a thin layer at the surface of the liquid a net force, **F** remains directed towards the interior of the liquid, perpendicular to the surface.

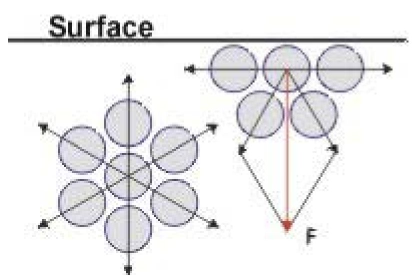

Figure 1

5. Consider an open container of water. A water molecule on the surface is only pulled downward and to the sides, but not upward. An individual water molecule is pulled more into the bulk liquid to cause the surface to become as small as possible. The result of this effect is to tighten the surface into a type of elastic film called surface tension.
6. On the microscopic scale this causes free drops of water to be spherical. The reason is that the exposed surface of the water is being minimized in that way. Therefore, surface tension is defined as the energy needed to increase the surface by a defined value. The minimum surface corresponds to the minimum energy.

7. This surface is reasonably strong and will support objects such as a paper clip, aluminum pop can tab and a dead leave.

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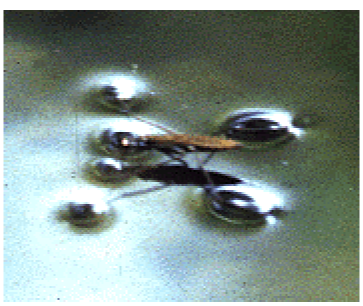
8. **Capillary action** or **capillarity** is the ability of a narrow tube to draw a liquid upwards against the force of gravity. It occurs when the adhesive intermolecular forces between the liquid and a solid are stronger than the cohesive intermolecular forces within the liquid. The effect causes a concave meniscus to form where the water is in contact with a vertical glass surface. The same effect is what causes porous materials to soak up liquids.

9. With some materials, such as mercury and glass, the inter-atomic forces within the liquid exceed those between the solid and the liquid, so a convex meniscus forms and capillary action works in reverse.

10. A plant makes use of capillary action to draw liquid water into its system, although larger plants require transpiration to move a sufficient quantity of water to where it is required.

DEMONSTRATIONS:

You can float a paper clip on the surface of a glass of water. Before you try this you should know that it helps if the paper clip is a little greasy so the water doesn't stick to it (rub it on your nose or forehead.) Place the paper clip on a fork and lower it slowly into the water. The paper clip is supported by the surface-tension skin of the water.



The water strider is an insect that hunts its prey on the surface of still water; it has widely spaced feet rather like the pads of a lunar lander. The skin-like surface of the water is depressed under the water strider's feet.

The shape of the surface of a liquid column in a tube (the meniscus) depends on the relative magnitude of the intermolecular bonding forces within the liquid and the attraction forces between the wall of the tube and the molecules of the liquid.

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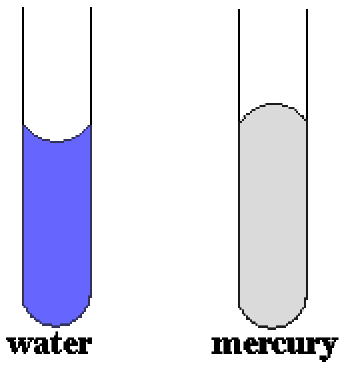

- If the attraction forces between liquid and wall exceed the intermolecular bonding interactions within the liquid, the liquid will maximize the contact with the wall and a **concave meniscus** is formed (example: ethyl alcohol or water in glass).
- If the intermolecular bonding interactions within the liquid exceed the attraction forces between liquid and wall, the liquid will minimize the contact with the wall and a **convex meniscus** is formed

Development of Understanding

The following demonstration is adapted from “Tokar’s Question”, Physics Teacher **38,** 488 (november2000). It brings up a challenging question and the ensued class discussion will help students to a better and more in depth understanding of the concepts of surface tension, buoyant force, electrostatics and the effect of the polarity of molecules of water.
Fill a tray with water and place an empty aluminum soft-drink can on water. Approach a charged plastic rod (either positive or negative) to the can. You can charge the rod by rubbing it with a cloth or for a more attention-grabbing performance you may use an electrostatic machine such as Van de Graff generator or Wimshurst machine to charge the rod. Students will observe that the can is attracted to the charged rod. This simple electrostatic display is expected: The neutral aluminum can will be polarized (due to an induced charge separation). The side of the can closer to the rod will obtain an opposite charge and hence attracts the rod.
Now, try this even more interesting experiment: Cut a piece (2cm by 3cm) out of the can, flatten it out, and gently place it on the water surface so that it floats. Bring the charged plastic rod close to the floating piece of metal. Surprisingly, the metal is *repelled* by the rod. The net force is weak and so the metal reacts very slowly.
The demonstration may be presented in a clear container atop an overhead projector.
Ask the class why does it work that way? How does it happen that the same material approached by the same charged rod can be attracted(the can) or repelled (the small piece of the same can)?
Explanation: There are two primary mechanisms by which an object will float on water: buoyancy and surface tension. An object floating due to the buoyant force is partially submerged in the liquid, but the induced charge separation primarily occurs in the portion of the object above the water. (One can see this by the

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manner in which an aluminum boat will also tip towards the charged rod.) An object floating due to surface tension does not submerge in water. A buoyant object shows little deflection of the water surface, while around the object floating due to surface tension, there is a distinct depression in the water surface.

Consider one further detail: water is a polar liquid; thus, it too will have an effective 'charge separation', and can be attracted to the charged rod; this is can be easily demonstrated by deflecting a thin stream of water with a charged rod. Thus, the water will 'mound up' on the side of the charged rod. When the object is (partially) beneath the liquid (buoyancy), this mounding does not produce a strong net force. However, when the object is on top of the water (surface tension), this effect is dominant, and the object tends to slide down the mound, and thus the net effect is a force away from the charged rod.

This effect is independent of the sign of the charged rod (as would be expected), and can be seen in many different materials, when surface tension is the dominant force (metal, including paper clips & aluminum foil & coins), thin sheets of plastic.

A laboratory activity on basic characteristics of surface tension may be introduced at this time. Attached

Checkpoint
The questions at the end of the lab activity may be assigned as homework and will serve as the checkpoint indicative of the students' understanding of the concepts of the surface tension and the capillary action.

Further Development of Understanding

At this time you may introduce a formal definition for the surface tension:

The contracting force per unit length around the perimeter of a surface is usually referred to as surface tension if the surface separates gas from liquid or solid phases, and interfacial tension if the surface separates two nongaseous phases. The common measurement units used is mN/m.
Surface tension can also be expressed in units of energy per unit surface area. For practical purposes surface tension is frequently taken to reflect the change in surface free energy per unit increase in surface area.

Assessment:

Sample of questions pertaining to this topic follows

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Type A Question:

Basilisk lizards can run on the surface of a pond. What force holds the basilisk lizard from sinking in the water?

1. gravitational force
2. surface tension
3. buoyant force
4. magnetic force

Type B Question:

What is the common SI unit to measure the surface tension?

Type C Question

Illustrate by drawing a sketch of molecules on the surface of a water pond and deep in the pond the difference between net force acting on the. Show the direction of the net force in both cases.

Science Research Program

The attached is the outline of the research work that I have done at Cornell. This work, maybe in a redesigned format is readily can be used as a guideline for a science project or a science research project for an individual student or a group of students.

References:

The following references are used in the preparation of this lesson plan and also my research (attached) and are recommended for further studies.

Books

1. Made to Measure by Phillip Ball, Princeton University Press, 1997
2. Chemistry of interfaces by M.J. JayCock, G.D. Parfitt, Ellis Horwood series
3. Physical Chemistry of Surfaces, A. W. Adamson and A. Gast, 6th edition
4. Surface Tension & the Spreading of Liquids, by R. S. Burdon
5. Hydrophobic Surfaces by Frederick Fowkes

Articles/ manuals

1. **Chemistry Demos : section 3: Water and its properties: http:// www.iserv.net/_charges/chem/seccsurftens.htm**
2. **Surface tension and minimal surfaces by Carl von Ossietzky, University Oldenberg, Introductory laboratory course**

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3. Low voltage electrowetting on dielectric, Hyejin Moon et al, Journal of applied Physics, May 2002
4. Creating, transporting, Cutting and Merging Liquid droplets, Hyejin Moon et al, Journal of Microelectrochemical Systems, Vol. 12 No 1 Feb. 2003
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6. Light actuation of liquid by optoelectrowetting, Pei Yu Chiou et al, www.elsevier.com/locate/sna
7. A surface Chemistry Experiment Using an Inexpensive Contact angle Goniometer
8. Water Wonders, national teacher training Institute, http://www.wgby.org/edu/lessonplans/ntti/archive/water.htm

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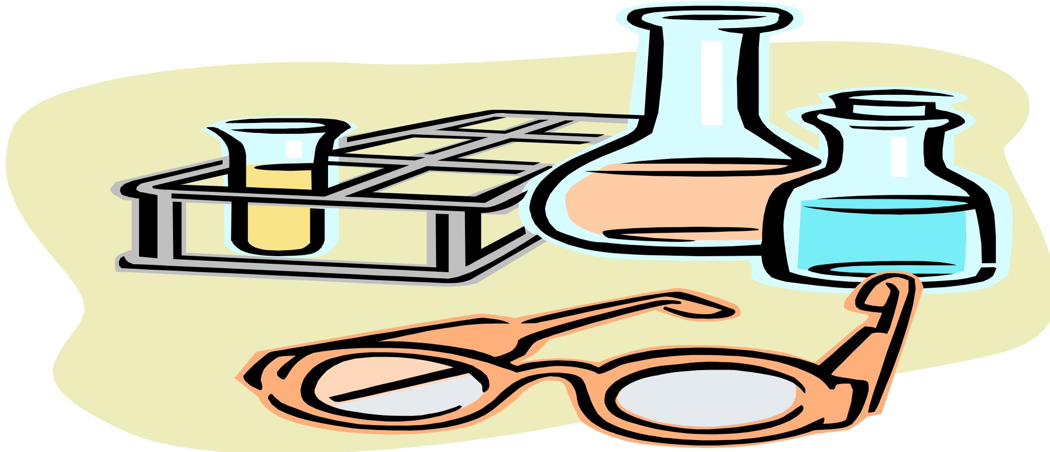

ACTIVITY

Surface Tension

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Note: This is only the outline of a chemistry lab activity. Teachers must prepare the actual lab manual, including the preparation of chemicals and all safety measures and methods disposal of waste material.

Materials and chemicals needed per group of students:

Test tubes (25mmm diameter): 2
Test tubes (5mmm diameter): 2
Test tube rack
Graduated cylinders 50 mL and 10 mL
Digital balance with a precision of .01 gram
Magnifying glass
Small glass beads: 10
Methanol (to clean and wash the Teflon coating)
Distilled water
5% Teflon solution : 5 ml
Perfluoro-compound FC-7
Oven for baking the coats at 150 ^{0}C

Note: The solution must be prepared by the teacher.
If a 25% Teflon solution is available , prepare the 5% solution by diluting it with perfluoro- compound FC-75. *Both Teflon Solution and the perfluoro- compound may be purchased from:*
Dupont Fluoroproducts, 1007 Market Street, Wilmington, DE 19898

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MSDS are available online from the company.

Pre Lab discussion

Review and demonstrate of the theory of surface tension and the shape of meniscus for different liquids (water, mercury) and also capillary action.

Procedure:

PART A

1. Fill the 25mm test tube with distilled water 5 millimeter to the top.
2. Draw the shape of the meniscus on your report. Is the shape convex or concave? You may use the magnifying glass.
3. Measure and record the mass of the test tube within 0.01 gram precision. Be careful not to spill the water.
4. Calculate the volume of this water
5. Pour the water in a graduated cylinder and read (under the meniscus) and record the volume of water. Compare this volume with the result obtained in part **5**. Which one is more accurate? Explain why.
6. Place the test tube in a test tube rack vertically. Begin dropping glass beads one by one into water. Avoid splashing or violent agitation of water. Drop the beads as close to the test tube rim as possible. Count the number of glass beads added.
7. Continue to drop the glass beads and observe that the water rises higher than the test tube rim and is "hanging". Explain what force is keeping the water from being spilled.
8. Mark the total number of beads added just before the water spills over the rim
9. Measure and record the mass of the test tube within 0.01 gram precision. Be careful not to spill the water.
10. Calculate the volume of this water
11. Measure the height of the meniscus.
12. Calculate the percent by mass of water in the water-glass beads heterogeneous mixture.

PART B

13. Fill the 25mm Teflon coated test tube with distilled water 5 millimeter to the top.
14. Repeat the procedures 2 to 12 and write your observations.
15. Make a table and compare your answers for the different test tubes.

PART C

16. Repeat the experiment with the 5-mm test tube. Compare the results with the previous experiment.

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Evaluation:

1. In what test tube was the shape of the meniscus concave? Explain that in terms of the intermolecular forces of attraction between the glass and the water molecules.
2. What is the direction of the surface tension forces?
3. How does the diameter of the glass affects the height of the meniscus?
4. List the sources of possible errors in these experiments.
5. What is the capillary action. In which experiment is it most prominent?

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