DROPS OF LIQUID ON A PENNY

The following problem is an exercise in intermolecular forces. This has been modified to use household materials, to be run in microscale, and to minimize safety hazards.

This problem was used in an academic competition where teams of students worked to solve the problem and then presented their results to a team of evaluators.

The factors that the evaluators looked for were first outlined by this author. That list of factors was sent to outside evaluators, in the field, to criticize and modify. The comments and modifications were reviewed, corrections were made, and the modified list was again sent out for review and further modification. It should be noted, that the process of evaluating active assessment-type questions is a process that takes time and the input of several people. The goal is to try to develop a more objective evaluation that identifies the knowledge of the students working on the problem. The final answer is only a small part of this type of problem solving.

Most practical exams, administered in a small department setting, are evaluated in a somewhat subjective manner and the same criteria are not uniformly applied to all the students or teams working on the problem. This is not necessarily a result of favoritism toward certain students, although it may play a role, but rather a result of limited time for evaluation, different evaluators, or just a cursory scan of results where the evaluator concentrated mainly on the answer.

One may consider the extensive list of items to consider to be overkill for the problem, but it is important to develop a fair evaluation process. Another consideration is that all points are **positive points**, that is, students or teams get points added for each correct part of the solution to the problem. The author believes this produces more of a positive feedback to the student/team.

DROPS ON A PENNY

Materials:

- 4 Beral pipettes
- 4 Pennies
- Water
- Water-detergent solution
- Ethyl alcohol solution
- Mineral spirits
- Paper towels
- Safety goggles or glasses
- Rubber gloves

NOTE: Read all instructions before you begin. All students must wear safety glasses and gloves during experimentation.

Task:

Your team has 20 minutes to determine:

How many drops of each liquid can be placed on a penny.

Explain the reasons for any differences you observe for the four liquids.

At the end of 20 minutes, you will give 5-minute presentation to the evaluators explaining your results and reasons for the differences you observe.

All members of your team must participate in the presentation.

DROPS OF LIQUID ON A PENNY
Information and set-up

Materials

4 Beral pipettes
4 U.S. Pennies or similar small coins
Water in a small bottle (2 or 4 ounce)
Water-detergent solution in a small bottle (2 or 4 ounce)
Ethyl alcohol solution in a small bottle (2 or 4 ounce)
Mineral spirits (odorless) in a small bottle (2 or 4 ounce) Note: substitute hexane or heptane
Safety goggles or glasses
Gloves

Task

How many drops of each liquid can be placed on a penny?

Explain the reasons for any differences you observe for the four liquids.

Reactions and Solution to Problem

This experiment demonstrates the intermolecular forces (or cohesive forces) between molecules of a substance. These forces are responsible for the observed surface tension in liquids.

Surface tension is the phenomenon where strong forces between molecules cause the surface of a liquid to contract. That contraction of the surface molecules of a liquid results in the drops of liquid being formed into a spherical shape. Substances where the surface tension is strong, such as water, will tend to bead up on a smooth surface. This is the reason for water to form "beads" of liquid on a waxed surface. Substances where the surface tension is weak will tend to spread out on a smooth surface such as an oil spreading over a surface.

The forces of attraction between two molecules is due to the types of atoms bonded together in the compound and the shape of the molecule.

A chemical bond is formed between two atoms when they share electrons between them. In the ideal case, both atoms attract the electrons equally, like a tug-of-war between two equal teams. When two different atoms are bonded together, each attracts the electrons differently like a tug-of-war between two unequal teams. That unequal attraction of the electrons produces a polarity in the molecule, making one part of the molecule positive and one part of the molecule negative. (This is similar to the polarity that occurs in a magnet.) The positive part of one molecule with be attracted to the negative part of another molecule.

The shape of a molecule also contributes to the polarity. Molecules containing three or more atoms may be linear in shape or bent. Depending on how symmetrical or how bent the molecule is, the polarity of the molecules will differ. For example, a water molecule, which consists of two hydrogen atoms attached to a single oxygen atom, is bent in an angle of 104°, which is slightly more than a right angle (90^o). The unequal attractions of the hydrogen atoms and the oxygen atom produce a polarity in the individual bonds (see diagram below) and the bend in the water molecule increases the overall polarity making the total polarity of the molecule stronger than that of the bond by itself.

- O – H +
(negative end) (positive end)

A oxygen-hydrogen bond

- (negative end)
O
/ \
H H
+ (positive end)

A water molecule

The polarity of the water molecules is quite strong and results in a strong attraction between two adjacent water molecules (and, to some degree, between all surrounding water molecules). Since this type of bonding, where a hydrogen-oxygen group occurs in a molecule, is quite common in a number of substances, it is given the special name, **hydrogen bonding**.

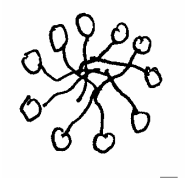
Water has the strongest hydrogen bonding and the highest surface tension. Because of the strong attraction between water molecules, the water forms a large "sphere" of water on coin. The number of drops that the students can put on the penny will vary from about 30 to 50 depending on size of drops. (NOTE: The actual number of drops of water is not important to the solution of the problem. The relative number of drops of water, as compared to the other liquids is important.)

A detergent reduces the surface tension of the water. Detergent molecules are polar on one end and non-polar on the other end. The polar end is attracted to water molecules and the non-polar ends are hydrophobic, that is, they will not mix with water molecules (like oil separates from water). In water, the detergent molecules will form a cluster and will orient themselves with their polar ends toward the water molecules and their non-polar ends oriented toward the center of the cluster. The resulting cluster, called a *micelle*, is essentially a large polar molecule. The presence of the clusters (micelles) reduces forces of attraction between the water molecules and the overall surface tension of the detergent solution. When washing clothes, dirty hands, etc., the detergent molecules will surround dirt like football players surrounding the ball carrier on the opposite team and hold the dirt in solution. About 20 to 30 drops of the detergent solution can be placed on the coin depending on drop size. (Note: students may not be familiar with detergent structure and the name "micelle")

O————————

Polar non-polar
End end

A detergent molecule
(schematic diagram)



A micelle
(cluster of detergent molecules)

In a compound such as ethane, (commonly referred to as a hydrocarbon molecule since it is composed of carbon and hydrogen atoms) the small polarities in the bonds between the carbon atoms and the hydrogen atoms are canceled out due to the symmetry of the molecule, making the molecule non-polar. (Note: The actual structure of an ethane molecule is 3-dimensional, but it is symmetrical.)

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    H   H
    |   |
H—C—C—H
    |   |
    H   H
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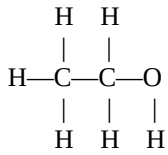
An ethane molecule

As a result, an ethane molecule has little or no attraction for other ethane molecules.

Ethyl alcohol has a structure that is similar to both ethane and water. The O-H group on one end of the molecule is bent, similar to the O-H in a water molecule, but the other side of the O-H bond is a C-O bond

that is less polar than the O-H bond. This configuration in the molecule produces some hydrogen bonding which is weaker than that in water molecules. As a result, the ethyl alcohol has less surface tension than water. About 20 to 30 drops of ethyl alcohol can be placed on a coin depending on drop size.



An ethyl alcohol molecule

Mineral spirits is a mixture of molecules similar to the ethane, diagrammed above, but larger in size. (In reality, ethane is a gas at room temperature. Liquid hydrocarbon compounds must contain a central carbon skeleton of 5 or more atoms.) Mineral spirits is a mixture of non-polar hydrocarbon compounds, similar to the ethane molecule shown above (but larger in size). Only 2 to 5 drops of mineral spirits will stay on a coin before overflowing the edges.

Students should be able explain polarity of liquids. They should recognize the following points:

Hydrogen bonding is strongest in water and weaker in the alcohol.
Detergent reduces the hydrogen bonding of the water.
There is no hydrogen bonding in the mineral spirits

Drops on a Penny
SCORESHEET
TOTAL of 500 points

Demonstration (125 points)

Possible Points

1) Water: Successfully getting the maximum number of drops on a penny in comparison to the other liquids. (30 to 50 drops expected) 25 pts_____
Note: Award less points if use significantly fewer than 30 drops and stop the investigation

2) Ethyl Alcohol: Successfully get approximately half as many drops on a penny as compared to water (20 to 30 drops expected) 25 pts_____
Note: Award less points if use significantly fewer than 20 drops and stop the investigation. This shows inconsistent technique in creating the drops.

3) Mineral spirits: Successfully get the least number of drops on a penny as compared to the other liquids (2 to 3 drops expected) 25 pts_____
Note: Award less points if use more than about 5 drops. This shows inconsistent technique in creating the drops.

4) Detergent solution: Successfully get approximately half as many drops on a penny as compared to water (20 to 30 drops expected) 25 pts_____
Note: Award less points if use significantly fewer than 20 drops and stop the investigation. This shows inconsistent technique in creating the drops.

5) If they note that water forms a large sphere (or bubble) on the penny, that the ethyl alcohol and detergent form smaller spheres, and that the mineral spirits hardly forms a sphere at all. 25 pts_____

SUBTOTAL (100 points max) _____

Explanation/Presentation (360 points)

1) Water- look for explanation of attractive forces among molecules and of molecular shape. 40 pts_____

If they use the term "surface tension" 10 pts_____
If they define the term "surface tension" 10 pts_____
If they draw a diagram showing the molecular geometry of water 10 pts_____
If they say the term "bent molecule" 10 pts_____

If they use the term "polar molecule" or "polarity" 10 pts_____
If they say that the bent molecule increases polarity of the molecule as compared to the polarity of a hydrogen-oxygen bond 5pts_____
If they say water has a bond angle of approximately104 degrees 5 pts_____

2) Water/Detergent- look for explanation that detergent interferes with attractive forces between water molecules and reduces surface tension 40 pts_____

If they use the word "surfactant" 10 pts_____
If they give a schematic representation of a detergent molecule 5 pts_____
If they say a detergent is mainly composed of carbon and hydrogen (a hydrocarbon) 5 pts_____
If they say a detergent is polar on one end and non-polar on the other end 5 pts_____
If they give a schematic representation of detergent molecules dispersed in water (a micelle) 10 pts_____

3) Ethyl alcohol- look for explanation of a non-polar molecule with a polar group on one end 40 pts_____

If they draw the molecular geometry of the alcohol 10 pts_____
If they indicate hydrogen bonding is less than water 10 pts_____
If they indicate polarity is less than water 5 pts_____
If they indicate surface tension is less than water 5 pts_____
If they indicate OH group on the molecule is at an angle 5 pts_____

4) Mineral spirits- look for discussion of non-polarity and symmetry of molecules 40 pts_____

If they say mineral spirits is mainly composed of carbon and hydrogen Compounds (hydrocarbons) 5 pts_____
If they indicate polarities in molecules cancel each other out 10 pts_____
If they indicate there is no surface tension (or very low) 10 pts_____
If they indicate there is little or no attraction between molecules to hold them together 10 pts_____

5) If they consider difference in surfaces of the two sides of the penny and how that might affect the number of drops of liquid it could hold 10 pts _____

SUBTOTAL (360 points max) _____

Quality of Presentation (40 points)

For all team members actively participating in the presentation.
(5 pts for each team member) (20 points max) _____

Use of general public speaking skills such as voice projection,
Eye contact, proper grammar, etc.
(5 pts for each team member) (20 points max) _____

SUBTOTAL (40 points max) _____

TOTAL POINTS (500 max) _____