YUSO 2017 MATERIALS SCIENCE EXAMINATION

In this exam, you will answer a series of questions and complete tasks involving the science processes of chemistry focused in the area of materials science. The exam is 50 minutes long and consists of two sections on the topics of (1) material performance and (2) intermolecular forces of materials. Each section is worth 50% of the total score and will each contain a laboratory practical along with the written component. It is suggested that approximately 25 minutes be allotted to each section, with 10 minutes for the written exam and 15 minutes for the laboratory practical.

SECTION ONE: MATERIAL PERFORMANCE

I. Written Questions (2 total, 10 points each)

1. To determine the wettability of a surface material, a drop of liquid—such as water—is often placed on the surface of the material to measure the contact angle of the droplet with the surface. The contact angle is used as an indicator of surface tension between the liquid and the material, which can then be used to determine the hydrophobicity of the material. Below shows a diagram of a liquid on the surface material (the solid body).

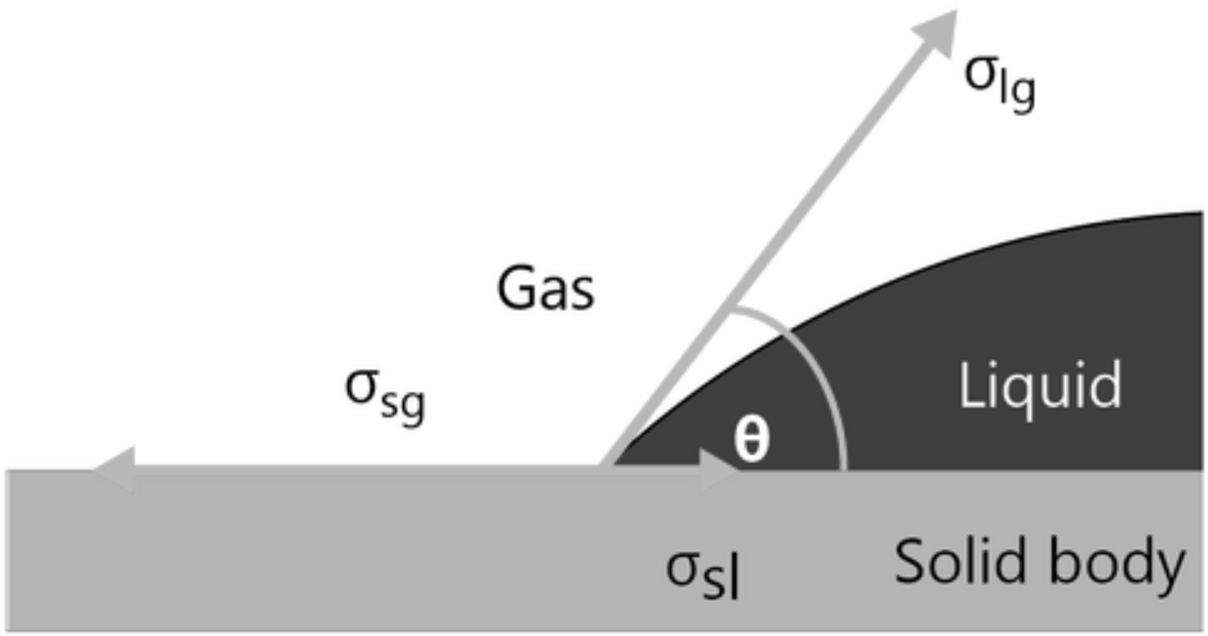


Figure 1. Reproduced schematic showing the surface tension between a liquid on a solid body[1].

Using the information from *Fig. 1*, a) derive Young's equation, which relates the relationship between contact angle (θ), the surface tension of the liquid (σ_{lg}), the interfacial tension (σ_{sl}) between the liquid and the solid, and the surface free energy (σ_{sg}) of the solid. Solve for σ_{sg} using only the variables σ_{lg}, σ_{sl}, and θ. Partial credit will be awarded for explanation even without the correct formula. Then, b) state whether a material is hydrophobic (bad wetting) or hydrophilic (good wetting) if a drop of water makes a contact angle of over 90°.

2. When constructing superconductors, doping is often used to modify the electrical properties of the superconductor. Doping, in this context, is the process whereby "impurities" are introduced into a pure intrinsic superconductor. Impurities include chemical elements that are either acceptors (p-type) or donors (n-type). Other forms of doping include chemical, electrochemical, magnetic, and neutron transmutation doping. Define what an acceptor is in the context of semiconductors and give

one example of an element that can be used as an acceptor. Then, briefly describe how an acceptor can form a p-type region in a semiconductor.

II. Laboratory Practical: 30 points

The Chemical Composition of Polymers: The Synthesis of Silly Putty

Objective: In this experiment, you will synthesize silly putty by the cross-linking of liquid latex and sodium borate to form a polymer[2]. After synthesizing silly putty, you will analyze some properties of the polymer and explain these characteristics.

Safety: Wear appropriate laboratory personal protective equipment (PPE). All chemicals used in this experiment are safe to handle as long as they are used properly. Although all material is non-toxic, sodium borate may irritate skin and eyes, as it is a bleaching agent, so you must wear lab goggles and gloves at all times while performing the experiment.

Materials:

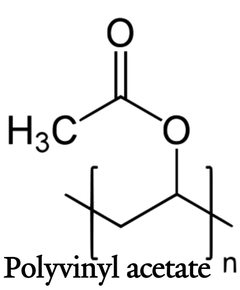
- 55% Elmer's glue (liquid latex) solution in water, 20 mL
- 4% borax solution (sodium borate), 10 mL
- Styrofoam cups
- zip-lock bags
- wooden stick
- food coloring (optional)

Method:

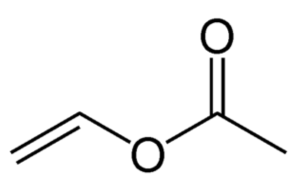
1. Pour 20 ml of the Elmer's glue solution into a Styrofoam cup.
2. Add 10 ml of the cross-linker (borax solution) to each cup.
3. Immediately begin stirring the solutions together using the wooden stick.
4. After a couple of minutes of mixing, the silly putty can be taken out of the cup and kneaded with your hands. Continue to knead until the desired consistency is reached.

Discussion:

In this experiment, the glue is liquid latex that undergoes emulsion polymerization. The primary polymer monomer of this latex is vinyl acetate, which is shown below right[3]. The polymerized product is polyvinyl acetate, shown below left. The part of the molecule in brackets indicates the repeating subunit, and *n* represents a polymer of *n* subunits. The cross-linker is sodium borate.



Polyvinyl acetate
$(C_4H_6O_2)_n$



Vinyl acetate
$C_4H_6O_2$

Post-lab Question:

1. During the free radical polymerization of vinyl acetate using the cross-linker sodium borate, three steps are involved in this reaction: initiation, propagation, and termination. Using your knowledge of chemical reactions and polymerization, briefly describe each of the three steps of a free radical polymerization chain reaction. You do not need to provide a mechanism.

SECTION TWO: INTERMOLECULAR FORCES OF MATERIALS

I. Written Questions (2 total, 10 points each)

1. In a network covalent crystal, the atoms are held together in a continuous 3-dimensional array of covalent bonds[5]. An example of such structure is diamond, where sp^3-hybridized carbon atoms form a tetrahedral structure and packing. Some physical properties of network covalent crystals include a high melting point, physical hardness, and poor electrical conductivity. However, graphite is also network covalent in a sp^2-hybridized trigonal planar pattern, which forms layers of graphite "sheets" that are good at conducting electricity. Both diamond and graphite are composed of only carbon atoms, yet have different abilities for conducting electricity. Briefly explain why graphite is able to conduct electricity, but diamond is not able.

2. To determine which of two hypotheses is true regarding the intermolecular forces that allow gecko feet to stick to walls, researchers conducted an experiment to distinguish the hypotheses. The first hypothesis (A) was that polar molecules found on the feet of geckos were able to interact with a thin film of water on the wall's surface via dipole-dipole interactions. The second hypothesis (B) was that the van der Waals interaction was responsible for gecko feet "stickiness," since there are many setae (stiff, hair-like structures) found on the feet of gecko.

The experiment is as follows: observe if geckos can walk on silicon dioxide (polar) or gallium arsenide (nonpolar). Results indicate that geckos could walk equally well on either surface. Which hypothesis (A or B) does this study support? Explain your answer by explaining the intermolecular forces that play a role in each hypothesis, and how the results from the experiment support such intermolecular interactions.