# Science Olympiad
# Density Lab
# UT Regional

February 22, 2020
Austin, Texas

School: ______________________________

Team Number: ______________

Name(s): ______________________________

**Directions:**

- Each team is allowed one three-ring binder of any size as notes, and two calculators of any type.
- Do not write on this test! It is a class set. Please write all answers on the answer sheets; any marks elsewhere will not be scored.
- There is no penalty for wrong answers. Answer every question, even if you aren't sure if you're correct.
- This exam contains a 20 minute lab activity. Even-numbered teams go the first 20 minutes, followed by a 5 minute transition period, and then odd-numbered teams go for 20 minutes.
- Above all else, just believe!

**Written by: Aditya Shah**

For official use only:

| Section: | Lab | A | B | Total |
|---|---|---|---|---|
| Points: | 170 | 24 | 120 | 314 |
| Score: | | | | |

# Lab (170 points)

## General Information and Procedure

**All questions/subparts are worth 10 points each, for a total of 170 points**.

For the first 20 minutes of the timeblock, all teams with even team numbers will complete the lab portion. There will be a 5 minute transition period where the event supervisors reset everything. Afterwards, the teams with odd team numbers will complete the lab portion in 20 minutes.

All hands-on work pertaining to the lab, including cleaning up, must take place within the 20 minutes allotted to your team, but you may work on the pre-lab questions at any time throughout the timeblock. Teams that do not clean up will be penalized. This lab consists of two parts:

1. Estimating the composition of isopropyl alcohol in a mixture by measuring its density, approximating the solution as an *ideal solution*.
2. Observing how a *real solution* consisting of isopropyl alcohol and water behaves with regard to volume changes.

**Part 1**

1. Get an empty 10 mL graduated cylinder and place it on a balance. Record its mass, in grams.
2. Using a pipette, measure between 3 and 7 mL of the isopropyl alcohol/water solution in Beaker #1 in the 10 mL graduated cylinder from the previous step. Record the volume you measured out, in mL.
3. Record the mass of the solution, in grams, by subtracting the mass you of the graduated cylinder (which you found in Step 1) from the mass you see right now.
4. Using the mass and volume data you collected, determine the density of this solution, in g/cm$^3$.
5. Given that the density of anhydrous isopropyl alcohol (i.e. pure isopropyl alcohol not containing any water) is 0.785 g/cm$^3$ and the density of water is 0.997 g/cm$^3$, determine how much of the solution is isopropyl alcohol by volume. Leave your answer as a percentage (%).

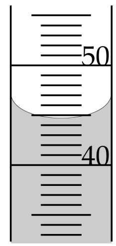
*Note: if you know how, feel free to tare the graduated cylinder when determining the mass of the isopropyl alcohol to save you time. You will not be graded on whether you determined the mass of the graduated cylinder.*

**Part 2**

1. In a 100 mL graduated cylinder, measure out between 35 and 45 mL of water. Record the volume, in mL.
2. Find the mass of the water you measured out, in grams.
3. In another 100 mL graduated cylinder, measure out between 35 and 45 mL of the isopropyl alcohol/water solution in Beaker #1. Record the volume, in mL.
4. Find the mass of the isopropyl alcohol/water solution you measured out, in grams, using the balance.
5. Pour the water you measured out in Step 1 into the graduated cylinder with the isopropyl alcohol you measured out in Step 2. Record the volume of the final solution, in mL.

## Pre-Lab Questions

1. While measuring the volume of a liquid with a 100 mL graduated cylinder, a student sees the following:




   (a) True or false: the graduated cylinder shown above has 0.1 mL divisions.
   (b) What is the volume of the liquid in the graduate cylinder, in mL? Take care with significant figures when giving your answer.
   (c) What is the name of the curved surface that represents the top boundary of the liquid?
   (d) In this case, what does the curvature of the liquid's surface imply about the strength of attractive forces between liquid and graduated cylinder wall vs. liquid and liquid?

2. When pouring liquid into a graduated cylinder, you should never crouch down so your head is on the same level as the table top. Why would doing so pose a safety hazard?

## Measurements and Results

If you are referring to something that involves a calculation, show your work in some way!

3. **Part 1, Step 2:** What volume, in mL, of the isopropyl alcohol/water solution did you measure out?

3. ______________

4. **Part 1, Step 3:** What was the mass, in grams, isopropyl alcohol/water solution you measured out?

4. ______________

5. **Part 1, Step 4:** What is the density of the solution, in g/cm$^3$?

5. ______________

6. **Part 1, Step 5:** How much of the solution is isopropyl alcohol, by volume? Leave your answer as a percent (%).

6. ______________

7. **Part 2, Step 1:** What volume, in mL, of water did you measure out?

7. ______________

8. **Part 2, Step 2:** What was the mass, in grams, of water you measured out?

8. ______________

9. **Part 2, Step 3:** What volume, in mL, of the isopropyl alcohol/water solution did you measure out?

   9. ______________

10. **Part 2, Step 4:** What was the mass, in grams, of the isopropyl alcohol/water solution you measured out?

    10. ______________

11. **Part 2, Step 5:** After pouring the water into the isopropyl alcohol/water solution, what was the final volume, in mL?

    11. ______________

## Post-Lab Questions

12. How did the volume of the final solution (Part 2, Step 5) compare to the volume if water and isopropyl alcohol formed an ideal solution?
13. Based on your answer to the previous question, how would you characterize the interactions between isopropyl alcohol molecules and water molecules compared to those in their pure forms?
14. Extending this idea, do you think mixing these two solutions together is endothermic or exothermic? Explain your answer.

## Section A (24 points)

**Choose the correct answer to the following multiple choice questions to the best of your ability. Each question is worth 2 points for a total of 24 points.**

15. Which of the following is not a state of matter?
    - A. Solid
    - B. Gas
    - C. Mixture
    - D. Liquid

16. A rock is dropped into a lake and sinks. As a result, it's reasonable to conclude that the density of the rock is greater than that of the water in the lake.
    - A. True
    - B. False

17. Generally speaking, gases are more dense than solids.
    - A. True
    - B. False

18. Box 1 is filled with cotton balls, while Box 2 (which is the same size as Box 1) is filled with heavy rocks. Which box is denser?
    - A. Box 1
    - B. Box 2

19. A student holds a can of diet soda and a can of regular soda that are the same size. As a result, they must weigh the same.
    - A. True
    - B. False

20. Which of the following gases are diatomic?
    - A. Nitrogen
    - B. Oxygen
    - C. Fluorine
    - D. Xenon
    - E. Hydrogen

21. Which of the following is not an intensive property?
    - A. Density
    - B. Melting point
    - C. Temperature
    - D. Mass

22. Gases exhibit their most ideal ideal behavior at ______ temperatures and ______ pressures.
    - A. high, high
    - B. high, low
    - C. low, high
    - D. low, low

23. Dissolving salt in water decreases its freezing point.
    - A. True
    - B. False

24. A ______ bond involves sharing electron pairs between atoms.
    - A. Covalent
    - B. Ionic
    - C. Hydrogen
    - D. Strong
    - E. Weak

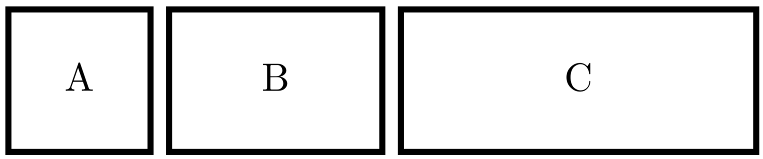
25. Boyle's law relates ________________.
    - A. Pressure and temperature
    - B. Temperature and volume
    - C. Temperature and moles
    - D. Pressure and volume

26. Based on ______ Law, two gases with the same volumes, temperatures, and pressures must also have the same number of molecules.
    - A. Avogadro's
    - B. Boyle's
    - C. Charles'
    - D. Gay-Lussac's

## Section B

**Use the attached Image Set for the questions in this section. Each part/subpart is worth 4 points for a total of 120 points.**

27. **Density.** A straight, uniform board is cut into three pieces labelled A, B, and C. They have equal widths and heights, but have different lengths, as shown in the figure below.




   (a) Which piece has the greatest volume?

   (b) Which piece has the greatest density?

   (c) Which piece has the greatest mass?

28. **Ideal gases.** A rigid 2 L container (i.e. the volume cannot change) has 1 mol of gas at a pressure of 1.2 atmospheres.

   (a) What is the temperature of the gas, in Kelvin?

   (b) If the temperature is doubled, what happens to the pressure of the gas?

29. **Density, but in space.** Neutron stars are among the densest objects in the universe and are thought to form after very massive stars undergo a supernova explosion. Typically, neutron stars have radii of about 10 kilometers and masses of about 1.4 solar masses. One solar mass is $1.99 \times 10^{30}$ kg.

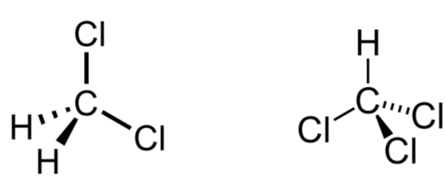
   (a) Given the information in the question, what is the density, in kg/m$^3$, of a typical neutron star? *Hint: Neutron stars are spherical, so use $V = (4/3)\pi r^3$.*

   (b) Consider a soccer ball with the same density as a neutron star. What would be its mass, in kilograms? The diameter of a soccer ball is 22 cm.

   (c) On the other end of the spectrum, Saturn is the least dense planet in the Solar System, with a radius of 58200 km and mass of $5.7 \times 10^{26}$ kg. What is the density of Saturn, in kg/m$^3$? Approximate Saturn as perfectly spherical.

   (d) Imagine that someone magically places Saturn in a giant pool of water without disturbing the planet's atmosphere. Based on your answer to the previous part, what fraction of Saturn's volume would be below the surface?

30. **Ideal solutions.** 40 mL of $CH_2Cl_2$ and 60 mL of $CHCl_3$ are mixed together. Assume that their mixture forms an ideal solution. $CH_2Cl_2$ is shown on the left, and $CHCl_3$ is shown on the right.



   (a) What will the volume of the final solution be? *Hint: it's as easy as it seems - just add the two volumes together.*

   (b) What is the density of the new solution, in g/mL? The density of $CH_2Cl_2$ is 1.33 g/mL and the density of $CHCl_3$ is 1.49 g/mL.

(c) A student says that in an ideal solution, the molecules do not interact with each other. Is this student correct? Why or why not?

(d) From the perspective of intermolecular forces, why is it reasonable to assume that a mixture of $CH_2Cl_2$ and $CHCl_3$ is (or is close to) ideal?

31. **Why is ice slippery?** One of the most commonly given reasons is that the pressure exerted by the skate causes some of the ice to melt, resulting in a thin layer of water between the skates and ice. In this question, we'll see whether this idea makes sense. Consider a skater with a mass of 60 kg whose skates' blades each have an area of 0.1 cm$^2$.

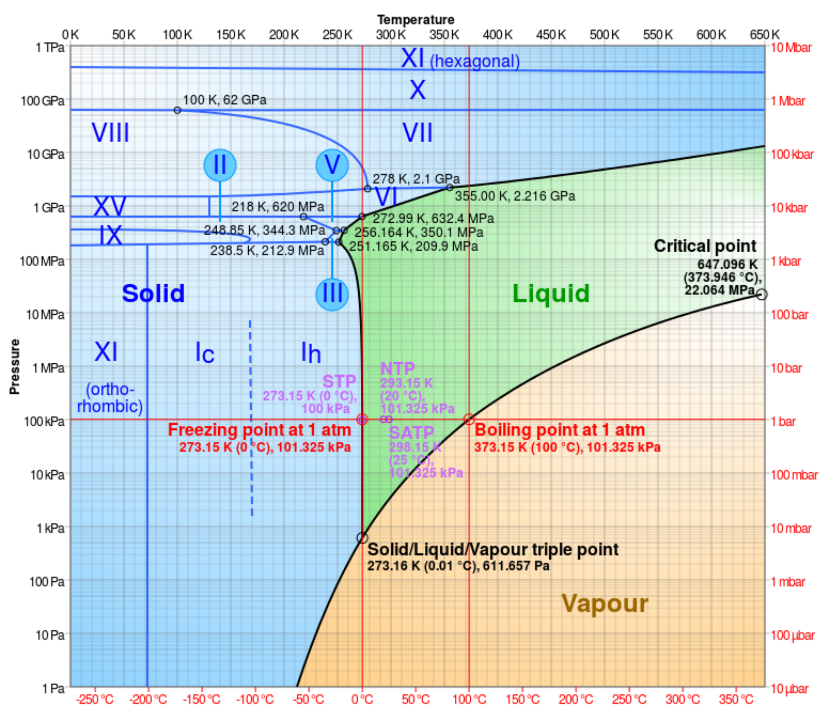
(a) In which direction does gravity point on Earth? Choose from up, down, left, or right.

(b) What is the weight of the skater, in Newtons? *Hint: multiply the mass of the skater by the acceleration due to gravity to find their weight.*

(c) When the skater stands on one leg, what is the pressure, in Pa, that they exert on the ice? *Hint: divide the skater's weight by the area of a single blade to find the pressure - just be careful with the units!*

(d) Suppose that the skater decides to skate outside when it's a frigid -15°C. Using the phase diagram given below and your answer to part (c), explain why the melting point change due to the pressure of the skater is not large enough to explain why ice skating is possible. In writing your response, begin by stating how the extra pressure affects the melting point of water and reference points, lines, areas, etc. on the phase diagram.

(e) At moderate pressures, the line separating the solid and liquid phases of water is very steep and negatively sloped. Why is this so? *Hint: compare the densities of ice and water.*




In truth, the chemical explanation for why ice is slippery is still under debate among physicists and chemists. If you're interested, you can read more about this in the *Nature* article that inspired this question: `https://tinyurl.com/slipperyicescioly`

32. **What if gases aren't ideal?** In working with ideal gases, we assume (among other things) that gas molecules' size and intermolecular interactions are negligible. The van der Waals equation attempts to correct for these two assumptions with two additional parameters, $a$ and $b$:

$$P = \frac{RT}{V - b} - \frac{a}{V^2}$$

where $a$ and $b$ are both positive constants. One of them acts to correct for intermolecular attractions, while the other corrects for the gas molecules' size.

(a) As the value of $a$ increases, what happens to the pressure of the gas? Assume that all other variables stay constant.

(b) As the value of $b$ increases, what happens to the pressure of the gas? Assume that all other variables stay constant.

(c) Based on your answers to the previous two parts, does $a$ correct for intermolecular attractions or the gas molecules' size? *Hint: you can also look at the units for what $a$ and $b$ should be to determine the answer.*

(d) Between hydrogen gas and methane, which compound would you expect to have higher values for $a$ and $b$? Explain your answer.

(e) *Challenge:* Consider two identical, rigid containers, one containing 1 mol ethanol and the other containing 1 mol toluene at the same temperature. A student is surprised to learn that although ethanol has extensive hydrogen bonding, the toluene exerts a lower pressure on the walls of its container. Why is this the case?

33. **Collapsing gas clouds.** Stars are formed by the collapse of large clouds of gas, a deceptively complicated process filled with some interesting thermodynamics. This collapse is thought to have several parts and is an active area of research in astronomy and physics.

    (a) Astronomers generally believe that at first, the collapse of a cloud is isothermal. What does "isothermal" mean?

    (b) As the cloud continues to collapse, it becomes denser. How would its increased density impact its ability to let light/heat escape?

    (c) Based on your answer to the previous part, do you expect its temperature to increase, decrease, or stay the same as it continues to contract? Specifically state whether you think the process will stay isothermal.

    (d) How does your answer to the previous part affect the *rate* at which the cloud contracts? *Hint: as given by the ideal gas law, temperature and pressure are proportional to each other when other variables are held constant.*

    (e) *Challenge:* During the last portion of the cloud's collapse, as described in part (c), how do you expect the entropy of the cloud to change? Assume that the collapse of the gas cloud happens very slowly.

34. **Galaxy collisions.** In a certain galaxy cluster, take the average radius of each galaxy to be $R$ and the average speed of each member galaxy to be $v$. Unless otherwise specified, assume that the motion of the galaxies within the cluster is random and linear (i.e. gravitational interactions between the galaxies are negligible). Originally, an astronomer models all of these galaxies as hard spheres of radius $R$ in their simulation.

    (a) In hope of getting a more accurate answer, they decide to model the galaxies not as spheres, but instead as thin disks of radius $R$. One of your collaborators says that since the radius of the disk is the same as that of the sphere, the cross-sectional area is the same, resulting in no change in the mean free path or mean time between collisions. Is the collaborator correct? Why or why not?

    (b) Next, they to improve on the original model by including an attractive gravitational force between the galaxies, but modelling them as spheres of radius $R$ to prevent the simulation from taking forever to run. How would this effect the mean free path and mean time between galaxy collisions? Is the effect of the gravitational attraction more significant at higher or lower average velocities? Explain your answers qualitatively.