Name: ________________________________

Lab 23. Oxygen Content of Air

Background: Air is a mixture of several different gases. The most chemically reactive of the major components is oxygen, O_2.

In this experiment you will determine the fraction of dry air that is oxygen. You will do this by removing the oxygen from a closed sample of air and comparing the volume of air in the sample with and without oxygen. You will remove the oxygen by reacting it with wet steel wool to form rust, which is a variable hydrate of iron (III) oxide.

$$4\ Fe\ (s) + 3\ O_2\ (g) + n\ H_2O \rightarrow 2\ Fe_2O_3 \cdot nH_2O\ (s)$$

The rusting of iron requires water as well as oxygen. It proceeds faster in the presence of acids and some salts. In this activity we will use the weak acid acetic acid to activate the steel wool. We will use it in dilute aqueous solution in the convenient form of white vinegar.

As a control to verify that the steel wool consumes oxygen completely, we will also react the steel wool with a known initial volume of oxygen to see how quickly the oxygen is consumed.

Objective: To determine experimentally the molar fraction of O_2 in air.

Safety: Wear chemical splash goggles, gloves, and an apron. Clean up any spills promptly.

Disposal: Liquid wastes from this activity may be disposed of down the drain. Waste steel wool should be rinsed with water and discarded in the regular trash.

Materials and equipment:

ring stand	thread
eudiometer tube	Flask, stopper, and tubing to produce O_2
buret clamp	sponge
100-mL volumetric flask	nonmercury thermometer
large (500-ml) beaker or bowl	stirring rod
small (100-ml) beaker	plastic ruler
funnel	household white vinegar
wire or thin rod	steel wool, ~0.5-g plug
balance	3% hydrogen peroxide solution
barometer	yeast slurry

Procedure:

1. Measure the mass of the empty 100-mL volumetric flask.
2. Fill the volumetric flask to the mark with vinegar. Measure and record the mass of

the flask containing vinegar.

3. Measure and record the mass of the steel wool plug.
4. If using oxygen, set up the oxygen generator flask, catalytically decomposing hydrogen peroxide so that the oxygen generated passes through the flexible tubing in the stopper.
5. Shape the plug of steel wool into a long and narrow wad, narrow enough to fit into the eudiometer tube but loosely packed so that there is room between the individual strands of iron wire. Tie one end of the thread around one end of the steel wool.
6. Hold the eudiometer tube mouth-up. Fill it with vinegar.
7. Insert the steel wool plug into the gas measuring tube. Insert the end tied with thread *last*.
8. Use the wire or narrow rod to gently push the plug of steel wool through the vinegar to the other end of the eudiometer tube. Take care not to compress the plug of steel wool: it should remain loosely packed. The loose end of the thread should come out the eudiometer tube.
9. Fill the bowl or large beaker with water nearly to the top. Allow at least 50 mL remaining capacity.
10. Stopper the mouth of the eudiometer tube or cover it with your finger. In one swift motion, invert the eudiometer so that its open end is under the water in the beaker or bowl. Most of the vinegar should still be inside the tube.
11. *If using air*: Allow air to enter the eudiometer tube by briefly lifting it above the water level several times. The goal is to allow the air bubble to fill the top of the tube nearly down to, but not beyond, the last (50 mL) mark.
    If using oxygen: position the flexible tubing from the oxygen generator so that oxygen bubbles into the eudiometer. Allow oxygen to collect in the tube nearly down to, but not beyond, the last mark.
12. Clamp the eudiometer tube in place with the buret clamp, with its open end beneath the surface of the water.
13. Measure and record the volume marks at the top and bottom of the bubble. Also measure and record the height of the water column. This is the vertical distance from the top of the water level in the beaker to the bottom of the air bubble.
14. Record the room temperature and the current barometric pressure.
15. Come back tomorrow. Iron rusts slowly.
16. *With the end of the eudiometer tube still under water*, slowly and gently pull the thread so that the steel wool plug is removed from the air bubble and is completely out of the bubble. Measure and record the volume of the bubble *without* the steel wool plug. Also measure and record the height of the water column in the eudiometer.
17. Record the current room temperature and barometric pressure.
18. Unclamp the eudiometer tube and remove it from the beaker. Allow its liquid contents to drain into the beaker. Remove the steel wool from the eudiometer tube. Discard the liquids used in the activity. Rinse the steel wool plug with water and discard.

Calculations:

1. Find the saturation vapor pressure of water at the temperature of the first and last reading of the air bubble volume. Assuming that the air in the bubble is saturated with water vapor, this is the partial pressure of water vapor. You can look up the saturation pressure of water at any temperature at a calculator from Engineering Toolbox.
2. Determine the mass of vinegar in the volumetric flask by subtracting the mass of the empty flask from the mass of the flask containing 100 mL vinegar.
3. Determine the density of vinegar in g/ml by dividing its mass in grams by its volume in milliliters.
4. Determine the volume of the bubble by finding the difference between the eudiometer marks at its top and bottom.
5. Determine the partial pressure of dry air inside the eudiometer bubble by correcting for the pressure of the vinegar column and the partial pressure of water vapor. (Neglect the partial pressure of the acetic acid in the vinegar.)
   a. **Pressure of vinegar column**: Convert the height of the water column in centimeters to a pressure in hectapascals by using the formula ρgh, where ρ is the density of the vinegar in g/mL, g = 0.98 (hPa·mL)/(g·cm) is the strength of the local gravitational field, and h is the height of the liquid column in cm.
   b. **Partial pressure of water vapor**: Using a table of water vapor pressure or an online calculator, determine p_w, the saturation vapor pressure of water at the ambient temperature. If the value is not given in hPa, you will need to convert to hPa. Record the value.
   c. **Partial pressure of dry air**: Determine p, the partial pressure of dry air by subtracting the pressure of the water column and the vapor pressure of water from the barometric pressure: $p = p_0 - \rho gh - p_w$.
6. Use the ideal gas equation of state, the initial volume of the bubble, and the initial partial pressure of dry air in the bubble to determine n_i, the initial amount of air in the bubble.
7. Calculate the final bubble volume and the final volume of dry air in the bubble in the same manner that you calculated the initial values.
8. Use the ideal gas equation of state, the final volume of air in the bubble, and the final partial pressure of dry air in the bubble to determine n_f, the final amount of air in the bubble.
9. Determine the moles of oxygen consumed as $n_{O2} = n_i - n_f$.
10. Determine the mole fraction of oxygen in air as $\chi_{O2} = n_{O2}/n_i$. If you used "pure" oxygen produced by decomposition of hydrogen peroxide, determine its empirical mole fraction of oxygen.
11. The accepted value of χ_{O2} in air is 0.21. The pure oxygen ought to be 100% O_2. Determine your absolute error. Determine your percent relative error.

Scoring

Lab technique and safety	5 points
Data	15 points
Calculations	10 points

Data Table

Quantity	**Value**	**Unit**
Mass of empty 100-mL flask		g
Mass of flask filled with vinegar		g
Mass of steel wool		g
Initial room temperature		°C
Initial barometric pressure		hPa
Initial top mark of bubble		mL
Initial bottom mark of bubble		mL
Initial height of column		cm
Time and date bubble introduced		hh:mm:ss mm/dd/yyyy
Final time and date		hh:mm:ss mm/dd/yyyy
Final room temperature		°C
Final barometric pressure		hPa
Final top mark of bubble		mL
Final bottom mark of bubble		mL
Final height of column		cm

Calculations Table

Quantity	Value	Unit
Mass of vinegar		g
Density of vinegar		g/mL
Initial bubble volume		mL
		L
Initial column pressure		L
Initial partial pressure of water vapor		hPa
Initial dry air partial pressure		hPa
		atm
Initial amount of gas		mol
Time of reaction		hh:mm:ss
Final bubble volume		mL
		L
Final column pressure		hPa
Final partial pressure of water vapor		hPa
Final dry air partial pressure		hPa
		atm
Final amount of gas		mol
Amount of oxygen		mol
Mole fraction oxygen		
Absolute error		
Percent relative error		%