MOLE-MOLE RATIO LAB (TEACHER KEY)

Teacher Information

1. This experiment conforms to the guidelines for the ninth laboratory experiment listed in the College Board AP Chemistry guide (the Acorn Book). It can be conducted with a temperature probe or any digital thermometer. It is suitable for Pre-AP students and is best performed in first-year chemistry.

2. Prepare the 0.50 M NaClO solution by diluting 745 mL of fresh bleach with distilled water to a total volume of 1.0 L. Grocery store laundry bleach works well, but do not use bleach labeled "color safe." Most commercial bleaches are labeled as 5.25% NaClO by mass, which is approximately 0.67 M. **Note**: If you use bleach labeled "Ultra", the NaClO concentration is 6%. Prepare the 0.50 M NaClO solution by diluting 653 mL of Ultra bleach with distilled water to a total volume of 1.0 L.

3. Prepare the 0.50 M $Na_2S_2O_3$ solution in three steps. To make 1.0 L of solution, first dissolve 124 grams of $Na_2S_2O_3 \bullet 5\ H_2O$ (or 79.1 g of anhydrous $Na_2S_2O_3$) in 500 mL of distilled water. Then add 8 g of solid NaOH and stir the mixture to dissolve the NaOH. Lastly, add distilled water to make 1.0 L of solution. It is best to invest in a set of 60 mL syringes for this lab. You will need one syringe for each reagent, labeled as such.

4. The laboratory technique used in this experiment is called *continuous variations*, in which a series of reactions is conducted using various ratios of the reactants. The temperature change of the exothermic reaction is measured and recorded for each ratio. The optimum ratio produces the greatest amount of heat energy, and thus the greatest change in temperature.

5. The solution volumes are measured with a graduated cylinder. The solutions are mixed in a polystyrene cup and the temperature change is measured with the precision allowed by the stainless-steel temperature probe (±0.1 °C) or a digital thermometer.

6. One 50-minute lab period is sufficient to complete the experiment. It is a good idea for students to plot their results on a graph as they complete each trial in case they need to conduct additional trials. This can be done easily when collecting data by using Logger Pro on a computer; data also can be manually entered into a graphing calculator or graphing software.

Hazard Alerts

- **Sodium thiosulfate**: Slightly toxic by ingestion; body tissue irritant. Hazard code: C—Somewhat hazardous.

- **Sodium hypochlorite solution**: Corrosive liquid; causes skin burns; reacts with acid to evolve chlorine gas; evolves chlorine when heated; moderately toxic by ingestion and inhalation; avoid contact with organic material. Hazard code: B—Hazardous.

- **Sodium hydroxide**: Corrosive solid; skin burns are possible; much heat evolves when added to water; very dangerous to eyes; wear face and eye protection when using this substance. Wear gloves. It deserves the instructor's special handling and storage attention. Hazard Code: B—Hazardous.

Sample Data

| Trial	Volume OCl^- (mL)	Volume $S_2O_3^{2-}$ (mL)	Temperature change (°C)
1	25.0	25.0	19.8
2	20.0	30.0	15.0
3	30.0	20.0	23.3
4	10.0	40.0	7.8
5	40.0	10.0	32.0
6	45.0	5.0	12.7
7	43.0	7.0	21.1

Answers to PRE-LAB QUESTIONS

1. What is the total reaction volume for this procedure?

50 mL; students have to read the procedure through step 6 to answer this correctly.

2. Predict the sign of ΔH for this reaction. Justify your prediction.

−ΔH (since the introduction states the reaction is exothermic); students may also explain that heat energy left the system, thus the negative sign on ΔH.

3. Using the set of axes provided below, properly label the y-axis and sketch the curve that you expect to see at the end of a given trial. Explain how you will use the graph to determine the maximum temperature change.
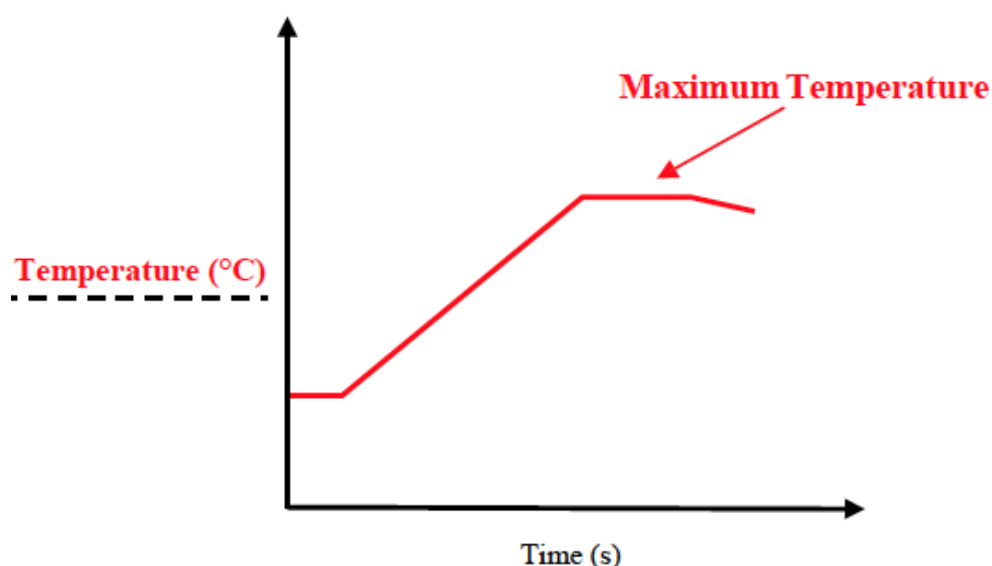
4. Explain how you will use this curve to determine the maximum temperature change for a given trial.

The procedure asks students to record a few temperature data points before mixing the solutions. This allows for an initial temperature of the NaOCl solution to be established. As the reaction proceeds, the temperature increases and levels off at a maximum. Students may take data long enough to even see a decline in temperature, as illustrated in red on the graph above.

5. A student conducts this experiment using two equimolar reactants, X &Y, and obtains the data shown in the table below. The optimum mole-to-mole ratio requires that you plot the temperature change recorded for each trial vs. the volume of X reacting.

To determine the optimum ratio, perform two linear regressions for the temperature change vs. volume of reactant X data. One regression will have a positive slope while the other will have a negative slope. Both regressions will involve all the points on the portion of the graph that approaches the maximum.

The optimum volume for reactant X is obtained by interpreting the point where the two

regression lines intersect.

Once you have established the simplest whole number optimum ratio for the reactants, write the moles of reactant X that react completely with reactant Y in the space provided below the data table.

Volume Reactant X (mL)	Volume Reactant Y (mL)	Temperature Change (°C)
25.0	25.0	24.9
30.0	20.0	33.0
20.0	30.0	19.8
40.0	10.0	22.3
10.0	40.0	7.8
45.0	5.0	14.1
43.0	7.0	18.0

How Can We Determine the Mole:Mole Ratio in a Chemical Reaction?

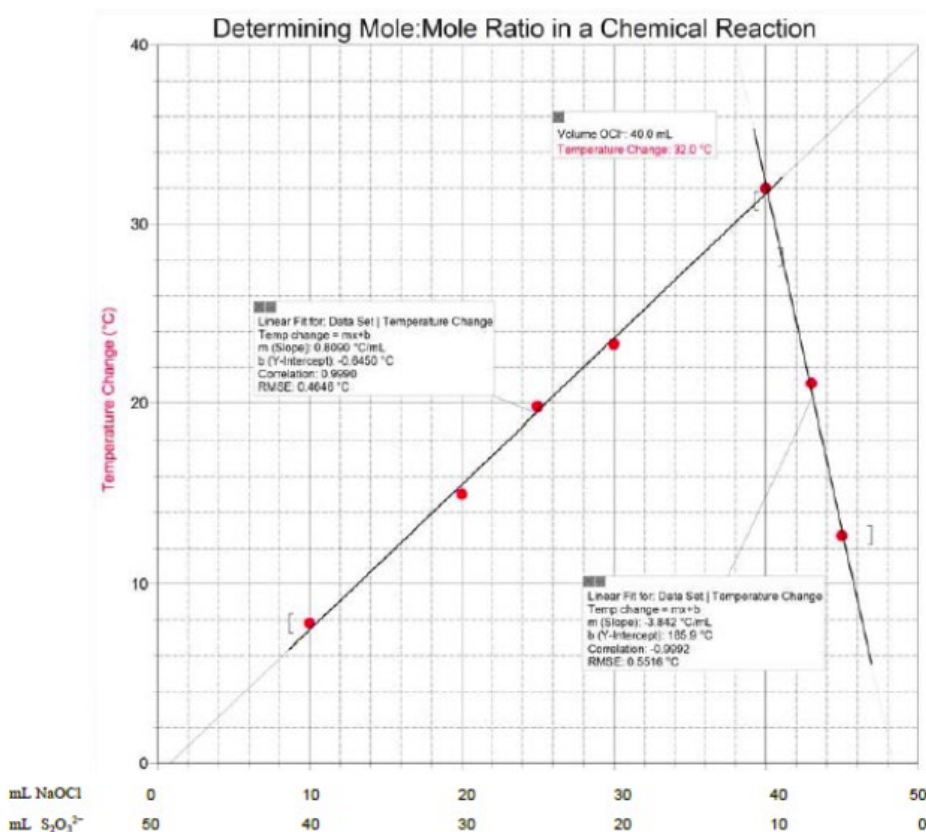__3__ moles of X react with __2__ moles of Y
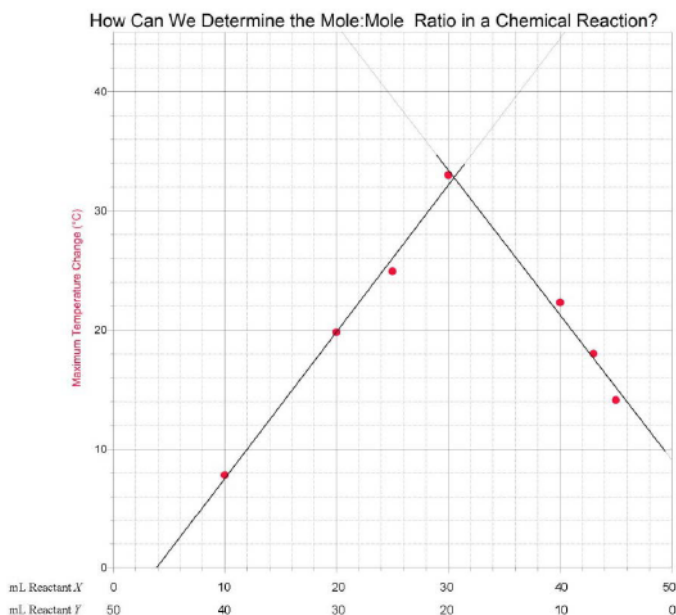
6. Is there enough data to make a valid conclusion? Justify your answer.

Yes. There are at least three data points on each side of the maximum. Two points define a straight line, but using three points assures that the values fall on a straight line.

Answers to POST LAB QUESTIONS AND DATA ANALYSIS

1. Use graphical methods to determine the whole-number mole ratio of the two reactants in this experiment.

(See next page.)

Determining Mole:Mole Ratio in a Chemical Reaction

mL NaOCl	0	10	20	30	40	50
mL $S_2O_3^{2-}$	50	40	30	20	10	0

The mole ratio is 4 moles OCl^- to 1 mole $S_2O_3^{2-}$.

2. Why must the total volume of the solution mixture be kept constant in all trials?

The maximum amount of heat was given off when the optimum mole ratio of reactants is combined. If the solution volume is a constant, the change in temperature will be proportional to the amount of heat evolved. If the volumes were not constant, a calculation would have to be made relating temperature change to heat evolved for each separate measurement.

3. The molarities of the reactant solutions were equal in this experiment. Is this necessary, or even important, for the success of the experiment?
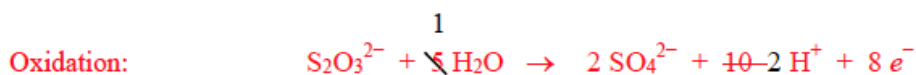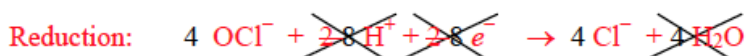
No, it just made it easier. If the molarities were not the same, then a calculation must be performed for each measurement to relate the temperature change to the heat evolved and the moles of reactant present.

4. Identify the limiting reactant for each trial that you performed.

For trials 1-4, OCl^- was the limiting reactant (up to 40 mL OCl^- added). For trials 6 and 7, $S_2O_3^{2-}$ was the limiting reactant (less than 10 mL $S_2O_3^{2-}$ added).

5. Write the balanced oxidation-reduction reaction for the reaction of OCl^- and $S_2O_3^{2-}$ in basic solution. Does the mole ratio that you determined in your experiment match the actual reaction equation's coefficients?

Begin by balancing the redox equation half-reactions in acidic medium, then neutralize any excess H^+ ions by adding equal numbers of OH^- ions to *both* sides of the balanced reaction:

Reduction: $4\ OCl^- + \cancel{28\ H^+} + \cancel{28\ e^-} \rightarrow 4\ Cl^- + \cancel{4\ H_2O}$

Oxidation: $S_2O_3^{2-} + \cancel{5}\ ^1 H_2O \rightarrow 2\ SO_4^{2-} + \cancel{10}\ 2\ H^+ + 8\ e^-$

$4\ OCl^- + S_2O_3^{2-} + 1\ \cancel{H_2O} \rightarrow 4\ Cl^- + 2\ H^+ + 2\ SO_4^{2-}$

Neutralize H^+: $2\ OH^- \rightarrow$ $2\ OH^-$

(2 waters form from neutralization; one water on the left is cancelled, leaving one water as a product)

$4\ OCl^- + S_2O_3^{2-} + 2\ OH^- \rightarrow 4\ Cl^- + 2\ SO_4^{2-} + H_2O$

Yes. The sample data shows that when 40 mL of equimolar NaOCl is mixed with 10 mL of equimolar $Na_2S_2O_3$, the maximum amount of heat is liberated. Therefore, the optimum mole:mole ratio is 4:1, which corresponds with the coefficients in the balanced net ionic equation.

6. Suggest a measurement (other than the temperature change) that could be used in an experiment involving the method of continuous variations that could be used to determine the mole ratios for a pair of reactants.

Students should cite observable and measurable quantities such as: color change (measured by spectrophotometer or colorimeter), mass of precipitate formed (filter, dry ppt., and mass on a balance), and volume of a gas formed (measured by pressure change or gas collection or simply counting bubbles). Other reasonable answers should also earn credit.

7. Why is it more accurate to use the point of intersection of the two lines to find the mole ratio rather than the ratio associated with the greatest temperature change?

The exact mole ratio may not have been chosen as a data point. Also, the graph averages several values to determine the optimum ratio as opposed to relying on a single value.

8. A student mixes two solutions that are not at the same initial temperature. If, 20 mL of Solution A at 23°C is mixed with 30 mL of Solution B at 30°C, suggest a method for making a correction so that the student does not have to repeat the experiment.

Initial temperature of mixture $= \dfrac{(20.0\ mL \times 23°C) + (30.0\ mL \times 30°C)}{50.0\ mL} = 27.2°C$, So if the measured maximum temperature is 35.3°C, then ΔT should be reported as $(35.3 - 27.2)°C = 8.1°C$.