Name **Period** **Date**

24. Heats of Reaction and Solution

Driving Questions

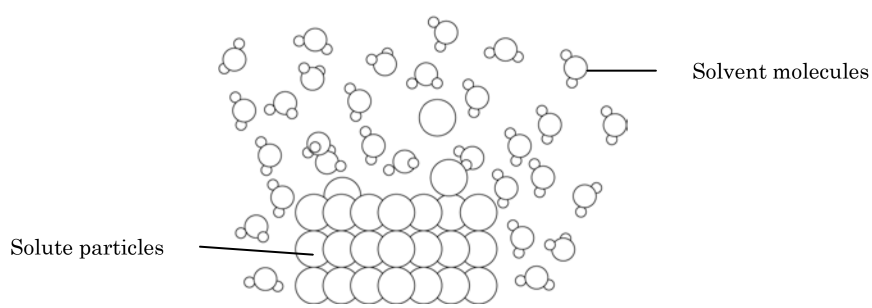
(Besides making new products, chemistry also provides information on the energy associated with chemical reactions, including those reactions that convert the food you eat into energy needed to live. Knowing how much energy is required or produced allow chemists to evaluate new fuels and efficiently make new products.

- How can the heat (energy) released or absorbed when solutes dissolve in a solvent be determined?
- How can the heat (energy) released or absorbed when chemicals react be determined?

Background

Physical changes and chemical reactions both may be accompanied by changes in energy, often in the form of heat or enthalpy. (The symbol for enthalpy is H.) Chemical and physical processes that absorb heat from their surroundings are endothermic. Chemical and physical processes that release heat into their surroundings are exothermic.

Phase changes, including the dissolving of a solute into a solvent, are types of physical changes that involve an exchange of heat. The heat absorbed by or released when a solute dissolves is called the heat of solution (or enthalpy of solution). The heat of solution results from the breaking of attractions between ions in a crystal lattice, and the forming of attractions between the freed ions and the solvent molecules.

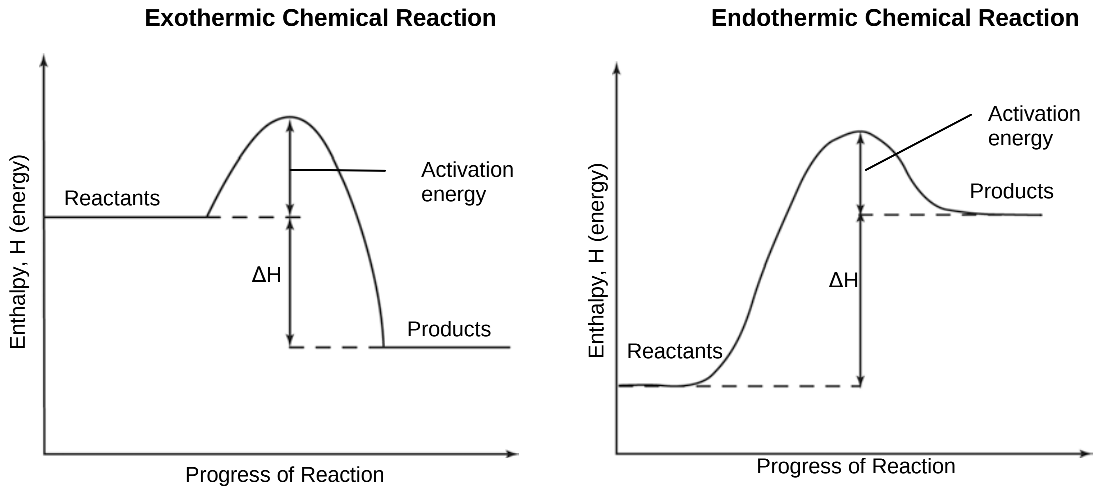


Solute dissolving in water.

Heat that is either released or absorbed during a chemical reaction is called the heat of reaction (or enthalpy of reaction). The heat of reaction results from the breaking of bonds in the reactants and the forming of bonds in the products.

Enthalpy diagrams illustrate the internal energy in the reactants compared to the products. When the reactants have more energy than the resulting products, the reaction is exothermic, and the excess energy is released, increasing the temperature of the surroundings. When the products have more energy than the original reactants, the reaction is endothermic, and the required energy is drawn from the surroundings reducing the temperature.

Enthalpy Diagrams



The heat of solution q and heat of reaction q can both be found by multiplying the mass m of the water or solution, the specific heat capacity c of water, and change in temperature ΔT together.

$$q = m \times c \times \Delta T$$

The temperature change of the surroundings is measured and thus the heat calculated is the heat change experienced by the surroundings. The enthalpy of reaction ΔH or heat of solution, which caused the measured change, is the opposite sign of the heat calculated.

$$\Delta H = -q$$

The energy for a physical change or chemical reaction can be described on a per mole basis by dividing the heat of solution or heat of reaction by the number of moles of substance present. The resulting term is called the molar heat of solution or molar heat of reaction.

$$\text{molar heat of solution/reaction} = \frac{\Delta H}{\text{moles of substance}}$$

Materials and Equipment

For each student or group:

- Data collection system
- Temperature sensor
- Beaker, 250-mL
- Graduated cylinder, 50-mL
- Balance, centigram
- Polystyrene cup (2)
- Spatula
- Stir rod
- Paper towels
- Weighing paper
- Sand paper or steel wool, 1 piece
- Wash bottle and waste container
- Sodium hydroxide (NaOH) pellets, 1 g
- Ammonium chloride (NH_4Cl), 1 g
- Magnesium metal ribbon, 0.10 g
- 1.0 M Hydrochloric acid (HCl), 25 mL
- Distilled (deionized) water, 50 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- Sodium hydroxide and hydrochloric acid are corrosive irritants. Avoid contact with the skin and eyes.
- Be sure that all acids and bases are neutralized before disposing of them down the drain.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

○	○	○	○	○
After recording the exact mass of liquid in the calorimeter, put a temperature sensor in the liquid and start recording data.	Write down the exact mass of each reactant (both the solid and the water).	Correct for heat loss and then calculate the heat of reaction or solution.	After the temperature stabilizes, add the solid to the liquid in the calorimeter and mix thoroughly.	Stop recording temperature data after the temperature has reversed for at least 1 minute.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Part 1 – Dissolving Sodium Hydroxide (NaOH) and Ammonium Chloride (NH_4Cl)

Set Up

1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect a temperature sensor to the data collection system. �(2.1)

3. ☐ Display Temperature (°C) versus Time (s) on a graph. �(7.1.1)

4. ☐ Measure approximately 1.0 g of sodium hydroxide (NaOH) pellets.

5. ☐ Record the exact mass of NaOH in the data table below.

Table 1: Data collected for dissolving sodium hydroxide in water

Mass of NaOH (g)	
Volume of Water (mL)	
Mass of Water (g)	

6. ☐ Measure approximately 25 mL of water using a graduated cylinder, and write the exact volume in the data table above.

7. ☐ Place a clean, dry polystyrene cup into another polystyrene cup to create a simple calorimeter. Place the calorimeter on the balance and tare the balance.

8. ☐ Pour the approximately 25 mL of water into the calorimeter.

9. ☐ Write the mass of the water in the data table above.

10. ☐ What does it mean to "tare" a balance? How would you find the mass of the water if you did not "tare" the balance?

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11. ☐ Compare the volume of the water with its mass. Is this what you would expect? Explain.

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12. ☐ Place the calorimeter containing the approximately 25 mL of water into a 250-mL beaker.

Collect Data

13. ☐ Place the temperature sensor in the water that is in the calorimeter.

14. ☐ While viewing the graph display, start recording data. �(6.2)

    Note: Allow the temperature to stabilize (remains constant for at least 30 seconds).

15. ☐ Add the solid NaOH to the water, and continuously stir the mixture until the NaOH completely dissolves. This may take several minutes.

    Note: You may need to adjust the scale of the axes to see the changes taking place. �(7.1.2)

16. ☐ Stop recording data once the temperature has decreased for at least one minute after reaching its maximum temperature. �(6.2)

17. ☐ Name the data run "NaOH". �(8.2)

18. ☐ Dispose of the NaOH solution according to the teacher's instructions.

19. ☐ Clean and thoroughly dry the calorimeter, temperature sensor, and stir rod.

20. ☐ Why must the calorimeter, temperature sensor, and stir rod be dried before using them in the next part of the experiment?

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21. ☐ Repeat the steps in the Set Up and Collect Data sections, this time substituting ammonium chloride (NH_4Cl). Take into account the following differences when you repeat the steps:

- Use approximately 1.0 g of ammonium chloride and approximately 25 mL of water.
- Record the data collected in the table below.
- Stop recording data when the temperature has increased for one minute or longer after reaching its minimum temperature. �(6.2)
- Name the data run “NH_4Cl”. �(8.2)

Table 2: Data collected for dissolving ammonium chloride in water

Mass of NH_4Cl (g)	
Volume of Water (mL)	
Mass of Water (g)	

22. ☐ Dispose of the NH_4Cl solution according to the teacher’s instructions.

23. ☐ Thoroughly clean and dry the calorimeter, temperature sensor, and stir rod.

Part 2 – Reacting Magnesium Metal and Hydrochloric Acid

Set Up

24. ☐ Cut a piece of magnesium ribbon 7- to 8-cm long (approximately 0.1 g). Use sandpaper or steel wool to remove any magnesium oxide that has formed on the magnesium ribbon.

25. ☐ Cut the cleaned magnesium ribbon into approximately 1-cm pieces.

26. ☐ Measure the mass of all the pieces together and record the mass in the data table below.

Table 3: Data collected for reacting magnesium metal and hydrochloric acid

Mass of Magnesium Metal Pieces (g)	
Volume of 1.0 M HCl (mL)	
Mass of 1.0 M HCl (g)	

27. ☐ Why is the magnesium ribbon cut into pieces?

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28. ☐ Measure approximately 25 mL of 1.0 M hydrochloric acid (HCl) using a graduated cylinder. Record the exact volume in the data table above.

29. ☐ Place a clean, dry calorimeter on the balance and tare the balance.

30. ☐ Pour the approximately 25 mL of 1.0 M HCl into the calorimeter.

31. ☐ Record the mass of the HCl in the data table above.

32. ☐ Why is a polystyrene cup used as the calorimeter instead of a beaker? Why is the polystyrene cup placed inside the beaker?

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Collect Data

33. ☐ While viewing the graph display, start recording data. �(6.2)

Note: Allow the temperature to stabilize (remain constant for at least 30 seconds).

34. ☐ Add the magnesium ribbon pieces, and stir until the magnesium has completely reacted. The reaction may take several minutes to occur.

Note: You may need to adjust the scale of the axes to see the changes taking place. �(7.1.2)

35. ☐ Stop recording data once the temperature has decreased for at least one minute after reaching its maximum temperature. �(6.2)

36. ☐ Record any observations you witnessed that suggest a chemical reaction occurred.

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37. ☐ Name the data run “Mg”. �(8.2)

38. ☐ Save the data file and clean up the lab station according to the teacher’s instructions. �(11.1)

Data Analysis

1. ☐ Determine the initial temperature T_{initial}, the highest temperature actually attained $T_{\text{final, actual}}$, and the temperature that would have been reached if there was no heat lost to the surroundings $T_{\text{final, corrected}}$ for each run of data collected. Follow the steps below to do this on your data collection system.

   a. Display the run of data you want to analyze. �(7.1.7)

   b. Find the initial temperature and the highest temperature actually attained by finding the coordinates at each of these points on the graph. �(9.1)

   c. Record the initial and final (actual) temperatures in Table 4 below.

   d. Select all the data points that were collected after the highest (including the highest temperature). �(7.1.4)

   e. Apply a linear fit to these selected data points. �(9.5)

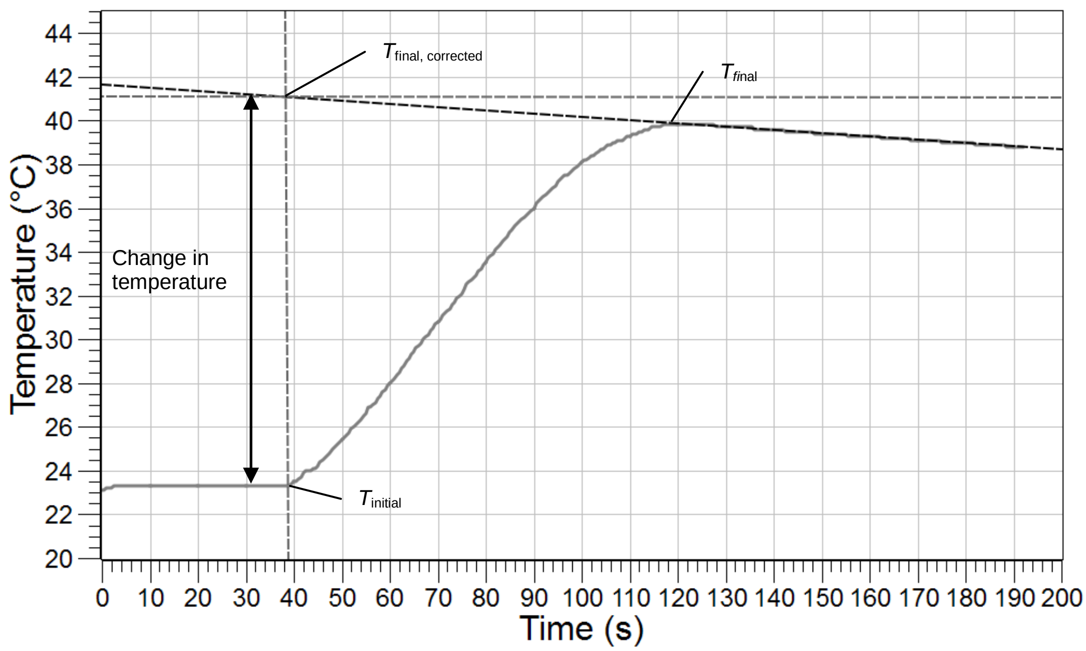
   f. Adjust the scale of the graph so that you can find the point where the linear fit line crosses an imaginary vertical line extending up from the initial temperature. �(7.1.2)

   Note: This is illustrated in the sample graph below.

   g. Record the final corrected temperature in Table 4 below.

Sample Graph

Extrapolation at the Same Rate of Cooling to Find the Final Corrected Temperature



Note: The difference between the final temperature and the corrected final temperature is because the solution was losing heat as the reaction occurred. The longer the reaction takes to occur the greater the extent of heat loss.

Table 4: Initial, final actual, and final corrected temperature values

Dissolving Sodium Hydroxide		**Dissolving Ammonium Chloride**		**Reacting Magnesium Metal with Hydrochloric Acid**	
T_{initial} (˚C)		T_{initial} (˚C)		T_{initial} (˚C)	
$T_{\text{final, actual}}$ (˚C)		$T_{\text{final, actual}}$ (˚C)		$T_{\text{final, actual}}$ (˚C)	
$T_{\text{final, corrected}}$ (˚C)		$T_{\text{final, corrected}}$ (˚C)		$T_{\text{final, corrected}}$ (˚C)	

2. ☐ Determine the change in temperature for each process by subtracting the initial temperature from the final corrected temperature. Show your work and record you answers in Table 5 below.

Table 5: Change in temperature

Process	**Show Your Work** $T_{\text{final, corrected}} - T_{\text{initial}}$ **(°C)**	**Change in Temperature ΔT (°C)**
Dissolving sodium hydroxide		
Dissolving ammonium chloride		
Reacting magnesium metal with hydrochloric acid		

3. ☐ Calculate the heat absorbed by the solution in each process, q, by using the formula given below. Convert joules to kilojoules in your final answer. Show all of your work, including the units, and record your answers in Table 6 below.

   $q = m \times c \times \Delta T$, where:

   q = heat lost or gained by the solution

   m = mass of the solvent (water in the dissolving processes and HCl in the reaction)

   c = the specific heat of the solution (use the specific heat of water, 4.18 J/(g·°C))

   $\Delta T = T_{\text{final, corrected}} - T_{\text{initial}}$

Table 6: Heat absorbed by the solution in each process

Process	**Show Your Work here:**	**Heat q (kJ)**
Dissolving sodium hydroxide		
Dissolving ammonium chloride		
Reacting magnesium metal with hydrochloric acid		

4. ☐ Find the molar enthalpy for each substance. Show your work and record your answers in Table 7 below.

$$\text{molar enthalpy of solution/reaction} = \frac{\Delta H}{\text{moles of substance}}$$

Note: The amount of heat absorbed or released by the solution is the opposite of the amount of heat absorbed or released by the process.

$$\Delta H = -q$$

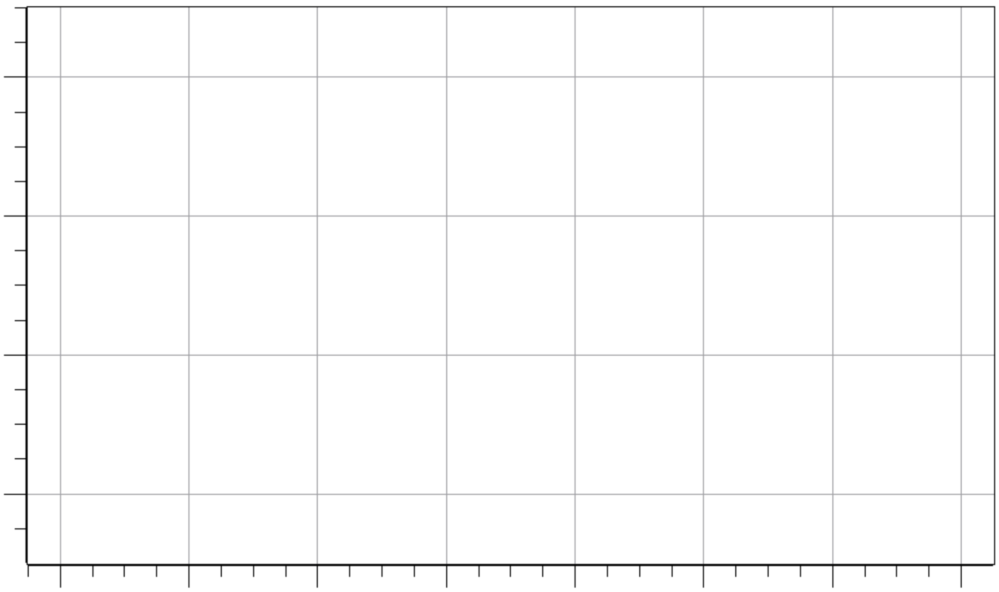
Table 7: Molar enthalpy for each substance

Process	**Calculate Number of Moles** (Show your work)	**ΔH (kJ)**	**Calculate Molar Enthalpy, ΔH/mol (kJ/mol)** (Show your work)
Sodium hydroxide			
Ammonium chloride			
Magnesium			

5. ☐ Create a graph with all three runs of data displayed on your data collection system. �(7.1.3)

Note: Not all data collection system will display all three runs of data. If this is not possible create one graph for part one (dissolving) and a second graph for part two (reacting).

6. ☐ Sketch or print a copy of your Temperature (°C) versus Time (s) graph with all three data runs on one set of axes. Label each data run as well as the overall graph, the x-axis, the y-axis, and include units on the axes. �(11.2)



Analysis Questions

1. **Determine the percent error for each process using the following known values:**

$$\textbf{percent error} = \left|\frac{(\text{accepted value} - \text{experimental value})}{\text{accepted value}}\right| \times 100$$

Process	**Accepted ΔH/mol (kJ/mol)**	**Percent Error** (Show your work)
Molar heat of solution for sodium hydroxide	–44.5	
Molar heat of solution for ammonium chloride	14.8	
Molar heat of reaction for magnesium metal with hydrochloric acid	–462.0	

2. **Suggest possible changes to the experimental procedure that could improve the accuracy of the results.**

3. **Why was it necessary to correct the final temperature reached?**

4. **Identify each process as exothermic or endothermic, and state your evidence in each case.**

Process	**Endothermic or Exothermic?**	**Evidence**
Dissolving sodium hydroxide		
Dissolving ammonium chloride		
Reacting magnesium metal with hydrochloric acid		

5. **Write the chemical equation that illustrates the heat changes that occurred for each physical and chemical process you performed in this experiment. Use your experimentally determined values for molar heat of reaction or solution in the equations. Be sure to include state symbols for all reactants and products.**

Synthesis Questions

Use available resources to help you answer the following questions.

1. **Draw a diagram that illustrates what happens at the molecular level to sodium hydroxide when it is dissolved in water.**

2. **Heat was either released or absorbed in all three processes, but only one of the processes was a chemical reaction. Explain how this is possible.**

3. **Describe what would have happened if the physical and chemical processes were performed at 50 °C instead of room temperature?**

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **Heat of reaction refers to**

   A. the heat released by a chemical reaction

   B. the heat absorbed by a chemical reaction

   C. The temperature of the solution after a chemical reaction occurs

   D. Both A and B

2. **Using the chemical equation below, determine the energy released by burning 2 moles of propane (C_3H_8)?**

   $$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l) + 2219.2\ kJ$$

   A. 2219.2 kJ

   B. 4438.4 kJ

   C. 1109.6 kJ

   D. 11096 kJ

Use the paragraph and Table 8 below to answer Multiple Choice Questions 3 to 5 below.

Two grams of salt A were added to 50 mL of water, and the initial and final temperatures were recorded on the left side of Table 8 below. In a separate experiment, 2 g of salt B were added to 50 mL of water, and the initial and final temperatures were recorded on the right side of Table 8 below.

Table 8: Temperature data for Salt A and Salt B.

Salt A		Salt B	
Initial Temperature	20 ˚C	Initial Temperature	20 ˚C
Final Temperature	35 ˚C	Final Temperature	10 ˚C

3. **What can be said about flow of energy in the two separate experiments?**

   A. For salt A, the energy flows from the water to the salt. For salt B, the energy flows from the water to the salt

   B. For salt A, the energy flows from the salt to the water. For salt B, the energy flows from the salt to the water

   C. For salt A, the energy flows from the salt to the water. For salt B, the energy flows from the water to the salt

   D. For salt A, the energy flows from the water to the salt. For salt B, the energy flows from the salt to the water

4. **What type of process occurred when salt A dissolved in water?**

A. Enthalpy

B. Heat

C. Endothermic

D. Exothermic

5. **Which equation illustrates the process that occurred when salt B dissolved in water?**

A. salt B(s) → salt B(aq) + heat

B. salt B(aq) → salt B(aq) + heat

C. salt B(s) + heat → salt B(aq)

D. salt B(aq) + heat → salt B(aq)

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. Physical changes and chemical reactions both may be accompanied by changes in ____________, often in the form of heat or ____________. Chemical and physical processes that absorb heat from their surroundings are ____________, while those that release heat into their surroundings are ____________. The energy released or absorbed by different physical and chemical processes comes from the different internal energies of the starting substances and ending substances. In exothermic processes, the starting materials have ____________ internal energy than the ____________. In endothermic processes, the ____________ are lower in energy than the ending substances.

2. In chemical reactions, the amount of energy released per mole of material reacted is the molar ________________________ of that material. Different physical processes have different names for the heat that is released based on the process that is taking place. For example, the amount of energy released per mole of material that is melting is called the molar heat of fusion. The amount of heat released per mole of substance being dissolved is called molar ________________________. The molar heat of any physical or chemical process can be calculated by multiplying the change in ________________________, the mass of the ________________________, and the specific heat capacity of the solvent all divided by the ________________________ of substance used. Exothermic processes have ________________________ heats of reaction/solution while endothermic processes have ________________________ heats of reaction/solution.

Key Term Challenge Word Bank

Paragraph 1	Paragraph 2
color	grams
endothermic	heat of reaction
energy	heat of solution
enthalpy	moles
exothermic	negative
less	neutral
mass	positive
more	solvent
products	temperature
reactants	