The Five Fingers of the Fist of Thermochemistry
Chapter 11

First Finger aka Thumb- Temperature The temperature of a substance measures the average kinetic energy of a substance. The warmer a substance is, the faster the molecules are moving and the more kinetic energy the substance has.

Second Finger aka Index Finger- Energy Energy is the capacity for doing work or supplying heat. Work is done when a force is used to move an object. Energy is weightless, odorless and tasteless. Energy is only detected because of its affects. Energy is stored within the structural units of chemical substances like gasoline and food. Different substances store different amounts of energy. Energy is measured in Joules.

Third Finger aka Middle Finger- Heat Heat is represented by the letter *Q* and is energy that transfers from one object to another because of a temperature difference between them. Heat is a form of energy that flows from warmer substances to cooler substances. Heat cannot be touched, smelled or measured. Only changes caused by heat can be measured. We feel the affects of heat from the Sun's rays on a warm summer day and we see the affect of heat when food is cooked. The formula to measure the amount of heat absorbed or released by a substance is:

Heat = mass x specific heat capacity x change in temperature or $Q = mc\Delta t$

Fourth Finger aka Ring Finger- Specific Heat Capacity Heat capacity is the ability of a substance to absorb or release heat. The specific heat of a substance is represented by the letter *c* and is defined by the amount of heat needed to make 1 gram of a substance increase its temperature by 1 degree Celcius. Water has a very high specific heat capacity, giving us one reason why the oceans don't boil in the summer and stay warmer into September. Iron, like most metals, has a very low specific heat capacity, giving us a one reason why metals heat up and cool down very quickly.

Fifth Finger aka Thumb- Calories

Name______________________________________ Date____________

Unit 2 Phases of Matter

Activity 2-1 Solids, Liquids, and Gases

Introduction

1. Choose words from the word list to fill in the blanks in the following paragraphs relating to solids, liquids, and gases. The list has been arranged to group words that have contrasting or related meanings.

Word List

addition/removal	kinetic/potential	solidification
boiling/freezing/melting	shape	temperature
greater/smaller	solid/liquid/gas	volume

Matter exists in three phases. The names given to these phases are solid, liquid, and gas. Each sample of substance in the solid phase has definite volume and definite shape. In the liquid phase, each sample has a definite volume but takes the shape of its container. In the gas phase, the sample has both the volume and the shape of its container.

A sample of matter can change from one phase to another by the addition or removal of energy. When a sample changes from solid to liquid, the phase change is called melting. At standard atmospheric pressure, the temperature at which this change occurs is called the normal melting point. Other terms often applied to phase change are:

- freezing, the changing from liquid to solid at the normal freezing point (solidification is a synonym for freezing);
- condensation, the changing from gas to liquid; and
- sublimation, the change directly from the solid phase to the gas phase without an intermediate liquid phase.

Change in phase is caused by the addition or removal of energy and can take place with no change in temperature. If no change in temperature occurs when energy is added to a sample, the potential energy of the substance increases. Particles in the solid phase, with rigid structure and fixed volume, have the lowest state of potential energy. When sufficient energy is added to change to the liquid phase, the particles move into positions of increased potential energy. If enough energy is added to a liquid at its boiling point, conversion to the gas phase takes place and the particles move into positions of even greater potential energy as they become separated by greater distances.

Differences between phases

2. Choose words from the word list to fill in the blanks in the following paragraphs relating to the differences between the phases of matter. The list has been arranged to group words that have contrasting or related meanings.

Word List

attraction	force	solid(s)/liquid(s)/gas(es)
between	greater/less	translational motion
close together/far apart	motion	

There are three main differences between the phases solid, liquid, and gas. One of these differences is in the distances between the particles making up the material. In gases under ordinary pressures, the gas particles are relatively far apart compared to the separations between particles in liquids and solids. The particles making up liquids are slightly farther apart than those making up solids.

A second main difference between phases is the force of attraction between particles. In gases, there are negligible forces of attraction between particles. In liquids and solids, relatively large forces of attraction exist between particles.

The third main difference is based upon the motion of the particles. A major difference between the phases is the amount of translational motion, the movement from one point to another. Gases have by far the greatest translational motion, as anyone who has been near a dead skunk can tell you. The translational motion associated with liquids is small, but is considerably greater than that of solids.

3. Complete the following table by writing in the boxes the names of common materials that illustrate the kinds of matter in each of the three phases.

Kinds of Matter		Phases: Gas	Liquid	Solid
Substances	Elements			
	Compounds			
Mixtures	Homogeneous Mixtures			
	Heterogeneous Mixtures	X		
		X		
		X		

3

Name ______________________________ Class ________ Date ____________

Activity 2-3

Role of Energy in Changes of Phase

Introduction

1 Choose words from the word list to complete the following paragraphs relating to changes in phase. The list has been arranged to pair words that have contrasting meanings.

Word List

absorption/release	heat/temperature	kinetic/potential
boiling/melting	increases/decreases	particles
cooling/heating	increasing/decreasing	phase

Most substances can change in phase from solid to liquid to gas by the absorption of heat. The temperature at which the change from solid to liquid occurs is called the melting point. The temperature at which the change from liquid to gas occurs is the boiling point.

The graph on page 36 shows the temperature of a substance as it is heated over a period of time. A graph of this kind is called a heating curve. Kinetic energy is the energy associated with the motion of the particles within a sample. Temperature is a measure of the average kinetic energy of the particles that make up the sample. Energy that is "stored" in the particles due to their composition and their position with respect to each other is called potential energy.

The behavior of a typical substance as it is heated is shown in the graph. The substance is a solid at time=0. Throughout the entire time the substance is being heated, heat is being added at a constant rate. The changes in temperature show increasing kinetic energy and the changes in phase show increases in potential energy. A cooling curve shows the same events in the reverse order. In the case of a cooling curve, changes in temperature show decreasing kinetic energy and changes in phase show decreases in potential energy.

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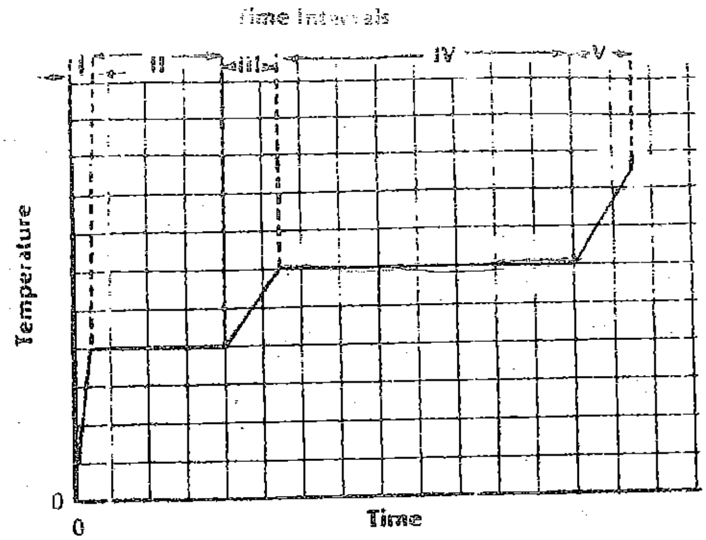


A heating curve

2. The table below describes the heating curve in the graph above for different intervals of time. Fill in the empty spaces in the table with one of the following:

no change or *increasing*

Time Interval on Heating Curve	The substance is . . .	Temperature (average kinetic energy of particles)	Potential Energy
Interval I	. . . being warmed as a solid	↑	—
Interval II	. . . melting	—	↑
Interval III	. . . being warmed as a liquid	↑	—
Interval IV	. . . boiling	—	↑
Interval V	. . . being warmed as a gas	↑	—

A cooling curve

A sample of naphthalene in the liquid phase was allowed to cool. Temperature readings of the naphthalene were taken every minute while the cooling was taking place, as shown below.

Time (minutes)	Temp. (°C)
0	93.4
1.0	87.2
2.0	82.6
3.0	80.6

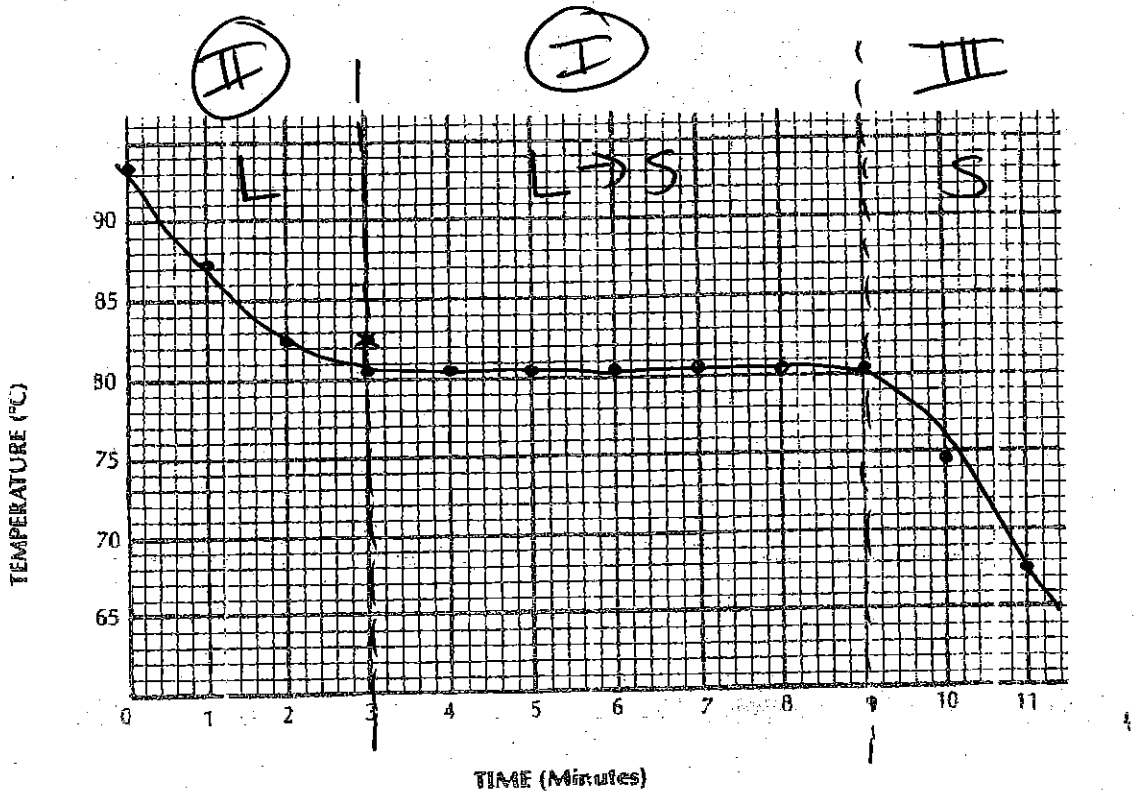
Time (minutes)	Temp. (°C)
4.0	80.6
5.0	80.6
6.0	80.6
7.0	80.6

Time (minutes)	Temp. (°C)
8.0	80.6
9.0	80.4
10.0	74.2
11.0	67.8

5

Name ______________________ Class______ Date__________

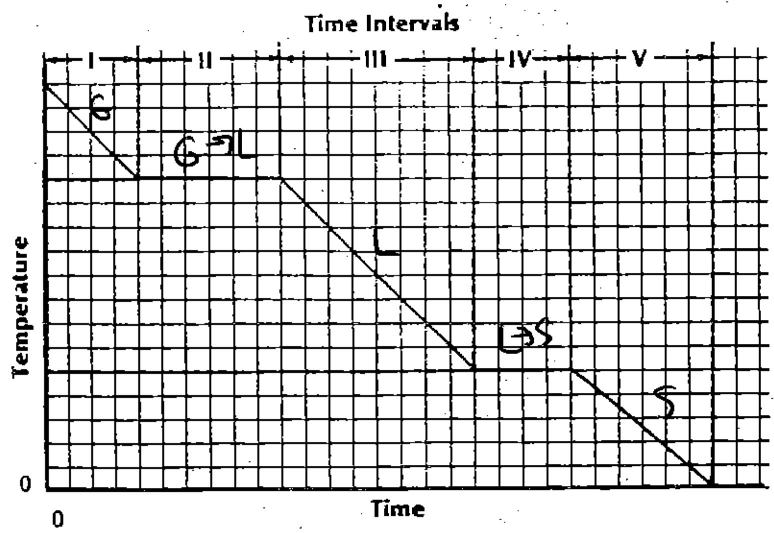
3. Using the following grid, make a cooling curve for naphthalene from the data above.



4. Based upon these data, what is the melting point of naphthalene? 80.6°C
5 Label the time intervals on the graph, as follows:
   I—for the interval where there is a phase change from a liquid to a solid
   II—for the interval where the liquid cools
   III—for the interval where the solid cools
6 In which region(s) is kinetic energy decreasing? Account for the decrease.
   Intervals II and III. Kinetic Energy is decreasing because Temp is decreasing
7 In which region(s) is potential energy decreasing? Account for the decrease.
   Interval I. It's freezing (L→S), so molecules are getting closer together, so potential energy ↓.
8. What is the significance of the flat portion on your graph? Why does the temperature stop falling for several minutes?
   The flat part is the phase change (L→S). The temp stays constant b/c the molecules are moving closer together.

Questions 6-13 are based on the following information.

The cooling curve below represents the behavior of a substance as the substance is losing energy (heat) at a constant rate. Select the best answer to each question and write its letter in the space at the right.

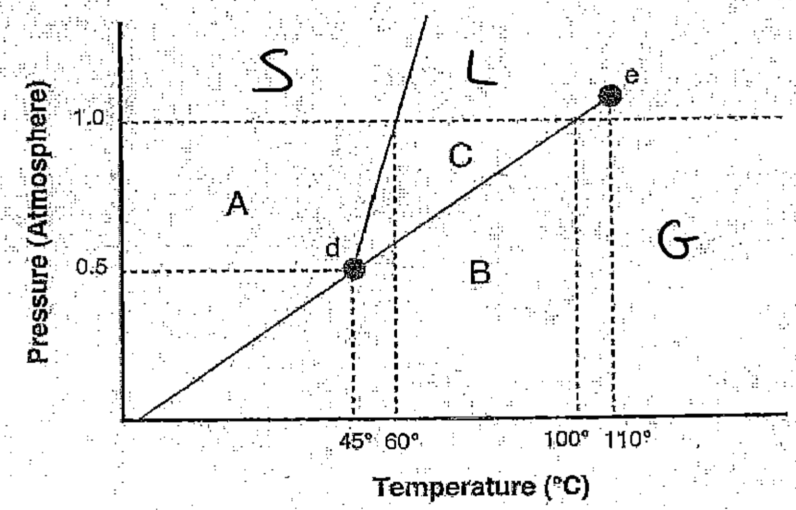


6. The number of phase changes represented by the graph is
(A) 5 (B) 2 (C) 3 (D) 4 — 6. B
7. The interval during which the molecules have the lowest kinetic energy is
(A) I (B) II (C) IV (D) V — 7. D
8. The interval during which there is the greatest loss of potential energy is
(A) I (B) II (C) III (D) V — 8. B
9. The interval during which there is the greatest loss of kinetic energy is
(A) I (B) III (C) IV (D) V — 9. B
10. The interval during which the substance is condensing is
(A) I (B) II (C) III (D) V — 10. B
11. The interval during which only the solid phase is present is
(A) I (B) III (C) IV (D) V — 11. D
12. If the quantity of substance to be observed were increased, which difference in the first plateau (interval II) would be expected?
(A) Interval II would occur at a higher temperature.
(B) Interval II would occur at a lower temperature.
(C) Interval II would represent a longer period of time.
(D) Interval II would represent a shorter period of time. — 12. C
13. The change experienced by the substance during interval III is
(A) exothermic (C) endothermic
(B) isothermic (D) nonthermic — 13. A

Name ______________________ Due Date ______________

PHASE DIAGRAM WORKSHEET
(Single Component)

Part A – Generic Phase Diagram.
Answer the questions below in relation to the following generic phase diagram.

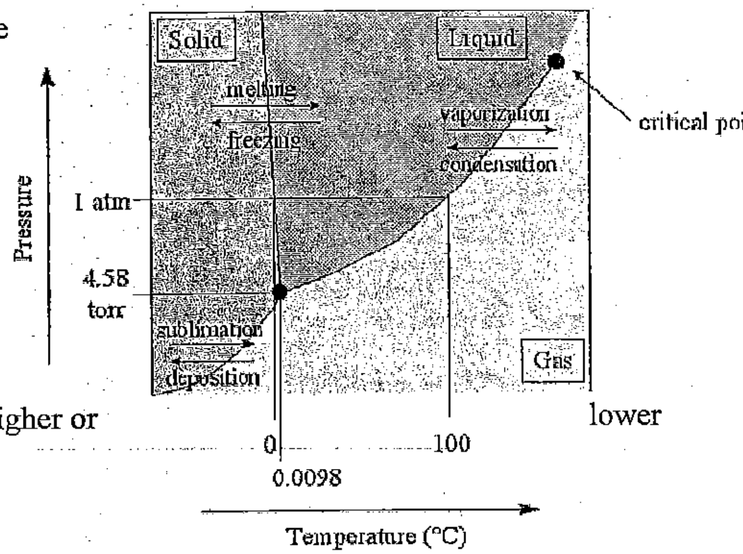


1. Which section represents the solid phase? A
2. What section represents the liquid phase? C
3. What section represents the gas phase? B
4. What letter represents the triple point? d In your own words, what is the definition of a triple point? The temp + pressure where all 3 phases exist in equilibrium.
5. What is this substance's normal melting point, at 1 atmosphere of pressure? 60°
6. What is this substance's normal boiling point, at 1 atmosphere of pressure? 100°
7. Above what temperature is it impossible to liquefy this substance, no matter what the pressure? 110°
8. At what temperature and pressure do all three phases coexist? .5atm, 45°C
9. At a constant temperature, what would you do to cause this substance to change from the liquid phase to the solid phase? increase pressure
10 What does sublimation mean? Solid → Gas Phase Change (No Liquid) it happens when you increase temperatures at pressures lower than triple point pressure.

Part B – Phase Diagram for Water.

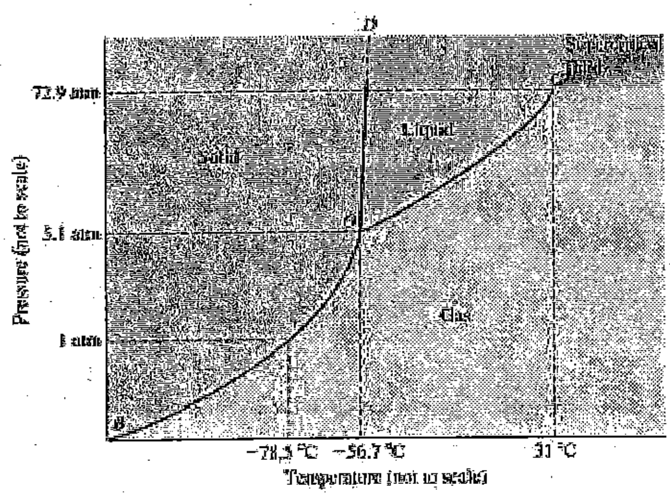
11. At a pressure of 1 atmosphere, what is the normal freezing point of water? 0°C

12. What is the normal boiling point of water, at one atmosphere of water? 100°C



13. In Albuquerque, we live approximately 5,500 feet above sea level, which means the normal atmospheric pressure is less than 1 atm. In Albuquerque, will water freeze at a lower temperature or a higher temperature than at 1 atmosphere? higher Will water boil at a higher or lower temperature, than at 1 atmosphere? lower

Part C – Phase Diagram for Carbon Dioxide.



14. At 1 atmosphere and room temperature (25°C), would you expect solid carbon dioxide to melt to the liquid phase, or sublime to the gas phase? Gas

15. Some industrial processes require carbon dioxide. The carbon dioxide is stored on-site in large tanks as liquid carbon dioxide. Assuming we lived at sea level (1 atm), how could carbon dioxide be liquefied? Increase the pressure on the CO_2 to liquify it.

Name: Date:

Worksheet: Specific Heat Capacity

$Q = mc\Delta t$

1. A 250-gram sample of water is heated from 20 °C to 35 °C. The specific heat of water is 4.184 joules/g-°C. How many calories were needed to bring about the raise in temperature? (1 calorie = 4.184 joules)

$$Q = (250\,g)(4.184\,J/g\text{-}°C)(35°C - 20°C) = \underline{15{,}690\,J}$$

$$15{,}690\,J\left(\frac{1\,cal}{4.184\,J}\right) = \underline{3{,}750\,cal}$$

2. From an original temperature of 15 °C, 100 grams of water is cooled to 10 °C. How much heat was lost by the water, in calories?

$$Q = mc\Delta t = (100\,g)(4.184\,J/g\text{-}°C)(10°C - 15°C) = \underline{-2092\,J}$$

$$-2092\,J\left(\frac{1\,cal}{4.184\,J}\right) = \underline{-500\,cal}\quad \underline{lost}$$

3. A piece of lead weighing 35 grams is cooled from 25 °C to -15°C. The specific heat of lead is 0.130 joules/g-°C. How much heat in joules was lost by the lead?

$$Q = mc\Delta t = (35\,g)(0.130\,J/g\text{-}°C)(-15° - 25°C) =$$

$$\underline{-182\,J}$$

4. The specific heat of aluminum is 0.902 joules/g-°C. What is the mass of a block of aluminum if 400 calories of energy are removed from the metal and its temperature drops from 50 °C to 10 °C? $-400\,cal\left(\frac{4.184\,J}{1\,cal}\right) = \underline{-1673.6\,J}$

$$m = \frac{Q}{c\Delta t} = \frac{-1673.6\,J}{(.902\,J/g\text{-}°C)(10 - 50°C)} = \frac{-1673.6\,J}{-36.08\,J/g} = \boxed{46.4\,g}$$

Name: Period: Date:

Specific Heat Capacity Worksheet

1. How much heat is absorbed by 250 g of water when it is heated from 10 °C to 100 °C? (The specific heat capacity of water is 4.184 J/g°C)

$$Q = mc\Delta t = (250_g)(4.184\ J/g°C)(100° - 10°) = 94,140J$$

2. How much heat is absorbed by 60 g of copper when it is heated from 20 °C to 80 °C? (The specific heat capacity of copper is 0.385 J/g°C)

$$Q = mc\Delta t = (60_g)(.385\ J/g°C)(80°C - 20°C) = 1386J$$

3. If a 400-g sample of aluminum absorbs 4000 calories of heat, will its temperature go up or down? ↑ How much will the temperature change? (The specific heat of aluminum is 0.902 J/g°C. 1 calorie = 4.184 joules)

$$Q = 4000\ cal\left(\frac{4.184\ J}{1\ cal}\right) = 16,736J$$

$$\Delta t = \frac{Q}{mc} = \frac{16,736\ J}{(400_g)(.902\ J/g°C)} = \frac{16,736J}{360.8\ J/°C} = 46.4°C$$

4. An 800-g block of lead is heated in boiling water until the temperature is the same as the water (100°C). The lead is then removed from the boiling water and dropped into 250 g of cool water at 12.2 °C. After a short time, the temperature of both the lead and the water reaches 20 °C.

a. How much heat did the water gain? $Q_w = Q_{water}$

$$Q_w = m_w c_w \Delta t_w = (250_g)(4.184\ J/g°C)(20 - 12.2°C) = 8,158.8J$$

b. On the basis of these measurements, what is the specific heat capacity of lead? $C_m = ?$

$$Q_{metal} = Q_m = -Q_{water} = -8,158.8J$$

$$C_m = \frac{Q_m}{m_m \Delta t_m} = \frac{-8,158.8J}{(800_g)(20°C - 100°C)} = \frac{-8158.8}{-64,000} = .127\ J/g°C$$

Name: Period: Date:

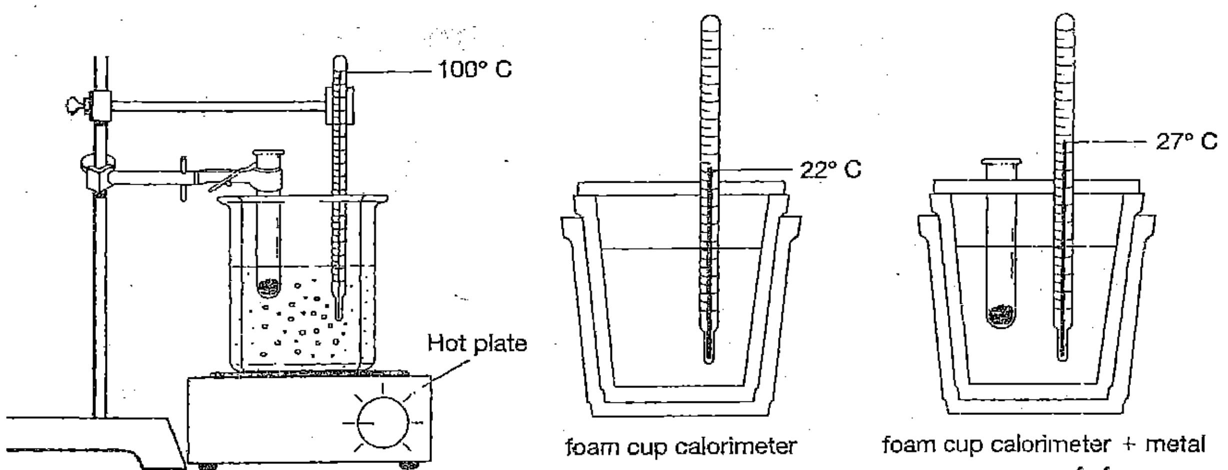
Chapter 15 Exercise

A student performed an experiment to determine the specific heat of an unknown metal. The data she collected is organized in the table below. Use this information to answer the following questions.

Quantity	Trial 1	Trial 2
1. Mass of test tube & metal	118.19 g	118.21 g
2. Mass of empty test tube	67.86 g	67.86 g
3. Mass of calorimeter	7.037 g	3.818 g
4. Mass of calorimeter & water	46.137 g	43.270 g
5. Initial temperature of metal	100.0 °C	100.0 °C
6. Initial temperature of water	22.0 °C	21.0 °C
7. Final temp of water	27.0 °C	26.5 °C

Formulas needed: $Q = mc\Delta t$ $-Q_{metal} = +Q_{water}$

Δt = final temp – initial temp



1. What is the final temperature of the metal? final temp of metal = final temp of water
   a. Trial 1

   27°C

   b. Trial 2

   26.5°C

2. What was the Δt for the metal?
   a. a. Trial 1 $\Delta t_m = t_f - t_i = 27°C - 100°C = \underline{-73°C}$

   b. Trial 2 $\Delta t_m = t_f - t_i = 26.5°C - 100°C = \underline{-73.5°C}$

3. What was the Δt for the water?
   a. a. Trial 1 $\Delta t = t_f - t_i = 27°C - 22°C = \underline{5°C}$

   b. Trial 2 $\Delta t = t_f - t_i = 26.5°C - 21°C = \underline{5.5°C}$

4. Calculate the heat change for the water. $Q_w = m_w C_w \Delta t_w$
   (Specific heat capacity for water is 4.184 J/g°C.)
   a. a. Trial 1

$M_w = 46.137 - 7.037 = 39.1g$ $Q = (39.1g)(4.184 J/g{\cdot}°C)(5°C) = \underline{817.972 J}$

   b. Trial 2

$M_w = 43.270 - 3.818 = 39.452$ $Q = (39.452g)(4.184 J/g{\cdot}°C)(5.5°C) = \underline{907.869 J}$

5. Calculate the heat change for the metal. $Q_m = -Q_w$
   a. Trial 1

$Q_m = \underline{-817.972 J}$

   b. Trial 2

$Q_m = \underline{-907.869 J}$

6. Calculate the specific heat capacity of the metal. $C_m = \frac{Q_m}{m_m \Delta t_m}$
   a. a. Trial 1

$M_m = 118.19g - 67.86 = 50.33g$ $C_m = \frac{-817.972 J}{(50.33g)(-73°C)} = \frac{-817.972}{-3674.09} = \underline{0.223 J/g{\cdot}°C}$

   b. Trial 2

$M_m = 118.21 - 67.86 = 50.35g$ $C_m = \frac{-907.869 J}{(50.35g)(-73.5°C)} = \frac{-907.869}{-3700.72J} = \underline{0.245 J/g{\cdot}°C}$

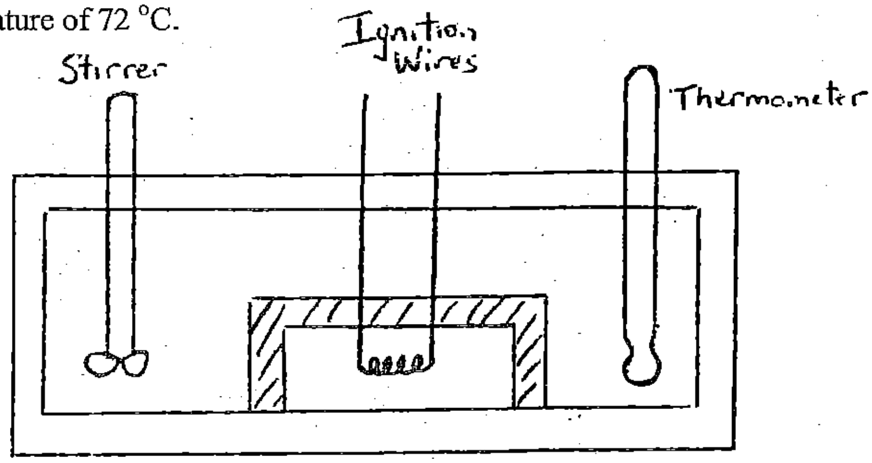
7. What metal might this have been?
   a. aluminum (c = 0.90 J/g°C) (b.) silver (c = 0.24 J/g°C)
   c. iron (c = 0.46 J/g°C) d. mercury (c = 0.14 J/g°C)

WORKSHEET: EXPERIMENTAL DETERMINATION FOR THE HEAT OF COMBUSTION

Problem: To determine the heat of a reaction (energy released) for the combustion of coal (C).

$$C + O_2 \rightarrow CO_2 + \text{Energy}$$

A 48-gram sample of coal is completely burned in a calorimeter (see diagram). Before the ignition, the calorimeter held 8000 mL of H_2O at 25 °C. After combustion, the same volume of water was at a temperature of 72 °C.



CALORIMETER

Processing the Data:

1. Determine the change in temperature (Δt) for the H_2O in the calorimeter.

$$\Delta t = t_f - t_i = 72° - 25° = 48°C$$

2. Calculate the energy released by the complete burning of 48 grams of coal. (Assume all of the energy released by the coal was absorbed by the water).

$$Q_w = m_w C_w \Delta t_w = (8000\,g)(4.184\,J/g°C)(48°C) = 1{,}606{,}656\,J$$

$$Q_{coal} = -Q_w = -1{,}606{,}656\,J$$

3. Where did this heat energy come from?

From the Burning Coal.

4. How much energy is released for 1 mole of coal? Molar mass of carbon is 12 g/mole.

$$48\,g\,C\left(\frac{1\,mole}{12\,g}\right) = 4\,mole\,C \qquad \frac{-1{,}606{,}656\,J}{4\,mole} = -401664\,J/mole = -401.664\,kJ/mole$$

5. Write an equation for the burning of 1 mole of coal. Include the heat released in the equation.

$$C + O_2 \rightarrow CO_2 + 401.664\,kJ$$