2024

AP® Chemistry

Sample Student Responses and Scoring Commentary

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Free-Response Question 4

☑ Scoring Guidelines

☑ Student Samples

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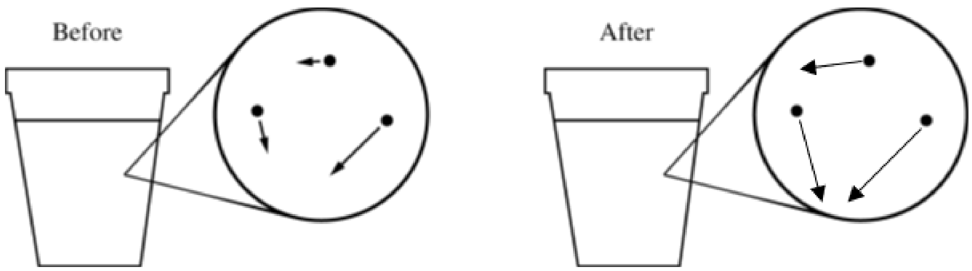
Question 4: Short Answer — 4 points

(a) For the correct answer, reported to the correct decimal place: **1 point**

38.5°C

(b) For a correct drawing: **1 point**

The "After" drawing should contain arrows that are longer, on average.



(c) For the correct calculated value, consistent with part (a): **1 point**

$q = mc\Delta T$

$$c_{metal} = \frac{q_{metal}}{m_{metal}\Delta T_{metal}} = \frac{-2940\text{ J}}{(98.1\text{ g})(38.5^\circ\text{C} - 100.0^\circ\text{C})} = 0.487\,\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$$

(d) For a valid explanation, consistent with part (c): **1 point**

Accept one of the following:

- *The value of ΔT_{Al} will be smaller because Al has a greater specific heat capacity than the metal in the original experiment. Therefore, the same thermal energy transfer applied to the same mass will result in a smaller change in temperature, according to the equation $q = mc\Delta T$.*
- $q = mc\Delta T$

  $$|\Delta T_{\text{Al}}| = \left|\frac{q_{\text{Al}}}{m_{\text{Al}}c_{\text{Al}}}\right| = \left|\frac{-2940\text{ J}}{(98.1\text{ g})(0.897\,\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}})}\right| = 33.4^\circ\text{C}$$

  $$|\Delta T_{metal}| = |38.5^\circ\text{C} - 100.0^\circ\text{C}| = 61.5^\circ\text{C}$$

  Thus, $\Delta T_{\text{Al}} < \Delta T_{metal}$

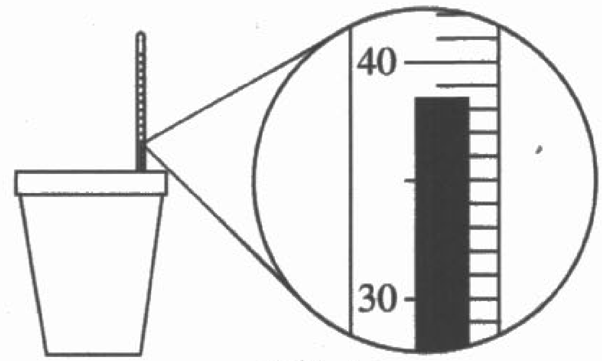
Total for question 4 — 4 points

Question 4

Begin your response to QUESTION 4 on this page.

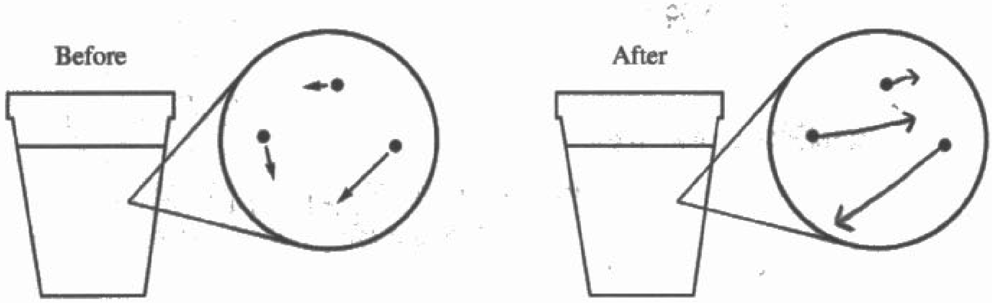
4. A student performs an experiment to determine the specific heat capacity of a metal. The student places a cube of the metal in boiling water so its temperature will be 100.0°C. The student then places the metal cube into a calorimeter that contains water and records the highest temperature of the water. A data table and a diagram of the thermometer at the highest temperature are shown.

Mass of metal cube	98.1 g
Mass of water	52.0 g
Initial temperature of metal cube	100.0°C
Initial temperature of water	25.0°C
Highest temperature of water	?



(a) What should the student report as the highest temperature of the water? 38.5 °C

(b) A particle-level representation of water molecules in the calorimeter before and after the metal cube was added is shown. The length of the arrows in the Before diagram represents the speed of the water molecules in the system. In the After diagram, draw an arrow for each molecule to indicate how the speed of each of the molecules changes after the metal cube is added.



Question 4

Continue your response to **QUESTION 4** on this page.

(c) Assuming the metal transfers 2940 J of thermal energy to the water, calculate the specific heat of the metal in J/(g·°C).

$q = mc\Delta T$

$c = \frac{q}{m\Delta T} = \frac{2940\,J}{(98.1\,g)(38.5 - 100.0\,°C)} = .487\ J/g\cdot°C$

(d) In a second experiment, 2940 J of thermal energy is transferred from 98.1 g of aluminum, which has a specific heat capacity of 0.897 J / (g·° C). Explain how the magnitude of the temperature change of the aluminum, ΔT_{Al}, compares with the magnitude of the temperature change of the metal in the original experiment.

Original experiment: $\Delta T = |38.5 - 100.0| = 61.5°C$

second:

$\Delta T = \frac{q}{mc} = \frac{2940\,J}{(98.1\,g)(0.897\,J/g\cdot°C)} = 33.4$

Since the specific heat capacity of Al is 2x that of the first metal, the same amount of thermal energy applied to the same mass produces a less significant change in temp.

Question 4

Begin your response to QUESTION 4 on this page.

4. A student performs an experiment to determine the specific heat capacity of a metal. The student places a cube of the metal in boiling water so its temperature will be 100.0°C. The student then places the metal cube into a calorimeter that contains water and records the highest temperature of the water. A data table and a diagram of the thermometer at the highest temperature are shown.

Mass of metal cube	98.1 g
Mass of water	52.0 g
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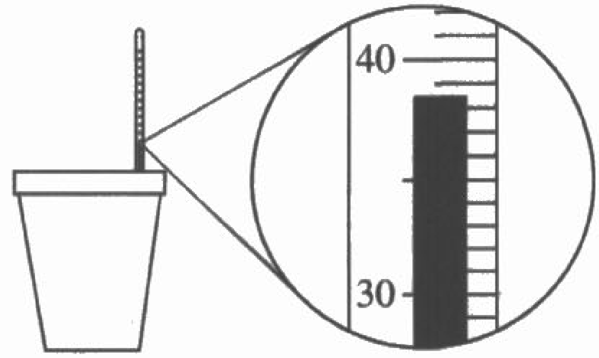
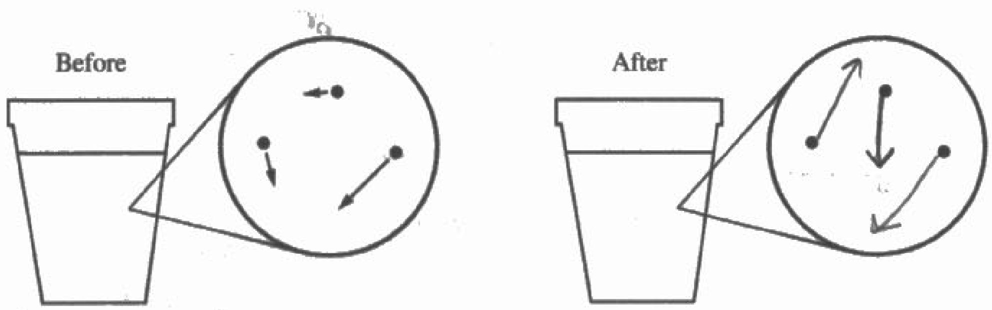


(a) What should the student report as the highest temperature of the water? 35.35 °C

(b) A particle-level representation of water molecules in the calorimeter before and after the metal cube was added is shown. The length of the arrows in the Before diagram represents the speed of the water molecules in the system. In the After diagram, draw an arrow for each molecule to indicate how the speed of each of the molecules changes after the metal cube is added.



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Question 4

Continue your response to **QUESTION 4** on this page.

(c) Assuming the metal transfers 2940 J of thermal energy to the water, calculate the specific heat of the metal in J/(g·°C).

q = mcΔT

-2940 J = 98.1 g (c)(35.35°C - 100.0°C)

-2940 J = 98.1 g (c)(-64.7°C)

c = .463 J/g°C

-sys = surr

-2940

(d) In a second experiment, 2940 J of thermal energy is transferred from 98.1 g of aluminum, which has a specific heat capacity of 0.897 J / (g·°C). Explain how the magnitude of the temperature change of the aluminum, ΔT_{Al}, compares with the magnitude of the temperature change of the metal in the original experiment.

q = mcΔT

2940 = 98.1 g (.897 J/g C)(T)

T = 33.4 °C

The magnitude of temperature change of Al is less than that of the original metal becuse Al has a greater heat capacity, meaning that it requires more heat before a gram of substance can change by 1°C. Since the specific heat capacity of the original metal is lower, the 2940 J can have a bigger effect on the magnitude of temperature.

Question 4

Begin your response to QUESTION 4 on this page.

4. A student performs an experiment to determine the specific heat capacity of a metal. The student places a cube of the metal in boiling water so its temperature will be 100.0°C. The student then places the metal cube into a calorimeter that contains water and records the highest temperature of the water. A data table and a diagram of the thermometer at the highest temperature are shown.

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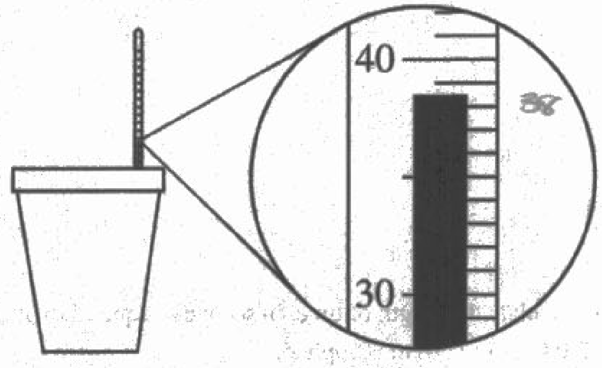
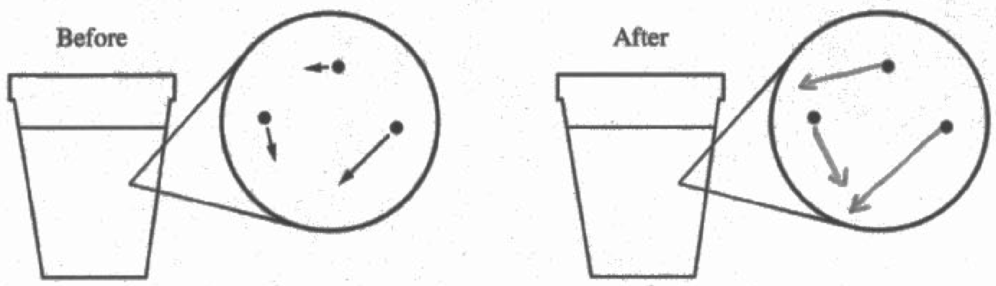


(a) What should the student report as the highest temperature of the water? 38°C

(b) A particle-level representation of water molecules in the calorimeter before and after the metal cube was added is shown. The length of the arrows in the Before diagram represents the speed of the water molecules in the system. In the After diagram, draw an arrow for each molecule to indicate how the speed of each of the molecules changes after the metal cube is added.



Question 4

Continue your response to **QUESTION 4** on this page.

(c) Assuming the metal transfers 2940 J of thermal energy to the water, calculate the specific heat of the metal in J/(g·°C).

J/g°C

2940/98.1g → C = 29.96

(d) In a second experiment, 2940 J of thermal energy is transferred from 98.1 g of aluminum, which has a specific heat capacity of 0.897 J / (g·° C). Explain how the magnitude of the temperature change of the aluminum, ΔT_{Al}, compares with the magnitude of the temperature change of the metal in the original experiment.

Aluminum reacts differently to the mystery metal provided. Although they're the same quantity - the mystery metal could've had a varying melting point

Question 4

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 4 presents students with an array of questions related to recording measurements in the laboratory, calorimetry, specific heat calculation for an unknown metal, and the comparison of temperature changes for different metals given equal masses and quantities of heat energy transferred.

Part (a) requires students to collect data from a representation of an analog thermometer and record the final temperature of the water in a calorimeter to the nearest 0.1°C (Learning Objective ENE-2.D/6.4.A, Skill 2.D from the *AP Chemistry Course and Exam Description*).

Part (b) requires students to explain the relationship between changes in temperature and the motion of water particles using a provided particle diagram. The left-side particle diagram provides students with a representation of three water molecules (represented with circles) in the calorimeter with arrows that represent the relative speed of the particles. The prompt asks students to draw arrows in the right-side diagram to represent the relative speed of the three water molecules at a higher temperature (SAP-7.B/3.5.A, 3.C).

Part (c) requires students to calculate the specific heat of the metal that is transferring a specified quantity of heat using calorimetry calculations and data from the table shown before part (a) (ENE-2.D/6.4.A, 5.F).

Part (d) requires students to explain the relationship between the magnitude of temperature change for two different metals with different specific heat values, given the same mass and quantity of heat transferred for each metal (ENE-2.D/6.4.A, 5.C).

Sample: 4A
Score: 4

This response earned 4 points. In part (a) the point was earned for the correct temperature, recorded to the correct decimal place. In part (b) the point was earned for arrows that are longer, on average, in the After diagram than in the Before diagram. In part (c) the point was earned for correctly calculating the specific heat of the metal that is consistent with the temperature recorded in part (a). In part (d) the point was earned for stating that a less significant temperature change results from the larger specific heat of aluminum. The supporting calculations are also correct but were not required to earn the point.

Sample: 4B
Score: 3

This response earned 3 points. In part (a) the point was not earned for recording an incorrect temperature from the thermometer. In part (b) the point was earned for arrows that are longer, on average. In part (c) the point was earned for a correctly calculated specific heat that is consistent with the response in part (a). In part (d) the point was earned for indicating that the magnitude of

Question 4 (continued)

aluminum's temperature change is smaller as compared to the metal in experiment 1, with a valid explanation that is consistent with the specific heat calculated in part (c).

Sample: 4C
Score: 1

This response earned 1 point. In part (a) the point was not earned because the temperature is not recorded to the correct number of significant figures. In part (b) the point was earned for drawing arrows in the After diagram that are longer, on average, than those in the Before diagram. In part (c) the point was not earned for an incorrectly calculated specific heat of the metal. In part (d) the point was not earned because there is no comparison made between the temperature changes of the two metals in the experiment.