Submit electronically (digital drop box) by **Sunday, January 31 – by 6 pm.**

**Note:** When submitting to digital Drop Box label your files with your name first and then the label - HmwkFour. **Please put you name in the ‘Header’ along with the already-inserted page #.**

The following information may be useful when solving the problems:

The atomic weight of an element listed in the periodic table is the mass of one mole of atoms in grams. This is termed the molar mass (i.e., mass per mole) of the element.

The molecular weight - determined from molecular formula as the sum of the atomic weights of all of the constituent atoms - is the mass of one mole of molecules in grams. This is termed the molar mass (i.e., mass per mole) of the molecule.

1 nm = 10⁻⁹ m ; 1 calorie (cal) = 4.184 joules (J) ; 16.0 oz = 1 lb. = 453.6 g

density of (liquid) water (H₂O) = 1.00 g/mL ; 1000 mL = 1 L

specific heat of (liquid) water (H₂O) = 1.00 cal/g°C.

\[ q = C \Delta T = mc \Delta T = nC_{\text{molar}} \Delta T \]

Dulong-Petit: \( C_{\text{molar}} = c \cdot AW = \text{specific heat} \times \text{atomic weight} \approx 6.0 \text{ cal/mole}°\text{C} \)

watt (W) = joule/s ; total energy delivered = watts • time (in s).

speed of light = 3.00 x 10⁸ m/s = (wavelength)•(frequency) = λ•f

1. A certain container (“coffee cup”) is used for calorimetry measurements. It has a heat capacity of 8.00 cal/°C. Two elemental solid samples, 70.00 g of iron (Fe) and 60.00 g of graphite (one form of carbon, C), are heated to 100°C and 80°C, respectively. While at these temperatures, they are transferred to this container which already contains 100.0 mL of water at 30°C. The specific heat of iron and graphite are 0.1074 cal/g°C and 0.170 cal/g°C, respectively. Assuming that the system is insulated, **determine the final temperature in °C. Show all work.**

**[Hint: There are 4 “q” terms which sum to zero (0): one for iron, one for carbon, one for the water, and one for the calorimeter. Every detail is known except for the final temperature (T_{final}). You can solve for it.]**
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\[ q_{\text{total}} = 0 = q(\text{Fe}) + q(C) + q(\text{H}_2\text{O}) + q(\text{cal}) \]

\[ 0 = [70\text{g} \times 0.1074 \text{ cal/g}^\circ\text{C}(T_i - 100^\circ\text{C})] + [60.0\text{g} \times 0.170 \text{ cal/g}^\circ\text{C}(T_f - 80^\circ\text{C})] + [100.0\text{g} \times 1.00 \text{ cal/g}^\circ\text{C}] \]

\[ 0 = T_i 7.518 \text{ cal}^\circ\text{C} - 751.8cal + T_i 10.2 \text{ cal}^\circ\text{C} - 81.6cal + T_i 100 \text{ cal}^\circ\text{C} - 300cal + T_i 8.00 \text{ cal}^\circ\text{C} - 240cal \]

\[ 0 = T_i 125.718 \text{ cal}^\circ\text{C} - 1373.4cal \]

\[ T_f = \frac{1373.4cal}{125.718 \text{ cal}^\circ\text{C}} \]

\[ T_f = 10.92^\circ\text{C} \]

2. **Dulong-Petit & Calorimetery**

(a) Another way to determine the heat capacity of a container (a.k.a. “calorimeter”) is to introduce a fixed amount of heat to the calorimeter – via a heating coil. The calorimeter will already contain a known amount of a known substance with a known heat capacity. A certain calorimeter is calibrated with liquid ethanol (\( \text{C}_2\text{H}_6\text{O}, \text{density} = 0.79 \text{ g/mL} \)). The specific heat of liquid ethanol is 0.583 \text{ cal/g}^\circ\text{C}. The source of heat is a heating coil with a power rating of 20 W (watt = J/s). When this source supplies heat for 4 minutes to 125.0 mL of ethanol, the temperature of the ethanol and calorimeter changes from 26.0^\circ\text{C} to 42.5^\circ\text{C}.

(i) Determine the total amount of energy delivered by the source of heat in 4 minutes in calories. 240s * 20w = 4800J 4800J / 4.184 cal per joule = 1147.2cal

(ii) Determine the heat capacity of the calorimeter (in cal/\(^\circ\text{C}\)), assuming the usual insulated conditions. Show all work.

**[Hint: The “\(q_{\text{total}}\)” equation will now look like this (think it through for yourself):**

\[ q_{\text{total}} = 0 = q_{\text{source}} + q_{\text{calorimeter}} + q_{\text{ethanol}} \]

As usual, \(q_{\text{calorimeter}}\) & \(q_{\text{ethanol}}\) will be expressed in terms of temperature change and the appropriate heat capacity factor, etc. But, \(q_{\text{source}}\) is the amount of heat released by the source, as calculated in (i).

Since this is a number that does not contain \(\Delta T\), the proper algebraic sign must be properly assigned. Since this energy is released, what should the sign be?]

\[ q_{\text{total}} = 0 = q_{\text{source}} + q_{\text{calorimeter}} + q_{\text{ethanol}} \]

\[ q_{\text{total}} = 0 = 1147.2cal + mc(-16.5^\circ\text{C}) + 98.75g \times 0.583 \text{ cal/g}^\circ\text{C} \times -16.5^\circ\text{C} \]

\[ 0 = 1147.2cal + mc(-16.5^\circ\text{C}) - 949.9cal \]

\[ 0 = 197.3cal + mc(-16.5^\circ\text{C}) \]

\[-197.3cal = mc(-16.5^\circ\text{C}) \]

\[ mc = \frac{-197.3cal}{-16.5^\circ\text{C}} = 11.9 \text{ cal/}^\circ\text{C} \]
(b) An elemental metal, believed to follow the law of Dulong and Petit, is analyzed in this same calorimeter. The calorimeter is cleaned and 80.0 mL of water at 20.00ºC is poured in. A 100.00 g sample of the elemental metal is heated to 120.00ºC and immediately transferred to the water in the calorimeter. The final temperature is determined to be 26.75ºC. Assuming the usual insulated conditions, determine the specific heat of the metal in cal/gºC.

$$0 = q_{metal} + q_{cal} + q_{water}$$

$$0 = 100g \times c \times (26.25 - 120.00ºC) + 80g \times c \times (26.25ºC - 20.00ºC) + 119\, \text{cal}$$

$$0 = 100g \times c \times (26.25 - 120.00ºC) + 803.25\, \text{cal} + 540.00\, \text{cal}$$

$$0 = 100g \times c \times (26.25 - 120.00ºC) + 1343.25\, \text{cal}$$

$$-1343.25\, \text{cal} = 100g \times c \times (6.25ºC)$$

$$c = -\frac{1343.25\, \text{cal}}{625gºC}$$

$$c = -2.1492\, \text{cal/gºC}$$

(c) Apply the Law of Dulong and Petit to determine the atomic weight of the elemental metal (in g/mole). Consult a periodic table and identify the elemental metal.

**specific heat \times atomic weight \approx 6.0 \text{cal/mole-ºC}**

$$AW = \frac{6.0\, \text{cal/mole-ºC}}{2.1492\, \text{cal/gºC}}$$

$$AW = 2.79 \, \text{g / mole}$$

The cold-pack & calorimetry

3. The heat flow due to a chemical reaction (q_{reaction}) can be determined via calorimetry.

Consider the reaction involved in a cold-pack. A cold-pack contains chemicals that when brought in contact will initiate a chemical reaction that will absorb heat from the environment and so lower the temperature of the injured area. For sake of argument, let’s assume that a particular cold-pack operates via the dissolution (dissolving) of ammonium chloride (NH₄Cl) in water. The reaction can be depicted as:

$$\text{NH}_4\text{Cl}(\text{solid}) \longrightarrow \text{NH}_4\text{Cl}(\text{dissolved})$$

The goal is to find the heat of reaction per mole of NH₄Cl that dissolves. A particular calorimeter (“coffee cup”) has a heat capacity of 10.50 cal/ºC. 50.00 grams of NH₄Cl is added to 200.0 mL of water and completely dissolved.

The temperature of the water before dissolution is 26.5ºC. The specific heat of the contents of the calorimeter after dissolution is 1.05 cal/gºC. The final temperature after complete dissolution is 14.4ºC. [The “q_{total}” equation will now look like this (think it through for yourself): q_{total} = 0 = q_{reaction} + q_{calorimeter} + q_{contents}. As usual, q_{calorimeter} & q_{contents} will be expressed in terms of temperature change and the appropriate heat capacity factor, etc. Hence, one can solve for q_{reaction}]

$$q_{total} = 0 = q_{reaction} + q_{calorimeter} + q_{contents}$$
Please determine the following. Show all work.

(a) Determine the mass of the contents of the calorimeter (NH$_4$Cl + water) in grams.

\[ 200\text{g water} + 50.00\text{gNH}_4\text{Cl} = 250\text{g(NH}_4\text{Cl + water)} \]

(b) Determine $q_{\text{contents}}$ and $q_{\text{calorimeter}}$ in calories.

\[ q(\text{contents}) = 10.50\text{cal/(14.4°C – 26.5°C)} + 50.00\text{g} \times 1.05\text{cal/g°C} \times (14.4°C – 26.5°C) \]
\[ q(\text{contents}) = -127.05\text{cal} – 635.25\text{cal} \]

(c) Assuming insulated conditions, determine $q_{\text{reaction}}$ in calories. Does the $q_{\text{reaction}}$ have the proper algebraic sign consistent with how the cold-pack operates?

YES

[Note that $q_{\text{reaction}}$ = heat flow due to the chemical reaction can be a positive or negative #. If the # is negative (-), the reaction releases heat (termed exothermic). Similarly, if the # is positive (+), the reaction absorbs heat (termed endothermic).]

(d) Express $q_{\text{reaction}}$ in kcal per mole of NH$_4$Cl dissolved.

\[ 0.07845 \text{ kcal per mole of NH}_4\text{Cl} \]

**Preamble to Question 4: The Bomb Calorimeter + “Burning Food”**

Often, the heat flow due to a chemical reaction ($q_{\text{reaction}}$) that involves combustion (i.e., the reaction of a substance with gaseous O$_2$ a.k.a. “burning”) - uses a bomb calorimeter. The device is merely a fancier version of the “coffee cup” calorimeter. The calorimeter is actually a thick-walled stainless steel container (the “bomb”). [The thick walls are required to withstand the high pressure of O$_2$ gas pumped in that is necessary for the combustion.]

In this case, the reactants of the desired chemical reaction (foodstuff + O$_2$) are placed inside the bomb. Now, a large water bath surrounds the bomb. The purpose of the water bath is to take up any heat exchange through the bomb arising from the chemical reaction – thus maintaining insulation. The thermometer is placed in the water bath. A diagram on the next page shows the set-up. (What is the purpose of the ignition switch?)
Hence, for this case, the “$q_{\text{total}}$” equation takes the form:

- $q_{\text{total}} = 0 = q_{\text{reaction}} + q_{\text{calorimeter}} + q_{\text{water bath}}$; where
- $q_{\text{calorimeter}} = C_{\text{calorimeter}} \Delta T = C_{\text{calorimeter}}(T_f - T_i)$; and
- $q_{\text{water bath}} = m_{\text{water}} c_{\text{water}} \Delta T = m_{\text{water}} c_{\text{water}}(T_f - T_i)$.
- Recall: $q_{\text{reaction}}$ is negative (-) if the reaction is exothermic (releases heat) and it is positive (+) if the reaction is endothermic (absorbs heat).

The diagram of a bomb calorimeter is provided on the next page.

4. (continued) **Diagram of a bomb calorimeter**:

![Diagram of a bomb calorimeter](modified_from: www.chm.davidson.edu/ronutt/che115/Bomb/picture.htm)

4. **The Food Calorie Content of Food**
   Nutritional tables quote that the (food) Calorie content of fats, carbohydrates, and proteins (per gram) are: 9.00, 4.00, and 4.00, respectively. A food Calorie is actually one kilocalorie, i.e., 1 (food) Cal = 1 kcal = 1000 cal. Thus, the values listed above refer to
the heat released in kcal when one (1.00) gram of each of the substances is completely combusted (reacted with O\textsubscript{2}). This is exactly what your body does but in many metabolic steps – rather than all at once. This should not effect the total energy released (why?).

*It should not effect it because the calorie content (energy) of the fuel is fixed. Energy cannot be created or destroyed, so no matter how many steps it takes to combust all of the fuel the total energy available will not change. Therefore the the total energy released must be the same as well.*

Thus, combusting (metabolizing) a foodstuff can be thought of as combusting its fat component plus its carbohydrate component plus its protein component. This sum would be \( q_{\text{reaction}} \).

Consider 5.00 g (< 0.2 oz.) of a “low fat - high protein” foodstuff that is (in mass %): 10.0 % fat, 75.0 % protein, and 15.0 % carbohydrate. This foodstuff is completely combusted in a bomb calorimeter. Assume the bomb (calorimeter) has a heat capacity of 660.0 cal/\degree C and is surrounded by 1.60 liters of water. Also assume that the initial temperature of the calorimeter and contents is 25.00\degree C. Please determine the following. *Show all work.*

(a) Determine the mass (in g) of each component of the 5.00 g foodstuff: fat, carbohydrate, and protein.

Fat content = 5.00 g \times 0.10 = 0.5 g
Carb content = 5.00 g \times 0.15 = 0.75 g
Protein content = 5.00 g \times 0.75 = 3.75 g

(b) Determine the total amount of heat that should be released by the foodstuff (\( q_{\text{reaction}} \)) if it is completely combusted. *Don’t forget to include the correct algebraic sign.*

\[
\begin{align*}
0.5 \text{ g} & \times 9000 \text{ cal/g} = 4500 \text{ cal}_{\text{fat}} \\
0.75 \text{ g} & \times 4000 \text{ cal/g} = 3000 \text{ cal}_{\text{carb}} \\
3.75 \text{ g} & \times 4000 \text{ cal/g} = 15000 \text{ cal}_{\text{protein}} \\
4500 \text{ cal} + 3000 \text{ cal} + 15000 \text{ cal} = 22500 \text{ cal}
\end{align*}
\]

(c) Assuming, as usual, that the system is insulated, determine the final temperature (\( T_{\text{final}} \)) that should result in \degree C.

- \( q_{\text{total}} = 0 = q_{\text{reaction}} + q_{\text{calorimeter}} + q_{\text{water bath}} \); where
- \( q_{\text{calorimeter}} = C_{\text{calorimeter}} \times \Delta T = C_{\text{calorimeter}} \times (T_f - T_i) \); and
- \( q_{\text{water bath}} = m_{\text{water}} \times c_{\text{water}} \times \Delta T = m_{\text{water}} \times c_{\text{water}} \times (T_f - T_i). \)
\[ q_{\text{total}} = 0 = C_{\text{calorimeter}} \otimes (T_f - T_i) + m_{\text{water}} \otimes c_{\text{water}} \otimes (T_f - T_i) + q_{\text{reaction}} \]
\[ q_{\text{total}} = 0 = 660.0 \text{ cal/}^\circ\text{C} \otimes (T_f - 25^\circ\text{C}) + 1600 \text{g} \otimes \text{lcal/g} \otimes (T_f - 25^\circ\text{C}) - 22500 \text{cal} \]
\[ q_{\text{total}} = 0 = 2260.0 \text{ cal/}^\circ\text{C} \otimes (T_f - 25^\circ\text{C}) - 22500 \text{cal} \]
\[ 22500 \text{cal} = 2260.0 \text{cal/}^\circ\text{C} \otimes (T_f - 25^\circ\text{C}) \]
\[ \frac{22500 \text{cal}}{2260.0 \text{cal/}^\circ\text{C}} = (T_f - 25^\circ\text{C}) \]
\[ 9.558^\circ\text{C} = (T_f - 25^\circ\text{C}) \]
\[ T_f = 34.558^\circ\text{C} \]

5. Electromagnetic Radiation “Quickies” – Frequency, Wavelength, & Total Energy

(a) Consider the hypothetical electromagnetic wave pictured below. The horizontal scale is in nanometers. The vertical scale is in arbitrary units of electric field strength. Each unlabeled tickmark on the horizontal axis is exactly half-way between its neighboring labeled tickmarks.

Determine the \textit{wavelength} of the wave (in nm) and the \textit{frequency} (in Hz). Is this wave in the visible region (400 nm – 700 nm) of the electromagnetic spectrum?

1 wavelength = 875 nm - 175 nm = 700 nm

The wavelength is 700 nm

If so, what color might it be?

This wavelength is bordering on ultraviolet-visible boundary. It would most probably be violet.

If not, what region of the electromagnetic spectrum is it? It would be ultraviolet light.
(b) For each of the listed sources of electromagnetic radiation determine the following. Show all work.

(i) The total energy delivered (in joules) in three minutes.

1.0kw*180s=180,000J
50.0kw*180=9000000J
800w*180s=144000

(ii) The wavelength in meters.

d=c/T

d = \frac{3 \times 10^8 \text{ m/s}}{88.5 \times 10^6 \text{ s}^{-1}} = 3.39 \text{ m}

d = \frac{3 \times 10^8 \text{ m/s}}{1.060 \times 10^6 \text{ s}^{-1}} = 283.0 \text{ m}

d = \frac{3 \times 10^8 \text{ m/s}}{2.45 \times 10^9 \text{ s}^{-1}} = .1228 \text{ m}

- Penn’s radio station (WXPN) 88.5 FM* - transmitting with a power of 1.0 kW.
- KYW News radio station 1060 AM* - transmitting with a power of 50.0 kW.
- A 2.45 GHz microwave oven (G = Giga = 10^9) – heating with a power of 800 W.

*The radio dial number for an **FM radio station** is its frequency in **MHz** (M = Mega = 10^6) while the radio dial number for an **AM station** is its frequency in **kHz**.