Calorimetry

Calorimetry: experimental technique used to measure the change in energy of a chemical reaction or phase change.

1. Put a chemical reaction or phase change in contact with a water bath.
2. Measure the change in temperature of the water bath and then calculate the energy gained or lost by water.
3. The energy change in the water is **EQUAL** and **OPPOSITE** to the heat change by the system!
   a. The system can be an object, a phase change, or a chemical reaction.
      ➔ energy gained by calorimeter = energy lost by the system

$$q_{H_2O} = -q_{object} \text{ or } -q_{rxn}$$

$$+[\text{mC}\Delta\text{T}]_{H_2O} = -[\text{mC}\Delta\text{T}]_{object} \text{ or } -[\text{mC}\Delta\text{T}]_{rxn}$$

➔ Remember the specific heat of water: 4.184 J/g°C (or 4.18)

$T_f = T_{final}$

$T_i = T_{initial}$

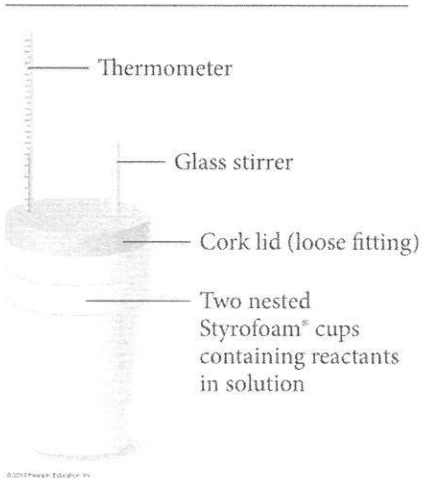
➔ $\Delta T = T_f - T_i$. When thermal equilibrium is reached, **BOTH** the water bath and the object/reaction will have the SAME final temperature! $T_f(H_2O) = T_f(\text{object})$

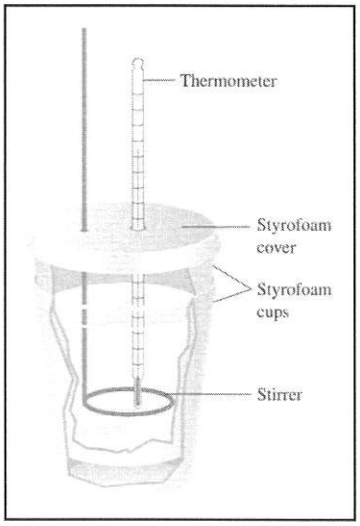
Warning: Experimental Error with Calorimetry!

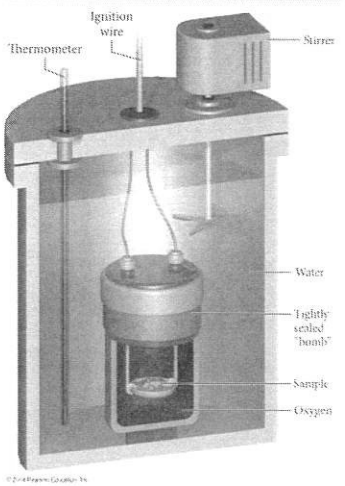
- We assume in the above equation that **ALL** energy lost by the system is gained only by the water, but that's not true!
- The calorimeter (container, usually a cup) can also absorb heat (which means the calorimeter has a measurable heat capacity!), or heat can be lost to the air.
- Both of these errors would lead to a calculated heat (q) that was ↓ than the actual heat exchange.

Types of Calorimeters:

1. Coffee **cup calorimeter**: coffee cups are commonly used as insulators in intro chemistry classes to measure temperature changes without a substantial loss of energy to the surroundings (they can be VERY effective!)
2. Bomb **calorimeters** are used at the professional level. Bomb calorimeters provide greater insulation and reduce heat loss to the surroundings (thus minimizing error).


The Coffee-Cup Calorimeter




The Bomb Calorimeter

Guided Practice

1. A 5.037 g piece of iron heated to 100.°C is placed in a coffee cup calorimeter that initially contains 27.3 g of water at 21.2°C. If the final temperature is 22.7°C, what is the specific heat capacity of the iron (J/g°C)? The specific heat capacity of water is 4.18 J/g K.

$$+q_{H_2O} = -q_{Fe}$$

$$(27.3\,g)(4.18\,\tfrac{J}{g^\circ C})(\underbrace{22.7^\circ C - 21.2^\circ C}_{\text{2 s.f! } 1.5^\circ C}) = -(5.037\,g)(C_{Fe})(\underbrace{22.7^\circ C - 100.^\circ C}_{-7\underline{7}.3^\circ C\ ]\ \text{2 s.f!}})$$

$$C_{Fe} = \frac{(27.3)(4.18)(1.5)}{(-5.037)(-77.3)} = \boxed{0.44\,\tfrac{J}{g^\circ C}}$$

2. A 376 g sample of gold at 400. K is placed in a coffee cup calorimeter containing 50.0 mL of water at 300. K. Determine the final temperature of the water (assuming that no heat is lost to the surroundings). The specific heat capacity of gold is 0.128 J/g°C.

$$+q_{H_2O} = -q_{Au}$$

$$(50.0\,g)(4.18\,\tfrac{J}{g^\circ C})(T_f - 300.\,K) = -(376\,g)(0.128\,\tfrac{J}{g^\circ C})(T_f - 400.\,K)$$

$$209(T_f - 300.) = \underbrace{-48.\underline{1}28}_{3\,s.f.}(T_f - 400.)$$

$$209\,T_f - 62{,}700 = -48.128\,T_f + 19{,}\underline{2}51.2$$

$$25\underline{7}.128\,T_f = 81{,}\underline{9}51.2$$

$$T_f = \frac{81{,}\underline{9}51.2}{25\underline{7}.128} = \boxed{319\,K}$$

More Practice: Yay!

3. When 25.0 g of a metal at 90.°C is added to 50. g of water at ~~25°C~~ 25.0°C, the temperature of the water rises to 29.8°C. What is the specific heat capacity of the metal? Assume no heat was lost to the surroundings. $(C_{H_2O} = 4.184\,\frac{J}{g^\circ C})$

$$+q_{H_2O} = -q_{metal}$$

$$(50.\,g)(4.184\,\tfrac{J}{g^\circ C})(\underbrace{29.8^\circ C - 25.0^\circ C}_{\underbrace{4.\underline{8}^\circ C}_{2\,s.f.}}) = -(25.0\,g)\,C_{metal}\,(\underbrace{29.8^\circ C - 90.^\circ C}_{\underbrace{-6\underline{0}.2^\circ C}_{2\,s.f.}})$$

$$C_{metal} = \frac{(50.)(4.184)(4.8)}{(-25.0)(-60.2)} = \boxed{0.67\,\tfrac{J}{g^\circ C}}$$

$394 - 273 = 121°C$ ↑

in °C?

$= 65.0 g$ $(d = 1.00 g/mL)$

4. A 120. g sample of titanium at 394 K is placed in a coffee cup calorimeter containing 65.0 mL of water at 23.0°C. If no heat is lost to the surroundings, what will be the final temperature of the titanium? The specific heat capacity of titanium is 0.523 J/g°C.

$$+q_{H_2O} = -q_{Ti}$$

$$(65.0 g)(4.18 \tfrac{J}{g°C})(T_f - 23.0°C) = -(120. g)(0.523 \tfrac{J}{g°C})(T_f - 121°C)$$

$$27\underline{1}.7(T_f - 23.0) = -62.76(T_f - 121)$$

$$27\underline{1}.7T_f - 62\underline{4}9.1 = -62.76T_f + 75\underline{9}3.96$$

$$33\underline{4}.46\,T_f = 13,8\underline{4}3.06$$

$$T_f = \frac{13,8\underline{4}3.06}{33\underline{4}.46} = \boxed{41.4°C}$$

5. A student is provided with a sample of an unknown metal, a coffee cup calorimeter, a temperature probe, and unlimited water. They are asked to identify the unknown metal.

a. Answering the following questions about the experimental method the student should use in this experiment.

i. What measurements will the student need to make in order to identify their unknown metal?

- initial temp. (T_i) and mass (m) of metal
- T_i and m of H_2O (in coffee cup)
- $\underbrace{T_f}_{\text{final temp.}}$ (metal + H_2O after they reach thermal equil.)

ii. What calculations will the student need to perform? Explain how the student could use the measurements described above to perform these calculations.

The student can plug the measurements above into the eqt'n below:

$$(mC\Delta T)_{H_2O} = -(mC\Delta T)_{metal}$$

They can then solve for C_{metal} (the unknown metal's specific heat capacity).

iii. How can the student use the results of their calculations to identify their unknown metal? What other information will they need?

- they need a table of specific heat capacities of different metals
- the student can match their calculated c_{metal} to a metal on the table with a specific heat capacity closest to their experimentally determined value.

Multiple Choice Practice FTW!

6. How much heat is required to raise the temperature of 100. g of Fe_2O_3 from 5.0°C to 25.0°C? The specific heat of Fe_2O_3 is 0.634 J/g°C.

[✓ a.] 1.27 kJ
b. 0.0634 kJ
c. 1.58 kJ
d. 0.845 kJ

$$q = mC\Delta T = (100.\,g)\left(0.634\,\frac{J}{g^\circ C}\right)(25.0^\circ C - 5.0^\circ C)$$
$$= (100)(0.634)(20) \approx 2{,}000 \times 0.6$$
$$= 1{,}200\,J = 1.2\,kJ$$

7. For an experiment, 50.0 g of H_2O was added to a coffee-cup calorimeter. The initial temperature of the H_2O was 22.0°C, and it absorbed 300.J of heat from an object that was carefully placed inside the calorimeter. Assuming no heat is transferred to the surroundings, which of the following was the approximate temperature of the H_2O after thermal equilibrium was reached? Assume that the specific heat capacity of H_2O is 4.2 J/(g·K). → Same as $\frac{J}{g^\circ C}$

a. 21.3°C
b. 22.0°C
c. 22.7°C
[✓ d.] 23.4°C

$$q = mC\Delta T$$
$$300\,J = (50.0g)\left(4.2\,\frac{J}{g^\circ C}\right)(T_f - 22.0^\circ C)$$
$$T_f - 22 = \frac{300}{(50)(4.2)} \approx \frac{300}{200} = 1.5$$
$$T_f = 1.5 + 22 = 23.5^\circ C$$

8. A 50 g sample of a metal is heated to 100°C and then placed in a calorimeter containing 100.0 g of water (c = 4.18 J/g°C) at 20°C. The final temperature of the water is 24°C. Which metal was used?

a. Lead (c = 0.14 J/g°C)
b. Copper (c = 0.20 J/g°C)
[✓ c.] Iron (c = 0.45 J/g°C)
d. Aluminum (c = 0.89 J/g°C)

$$q_{H_2O} = -q_{metal}$$
$$(100)(4.18)(24-20) = -50(C_{metal})(24-100)$$
$$(100)(4)(4) \approx (50)(75)\,C_{metal}$$
$$C_{metal} = \frac{(100)(16)}{(50)(75)} \approx \frac{2\cdot 15}{75} = \frac{2}{5} = 0.4\,\frac{J}{g^\circ C}$$