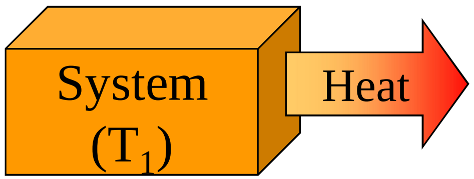
Heat capacity

Heat (q)

- **Heat:** the transfer of energy between objects due to a temperature difference
  - Flows from higher-temperature object to lower-temperature object

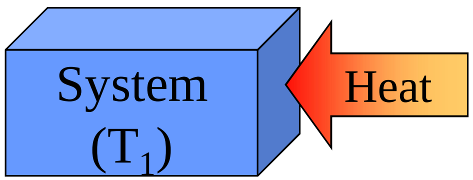


Surroundings
(T_2)

If $T_1 > T_2$

$q_{\text{system}} = -$

exothermic



Surroundings
(T_2)

If $T_1 < T_2$

$q_{\text{system}} = +$

endothermic

Calorimetry: the measurement of heat flow

- device used is called a... calorimeter

specific heat capacity (C): amount of heat needed to raise temperature of 1 g of a substance 1^{o}C (1 K)

- Only useable <u>within</u> a state of matter (i.e. s, l, or g)

For energy changes involving…

heat of fusion (ΔH_{fus}): melting/freezing

heat of vaporization (ΔH_{vap}): boiling/condensing

There are <u>NO</u> temp changes during a phase change.

Various Specific Heat Capacities

Substance	Specific heat capacity (J/K g)
Gold	0.129
Silver	0.235
Copper	0.385
Iron	0.449
Aluminum	0.897
$H_2O_{(l)}$	4.184
$H_2O_{(s)}$	2.03
$H_2O_{(g)}$	1.998

Metals do not generally require much energy to heat them up
(i.e. they heat up easily)

Water requires much more energy to heat up

We can find the heat a substance loses or gains using:

where q = heat (J)

m = mass of substance (g)

C = specific heat (J/g^{o}C)

ΔT = temperature change (^{o}C)

ΔH = heat of vap/fus (J/g)

$$\boxed{q = m\,C\,\Delta T}$$

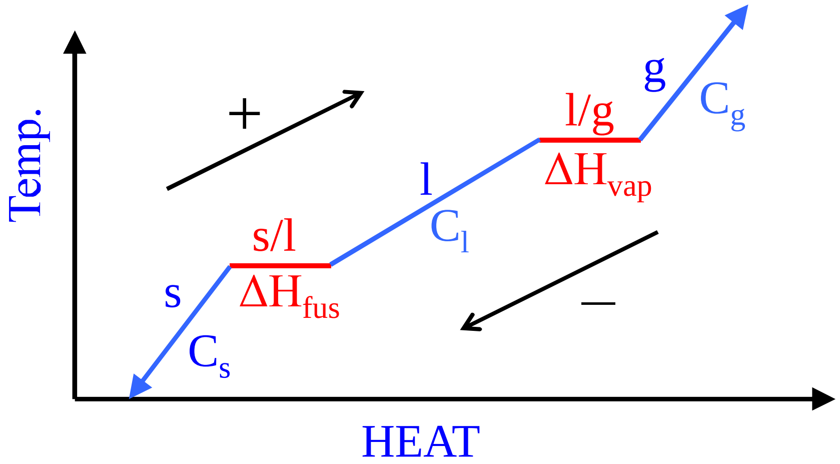
(used <u>within</u> a given state of matter)

AND

$$\boxed{q = m\,\Delta H}$$

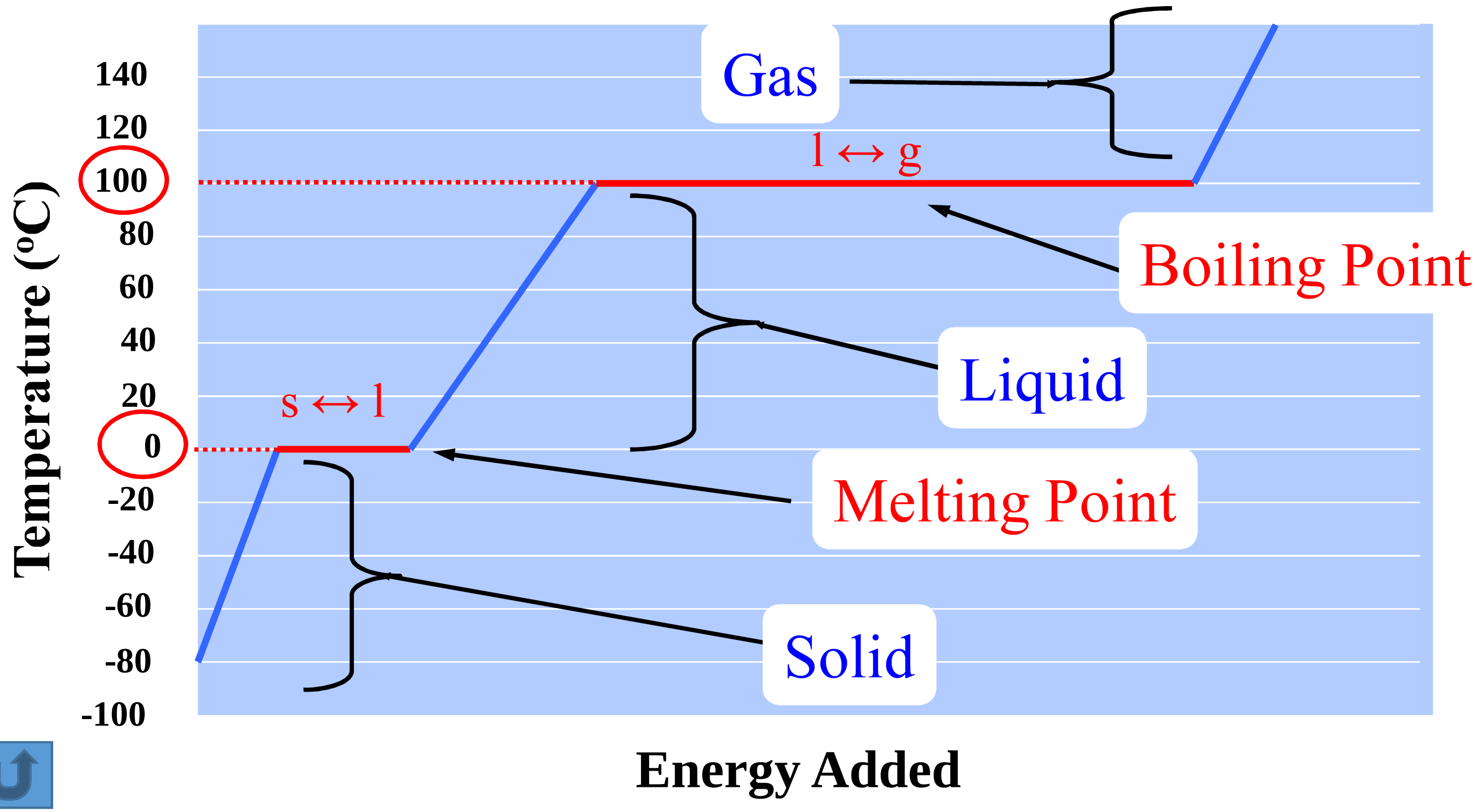
(used <u>between</u> two states of matter or during a phase change)

Heating Curve

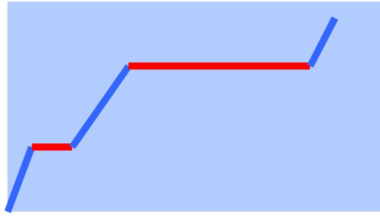


Δ = final – initial

Heating Curve of water



Heating Curves



- **Temperature Change within phase**
  - change in KE (molecular motion)
  - depends on heat capacity of phase

    C H_2O (l) = 4.184 J/g°C

    C H_2O (s) = 2.077 J/g°C (requires the most heat)

    C H_2O (g) = 2.042 J/g°C

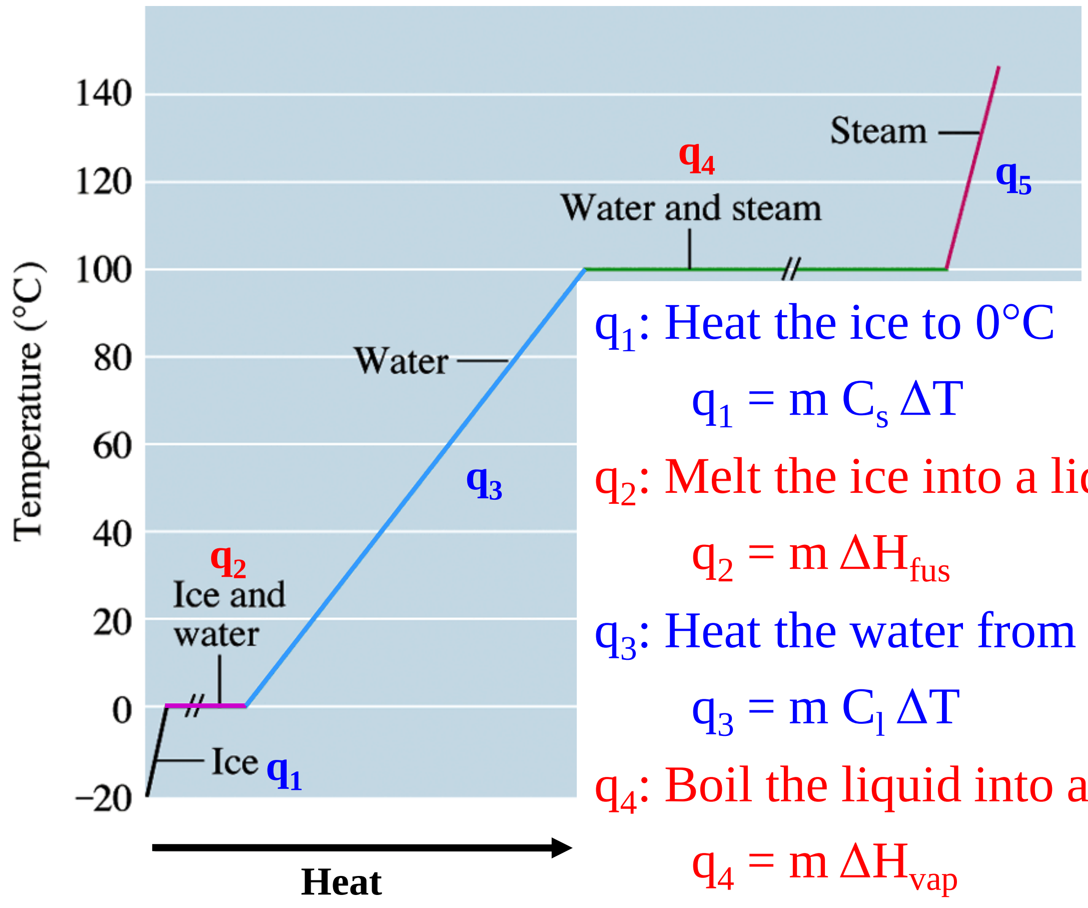
- **Phase Changes (s ↔ l ↔ g)** (requires the least heat)
  - change in PE (molecular arrangement)
  - temperature remains constant
  - overcoming intermolecular forces

ΔH_{fus} = 333 J/g **(s ↔ l)**

ΔH_{vap} = 2256 J/g **(l ↔ g)** Why is this so much larger?

Heating Curve of Water

From Ice to Steam in Five Easy Steps



q_1: Heat the ice to 0°C

$$q_1 = m\,C_s\,\Delta T$$

q_2: Melt the ice into a liquid at 0°C

$$q_2 = m\,\Delta H_{fus}$$

q_3: Heat the water from 0°C to 100°C

$$q_3 = m\,C_l\,\Delta T$$

q_4: Boil the liquid into a gas at 100°C

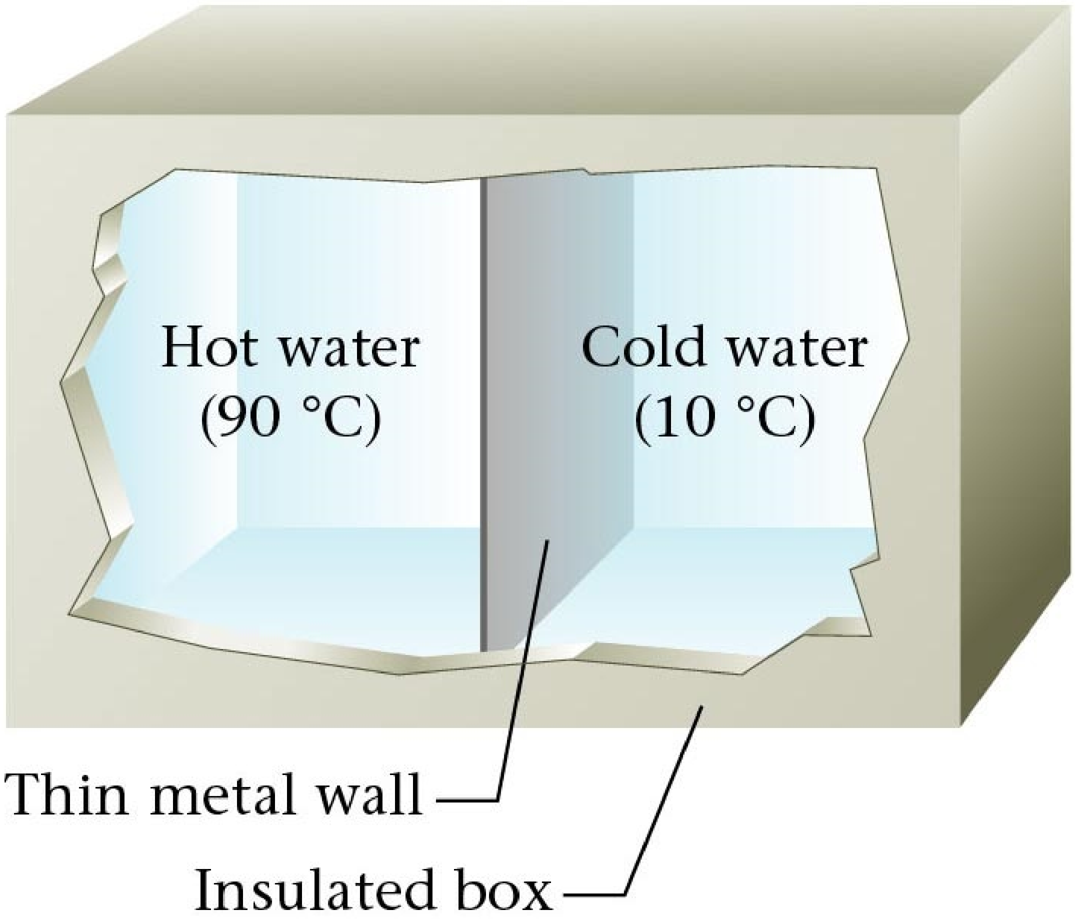
$$q_4 = m\,\Delta H_{vap}$$

q_5: Heat the gas above 100°C

$$q_5 = m\,C_g\,\Delta T$$

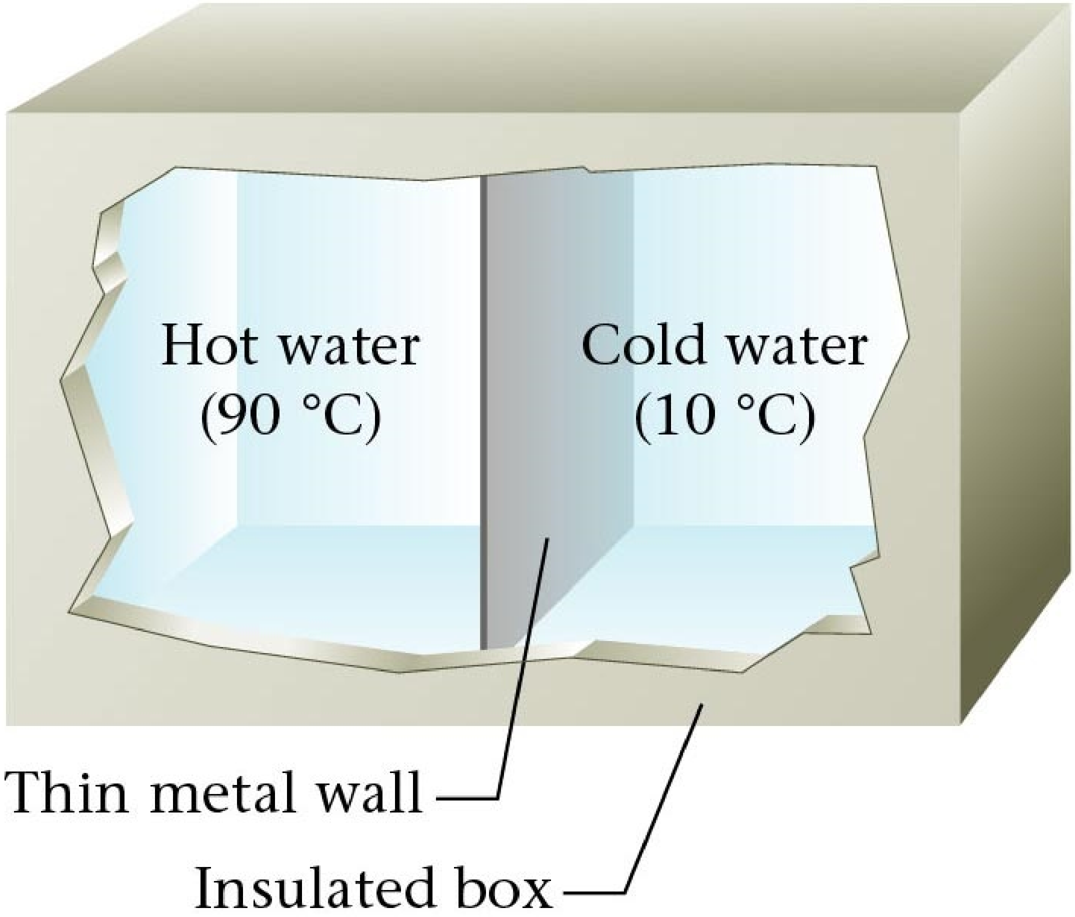
$$\boxed{q_{tot} = q_1 + q_2 + q_3 + q_4 + q_5}$$

What will happen over time?



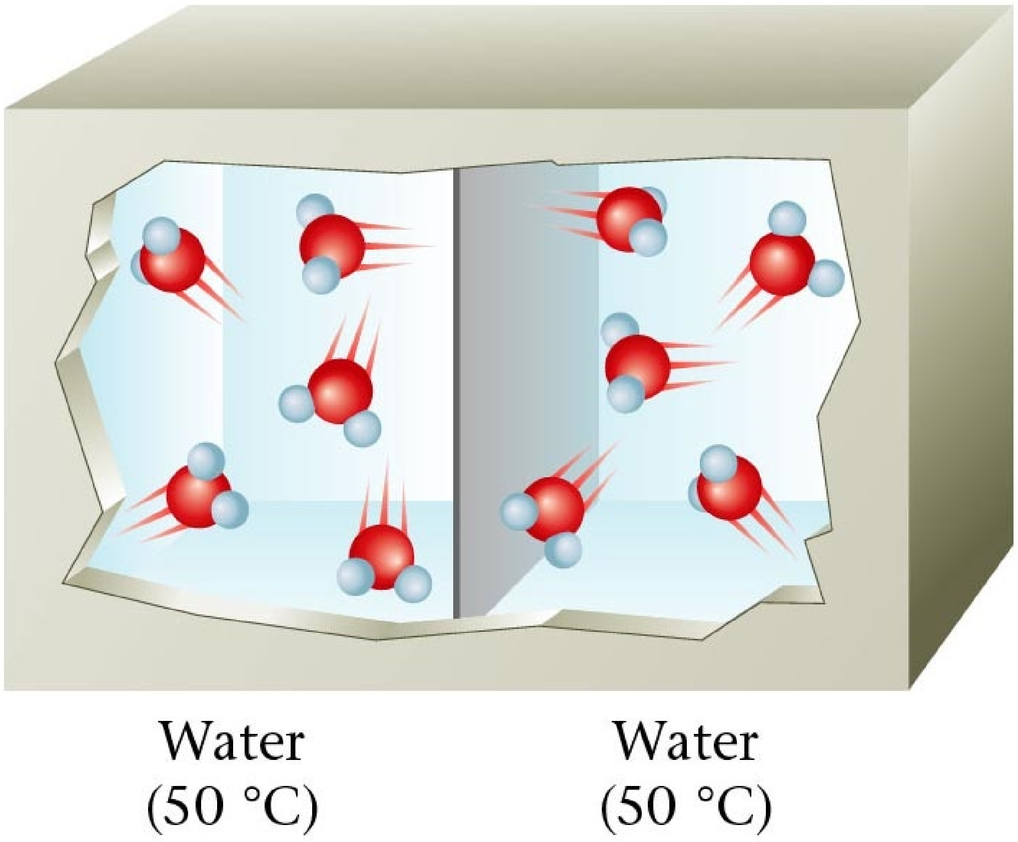
Zumdahl, Zumdahl, DeCoste, World of Chemistry 2002, page 291

Let’s take a closer look…



Zumdahl, Zumdahl, DeCoste, World of Chemistry 2002, page 291

Eventually, the temperatures will equalize

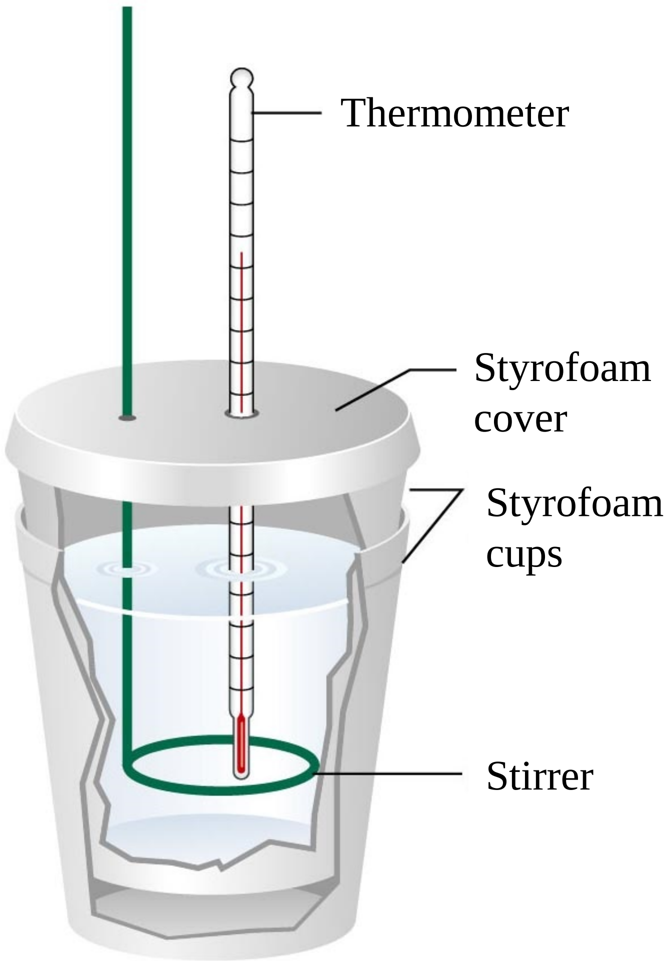


Zumdahl, Zumdahl, DeCoste, World of Chemistry 2002, page 291

Calorimetry

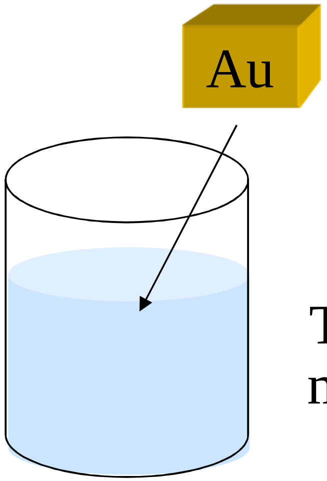
If we assume that no heat is lost to the surroundings, then the energy absorbed inside the calorimeter must be equal to the energy released inside the calorimeter.

$$q_{\text{absorbed}} = -\, q_{\text{released}}$$



An example: (Ignore from heat exchange of the calorimeter)

2. A 97.0 g sample of gold at 785^{o}C is dropped into 323 g of water, which has an initial temperature of 15.0^{o}C. If gold has a specific heat of 0.129 J/g^{o}C, what is the final temperature of the mixture? Assume that the gold experiences no change in state of matter.



T = 785^{o}C
mass = 97.0 g

T = 15.0 ^{o}C
mass = 323 g

lose heat = gain heat

$$[(C\ Au)\ (mass)\ (\Delta T)] = (C\ H_2O)\ (mass)\ (\Delta T)$$

$$[(0.129)\ (97)\ (785 - T_f)] = (4.184)\ (323)\ (T_f - 15)]$$

$$[(12.5)\ (785 - T_f)] = (1.35 \times 10^3)\ (T_f - 15)]$$

$$-12.5\ T_f + 9.82 \times 10^3 = 1.35 \times 10^3\ T_f - 2.02 \times 10^4$$

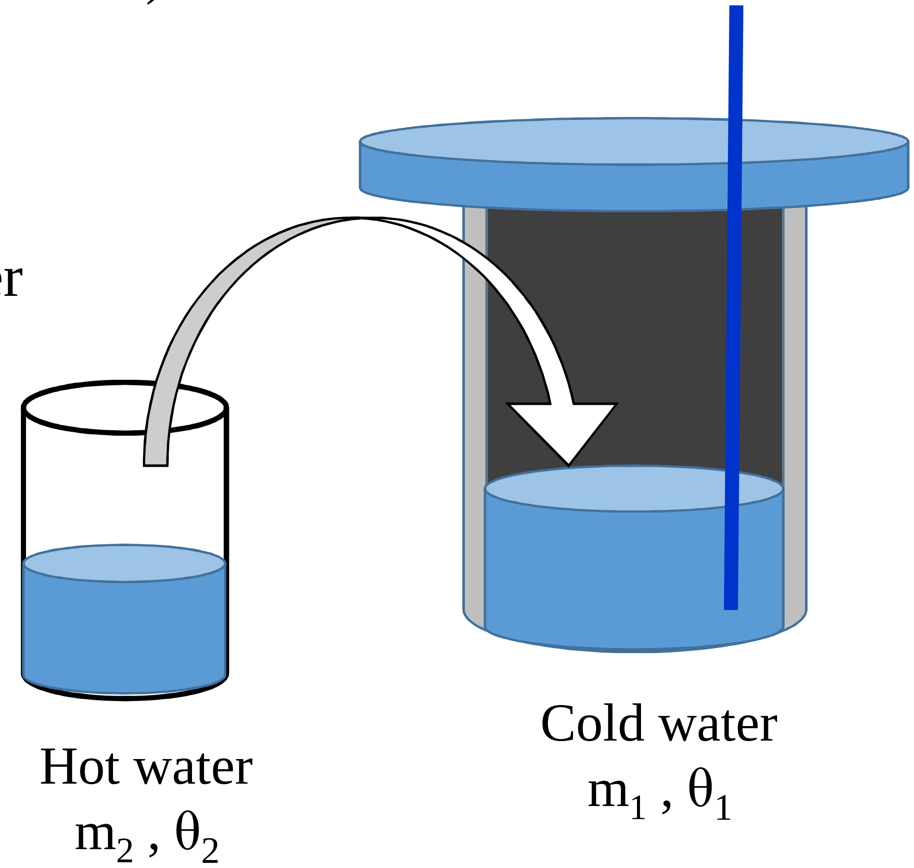
$$3 \times 10^4 = 1.36 \times 10^3\ T_f$$

$$T_f = 22.1^{o}C$$

Calorimetry experiment

First Step (measurement of heat capacity of calorimeter = A):

- m_1 = mass of cold water in calorimeter
- θ_1= temperature of cold water and calorimeter
- m_2 = mass of hot water
- θ_2 = temperature of hot water
- θ_e = equilibrium temperature
- c_w= specific heat capacity of water
- A = heat capacity of calorimeter



Equations of heat exchange in the calorimeter

Lose heat = Gain heat → A = ?

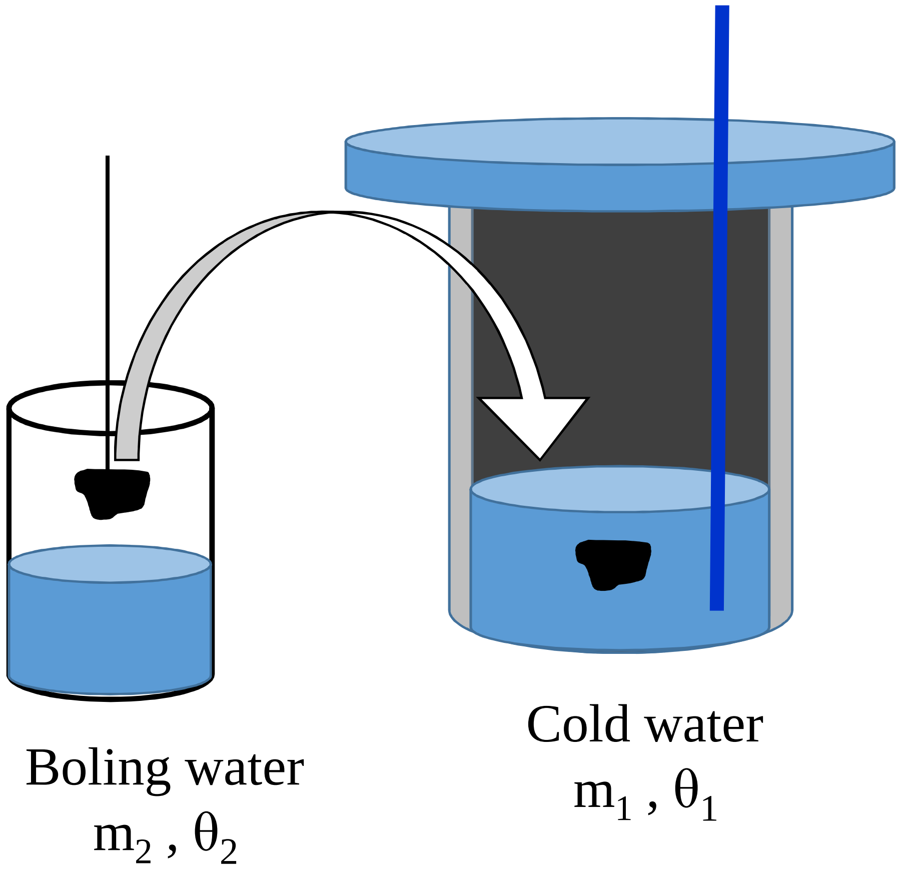
$$m_2\, c_w\, (\theta_2 - \theta_e) = m_1\, c_w\, (\theta_e - \theta_1) + A\, (\theta_e - \theta_1)$$

$$A = \frac{1}{(\theta_e - \theta_1)}[m_2\, c_w\, (\theta_2 - \theta_e) - m_1\, c_w\, (\theta_e - \theta_1)]$$

Calorimetry experiment

Second Step (measurement of specific heat capacity of metal):

- ❖ m_1 = mass of cold water in calorimeter
- ❖ θ_1= temperature of cold water and calorimeter
- ❖ m_2 = mass of metal
- ❖ θ_2 = temperature of water vapor
- ❖ θ_e = equilibrium temperature
- ❖ c_w= specific heat capacity of water
- ❖ A = heat capacity of calorimeter
- ❖ c_m = specific heat capacity of metal



Equations of heat exchange in the calorimeter

Lose heat = Gain heat $\rightarrow c_m = ?$

$$m_2 c_m (\theta_2 - \theta_e) = m_1 c_w (\theta_e - \theta_1) + A (\theta_e - \theta_1)$$

$$c_m = \frac{1}{m_2(\theta_2 - \theta_e)}[m_1 c_w (\theta_e - \theta_1) + A(\theta_e - \theta_1)]$$