Thermochemistry

- The study of the ENERGY CHANGES that accompany changes in matter

3 Ways:

Physical: Hydrogen boils at −252°C (or only about 20°C above absolute zero):
$H_{2(l)} \rightarrow H_{2(g)}$

Chemical: Hydrogen is burned as fuel in the space shuttle's main engines:
$2\ H_{2(g)} + O_{2(g)} \rightarrow 2\ H_2O_{(l)}$

Nuclear: Hydrogen undergoes nuclear fusion in the Sun, producing helium:
$H + H \rightarrow He$

Thermodynamics

FIRST LAW OF THERMODYNAMICS

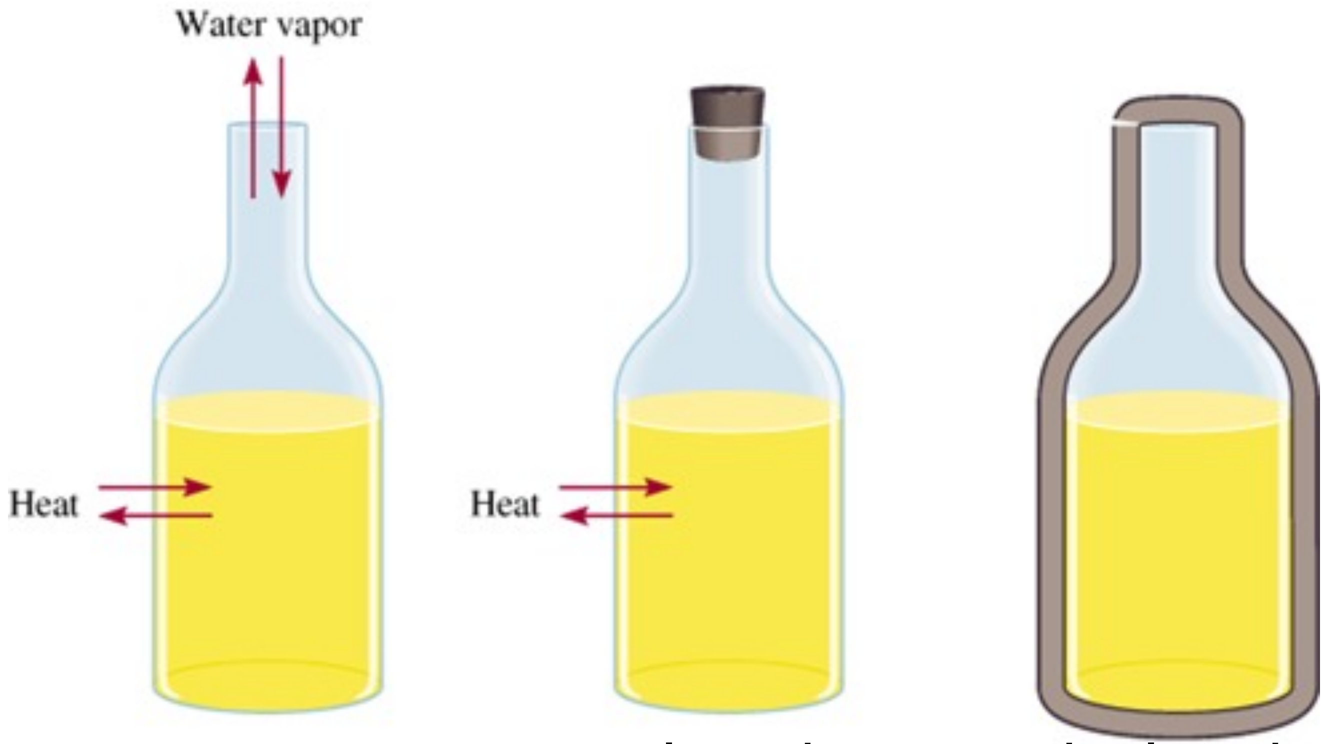
the total amount of energy in the universe is constant

(conservation of energy)

System v. Surroundings

chemical system a set of reactants and products under study, usually represented by a chemical equation

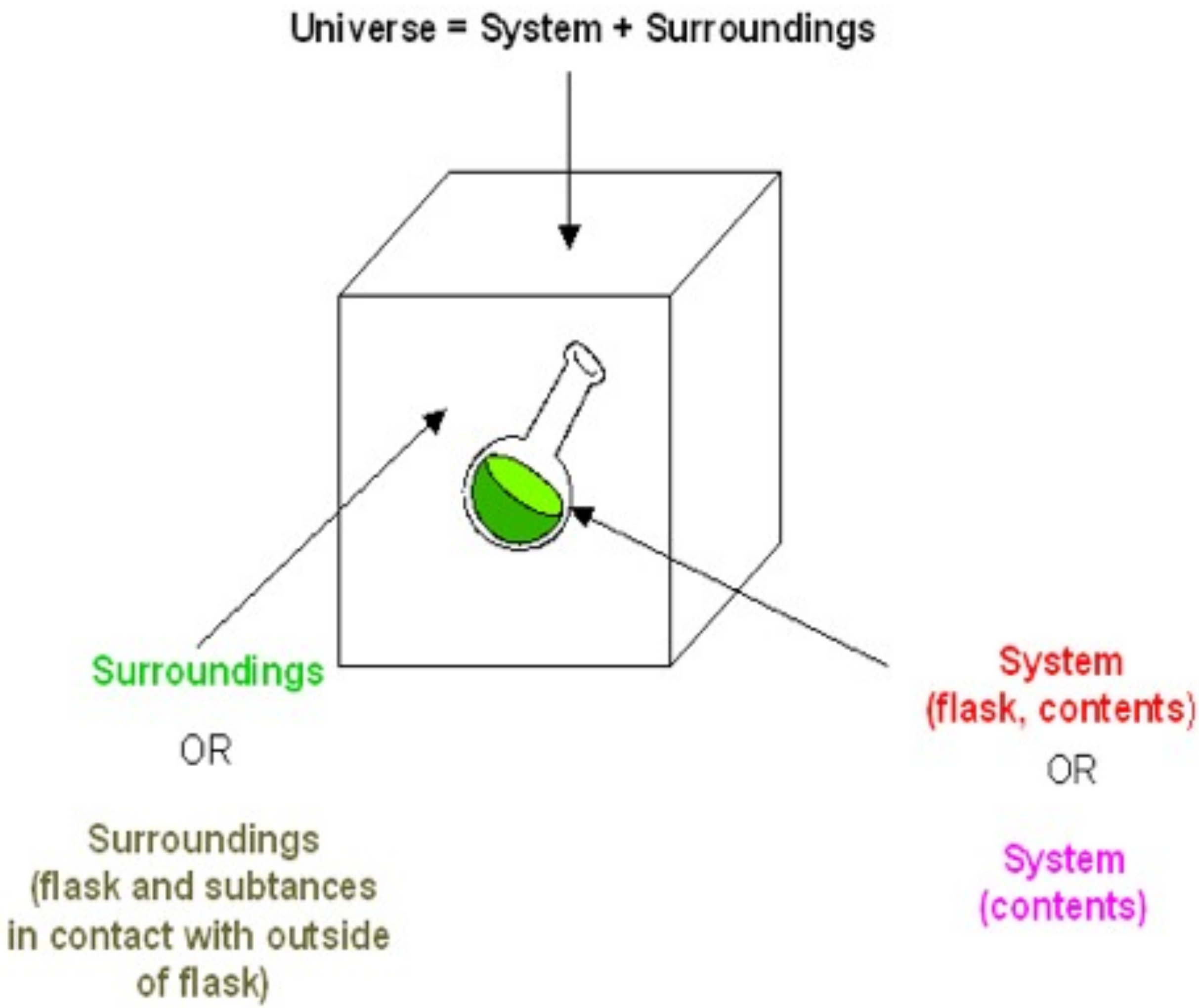
surroundings all matter around the system that is capable of absorbing or releasing thermal energy



open | closed | isolated

Exchange: mass & energy | energy | nothing

- Universe = System + Surroundings

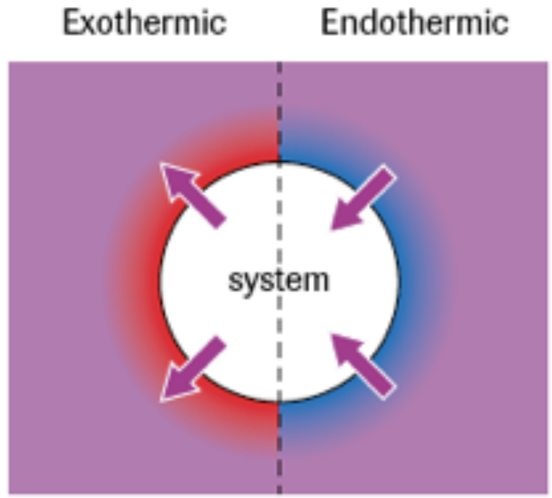


Endothermic v. Exothermic

Exothermic process is any process that gives off heat – transfers thermal energy from the system to the surroundings.

$$2H_2\ (g) + O_2\ (g) \longrightarrow 2H_2O\ (l) + \text{energy}$$

$$H_2O\ (g) \longrightarrow H_2O\ (l) + \text{energy}$$



Endothermic process is any process in which heat has to be supplied to the system from the surroundings.

$$\text{energy} + 2HgO\ (s) \longrightarrow 2Hg\ (l) + O_2\ (g)$$

$$\text{energy} + H_2O\ (s) \longrightarrow H_2O\ (l)$$

Thermodynamics

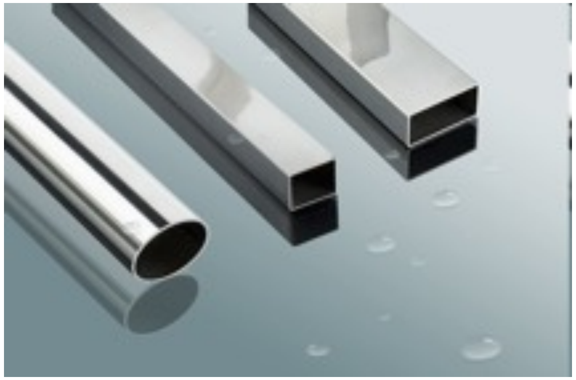
1. heat, symbol: q – the transfer of energy due to contact

2. thermal energy – the energy of an object directly related to temperature

3. temperature – measure of internal energy of an object due to particle motion (kinetic energy)

Heat Capacity

Different types of matter require different amounts of heat transfer to change the same amount of temperature .


Water is unusual in that it can absorb and release a lot of heat without the temperature changing drastically.

Specific Heat Capacity

specific heat capacity, c – the amount of heat transfer required to change the temperature of one gram of a substance one degree Celsius or Kelvin

Table 1 Specific Heat Capacities of Substances

Substance	Specific heat capacity, c
ice	2.01 J/(g•°C)
water	4.18 J/(g•°C)
steam	2.01 J/(g•°C)
aluminum	0.900 J/(g•°C)
iron	0.444 J/(g•°C)
methanol	2.918 J/(g•°C)

$$c = q / m\Delta T$$

Pick one!

- Would you rather stir hot soup with an aluminum spoon (c=0.900) or a wooden spoon (c = 2.01)? Why?

$q = mc\Delta T$

1. c – specific heat capacity
   - J / g • °C <u>OR</u> J / g • K
2. q – heat
   - J
3. m – mass
   - g
4. ΔT – change in temperature
   - °C <u>OR</u> K

Example #1

If a gold ring with a mass of 5.5 g changes in temperature from 25.0°C to 28.0°C, how much heat energy, in Joules, has it absorbed?

The value of the specific heat capacity of gold is 0.129.

Solution

- $m = 5.5$ g
- $\Delta T = 28 - 25 = 3°C$
- $c = 0.129$ J/g°C
- q = ???

- $q = mc\Delta T$
- $q = (5.5)(0.129)(3)$
- $q = 2.12$ J

Example #2

What would be the final temperature if 250.0 J of heat were transferred into 10.0g of methanol ($c = 2.9$ J / g • °C) initially at 20 °C?

Solution

- $q = 250$ J
- $m = 10$ g
- $c = 2.9$ J/g°C
- $T1 = 20$°C
- $T2 = ?$

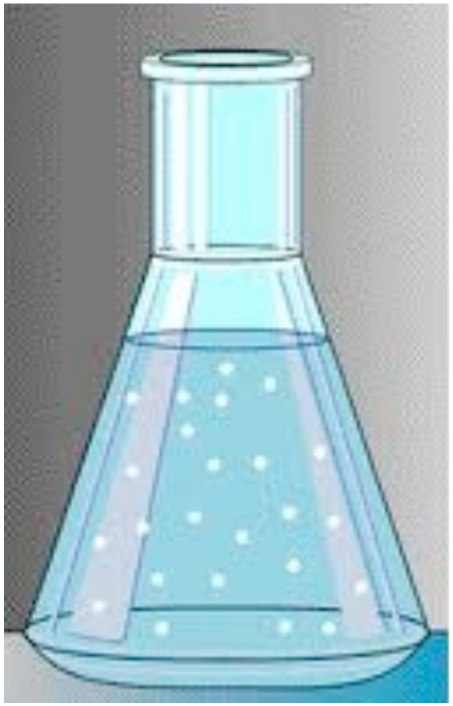
- $q = mc\Delta T$
- $q = mc(T2 - T1)$
- $T2 = q/mc + T1$
- 28.6°C

Application of Heat Capacity

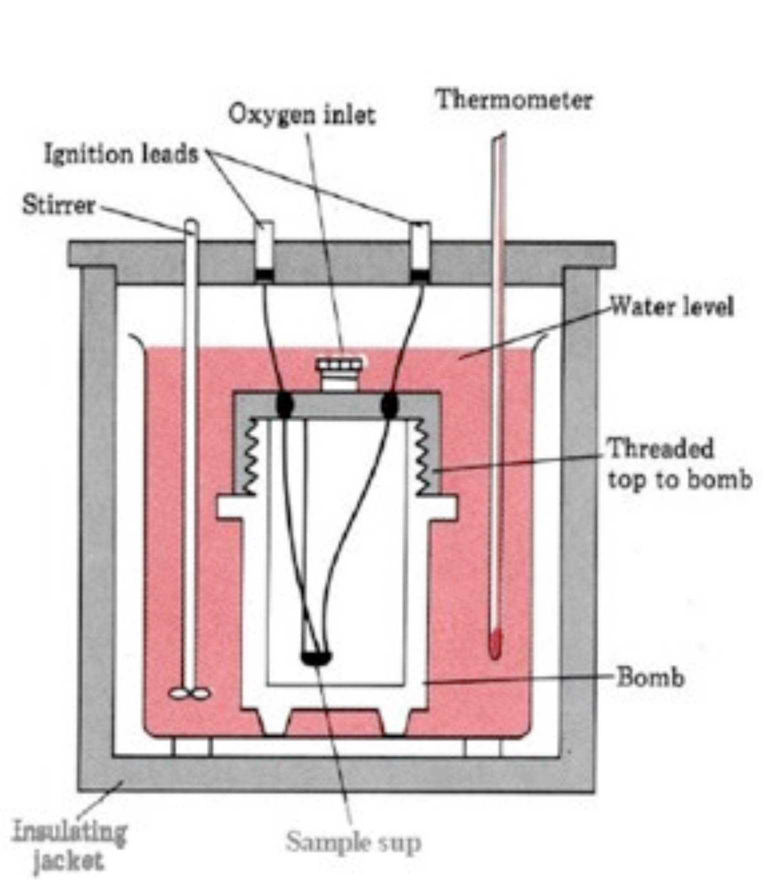
- all chemical reactions result in heat transfer
- understanding heat transfer properties is important for building materials
- food is evaluated by the amount of energy it releases

Calorimetry

calorimetry – the measure of heat change due to a chemical reaction



Calorimetry

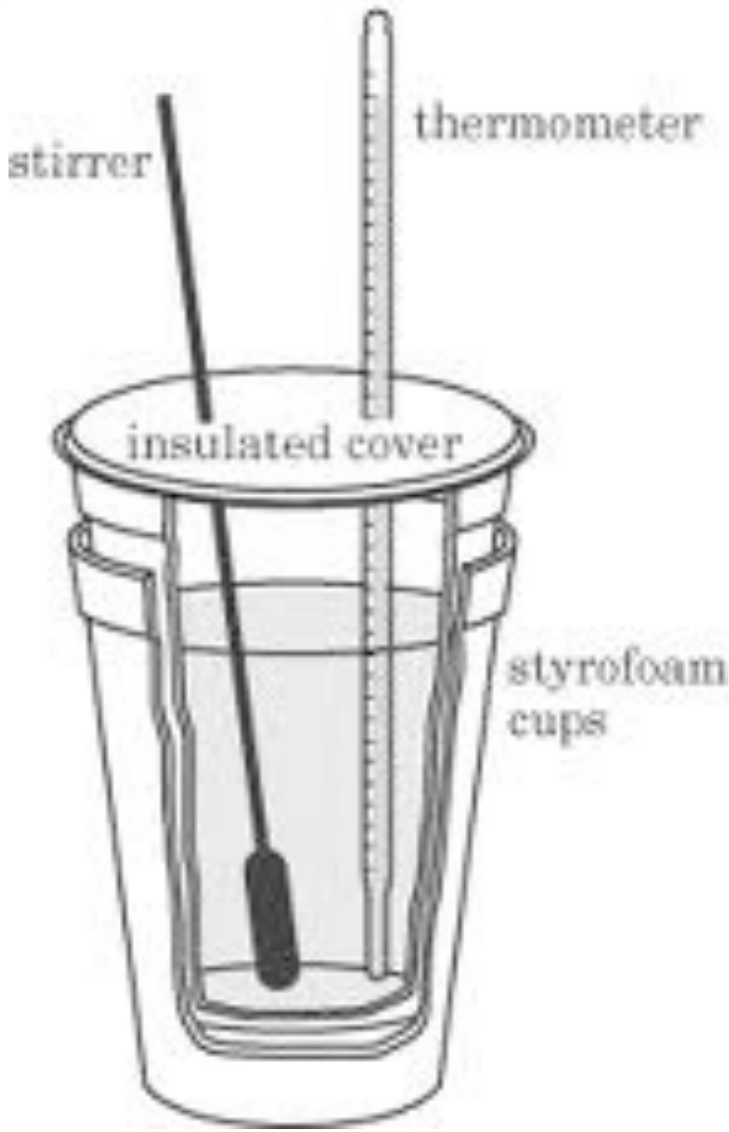


bomb calorimeter

– reaction chamber allows heat transfer to the surrounding water, all contained within an insulated container

Calorimetry

coffee cup calorimeter



Example #3

When 1.02g of steric acid, $C_{18}H_{36}O_2$, was burned completely in a bomb calorimeter, the temperature of the calorimeter rose by 4.26°C. The heat capacity of the calorimeter was 9.43 kJ/°C. Calculate the total heat of combustion of steric acid in kJ / mol.

Solution

- $m = 1.02$ g
- $s = 9.43$ kJ/°C (notice no grams!)
- $\Delta T = 4.26$ °C
- $q = s\Delta T$
- $q = (9.43)(4.26)$
- $q = 40.17$ kJ

- Find moles using $n=m/M$
- $n=1.02/284.36$
- $n=0.0036$ mol
- Final: 11158.3 kJ/mol

Example #4

175g of water was placed in a coffee cup calorimeter and chilled to 10°C. Then 4.90 g of sulfuric acid was added at 10°C and the mixture was stirred. The temperature rose to 14.9°C. Assume the specific heat capacity of the solution is 4.2 J/g •°C. Calculate the heat produced in kJ and the heat produced per mole of sulfuric acid.

Solution

- m_{water} = 175g
- m_{acid} = 4.9g
- T1 =10 °C
- T2 = 14.9 °C
- c = 4.2 J/g°C

- $q = mc\Delta T$
- q = (175+4.9)(4.2)(4.9)
- q = 3702.3 J ---- 3.7 kJ
- Find moles of sulfuric acid
- n = 4.9/98 = 0.05 mol
- Final answer 74 kJ/mol

Example #5

The reaction of HCl and NaOH is exothermic. A student placed 50.0 mL of 1.00 M HCl at 25.5°C in a coffee cup calorimeter and then added 50.0 mL of 1.00 M NaOH also at 25.5°C. The mixture was stirred and the temperature quickly increased to 32.4°C. What is the heat of the reaction in J/mol of HCl?

c of H_2O = 4.2 J / g •°C

liquid density = 1.00 g/mL

Solution

- $T1 = 25.5°C$
- $T2 = 32.4°C$
- $v_{total} = 100$ mL $m = 100$ g
- $c = 4.2$ J/g°C

- $q = mc\Delta T$
- $q = (100)(4.2)(6.9)$
- $q = 2898$ J
- Find moles HCl (50 mL of 1.0M)
- $n = cv$
- $n = (1.0)(0.05) = 0.05$ mol
- Final answer: 57960 J/mol

Heat lost = Heat gained

A 26.6 g sample of mercury is heated to 110.0°C and then placed in 125 g of water in a coffee-cup calorimeter. The initial temperature of the water is 23.00°C. The specific heat capacity of water is 4.184 J/g•°C, and the specific heat capacity of mercury is 0.139 J/g•°C. What is the final temperature of the water and the mercury?

Solution

- MERCURY
- m = 26.6g
- T1 = 110°C
- c = 0.139
- T2 = ?

SAME

- WATER
- m = 125g
- T1 = 23°C
- c = 4.184
- T2 = ?

q lost = q gained

$$-q = q$$

$$-mc\Delta T = mc\Delta T$$

Solution

- $- mc\Delta T = mc\Delta T$
- $-(26.6)(0.139)(T2-110) = (125)(4.2)(T2-23)$