Section 2: Heat

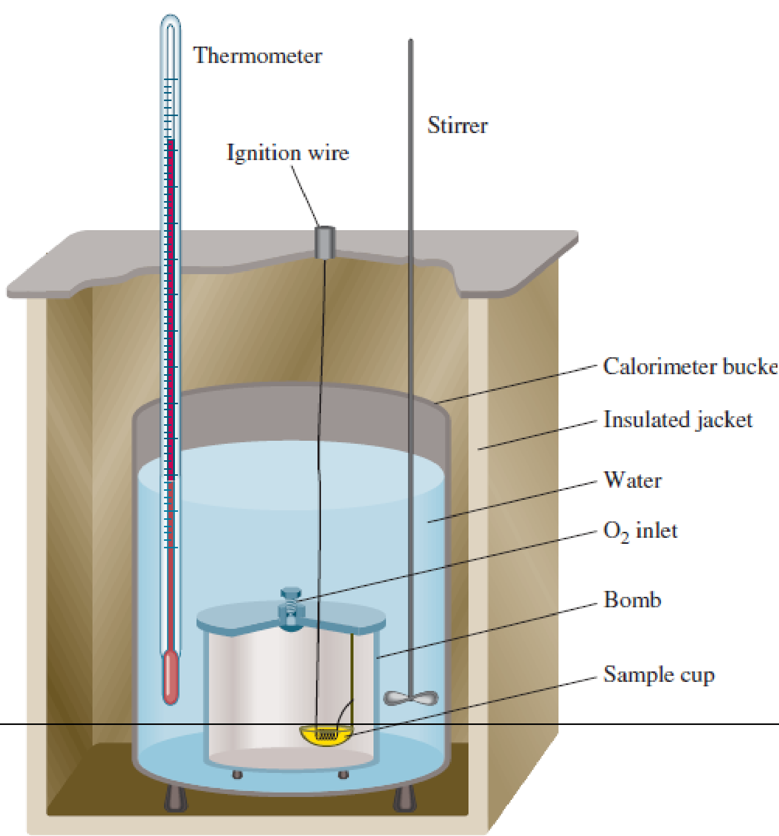
Heat Measurement:

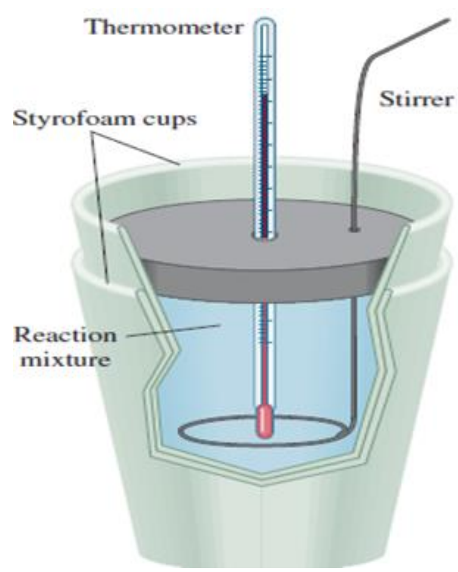
• Nutritional chemists obtain the calorie information written on canned foods from the combustion reactions that are carried out in calorimeters.

A calorimeter: is an insulated device used to measure the amount of heat that has been absorbed or released during a chemical or physical process.

types of calorimeters:

constant-volume bomb calorimeter	Constant-Pressure Calorimeter
1-filled with oxygen at about 30 atm of pressure. The closed bomb is immersed in a known amount of water 2-used for combustion reactions 3- work under constant volume 4- used by nutritional chemist to calculate the calorie of different foods	1-simple device 2-used for non combustion reactions (ex: neutralization reactions) 3- work under constant pressure





The general idea of the calorimeter:

A quantity of water is placed in an isolated room to absorb the energy resulting from the combustion of the material in the combustion chamber. The change in water temperature is measured and the amount of heat energy released is calculated.

Combustion calorimeter used by nutrition chemists:

1- The sample is placed in a steel inner chamber called the bomb.

2- The chamber is filled with oxygen under high pressure.

3- The bomb is surrounded by a specific amount of water, which is stirring by a low-friction motor to ensure a uniform temperature.

4- The reaction starts vigorously, and the maximum temperature is recorded.

➢ **Why is it important for the calorimeter to not generate friction?**

Tool	Function
Thermometer	Measures the initial and final temperature.
Ignition terminals	The energy source where the spark occurs in the reaction chamber.
Stirrer	Stir water to distribute heat.
Water	Absorbs heat from the reaction chamber, so the temperature change can be measured.
Insulating material	prevent thermal energy leakage into the surrounding environment.
Sealed reaction Chamber (The Bomb)	Filled with compressed oxygen and the substance to be determined by the amount of energy that it emits or absorbs.

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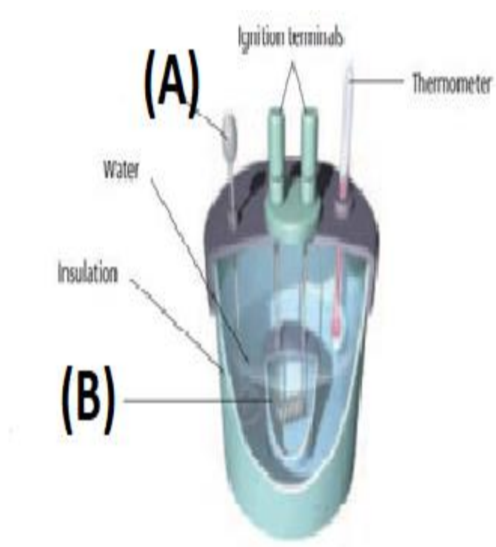
1- Answer the following questions from drawing:



¬ What is the name of the device shown in the drawing?

Foam-cup calorimeter / constant pressure calorimeter.

¬ What is this device used for?

Measuring specific heat be the calculating change in temperature.

¬ What is the function of part (A)?

Stirrer : stir the water to ensure a uniform temperature.

¬ What is the name of part (B)? **Sealed reaction champer: which the combustion of oxygen and the substance takes place.**

How to use foam-cup calorimeter to measure the specific heat of unknown metal?

A calorimeter made of a foamed plastic cup is used to calculate the specific heat of an unknown metal.

¬ Which works in the open air, so all the reactions that occur inside it occur under constant pressure.

1- Suppose you put 125 g of water in the foam plastic cup and find that its initial temperature is 25.60°C.

2- Then, a sample of mass 0.050 g of an unknown metal was heated to 115.0 °C and placed in water.

3- Heat transfers from the hot metal to the cold water, and the temperature of the water increases.

4- Heat transfer stops only when the temperature of the metal and water becomes equal, the final temperature is 29.30 ° C.

m_{H2O} = 125 g

$T_{i\ H2O}$ = 25.6 C

C_{H2O} = 4.184 (J/g.c)

m_{metal} = 50.0 g

$T_{i\ metal}$ = 115.0 C

C_{metal} = ?? (J/g.c)

(J/g.c)

T_f metal = 29.30 C

= T^f water=29.3 C

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

First, calculate the heat gained by the water. To do this, you need the specific heat of water, 4.184 J/(g·°C).

$$q_{water} = 4.184\ J/(g\cdot°C) \times 125\ g \times (29.30°C - 25.60°C)$$

$$q_{water} = 4.184\ J/(\cancel{g\cdot°C}) \times 125\ \cancel{g} \times 3.70\cancel{°C}$$

$$q_{water} = 1940\ J$$

The heat gained by the water, 1940 J, equals the heat lost by the metal, q_{metal}, so you can write this equation.

$$q_{metal} = q_{water}$$
$$q_{metal} = -1940\ \text{J}$$
$$c_{metal} \times m \times \Delta T = -1940\ \text{J}$$

Now, solve the equation for the specific heat of the metal, c_{metal}, by dividing both sides of the equation by $m \times \Delta T$.

$$c_{metal} = \frac{-1940\ \text{J}}{m \times \Delta T}$$

The change in temperature for the metal, ΔT, is the difference between the final temperature of the water and the initial temperature of the metal (29.30°C − 115.0°C = −85.7°C). Substitute the known values of m and ΔT (50.0 g and −85.7°C) into the equation and solve.

$$c_{metal} = \frac{-1940\ \text{J}}{(50.0\ \text{g})(-85.7°\text{C})} = 0.453\ \text{J/(g·°C)}$$

The unknown metal has a specific heat of 0.453 J/(g·°C). shows that the metal could be iron.

Example

of metal with a mass of 4.68 g absorbs 256 J of heat when its temperature increasesby 182°C.

m = 4.68g c =? △T =	$c = \frac{q_{metal}}{m \times \triangle T} =$

1- A 90.0-g sample of an unknown metal absorbed 25.6 J of heat as its temperature increased 1.18°C. What is the specific heat of the metal?

m q ΔT

$c = \frac{m \cdot q}{\Delta T} = 1952.5$

2- The temperature of a sample of water increases from 20.0°C to 46.6°C as it absorbs 5650 J of heat. What is the mass of the sample?

T_i T_f

5650 = 4.184 × 26.6 × (m)

m = 50.8 g

3- How much heat is absorbed by a 2.00×10^{3} g granite boulder (c granite = 0.803 J/(g·°C)) as its temperature changes from 10.0°C to 29.0°C?

4- If 335 g of water at 65.5°C loses 9750 J of heat, what is the final temperature of the water?

T_f = 72.5

5- If the temperature of 34.4 g of ethanol increases from 25.0°C to 78.8°C, How much heat has been absorbed by the ethanol?

6- 155g sample of an unknown substance was heated from 25.0°Cto 40.0°C. In the process, the substance absorbed 5696 J of energy.What is the specific heat of the substance? Identify the substance among those listed in Table?

7- 4.50g nugget of pure gold absorbed 276 J of heat.The initial temperature was 25.0°C. What was the final temperature?

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8- The temperature of a sample of water increases from 20.0°C to 46.6°C as it absorbs5650 J of heat. What is the mass of the sample?

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9- When a 58.8 g piece of hot alloy is placed in 125 g of cold water in a calorimeter, the temperature of the alloy decreases by 106.1°C, while the temperature ofthe water increases by 10.5°C. What is the specific heat of the alloy?

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10- Calorimeter from a foam cup containing 75.0 g of water at 24.0 °C. A sample of metal 26.0 g at 82.25 °C is added to the calorimeter. The final temperature of the water is 28.34 °C, what is the specific heat of the metal?

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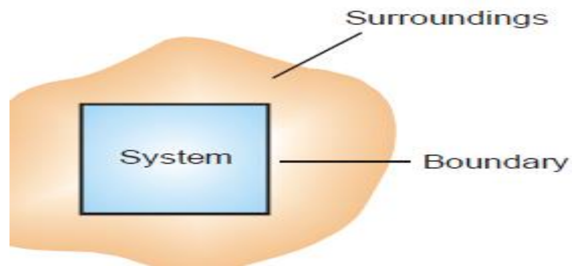
Thermochemistry: ***is the study of heat changes that accompany chemical reactions and phase changes.***

SYSTEM , SURROUNDINGS,UNIVERSE:



universe = system + surroundings

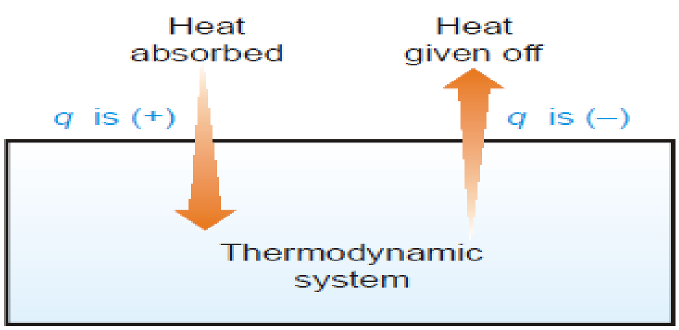
A system: ***is that part of the universe that contains the reaction under study***

Surrounding: ***Everything in the universe other than the system***

Sign of heat: The symbol of heat is q.

If the heat flows from the surroundings into the system to raise the energy of the system, it is taken to be positive, +q.

If heat flows from the system into the surroundings, lowering the energy of the system, it is taken to be negative, –q.



Examples of exothermic reactions:

¬ Burning fuel always generates heat.

¬ Soldiers in the field use an exothermic reaction to heat their meals.

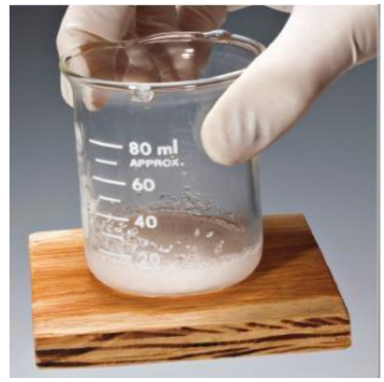
¬ Hot pack: A hot pack is used to produce heat that warms parts of your body, where iron reacts with oxygen and produces heat energy according to the following equation:

$$4Fe\ (s) + 3O_2\ (g) \longrightarrow 2Fe_2O_3 + 1625\ KJ$$

¬The heat energy resulting from the reaction is transferred from the hot pack (the reaction system) to your cold hands (part of the surrounding).

¬ Examples of endothermic reactions:

¬ The heat of the endothermic reaction is transferred from the surroundin to the system.



¬ In the opposite picture, the cup sticks to the moistened wood, because the water freezes due to the reaction.

¬The reaction in the cup is between two substances, ammonium thiocyanate and barium hydroxide.

¬This endothermic reaction causes absorbing heat from the water and freezes it.

$$Heat + Ba(OH)_2.8H_2O_{(s)} + 2NH_4SCN_{(s)} \rightarrow Ba(SCN)_2 + 2NH_3 + 10H_2O$$

Why does a cup containing a mixture of barium hydroxide and ammonium thiocyanate crystals stick to a wet plate of wood ?

Because the reaction mixture absorbs heat from the water at the bottom of the beaker, so it freezes, and the beaker sticks to the plate.

Enthalpy and enthalpy change:

¬ Internal energy: is the sum of potential and kinetic energies.

¬ The internal energy of a substance depends on several factors, including the movement of atoms, the movement of electrons, the energy stored in the atom, and chemical bonds.

¬ It is difficult to measure these factors accurately, so it has become impossible to know the total energy content of the substance.

¬ Therefore, chemists were more concerned with the energy changes that occur during reactions than they were concerned with the quantities of energy in the reactants and products.

Why are chemists more concerned with energy changes than with the internal energy of matter?..

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- The heat lost or gained in many reactions can be conveniently measured with a Calorimeter at a constant pressure.
- The foamed plastic cup is not closed, so it is at a constant pressure (1 atm).
- Many reactions occur under constant pressure:
  - ✓ Interactions that occur within living organisms on the Earth's surface.
  - ✓ Reactions that occur in open beakers and flasks in the laboratory.
- The energy released or evolved from reactions carried out at constant pressure is sometimes given the symbol (q_p).
- Chemists define ***enthalpy (H)*** as: the heat content of a system at constant pressure.
- ***The change in enthalpy of a reaction***: the heat that is absorbed or released during a chemical reaction.
- It is also called the enthalpy of reaction (heat of reaction) (ΔH_{rxn}).

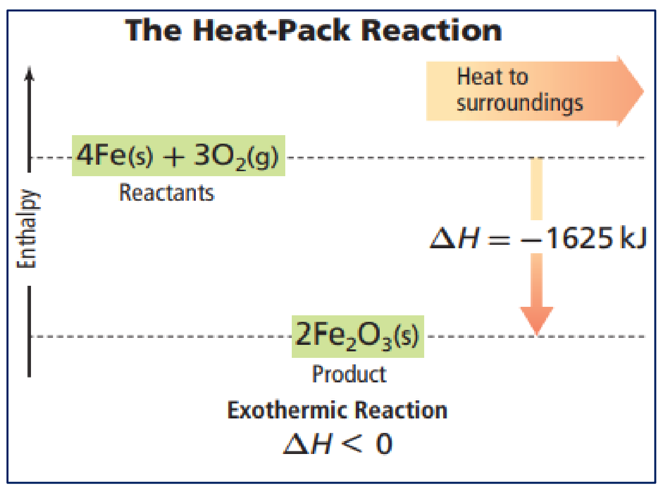
The change in enthalpy (ΔH_{rxn}): is the difference between the enthalpy of the substances that exist at the end of the reaction and the enthalpy of the substances present at the start.

$$\Delta H_{rxn} = H_{final} - H_{initial}$$

Since the reactants at the beginning of the reaction and the products at the end of the reaction, the equation becomes as follows: $\Delta H_{rxn} = H_{product} - H_{reactants}$

- ***The sign of the enthalpy of reaction:***
- ***Exothermic reaction: example of a hot pack.***

$4Fe\ (s) + 3O_2\ (g) \rightarrow 2Fe_2O_3 + 1625\ KJ$

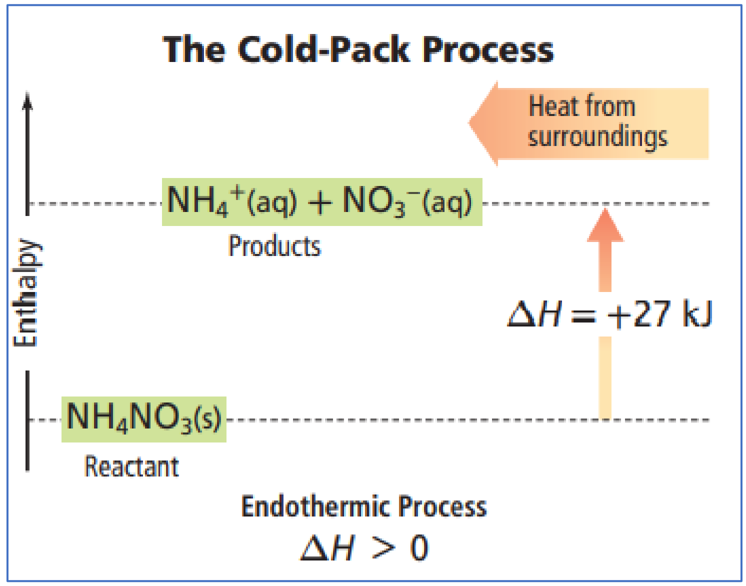


- In an Exothermic reaction, the energy of the reactants is greater than the energy of the products
- Therefore, the H of the reactants is greater than the H of the products.
- When H reactants is subtracted from the smaller H products , a negative value for ΔH_{rxn} results.
- Enthalpy changes for exothermic reactions are always negative.
- The equation for the heat-pack reaction and its enthalpy change are usually written as shown. $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$ $\Delta H_{rxn} = -1625$ kJ

- ***Endothermic reaction: example of a cold pack.***

$27KJ + NH_4NO_3 (s) \rightarrow NH_4^+ (aq) + NO_3^-$

- In endothermic reaction The energy of the products is greater than the energy of the reactants.
- Therefore, when H reactants is subtracted from the larger H products , a positive value for Δ H rxn is obtained.
- Chemists write the equation for the cold-pack process and its enthalpy change in the following way.



$NH_4NO_3 (s) \rightarrow NH_4^+(aq) + NO_3^-(aq) \qquad \Delta H_{rxn} = 27\ kJ$

1. How does a cold pack to cool your leg?

When the pack is applied to your leg, it absorbs 27 KJ of heat energy from your leg to break down the ammonium nitrate and your leg automatically cools.

- The enthalpy change, ΔH, is equal to q_p , the heat gained or lost in a reaction or process carried out at constant pressure.
- Because all reactions occur at constant pressure, you might assume that $q = \Delta H_{rxn}$

Endothermic reaction	Exothermic reaction
Thermal energy is transferred into the system	Thermal energy is transferred out of the system
The energy of the products is greater than the energy of the reactants	The energy of the reactants is greater than the energy of the products
The change in enthalpy is always positive	The change in enthalpy is always negative
Example: a cold pack	Example: a hot pack

Revision:

1- Why do we use polystyrene cup instead of a glass one as a calorimeter?

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From Figure, answer question 2,3.

2- Explain the type of reaction, endothermic or exothermic? Justify your answer.

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3- What is the sign (ΔH) for the reverse reaction?

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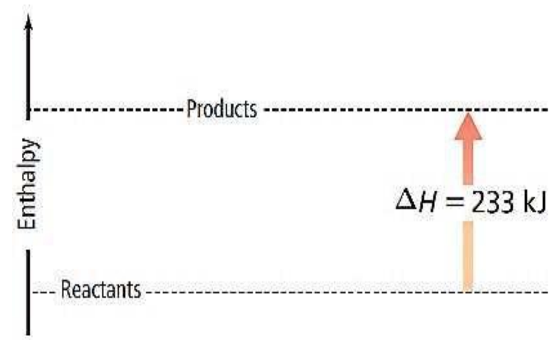

4- When is the amount of energy released or absorbed in a chemical reaction equal to the change in enthalpy (ΔH)?

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5- Describe how to calculate the amount of heat gained or released from a substance when its temperature changes?

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6- Explain why the H_{rxn} sign is negative for the exothermic reaction?

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7- Explain why the known volume of water is an important part of the calorimeter?

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8- Explain why do you must know the specific heat of a substance in order to calculate the heat gained or lost from it as a result of the temperature change?

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9- Describe the meaning of system in thermodynamics and explain the relationship between the system, the surrounding, and the universe.

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10- if the value of the change in the heat content H of a reaction is negative. what does this tell you about the chemical potential energy of the system before and after the reaction?

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11- What is the H sign for an exothermic and endothermic reaction?

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12- Calculate the heat, 3580 Kg of granite lose when its temperature cools from 41.2°C to -12.9°C?

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13- A swimming pool measuring 20.0m×12.5 m is filled with water to a depth of 3.75m. If the initial temperature is 18.4°C, how much heat must be added to the water to raise its temperature to 29.0°C? Assume that the density of water is 1.000 g/mL.

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14- How much heat would a piece of lead of mass 44.7g absorb if its temperature increased by 65.4°C?

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15- 10.2g of canola oil is placed in a frying pan, it takes 3.34kJ to raise its temperature from 25°C to 196.4°C. What is the specific heat of canola oil?

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16- When a 58.8g piece of hot alloy is placed in 125g of cold water in a calorimeter, the temperature of the alloy decreases by 106.1°C, while the temperature of the water increases by 10.5°C. What is the specific heat of the alloy?

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