Thermochemistry

Chapter 6

ENERGY

- Energy is the capacity to do work.
- Kinetic Energy – thermal, mechanical, electrical, sound
- Potential Energy – chemical, gravitational, electrostatic

Heat

- *Heat*, or *thermal energy*, is generally measured in one of two units in Chemistry.
- The ***calorie*** is the amount of heat required to raise the temperature of one gram of water by one Celsius degree.
- When talking about food, one **Calorie** (*with a capital C*) is equal to one kilocalorie (kcal) or 1000 calories (*with a lowercase c*).
- However, in recent years, energy is most commonly measured in ***joules (J)***. This is an SI derived unit:
  $1\ J = 1\ kg \bullet m^2 \bullet s^{-2} = N \bullet m$
- Joules and calories are easily converted:
  4.184 J = 1 cal *(this is an EXACT conversion - the calorie is now defined in this way.)*

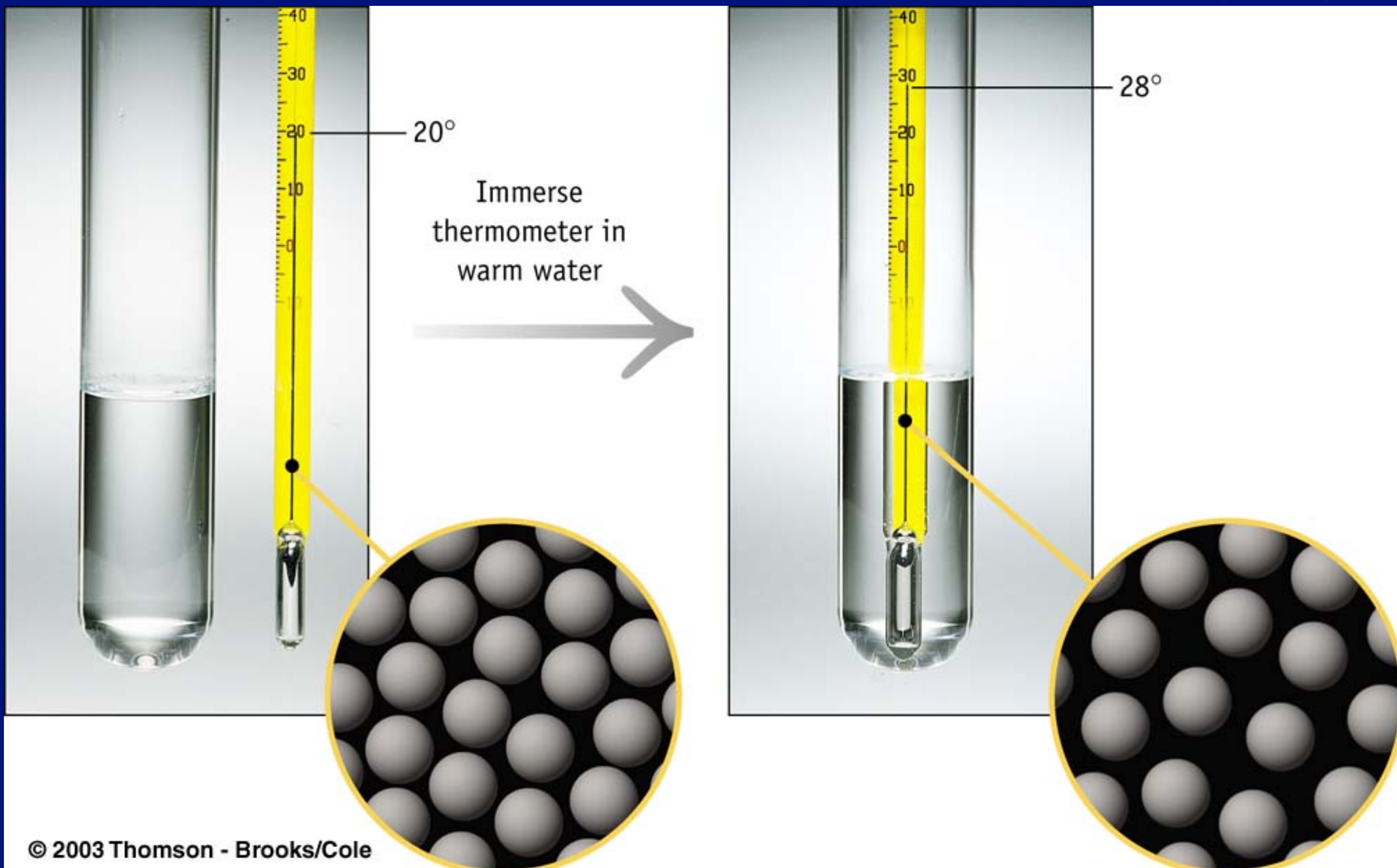
Temperature & Heat

- ***Misconception:*** Temperature is a measure of the heat within an object (this is ***incorrect***!).
- ***Definitions:***
  - **Temperature** is a measure of the average kinetic energy of particles in a sample. Temperature is DIRECTLY proportional to the average kinetic energy of the particles. $T \propto KE$
  - **Kinetic Energy** is the energy of motion, and is related to the mass of a particle and its velocity (or speed).

$$KE = \tfrac{1}{2} mv^2$$

  - **Heat** (represented by the variable **q**) is a transfer of energy between two objects at different temperatures.

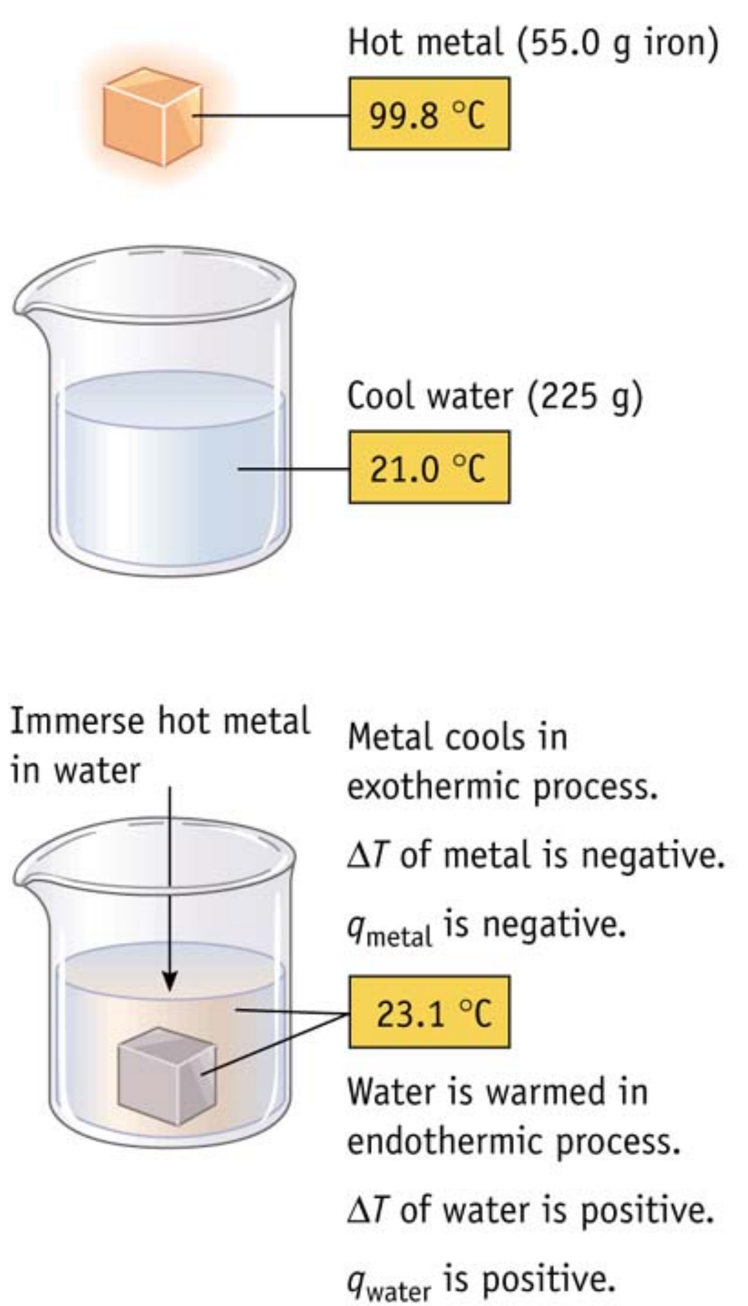
Thermometers & Temperature



Temperature & Heat

HOT object (at high Temp)	Molecules have a high average kinetic energy. They are moving very fast.
Comes into contact with:	
COLD object (at low Temp)	Molecules have a low average kinetic energy. They are moving more slowly.

- Particles in the HOT object collide with particles in the COLD object.
- The kinetic energy of the particles of the HOT object will be transferred to the particles of the cold object.
- The particles in the HOT object move more slowly, and the particles in the COLD object move more quickly.
- This transfer of energy continues until the particles of both objects have the same average kinetic energy, and therefore, the same temperature.
- This process of energy transfer in the form of heat is called **conduction.**



Heat Transfer

Thermal Equilibrium:

When the system and the surroundings reach the same temperature, they are in a state of thermal equilibrium.

Heat Calculations and Heat Capacity

- ***Specific Heat Capacity*** is the heat required to raise the temperature of ***one gram of a substance*** by 1 C°.

$$\text{specific heat capacity} = \frac{\text{heat}}{\text{mass} \times \text{change in temperature}} = C_P = \frac{q}{m \times \Delta T}$$

rearranging: $q = mC_p\Delta T$

where: $\Delta T = T_{final} - T_{initial}$

- ***Heat Capacity*** is the amount of energy required to raise the temperature of an ***object*** by one Celsius degree (C°).

$$\text{heat capacity} = \frac{q}{\Delta T}$$

rearranging: $q = (\text{heat capacity})\,\Delta T$

Heat Examples

1. How much heat (in Joules) is required to heat 30.0 g of iron from 45.0 °C to 95.0 °C?

   $(C_{p,iron} = 0.449\ {}^{J}/_{g \cdot C^{\circ}})$

2. What will be the final temperature if 15.5 kJ of heat is added to 238 g of water at 22.0 °C?

   $(C_{p,H_2O} = 4.184\ {}^{J}/_{g \cdot C^{\circ}})$

Work

- The work that we will focus on in this course is the work done by an expanding (or compressing) gas, sometimes called PV work.
- It is called PV work because it is measured by looking at the expansion of a gas (ΔV) against some pressure (P).
- Work: $w = -P\Delta V$
- ***Example:*** Calculate the amount of work done by a system when it causes the volume in a piston to expand from 2.0 m^3 to 5.5 m^3.

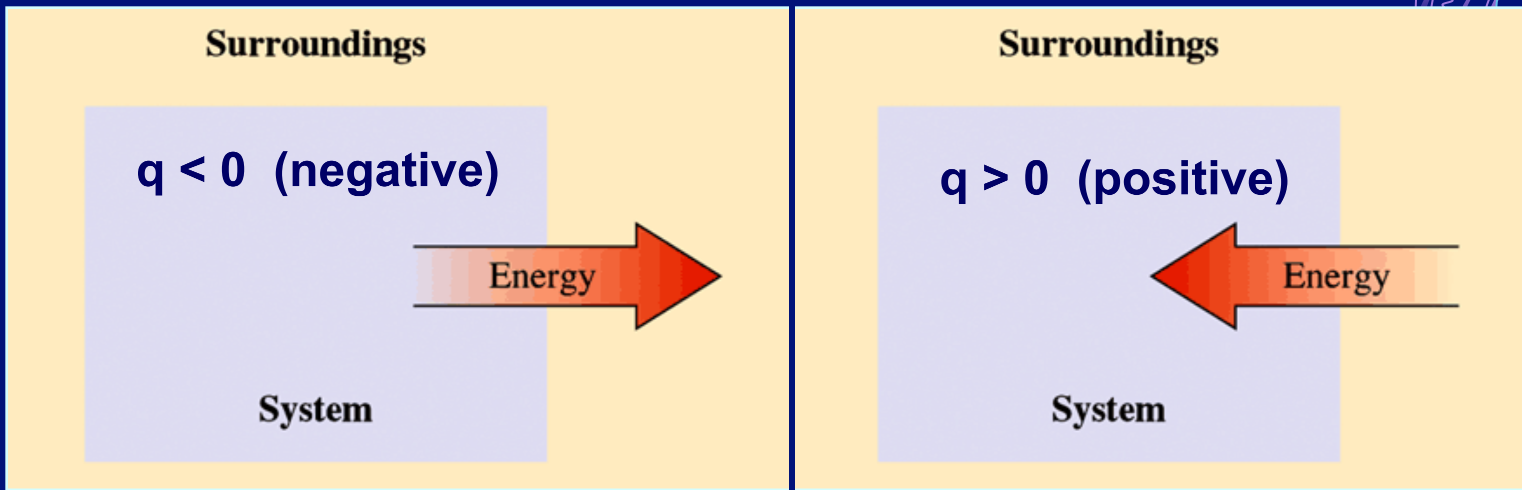
The First Law of Thermodynamics

- The first law of thermodynamics is the law of conservation of energy – ***the energy in the universe is constant***.

- Mathematical Expression of the 1st Law:

$$\Delta E = q + w$$

The First Law of Thermodynamics



Exothermic:

Heat flows from the system to the surroundings (q is negative) The temperature of the surroundings increases.

Example: Burning Wood.

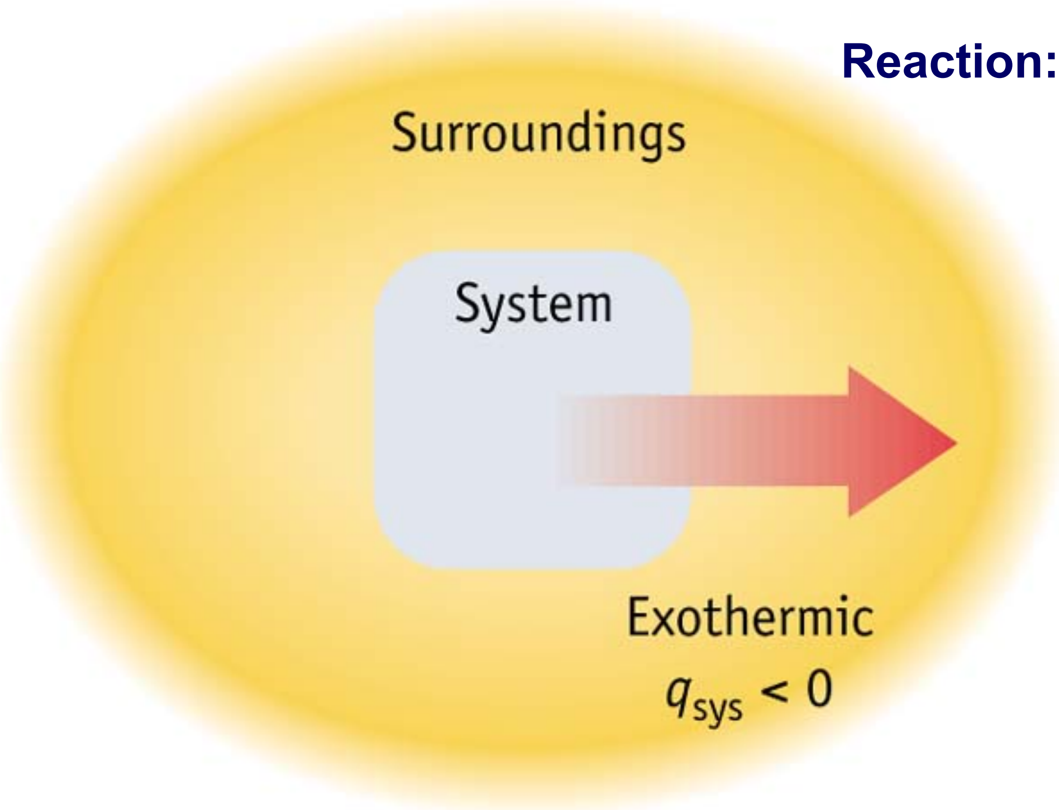
Endothermic:

Heat flows to the system from the surroundings (q is positive). The temperature of the surroundings decreases.

Example: Water evaporating off of skin.

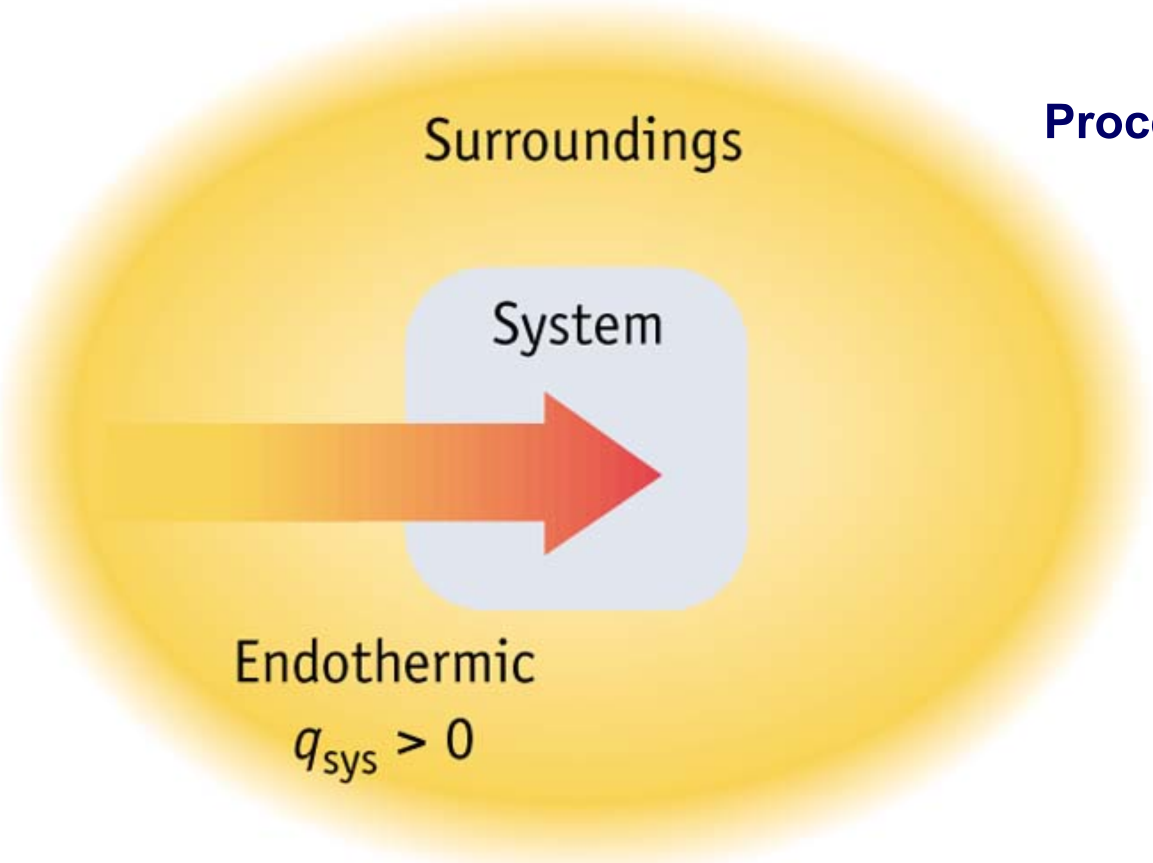
Exothermic System

Reaction:



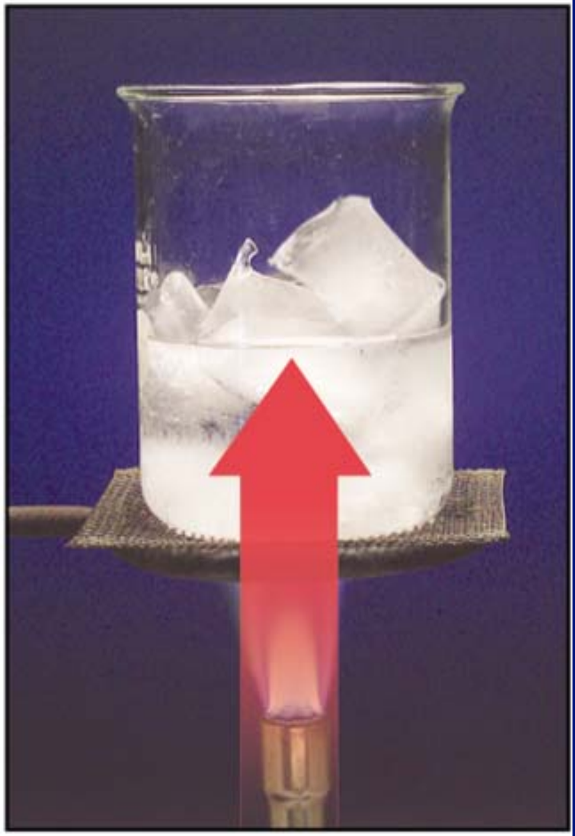
Exothermic: energy transferred from system to surroundings

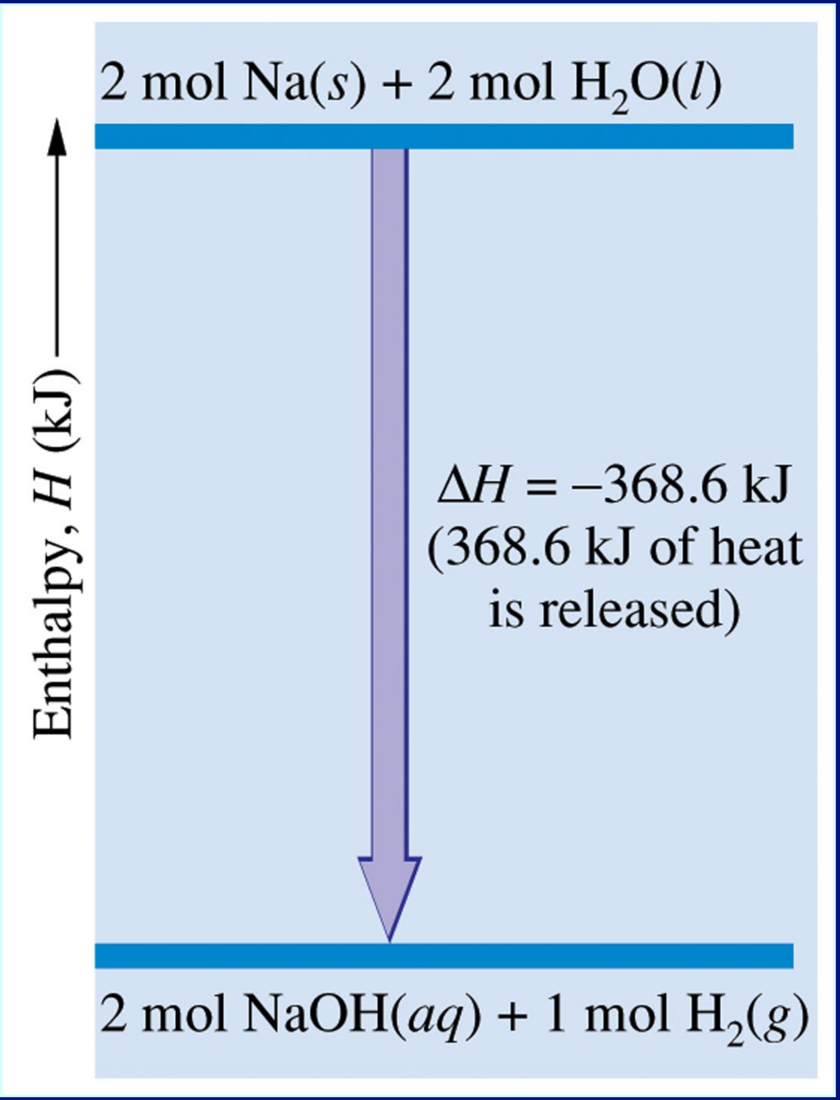
Endothermic System



Endothermic: energy transferred from surroundings to system

Process: $H_2O_{(l)} \rightarrow H_2O_{(g)}$





Enthalpy Diagram

Note: Enthalpy & heat are the same thing at constant pressure.

Heat is released in this process – it moves from the system to the surroundings.

Reaction:

$2\ Na_{(s)} + 2\ H_2O_{(l)} \rightarrow 2\ NaOH_{(aq)} + H_{2(g)} +$ HEAT

The 1st Law and Heat Problems

- **Calorimetry – An application of the first law.**

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

  $-\ q_{lost} = q_{gained}$

- ***Calorimetry*** is the measure of heat transferred in a chemical or physical process. A calorimeter is an apparatus that allows us to measure heat transferred in chemical or physical processes.

Example Problems: Calorimetry

3. What is the specific heat of an unknown metal if a 47.55-g block of the metal at 75.2°C is placed in 100.0 g of water at 22.4°C and thermal equilibrium is reached at 28.2°C ?

   (Assume no heat is transferred to the calorimeter.)

Bunsen Burner Flame

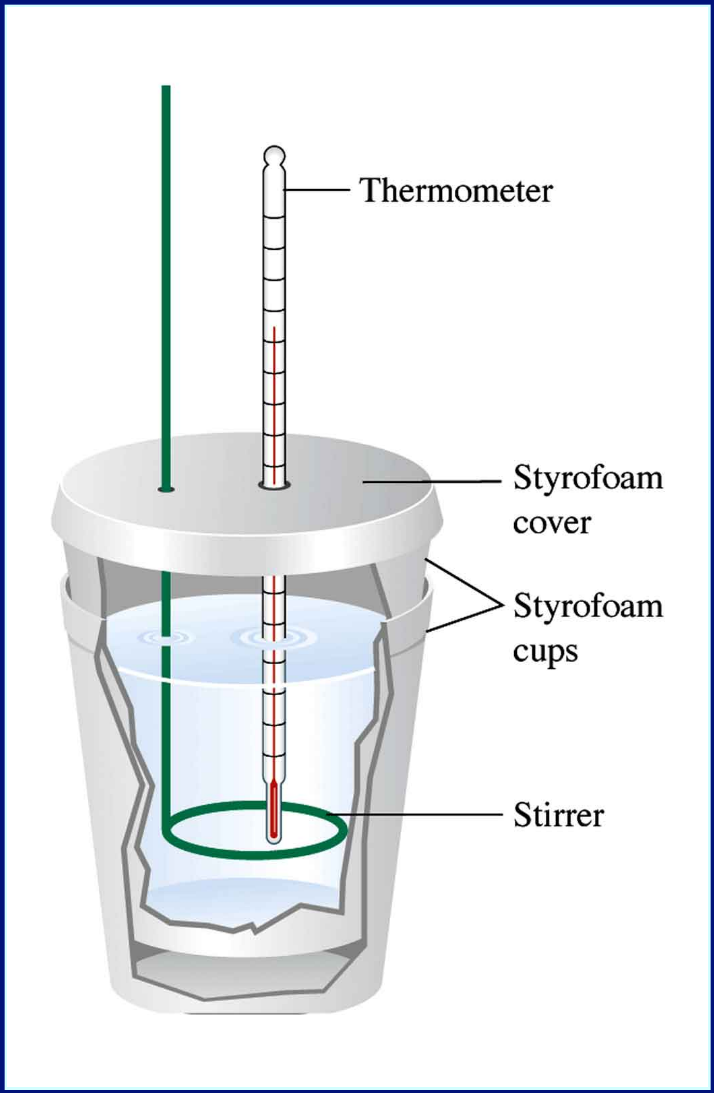
4. In order to measure the temperature of a Bunsen burner flame, a block of iron with a mass of 70.0 g is heated in the flame of a Bunsen burner. (The temperature of the iron is assumed to reach the same temperature as the flame.)

   The iron is then dropped in a calorimeter that contains 400.0 g of H_2O at 20.7°C. The final temperature of the system is 36.2 °C. What was the initial temperature of the iron? (Assume no heat is transferred to the calorimeter.)

Heat Capacity & the Calorimeter

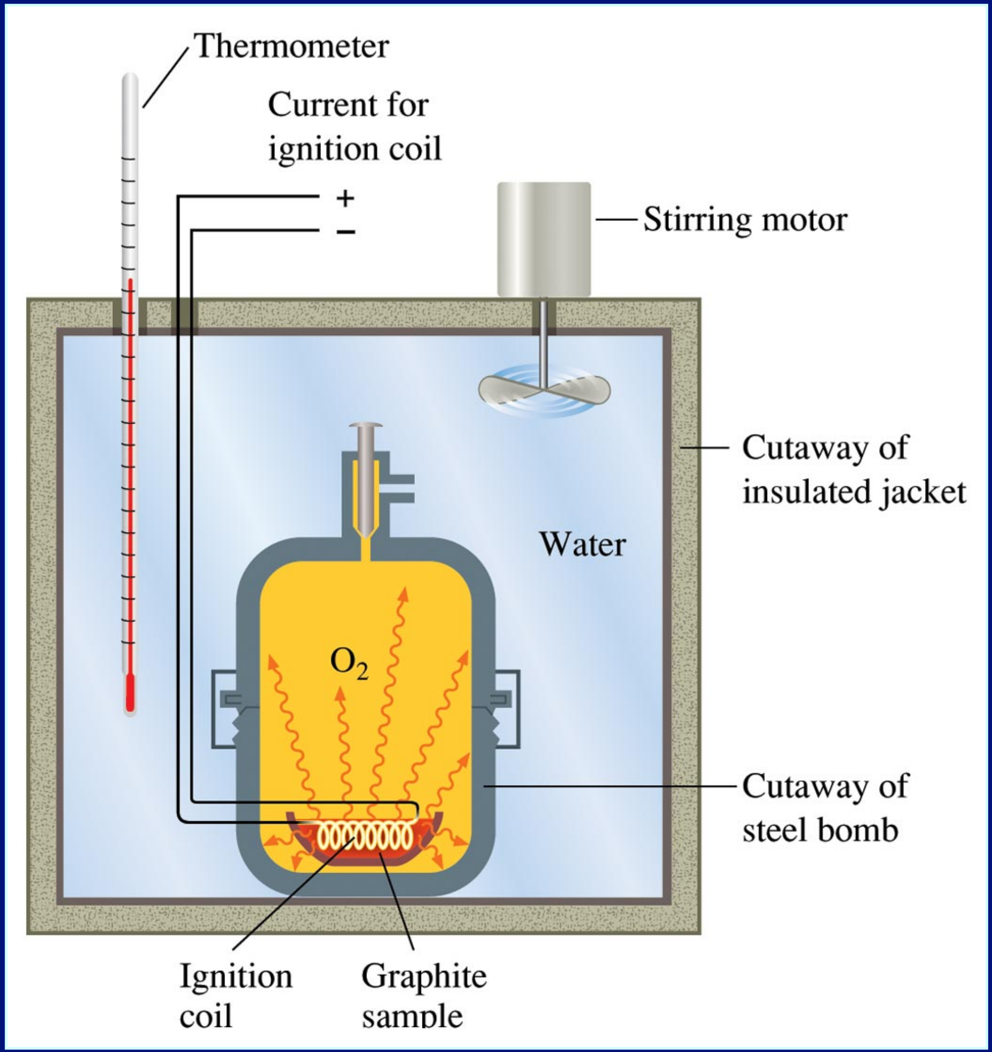
In the above reactions, we assumed no heat was absorbed by the calorimeter. In reality, heat is absorbed by a calorimeter in a calorimetry experiment. The amount of heat that the calorimeter absorbs can be accounted for if the heat capacity of the calorimeter is known.

$$\mathbf{q_{object} = (heat\ capacity)\Delta T}$$



Coffee-cup Calorimeter made of two Styrofoam cups.

Bomb Calorimeter



Calorimetry Example

5. What is the heat capacity of a calorimeter if adding a 55.0-g block of iron at 50.0 °C to 75.0 g of water at 25.0 °C results in a final temperature of 26.5 °C?