# Thermochemistry: Hot, hot, hot!

**Thermochemistry**: deals with the energy changes that occur during chemical reactions.

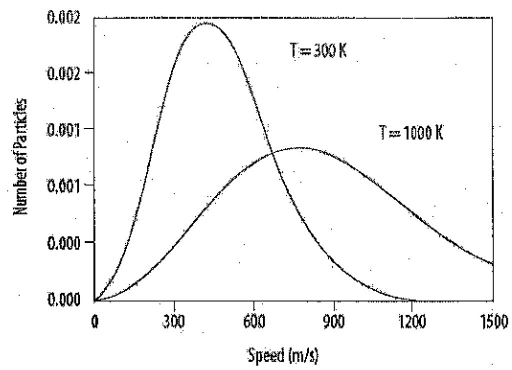
**Temperature**: measure of the average kinetic energy of the particles of a substance

→ Temperature is an intensive property: amount of matter doesn't affect it!

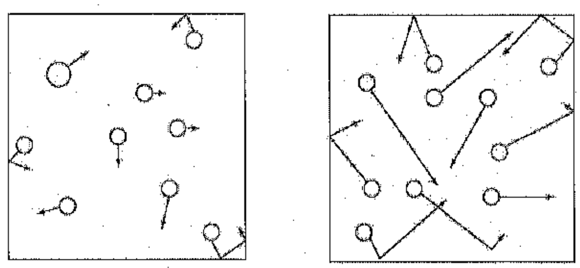
→ The Kelvin temperature is directly proportional to the average kinetic energy. For example, doubling the Kelvin temperature doubles the average kinetic energy.

→ As absolute zero is approached (0 K), the particles approach zero kinetic energy.

A Maxwell-Boltzmann distribution shows how the particles at a high temperature have greater kinetic energies than those at a low temperature.




Particle diagrams with vectors can be used to illustrate differing kinetic energies at differing temperatures.



Low Temperature High Temperature

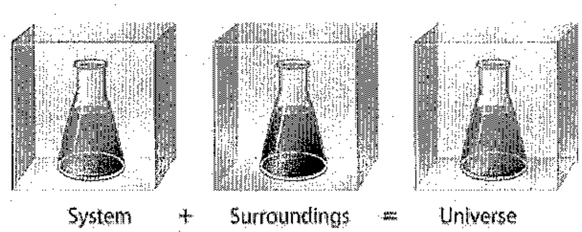
**Thermal energy:** internal energy of (capable of being) an object due to the kinetic energy of its particles

**Heat (q)**: amount of thermal energy transferred from one object to another

→ heat is an extensive property (depends on how much of a substance you have), unlike temperature.

→ Heat always flows from a warmer object to a cooler object.

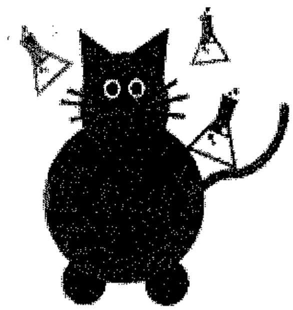
In thermochemistry, the universe is divided into two halves:




a. the system: the substance of interest

b. the surroundings: whatever is outside the system

How to calculate heat transferred: mCAT!



$$q = mC\Delta T$$

q = heat transferred

m = mass of substance

c = specific heat capacity

$\Delta T = T_{final} - T_{initial}$ = change in temperature

| ΔT Object | Sign of ΔT | Sign of *q* | Direction of Heat Transfer |
|---|---|---|---|
| Increase | + | + | Heat transferred into object |
| Decrease | – | – | Heat transferred out of object |

**Specific Heat Capacity (C)**: the amount of heat (energy) required to raise temperature of 1 g of a substance by 1 K (1 °C)

- Units are $\frac{J}{g\,°C}$ or $\frac{J}{g\,K}$
- Metals have relatively low specific heats - relatively less energy is required to raise their temperatures.
- Water has a relatively high specific heat - requires much more energy to achieve a similar temperature change.

$$\text{Specific Heat Capacity } (C_p) = \frac{\text{quantity of heat supplied}}{\text{(mass of object)(temperature change)}}$$

| Substance | Specific Heat (J/g · K) |
|---|---|
| Al | 0.902 |
| $H_2O$ (l) | 4.184 |
| Glass | 0.84 |

*Note: the mCAT equation can also be used to calculate heat using moles!

$$q = nC\Delta T$$

n = moles of substance

C = *molar* heat capacity (units $\frac{J}{mol\,°C}$)

**Watch out for units!!!** ☺

<u>Important</u>: It does NOT matter if you are given °C or K, as long as initial and final temperatures are in the same unit.

Why? Let's try an example. $\Delta T = T_f - T_i$

1. Calculate ΔT for a sample that started at 2°C and was heated up to 27°C: $\Delta T = 27 - 2 = \boxed{25°C}$ ← same #!
2. Calculate ΔT for a sample that started at 275 K and was heated up to 300. K: $300. - 275 = \boxed{25\text{ K}}$

When adding a FINITE ( Specific ) amount of energy:

- Matter with a low specific heat will change temperature more
- Matter with a high specific heat will change temperature less

When adding an unlimited supply of heat (e.g. sitting in the sun)

- Matter with low specific heat will change temperature more quickly
- Matter with high specific heat will change temperature more slowly

**Let's Practice!**

1. The specific heat (in J/g °C) of solid aluminum is 0.89, of solid iron is 0.45, of liquid mercury is 0.14, and of carbon graphite is 0.71.
   a) When the same amount of heat is applied to one gram of these substances, which one will reach the highest temperature? Explain.

   $Hg_{(l)}$ would reach the highest temp. b/c it has the lowest specific heat capacity, thus the same quantity of added heat will increase its temp. the most.

   b) If each substance is heated until they are all the same temperature, which substance required the most heat energy? Explain.

   $Al_{(s)}$ would require the most added heat energy, b/c it has the highest specific heat capacity and therefore requires more heat per unit of mass to raise its temp.

2. You are given a 45 cm³ sample of copper metal at 300 K and a 30 cm³ sample of copper metal at 300 K. Which sample contains the most heat? Explain.

   The 45 $cm^3$ sample contains more heat: heat is an extensive property, and the 45 $cm^3$ sample has more volume = more mass = more heat.

3. How much energy, in joules, does it take to heat 15 mL of water from 273 K to 305 K? (The density of water is 1.0 g/mL and the specific heat capacity of water is 4.18 J/g °C).

15 mL = 15 g! (since density = 1.0 g/mL)

$$q = mC\Delta T = (15\,g)(4.18\,\frac{J}{g\,°C})(305 - 273) = 2008 \text{ w/ 2 s.f.} \Rightarrow \boxed{2.0 \times 10^3\,J}$$

($T_f - T_i$ = 305 − 273)

4. If 0.596 kJ of heat are removed from 29.6 g of water at 22.9°C, what will be the final temperature of the water? (The specific heat capacity of water is 4.18 J/g °C).

$$-596\,J = (29.6\,g)(4.18\,\frac{J}{g\,°C})(T_f - 22.9°C)$$

$$\Rightarrow T_f - 22.9 = \frac{-596}{(29.6)(4.18)} = -4.82 \Rightarrow T_f = 22.9 - 4.82 = \boxed{18.1\,°C}$$

5. If 1.82 kJ of heat is required to raise the temperature of a sample of mercury 52°C, and the molar heat capacity of mercury is 28.1 J/mol °C, what is the mass of the sample of mercury?

$$1{,}820\,J = n\,(28.1\,\frac{J}{mol\,°C})(52\,°C)$$

$$n = \frac{1{,}820}{(28.1)(52)} = 1.3\,mol\,Hg \times \frac{200.59\,g\,Hg}{1\,mol\,Hg} = \boxed{250\,g\,Hg}$$

6. The temperature of a 95.4 g piece of copper increases from 25.0°C to 48.0°C when the copper absorbs 849 J of heat. What is the specific heat of copper?

$$849\,J = (95.4\,g)(x)(48.0 - 25.0)$$

$$x = \frac{849\,J}{(95.4\,g)(23.0\,°C)} = \boxed{0.387\,\frac{J}{g\,°C}}$$