Name: ____________________

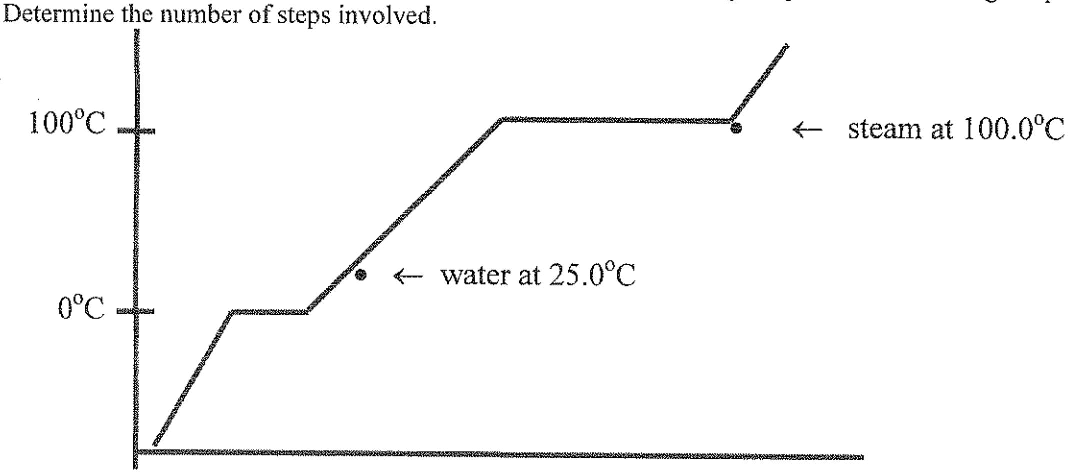
Phase changes

Many times when we heat or cool a substance we produce both a temperature change and a phase change. For example, we start with a liquid and heat it to its boiling point and then convert it to a vapor; or we start with a liquid and cool it to its freezing point and then freeze it. Processes like these involve calculations with two or more steps. There are two formulas that we have already discussed and will aid you in calculating the energies required to change a substance's phase. Think in terms of the Kinetic Theory when deciding which equations to use. One equation is temperature dependent the other is not.

$q = mCp\Delta T$ **$q = m\Delta H$**

Example: Calculate the heat needed to change 3.00×10^2 grams of water at 25.0°C to steam at 100.0°C. The heat of vaporization of water is 2258 J/g.

Solution: Draw a phase diagram of this substance. Mark the starting temperature and ending temperature. Determine the number of steps involved.



This problem involves two heat calculations:

Heat the water from 30°C to 100°C. $q = mCp\Delta T$

Vaporize the water. $q = m\Delta H_v$

The total heat needed will be the sum of these two calculations.

$$q = mCp\Delta T + m\Delta H_v$$

$$q = (3.00 \times 10^2 g)(4.184 \frac{J}{g°C})(75.0°C) + (3.00 \times 10^2 g)(2258 \frac{J}{g}) = 7.72 \times 10^5 J$$

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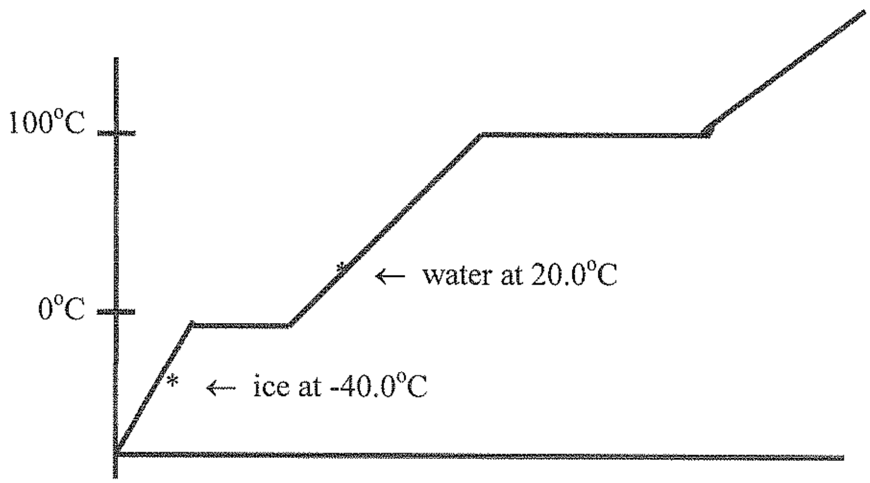
Example: Calculate the heat needed to change 75.0 grams of ice at -40.0 °C to water at 20.0 °C. The specific heat of solid ice is 2.04 J/g C and the heat of fusion of ice is 333.6 J/g.

Solution: Draw a phase diagram of this substance. Mark the starting temperature and ending temperature. Determine the number of steps involved.



This problem involves three steps:

1. heats the ice from -40°C to its melting point of 0.0°C. $q = mCp\Delta T$
2. completely melt the ice. $q = m\Delta H_f$
3. heat the water from 0.0°C to 20.0°C. $q = mCp\Delta T$.

The amount of heat required is equal to the sum of these three steps.

$q = (75.0g)(2.04\ J/g\ ^{\circ}C)(40^{\circ}C) + (75.0g)(333.6J) + (75.0g)(4.184\ J/g\ ^{\circ}C)(20.0^{\circ}C) = 3.74 \times 10^4\ J$

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Solve the following problems neatly and orderly showing all work.

Useful Information:

specific heat of water, $H_2O(l)$ = 4.184 J/g °C
specific heat of ice, $H_2O(s)$ = 2.04 J/g °C
specific heat of steam, $H_2O(g)$ = 2.00 J/g °C
heat of fusion of ice (0°C) = 333.6 J/g
heat of vaporization of water (100°C) = 2260 J/g
heat of crystallization of water = 333.6 J/g
heat of condensation of water = 2260 J/g

20.) Calculate the heat released when 454 grams of steam at 100°C condenses and then cools to water at 30.0°C. **(ans. 1.2 x 10^6 J)**

21.) Calculate the heat needed to change 475 grams of water at 40.0°C to steam at 100.0°C. **(ans. 1.19 x 10^6 J)**

22.) Calculate the heat needed to change 2.50 x 10^2 grams of ice at 0.0°C to steam at 100.0°C. **(ans. 7.53 x 10^5J)**

23.) How much heat is needed to change 3.00 x 10^2g of ice at -30.0°C to steam at 130.0°C? **(ans. 9.40 x 10^5 J)**

24.) How much heat is removed from 60.0 g of steam at 100.0°C to change it to 60.0 g of water at 20.0°C? **(ans. 1.56 x 10^5 J)**

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Phase Changes

Imagine a simplified model of a solid as tiny particles bonded together by springs. The spring represents the electromagnetic forces between the particles. If the thermal energy of a solid is increased, both the potential and kinetic energy of the particles increase. The temperature is a measure of the average kinetic energy of the particles.

At higher temperatures, the forces between the particles are no longer strong enough to hold them in fixed locations. Eventually, the particles become free to slide past each other. The substance has changed from a solid to a liquid. The temperature at which this occurs is called the melting point.

When a substance is in the process of melting, added thermal energy increases the potential energy of particles, breaking the bonds holding them together. The added thermal energy does not increase the kinetic energy of the particles. Thus, the temperature does not increase.

The amount of energy needed to melt a unit mass of a substance is called the heat of fusion of that substance. For example, the heat of fusion of ice is 3336 J/g. If one gram of ice at its melting point, 0°C, absorbs 333.6 J, it will become 1 gram of water at the same temperature, 0°C. The added energy causes a change in state but not in temperature.

After the substance is totally melted, a further increase in thermal energy once again increases the temperature. Added thermal energy increases both the kinetic and potential energy. As the temperature increases, some particles in the middle of the liquid obtain enough energy to break free from other particles. A tiny bubble of vapor is formed and rises to the surface. The liquid begins to boil. Any added thermal energy is used to increase the potential energy of particles and change them from the liquid to the vapor state. This temperature is known as the boiling point. The amount of thermal energy needed to vaporize a unit mass of liquid is called the heat of vaporization. For water, the heat of vaporization is 2260 J/g. Every substance has a characteristic heat of vaporization and of fusion.

When substances are condensed and frozen energy is released. These processes are exothermic. The heat of condensation is the amount of energy per gram released when condensing a gas into a liquid. The heat of crystallization (solidification) is the amount of energy per gram released when freezing a liquid into the solid phase. The amount of energy released, is the same amount as was taken in during the endothermic processes of boiling and melting. A negative sign is used to indicate the release of energy.

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Example:
Calculate the heat energy required, in joules, to melt 5.00 x 10^2 grams of ice, which is at 0.0 °C. The heat of fusion of ice is 333.6 J/g.

ice (0.0 °C) → water (0.0 °C)

$q = mH_f$

= (5.00 x 10^2 g)(333.6 J/g) = 1.667 x 10^5 J = 1.67 x 10^5 Joules needed

Calculate the heat released when 2.00 x 10^2 grams of steam at 100°C condenses to form water at 100°C. The heat of condensation of steam is 2258 J/g.

steam (100°C) → water (100°C)

heat energy = mass x the heat of condensation

= (2.00 x 10^2 g)(2258 J/g) = 4.516 x 10^5 joules = 4.52 x 10^5 J

Liquid ammonia is a common refrigerant because it absorbs so much heat energy when it turns from the liquid to a gas. The heat of vaporization of liquid ammonia is 1374 J/g. Calculate the heat needed to turn 454 grams of liquid ammonia at its boiling point to ammonia gas at the same temperature.

$NH_{3(l)} \rightarrow NH_{3(g)}$

heat energy = mass x the heat of vaporization

= (454 g)(1374 J/g) = 6.237 x 10^5 joules = 6.24 x 10^5 J

Solve the following problems on a separate sheet of paper following the method shown above.

Useful Information:

- specific heat of water, $H_2O(l)$ = 4.184 J/g °C
- specific heat of ice, $H_2O(s)$ = 2.04 J/g °C
- specific heat of steam, $H_2O(g)$ = 2.00 J/g °C
- heat of fusion of ice (0°C) = 333.6 J/g
- heat of vaporization of water (100°C) = 2260 J/g
- heat of crystallization of water = 333.6 J/g
- heat of condensation of water = 2260 J/g

25.) Calculate the number of joules needed to turn 325 grams of water at 100°C to steam at 100°C. **(ans. 7.34 x 10^5 J)**

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26.) Calculate the heat released when 875 grams of water at 0.0°C turns to ice at 0.0°C. **(ans. 2.9 x 10^5 J)**

27.) Calculate the number of joules needed to vaporize 2.00 x 10^2 grams of liquid ammonia at its boiling point and produce ammonia vapor at the same temperature. The heat of vaporization of liquid ammonia is 1374 J/g. **(ans. 2.75 x 10^5 J)**

28.) How much heat is needed to melt 25.4 g of iodine? H_f = 61.7 J/g. **(ans. 1570 J)**

29.) How much heat is needed to melt 4.24 g of Pd? H_f = 162 J/g. **(ans. 687 J)**