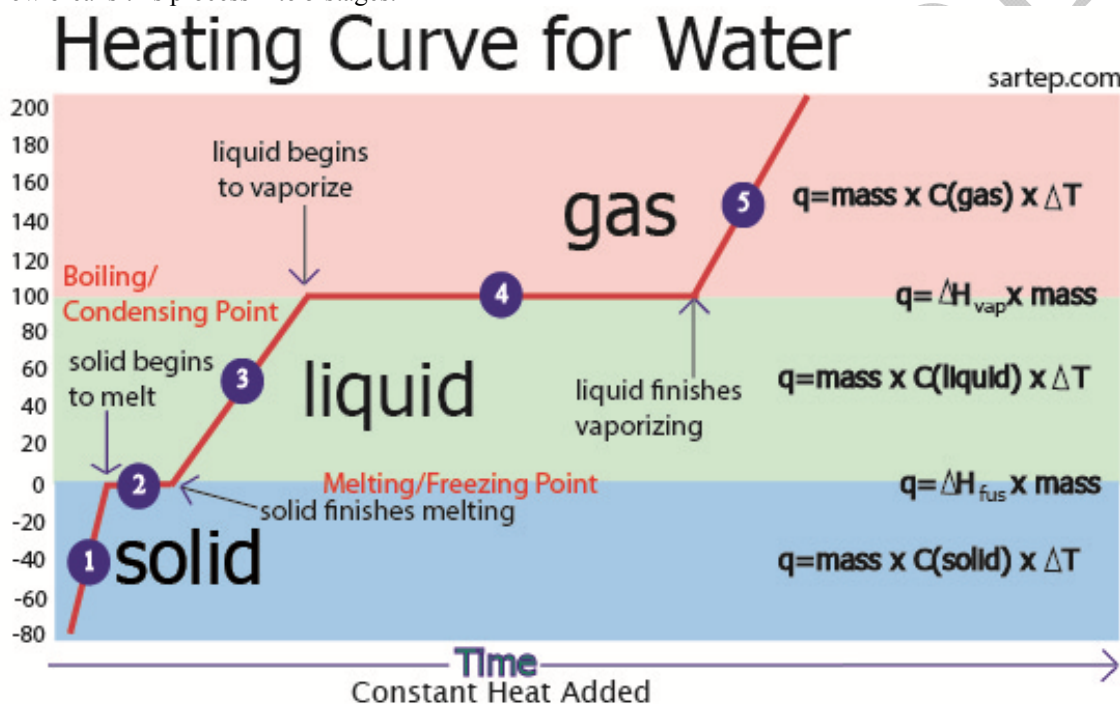


Understanding Phase Changes

As a piece of ice is exposed to a warmer environment, it begins to absorb heat. The heat causes the solid molecules to vibrate faster. Eventually, the ice molecules break loose of their lattice positions and melting will begin to occur. Ice melts at 0°C. At this temperature all of the heat added is used to crack apart the ice structure by breaking the hydrogen bonds between the ice molecules. The temperature remains at the melting point from the time the first molecule of ice melts until the last molecule of ice melts. Although heat added at this time does not cause a rise in temperature, it does increase the potential energy of the water. Once all of the ice molecules have melted, heat added will cause an increase in the water temperature until the boiling point is reached. Water boils at 100°C. At the boiling point, heat added is used to break the intermolecular attractions between molecules. Once all the molecules have changed from liquid to gas, the temperature of the vapor will begin to increase.

The graph below breaks this process into 5 stages.



Stage 1: Ice is heated to its melting point. Since there is an increase in temperature with the addition of heat, the formula to use to calculate the heat change in this stage is: $q = \text{mass} \times C \times \Delta T$. It is important to remember to use the specific heat capacity of the solid state. At stage one, since the temperature is increasing, kinetic energy is increasing.

Stage 2: Since added heat does not cause an increase in temperature ($\Delta T=0$), you cannot use the same formula as in stage one. Instead, for stage two the formula to use is: $q = H_{\text{fus}} \times \text{mass}$. ΔH_{fus} represents heat of fusion which is defined as the amount of energy needed to melt one gram of a substance. There is no change in temperature at stage two so the heat added causes an increase in potential energy.

Stage 3: As in stage one, added heat leads to an increase in temperature. For this stage the formula to use is: $q = \text{mass} \times C \times \Delta T$. The C value of the liquid state should be used. Since the temperature is increasing, kinetic energy is increasing.

Stage 4: Like stage two, heat added to the water does not cause an increase in temperature. The formula to use in stage four is: $q = H_{\text{vap}} \times \text{mass}$. ΔH_{vap} represent the heat of vaporization, the amount of heat needed to vaporize one gram of a substance. There is no change in temperature at stage two so the heat added causes an increase in potential energy.

Stage 5: Added heat leads to an increase in temperature (like in stages one & three) so the formula to use is: $q = \text{mass} \times C \times \Delta T$. The C value of the gaseous state should be used. At stage five, since the temperature is increasing, kinetic energy is increasing.

Example: Calculate the amount of heat needed to raise the temperature of 250.0 grams of water from -80.0°C to 200.0°C . Important constants for H_2O : Melting point: 0°C , Boiling point: 100°C , $C(\text{solid})$: $2.09 \text{ J/g}^{\circ}\text{C}$, $C(\text{liquid})$: $4.184 \text{ J/g}^{\circ}\text{C}$, $C(\text{gas})$: $2.01 \text{ J/g}^{\circ}\text{C}$, ΔH_{fus} : 335.0 J/g , ΔH_{vap} : 2259.0 J/g .

Stage 1: $q = \text{mass} \times C \times \Delta T$
 $q = (250.0 \text{ g}) \times (2.09 \text{ J/g}^{\circ}\text{C}) \times (0^{\circ}\text{C} - (-80.0^{\circ}\text{C}))$
 $q = 41800 \text{ J}$

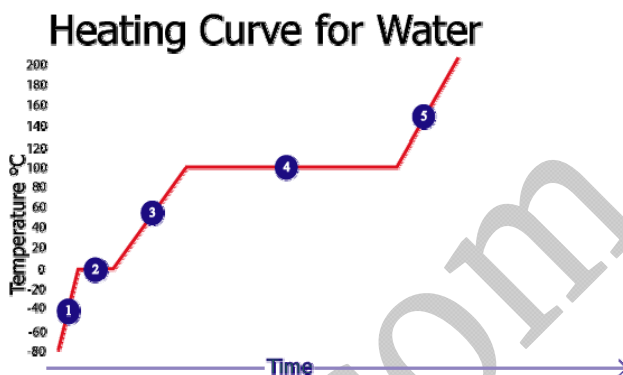
Stage 2: $q = H_{\text{fus}} \times \text{mass}$
 $q = (335 \text{ J/g}) \times (250.0 \text{ g})$
 $q = 83750 \text{ J}$

Stage 3: $q = \text{mass} \times C \times \Delta T$
 $q = (250.0 \text{ g}) \times (4.184 \text{ J/g}^{\circ}\text{C}) \times (100.0^{\circ}\text{C} - 0^{\circ}\text{C})$
 $q = 104600 \text{ J}$

Stage 4: $q = H_{\text{vap}} \times \text{mass}$
 $q = (2259 \text{ J/g}) \times (250.0 \text{ g})$
 $q = 564750 \text{ J}$

Stage 5: $q = \text{mass} \times C \times \Delta T$
 $q = (250.0 \text{ g}) \times (2.01 \text{ J/g}^{\circ}\text{C}) \times (200.0^{\circ}\text{C} - 100.0^{\circ}\text{C})$
 $q = 50250 \text{ J}$

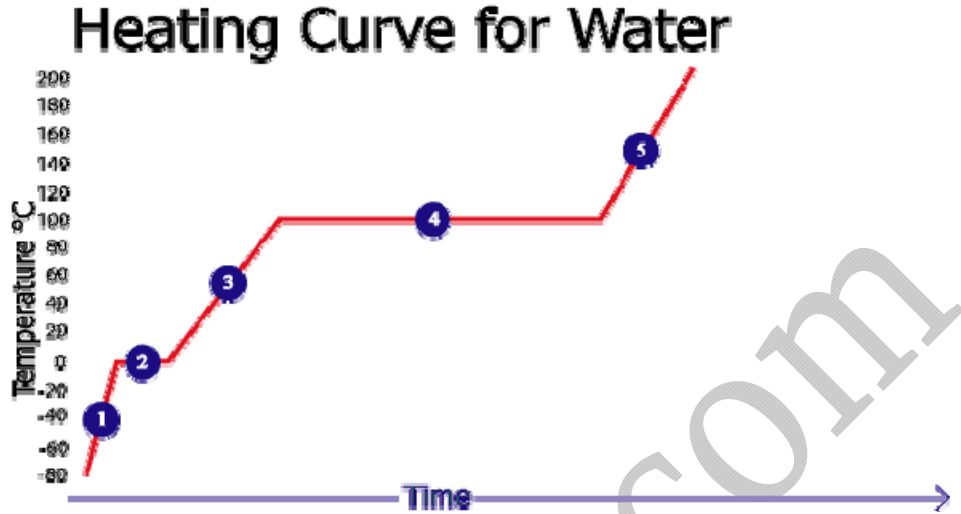
$q_{\text{total}} = \text{Stage 1} + \text{Stage 2} + \text{Stage 3} + \text{Stage 4} + \text{Stage 5}$
 $q_{\text{total}} = 41800 \text{ J} + 83750 \text{ J} + 104600 \text{ J} + 564750 \text{ J} + 50250 \text{ J}$
 $q_{\text{total}} = 845150 \text{ J} = 845 \text{ kJ} = 202 \text{ kilocalories}$



If the reverse of the above reaction were carried out, the magnitude of the q_{total} would be the same but sign would be negative (-845 kJ or $-202 \text{ kilocalories}$). The negative value indicates that it would be an exothermic process. A positive q value indicates that a process is endothermic. In cooling, heat of solidification (H_{solid}) is used instead of heat of fusion (H_{fus}) and heat of condensation (H_{cond}) is used instead of heat of vaporization (H_{vap}). Heats of fusion and solidification are the exact same magnitude but of different sign ($H_{\text{solid}} = -H_{\text{fus}}$) and heats of vaporization and condensation are the exact same magnitude but of different sign ($H_{\text{cond}} = -H_{\text{vap}}$).

Homework: Answer each of the following questions.

Use this graph to answer questions 1-15.



1. _____ Which number represents the freezing point?
2. _____ Which number represents the melting point?
3. _____ Which number represents the vaporization of a liquid?
4. _____ Which number represents the condensation point?
5. _____ Which number represents the warming of a solid?
6. _____ Which number represents the crystallization?
7. _____ Which number represents the solid state?
8. _____ Which number represents the melting of a solid?
9. _____ Which number represents the liquid state?
10. _____ Which number represents the gaseous state?
11. _____ Which number represents the warming of a vapor?
12. _____ Which number represents the warming of a liquid?
13. _____ Which number represents the boiling point?
14. _____ Which numbers show a change in potential energy?
15. _____ Which numbers show a change in kinetic energy?
16. _____ What formula is used when there is a change in kinetic energy?
17. _____ What formula is used at the melting point of a substance?
18. _____ What formula is used at the boiling point of a substance?
19. Draw a heating curve for ammonia between -120°C & 20°C . Label: solid, liquid, gas, boiling point, freezing point, melting point, condensing point and the formula that would be used at each stage. Boiling point (NH_3): -33.5°C , Melting point (NH_3): -77.9°C .

20. Calculate the amount of heat (in kilocalories and kilojoules) needed to raise the temperature of 500.0 grams of water from -20°C to 120°C . Important constants for H_2O : Melting point: 0°C , Boiling point: 100°C , $C(\text{solid})$: $2.09 \text{ J/g}^{\circ}\text{C}$, $C(\text{liquid})$: $4.184 \text{ J/g}^{\circ}\text{C}$, $C(\text{gas})$: $2.01 \text{ J/g}^{\circ}\text{C}$, ΔH_{fus} : 335.0 J/g , ΔH_{vap} : 2259.0 J/g .

a. Stage 1: _____

b. Stage 2: _____

c. Stage 3: _____

d. Stage 4: _____

e. Stage 5: _____

f. Total: _____

21. Calculate the amount of heat (in kilocalories and kilojoules) released as 1.0 liter of water at 80°C is frozen to -3°C . Important constants for H_2O : Melting point: 0°C , Boiling point: 100°C , $C(\text{solid})$: $2.09 \text{ J/g}^{\circ}\text{C}$, $C(\text{liquid})$: $4.184 \text{ J/g}^{\circ}\text{C}$, $C(\text{gas})$: $2.01 \text{ J/g}^{\circ}\text{C}$, ΔH_{fus} : 335.0 J/g , ΔH_{vap} : 2259.0 J/g . The density of water is 1.0 g/mL .

a. Stage 1: _____

b. Stage 2: _____

c. Stage 3: _____

d. Total: _____

22. Calculate the amount of heat (in kilocalories and kilojoules) burned if you eat 300.0 grams of ice at -5°C and it is warmed to body temp (37°C). Important constants for H_2O : Melting point: 0°C , Boiling point: 100°C , $C(\text{solid})$: $2.09 \text{ J/g}^{\circ}\text{C}$, $C(\text{liquid})$: $4.184 \text{ J/g}^{\circ}\text{C}$, $C(\text{gas})$: $2.01 \text{ J/g}^{\circ}\text{C}$, ΔH_{fus} : 335.0 J/g , ΔH_{vap} : 2259.0 J/g .

a. Stage 1: _____

b. Stage 2: _____

c. Stage 3: _____

d. Total: _____

23. Draw and label a cooling curve for water and calculate the amount of heat (in kilocalories and kilojoules) released as 750 g of H₂O cools from 220°C to -110°C. Important constants for H₂O: Melting point: 0°C, Boiling point: 100°C, Cp(solid): 2.09 J/g°C, Cp(liquid): 4.184 J/g°C, Cp(gas): 2.01 J/g°C, ΔH_{fus}: 335.0 J/g, ΔH_{vap}: 2259.0 J/g.

a. Stage 1: _____

b. Stage 2: _____

c. Stage 3: _____

d. Stage 4: _____

e. Stage 5: _____

f. Total: _____

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