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Topic 6.5: Energy of Phase Changes

Revision Notes · AP Chemistry

UNIT 6 · THERMOCHEMISTRY

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The Heating Curve: Five Segments, Two Kinds of Step

A heating curve plots temperature against heat added, for a steadily heated sample. For water, from ice below 0 °C to steam above 100 °C, it has five segments of two kinds.

The three sloped segments are warmings: ice warms to 0 °C, liquid warms to 100 °C, steam warms beyond. On a slope, heat is priced by

$q = mc\Delta T$,

with the specific heat capacity of the phase being warmed.

The two flat segments are phase changes: melting at 0 °C and vaporization at 100 °C. On a plateau the temperature does not move, and the heat is priced per mole by

$q = n\Delta H$:

ΔH_{fus} for melting, ΔH_{vap} for vaporization.

Why the Temperature Refuses to Move on a Plateau

Temperature measures the average kinetic energy of the particles; heat that speeds particles up raises it.

During melting, the added heat is spent pulling particles partly free of the attractions holding them in the solid lattice. It raises their potential energy, not their kinetic energy, so the thermometer sits still until the last of the solid has melted.

Vaporization spends the heat the same way, only more completely: particles are separated entirely and escape. Only when the change is finished can further heat speed particles up again.

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Two Prices: ΔHfus and ΔHvap

ΔHfus is the heat absorbed to melt one mole of solid at its melting point: 6.01 kJ mol^{-1} for water. ΔHvap is the heat absorbed to vaporize one mole of liquid at its boiling point: 40.7 kJ mol^{-1} for water.

The gap is the particle story. Melting loosens the solid's structure but leaves particles in contact, so only some attractions are overcome; vaporization overcomes all of them, costing 40.7 ÷ 6.01, about 6.8 times as much per mole for water.

Both dwarf ordinary warming: one mole of ice warmed by 10 °C costs 18.02 × 2.09 × 10 = 377 J, about 0.38 kJ, and one mole of steam warmed by 10 °C costs about 0.36 kJ, against 6.01 kJ to melt it and 40.7 kJ to vaporize it.

Plateau length follows the same ratio: at a steady heating rate, the vaporization plateau runs about 6.8 times longer than the melting plateau. Stronger intermolecular forces raise both prices: hydrogen-bonded liquids have far larger ΔHvap values than dispersion-only ones.

Pricing a Multi-Stage Path

A path crossing a phase boundary is priced stage by stage: split at each boundary, price each stage with its own equation, convert to one unit, then add.

Warming stages use the mass and that phase's specific heat capacity: ice 2.09, liquid water 4.18, steam 2.01 J g^{-1} $°C^{-1}$. Plateau stages use moles: divide mass by the molar mass, 18.02 g mol^{-1} for water, first.

Never carry q = mcΔT across a phase boundary: one large ΔT prices none of the plateau energy, where most of the total usually sits.

Signs follow the system's point of view, as in Topic 6.1: absorbed heat is positive, released heat negative. A heating path totals positive; a cooling path gives the same stages with signs reversed.

Cooling Curves and the Reverse Changes

A cooling curve is the heating curve run backwards: the steam cools, condenses at 100 °C, the liquid cools, freezes at 0 °C, the ice cools. The plateaus sit at the same temperatures: they mark the same two boundaries.

Each reverse change keeps the magnitude and flips the sign: freezing is −ΔHfus, −6.01 kJ mol^{-1} for water; condensation is −ΔHvap, −40.7 kJ mol^{-1}.

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The reverse changes are exothermic because they run the particle story backwards: condensing and freezing form attractions, and forming attractions releases energy. Condensing 2.00 mol of steam releases 2.00 × 40.7 = 81.4 kJ.

Sublimation and Deposition

Sublimation is the direct change from solid to gas, skipping the liquid; dry ice, solid CO_2, is the standard example. Deposition is its reverse, gas straight to solid: frost is its work.

Sublimation does melting's loosening and vaporization's full separation in one step, so its enthalpy is the sum:

$\Delta H_{sub} = \Delta H_{fus} + \Delta H_{vap} = 6.01 + 40.7 = 46.7$ kJ mol^{-1} for water

Signs follow the reverse-pair rule: sublimation endothermic at +46.7 kJ mol^{-1} for water, deposition exothermic at −46.7 kJ mol^{-1}.

Worked Examples

Example 1: One plateau. How much heat melts 36.0 g of ice at 0 °C? A plateau is priced per mole: n = 36.0 ÷ 18.02 = 1.998 mol, about 2.00 mol. q = nΔHfus = 1.998 × 6.01 = 12.0 kJ, absorbed, so positive.

Example 2: Melt, then warm. How much heat takes 25.0 g of ice at 0 °C to liquid water at 50.0 °C? Stage 1, melting: n = 25.0 ÷ 18.02 = 1.387 mol, so q = 1.387 × 6.01 = 8.34 kJ = 8,338 J. Stage 2, warming the liquid: q = mcΔT = 25.0 × 4.18 × 50.0 = 5,225 J. Total: 8,338 + 5,225 = 13,563 J, about 13.6 kJ.

Example 3: The full five stages. How much heat takes 50.0 g of ice at −10.0 °C to steam at 110.0 °C? The sample is n = 50.0 ÷ 18.02 = 2.775 mol throughout. Warm the ice: 50.0 × 2.09 × 10.0 = 1,045 J. Melt: 2.775 × 6.01 = 16,676 J. Warm the water: 50.0 × 4.18 × 100.0 = 20,900 J. Vaporize: 2.775 × 40.7 = 112,930 J. Warm the steam: 50.0 × 2.01 × 10.0 = 1,005 J. Total: 1,045 + 16,676 + 20,900 + 112,930 + 1,005 = 152,556 J, about 153 kJ. Vaporization alone is 112.9 kJ of the 153 kJ, roughly three quarters.

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Example 4: A cooling path. How much heat is released when 10.0 g of steam at 100 °C condenses and the water cools to 25.0 °C? Condensing: n = 10.0 ÷ 18.02 = 0.555 mol, so q = −0.555 × 40.7 = −22,586 J. Cooling: q = mcΔT = 10.0 × 4.18 × (25.0 − 100) = −3,135 J. Total: −22,586 + (−3,135) = −25,721 J, about −25.7 kJ. Negative, as a cooling path must be: the sample gives this heat up.

Traps That Cost Marks in Topic 6.5

"The temperature rises steadily while a sample melts." It cannot: until the change is complete, every joule goes into overcoming attractions, so the temperature holds at the melting or boiling point.

"One mcΔT from start to finish." q = mcΔT prices warming inside one phase only. A path crossing a boundary needs a plateau term per phase change; skipping them throws away most of the energy.

"ΔHfus for boiling, and grams into the plateau." Fusion prices melting and vaporization prices boiling, and both are per mole: grams must be converted via the molar mass before meeting ΔHfus or ΔHvap.

"Condensation has ΔH = +40.7 kJ mol^{-1}." Reverse changes flip the sign. Condensation and freezing release heat: −40.7 and −6.01 kJ mol^{-1} for water.

"ΔHvap is bigger because boiling happens at a higher temperature." The price is set by the separation achieved, not the temperature: melting loosens particles, vaporization separates them completely.

"Add the joules to the kilojoules." Warming stages come out in joules and plateau stages in kilojoules. Convert every stage to one unit before adding.

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Key Relationships to Remember

- Heating curve for water: five segments, three sloped warmings priced by q = mcΔT and two flat plateaus priced by q = nΔH
- On a plateau the temperature is constant because the heat raises potential energy by overcoming intermolecular forces, not kinetic energy
- ΔHfus, 6.01 kJ mol^{-1} for water: heat absorbed per mole melted; freezing is its exact reverse at −ΔHfus
- ΔHvap, 40.7 kJ mol^{-1} for water: heat absorbed per mole vaporized; condensation is its exact reverse at −ΔHvap
- ΔHvap far exceeds ΔHfus because vaporization separates particles completely while melting only loosens their arrangement; for water the ratio is about 6.8
- Specific heat capacities of water's phases: ice 2.09, liquid 4.18, steam 2.01 J g^{-1} $°C^{-1}$; each warming stage uses its own phase's value
- Multi-stage paths: split at each boundary, price each stage separately, convert joules and kilojoules to one unit, then add; heating positive, cooling negative
- ΔHsub = ΔHfus + ΔHvap, 46.7 kJ mol^{-1} for water; deposition carries the opposite sign

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Topic 6.5 Quiz: Energy of Phase Changes

Topic 6.5 Worksheet

Unit 6: All Topics

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