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Topic 6.3: Heat Transfer and Thermal Equilibrium

Worksheet · AP Chemistry

UNIT 6 · THERMOCHEMISTRY

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How to Use This Worksheet

Work in order. Section A checks the definitions and the rules: heat against temperature, the heat equation and its signs, specific heat capacity, and thermal equilibrium. Section B practises the calculations: warming and cooling with q = mcΔT, finding an unknown specific heat, and mixing samples to an equilibrium temperature. Section C is exam style: a full metal-in-water equilibrium, judging claims, and a timed heater problem.

Reference facts. Specific heat capacities, in J g^{-1} $°C^{-1}$: water 4.18, aluminium 0.897, iron 0.450, copper 0.385. q = mcΔT, with ΔT = T(final) − T(initial), and every sign is taken from the system's point of view: q is positive when the system absorbs heat, negative when it releases heat. In an insulated mixture, heat lost by the hot sample equals heat gained by the cold sample.

Three habits protect every answer. Always work out ΔT first, as final minus initial, before touching the equation. Keep the sign that the arithmetic gives you, and say in words which way the heat went. In mixing problems, compare the mc products before calculating: they tell you which starting temperature the answer must sit near.

Do not look at the answer key until you have attempted every question.

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Section A: Recall and Concepts

A1. (a) Define heat, and state its units. (b) State what temperature measures, and state its units. (c) State the direction in which heat flows spontaneously between two objects at different temperatures. (d) State two properties of the objects that do not decide that direction.

A2. (a) Write the equation connecting heat, mass, specific heat capacity and temperature change, and define each symbol with its units. (b) Write ΔT in terms of the initial and final temperatures. (c) State the condition that must hold for this equation to capture the whole heat transfer. (d) State when q is positive and when q is negative, from the system's point of view.

A3. (a) Define specific heat capacity, and state its units. (b) State the specific heat capacity of liquid water. (c) Equal masses of a high-c substance and a low-c substance receive equal heat. State which one warms more, and explain why in one sentence. (d) State what the product mc represents for a sample, with its units.

A4. For each event, state the sign of q for the named system. (a) The water in a beaker warming from 20 °C to 35 °C; system: the water. (b) A metal block cooling from 80 °C to 60 °C; system: the block. (c) Soup cooling on a counter; system: the soup. (d) Hands warming while wrapped around a hot mug; system: the hands. (e) A sample held for an hour at exactly the temperature of its surroundings; state the net q.

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A5. (a) Name the route by which heat is transferred through direct contact. (b) Name the other two routes, and state briefly how each carries energy. (c) Explain at particle level why the far end of a metal rod warms when only one end is heated. (d) State the two conditions that define thermal equilibrium between two objects.

Section B: Core Practice

B1. 75 g of water warms from 15 °C to 45 °C. (a) Calculate ΔT. (b) Calculate q, showing the substitution. (c) State the sign of q and what it means. (d) Give q in kilojoules. (e) A heater supplying 50 J per second did the warming. Calculate how long it ran.

B2. 120 g of water cools from 85 °C to 30 °C. (a) Calculate ΔT. (b) Calculate q. (c) State how much heat was released, in kilojoules. (d) All of that released heat is captured by 100 g of water starting at 20 °C. Calculate the temperature rise of that water, and its final temperature.

B3. A heater supplies 385 J to a 50 g sample of copper. (a) Calculate the temperature rise of the copper. (b) State its final temperature if it started at 25 °C. (c) Calculate the temperature rise if the same 385 J were supplied to 50 g of water instead. (d) Explain the difference between the two rises in one sentence.

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B4. A 60 g sample of an unknown metal absorbs 540 J and warms from 25 °C to 45 °C. (a) Calculate ΔT. (b) Calculate the specific heat capacity of the metal, showing the rearrangement you use. (c) Identify the metal from the reference values. (d) Calculate the heat needed to warm 600 g of this metal by the same temperature change.

B5. Water is mixed with water in an insulated jug. (a) 200 g at 90 °C is mixed with 200 g at 10 °C. State the final temperature, and the rule that gives it at once. (b) 150 g at 60 °C is mixed with 50 g at 20 °C. Calculate the final temperature, setting heat lost equal to heat gained. (c) What mass of water at 10 °C must be added to 200 g at 90 °C for the mixture to land at 50 °C?

B6. A small heater delivers 300 J to 30 g of water and, separately, 300 J to 30 g of copper. (a) Calculate the temperature rise of each sample. (b) Calculate the ratio of the copper rise to the water rise. (c) Show that this ratio equals the inverse ratio of the two specific heat capacities. (d) A student says the copper warms more because it is denser. State the property that actually decides the rises.

Section C: Exam Style

C1. A 50 g block of copper at 100 °C is dropped into 200 g of water at 25 °C in an insulated cup. (a) Write the heat balance equation for this mixture in symbols, using T for the final temperature. (b) Solve it for the final temperature. (c) Calculate the heat gained by the water. (d) Check your answer by calculating the heat lost by the copper. (e) Explain why the final temperature sits near 25 °C rather than near 62.5 °C, the average of the two starting temperatures.

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C2. Judge each claim, supporting each verdict with the rule it depends on. (a) "At thermal equilibrium, the two objects contain the same amount of heat." (b) "Heat always flows from the object with more internal energy to the object with less." (c) "Doubling the mass doubles the heat needed for the same temperature rise." (d) "Substance X warmed twice as much as substance Y when equal masses received equal heat, so X has twice the specific heat capacity of Y." (e) "At thermal equilibrium, heat stops moving between the two objects."

C3. A small immersion heater supplies heat at 25 J per second. (a) Calculate the heat needed to raise 80 g of water by 10 °C. (b) Calculate how long the heater takes to do this. (c) The heater is then used on 80 g of cooking oil, with c = 1.90 J g^{-1} $°C^{-1}$, for the same 10 °C rise. Calculate the heat needed and the time taken. (d) If the oil were left on the heater for the full time found in part (b), calculate its temperature rise. (e) State whether running the heater for longer changes the specific heat capacity of the oil, and give your reason.

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Answer Key

A1. (a) Heat is energy transferred between objects because of a temperature difference; it is measured in joules. (b) Temperature measures the average kinetic energy of the particles in a substance; measured in degrees Celsius or kelvin. (c) From the object at the higher temperature to the object at the lower temperature. (d) Any two of: mass, density, total internal energy (amount of stored energy).

A2. (a) $q = mc\Delta T$: q is the heat transferred, in joules; m is the mass, in grams; c is the specific heat capacity, in J g^{-1} $°C^{-1}$; ΔT is the temperature change, in °C or K. (b) $\Delta T = T(\text{final}) - T(\text{initial})$. (c) The substance must stay in a single phase throughout: no melting, boiling, freezing or condensing during the change. (d) q is positive when the system absorbs heat (warming); q is negative when the system releases heat (cooling).

A3. (a) The heat needed to raise the temperature of one gram of a substance by one degree Celsius; units J g^{-1} $°C^{-1}$. (b) 4.18 J g^{-1} $°C^{-1}$. (c) The low-c substance warms more: with q and m fixed, $\Delta T = q \div (mc)$, so the smaller c gives the larger temperature change. (d) mc is the heat capacity of the sample itself: the heat needed to raise that whole sample by one degree, in J $°C^{-1}$.

A4. (a) Positive: the water warms, so it absorbs heat. (b) Negative: the block cools, so it releases heat. (c) Negative: the soup cools, releasing heat to the room. (d) Positive: the hands warm, absorbing heat from the mug. (e) Net q = 0: temperatures are equal, so there is no net transfer, which is thermal equilibrium.

A5. (a) Conduction. (b) Convection: energy carried by the bulk movement of a fluid. Radiation: energy carried by electromagnetic waves, with no material contact. (c) Particles at the heated end gain kinetic energy and collide with their slower neighbours, passing energy along the rod particle by particle until the far end's average kinetic energy has risen. (d) The two objects have the same temperature, and the net heat flow between them is zero.

B1. (a) $\Delta T = 45 - 15 = +30$ °C. (b) $q = mc\Delta T = 75 \times 4.18 \times 30 = 9{,}405$ J. (c) Positive: the water absorbed heat as it warmed. (d) 9,405 J ÷ 1,000 = 9.41 kJ. (e) Time = 9,405 ÷ 50 = 188.1 s, about 188 s: at a fixed supply rate, the time is simply the heat needed divided by the joules arriving each second.

B2. (a) $\Delta T = 30 - 85 = -55$ °C. (b) $q = mc\Delta T = 120 \times 4.18 \times (-55) = -27{,}588$ J. (c) The negative sign means release: 27,588 J, which is 27.6 kJ, was released. (d) $\Delta T = 27{,}588 \div (100 \times 4.18) = 27{,}588 \div 418 = 66.0$ °C. Final temperature = 20 + 66.0 = 86 °C.

B3. (a) $\Delta T = q \div (mc) = 385 \div (50 \times 0.385) = 385 \div 19.25 = 20.0$ °C. (b) 25 + 20.0 = 45 °C. (c) $\Delta T = 385 \div (50 \times 4.18) = 385 \div 209 = 1.84$ °C. (d) The same heat is spread over the same mass in both cases, but water's specific heat capacity is nearly eleven times copper's, so its temperature rise is nearly eleven times smaller.

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B4. (a) ΔT = 45 − 25 = +20 °C. (b) c = q ÷ (mΔT) = 540 ÷ (60 × 20) = 540 ÷ 1,200 = 0.450 J g^{-1} $°C^{-1}$. (c) Iron, whose reference value is 0.450 J g^{-1} $°C^{-1}$. (d) q = mcΔT = 600 × 0.450 × 20 = 5,400 J, or 5.40 kJ: ten times the mass needs ten times the heat for the same rise.

B5. (a) 50 °C. Equal masses of the same substance have equal mc products, so the final temperature is the average of the two starts: (90 + 10) ÷ 2 = 50 °C. (b) Heat lost by the hot portion = heat gained by the cold portion: 150 × (60 − T) = 50 × (T − 20), the c values cancelling because both portions are water. Expanding: 9,000 − 150T = 50T − 1,000, so 10,000 = 200T and T = 50 °C. (c) Heat lost by the 200 g must equal heat gained by the added mass m: 200 × (90 − 50) = m × (50 − 10), so 8,000 = 40m and m = 200 g.

B6. (a) Water: ΔT = 300 ÷ (30 × 4.18) = 300 ÷ 125.4 = 2.39 °C. Copper: ΔT = 300 ÷ (30 × 0.385) = 300 ÷ 11.55 = 26.0 °C. (b) Ratio = 26.0 ÷ 2.39 = 10.9. (c) Inverse ratio of specific heats = 4.18 ÷ 0.385 = 10.9. The ratios match: with q and m equal, ΔT is inversely proportional to c, so the ratio of rises is the ratio of the c values turned upside down. (d) Specific heat capacity. Density never enters q = mcΔT; copper's low c, not its density, is why its temperature climbs further on the same heat.

C1. (a) Heat lost by copper = heat gained by water: 50 × 0.385 × (100 − T) = 200 × 4.18 × (T − 25), that is, 19.25 × (100 − T) = 836 × (T − 25). (b) Expanding: 1,925 − 19.25T = 836T − 20,900. Collecting: 22,825 = 855.25T, so T = 26.7 °C. (c) Heat gained by the water = mcΔT = 836 × (26.688 − 25) = 836 × 1.688 = 1,411 J, about 1.41 kJ. (d) Heat lost by the copper = 19.25 × (100 − 26.688) = 19.25 × 73.312 = 1,411 J, about 1.41 kJ. The two routes agree at 1,411 J, as conservation requires: using the rounded 26.7 °C in part (c) would give 1,421 J, which is a rounding artefact, not a real gap. (e) Averaging the starts would be right only if the two mc products were equal. Here the water's mc is 836 J $°C^{-1}$ against the copper's 19.25 J $°C^{-1}$, over forty times larger, so the final temperature is dragged to within 1.7 °C of the water's start.

C2. (a) False. Objects do not contain heat: heat is energy in transit, not a stored quantity. Equilibrium means the two objects share a temperature and the net flow between them is zero; their internal energies can be very different. (b) False. Direction is set by temperature alone. A large lukewarm object can hold more internal energy than a small hot one, yet heat flows from the small hot object into it, as with the nail and the bath in the notes. (c) True. In q = mcΔT, with c and ΔT unchanged, q is proportional to m, so double the mass needs double the heat. (d) False, and backwards. With q and m equal, ΔT is inversely proportional to c, so warming twice as much means X has half the specific heat capacity of Y, not twice. (e) False at particle level. Energy is still exchanged in both directions across the boundary; the flows are equal, so the net flow is zero and the temperatures hold steady.

C3. (a) q = mcΔT = 80 × 4.18 × 10 = 3,344 J. (b) Time = 3,344 ÷ 25 = 133.76 s, about 134 s. (c) q = 80 × 1.90 × 10 = 1,520 J. Time = 1,520 ÷ 25 = 60.8 s. (d) In 133.76 s the heater supplies the same 3,344 J, so ΔT = 3,344 ÷ (80 × 1.90) = 3,344 ÷ 152 = 22.0 °C: the oil rises 22.0 °C, more than double the water's rise, because its specific heat capacity is less than half of water's. (e) No. Specific heat

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capacity is a property of the substance; a longer run delivers more heat and produces a larger ΔT, but c stays at 1.90 J g^{-1} $°C^{-1}$ throughout.

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