CHEMDU · COMMUNITY CHEMISTRY · LEVEL 2 ADVANCED

LECTURE L2-8

Thermodynamics

How Much Heat? Calculating Calories, Hand Warmers, and Why Water Takes Forever to Boil

Duration: 75 minutes

Advanced lecture script — pre-requisite: Level 1

HOOK (3 minutes)

Teacher holds up (or shows photos of):

A pot of water boiling on a stove

A hand warmer (crack to activate)

A cold pack (squeeze to cool)

A nutrition label (showing calories)

Teacher says: "It takes 4 minutes to boil a pot of water. It takes 30 seconds to heat the same amount of water in a microwave. Why? Different power.

Your hand warmer gets hot — but there's no flame. Your cold pack gets cold — but there's no ice.

- Today's question: How much heat is involved in chemical reactions — and how do you calculate it? *

By the end of this session, you will be able to:

Calculate heat (q) using q = mcΔT

Distinguish between exothermic (ΔH negative) and endothermic (ΔH positive)

Calculate calories in food using a calorimeter

Use Hess's Law to add reaction heats together

Understand why water has a high specific heat (why it's used in car radiators)"

SEGMENT 1: Review from Level 1 and Previous Level 2 Lectures (5 minutes)

Teacher says: "Before we go deeper, let's recall what you already know."

Review from Level 1 (Thermodynamics - Basic)

Level 1 Concept	Definition	Household Example
Exothermic	Reaction that gives OFF heat (feels hot)	Hand warmer, burning match
Endothermic	Reaction that takes IN heat (feels cold)	Cold pack, melting ice
Heat transfer	Heat moves from hot to cold	Hot coffee cooling down

Review from Level 2-5 (Stoichiometry)

Level 2-5 Concept	Formula	Example
Moles	Mass ÷ Molar mass	18 g water ÷ 18 g/mol = 1.0 mol

Quick check (show of hands / chat): "Is burning wood exothermic or endothermic?" (Exothermic — releases heat) "Is a cold pack exothermic or endothermic?" (Endothermic — absorbs heat) "Does heat flow from hot to cold or cold to hot?" (Hot to cold)

Teacher: "Good. Now let's learn how to calculate heat using a simple formula."

SEGMENT 2: Heat and Temperature — What's the Difference? (5 minutes)

Teacher says: "Many people confuse heat and temperature. They are different."

Term	Definition	Household Example
Heat (q)	The energy transferred from one object to another (measured in Joules or calories)	The energy from the stove burner going into the pot
Temperature	A measure of the average kinetic energy (movement) of particles (measured in °C or °F)	How hot the water feels — 100°C when boiling

Analogy: A swimming pool and a cup of coffee can both be at 30°C (same temperature). But the pool contains much more heat because it has much more water.

Teacher: "Temperature tells you how intense the heat is. Heat tells you how much energy is transferred."

SEGMENT 3: Specific Heat Capacity — Why Water Is Special (12 minutes)

Teacher says: "Specific heat capacity (specific heat) is the amount of heat needed to raise the temperature of 1 gram of a substance by 1°C."

Specific heat (c) = heat per gram per degree Celsius. Units: J/(g·°C) or cal/(g·°C)

Specific Heat Values for Common Household Materials

Substance	Specific Heat (J/g·°C)	What It Means
Water	4.184	Very high — takes a lot of heat to warm up
Aluminum	0.900	Medium — heats up faster than water
Iron	0.450	Low — heats up quickly
Copper	0.385	Very low — heats up very quickly
Gold	0.129	Extremely low — heats up almost instantly
Air	1.020	Close to water, but less dense

Teacher: *"Water's high specific heat (4.184 J/g·°C) is why:*

It takes a long time to boil water

Oceans and lakes don't heat up or cool down quickly (moderating climate)

Your body (mostly water) maintains a steady temperature

Car radiators use water (or water/antifreeze) to absorb engine heat"

Household Example: Why Water Takes So Long to Boil

Teacher: "To raise 1 gram of water by 1°C, you need 4.184 Joules of energy. To raise 1000 grams (1 liter) of water from 20°C to 100°C (an 80°C increase), you need:

Step	Calculation
Energy = 1000 g × 4.184 J/g·°C × 80°C	= 334,720 J = 335 kJ

- "That's a lot of energy — about the same as running a 1000-watt microwave for 5-6 minutes."*

SEGMENT 4: The Heat Equation — q = mcΔT (15 minutes)

Teacher says: "The most important formula in thermodynamics is the heat equation."

$q = m \times c \times \Delta T$

Where:

q = heat (in Joules or calories)

m = mass (in grams)

c = specific heat (in J/g·°C or cal/g·°C)

ΔT = change in temperature = $T_{final} - T_{initial}$ (in °C)

Step-by-step method:

Step	What to Do
Step 1	Identify m, c, and ΔT from the problem.
Step 2	Plug numbers into q = m × c × ΔT.
Step 3	Calculate (watch units — mass in grams, ΔT in °C).
Step 4	Write answer with correct units (Joules or calories).

Worked Example 1: Heating Water for Tea

Problem: How much heat is needed to raise the temperature of 250 grams of water from 22°C to 100°C (boiling)? (c_water = 4.184 J/g·°C)

Step	Calculation
Step 1	m = 250 g; c = 4.184 J/g·°C; ΔT = 100 - 22 = 78°C
Step 2	q = 250 g × 4.184 J/g·°C × 78°C
Step 3	q = 250 × 4.184 × 78 = 250 × 326.352 = 81,588 J
Step 4	Convert to kJ: 81,588 J ÷ 1000 = 81.6 kJ

Answer: 81.6 kJ (about 19,500 calories — enough to power a 100W lightbulb for 13 minutes).

Worked Example 2: Cooling Down Hot Coffee

Problem: A cup of coffee (200 g of water) is at 95°C. It cools to 70°C. How much heat is released? (c_water = 4.184 J/g·°C)

Step	Calculation
Step 1	m = 200 g; c = 4.184 J/g·°C; ΔT = 70 - 95 = -25°C
Step 2	q = 200 × 4.184 × (-25)
Step 3	q = 200 × (-104.6) = -20,920 J

Answer: -20.9 kJ (negative means heat is RELEASED — exothermic for the coffee, but endothermic for the surroundings).

Worked Example 3: Heating a Metal Pan (vs. Water)

Problem: An aluminum pan (mass = 500 g, c = 0.900 J/g·°C) is heated from 25°C to 200°C. How much heat is needed? Same heat for water? Compare.

For aluminum:

Step	Calculation
Step 1	m = 500 g; c = 0.900 J/g·°C; ΔT = 200 - 25 = 175°C
Step 2	q = 500 × 0.900 × 175 = 78,750 J

For the same mass of water:

Step	Calculation
q = 500 × 4.184 × 175 = 366,100 J	

Comparison:

Substance	Heat Needed	Ratio (Water/Aluminum)
Aluminum pan	78,750 J	1x
Water	366,100 J	4.65x more heat

Teacher: "That's why your metal pan heats up fast, but the water inside takes much longer to boil."

Worked Example 4: Finding Specific Heat (Identifying a Metal)

Problem: A 50.0 g metal sample is heated to 100°C and placed in 100 g of water at 22°C. The water temperature rises to 25°C. What is the specific heat of the metal? (c_water = 4.184 J/g·°C)

Step 1: Heat gained by water

Step	Calculation
q_water = m × c × ΔT = 100 g × 4.184 J/g·°C × (25 - 22)°C	
q_water = 100 × 4.184 × 3 = 1,255.2 J	

Step 2: Heat lost by metal = heat gained by water (but negative)

Step	Calculation
q_metal = -1,255.2 J	

Step 3: Use q_metal = m_metal × c_metal × ΔT_metal

Step	Calculation
-1,255.2 J = 50.0 g × c_metal × (25 - 100)°C	
-1,255.2 = 50.0 × c_metal × (-75)	
-1,255.2 = -3,750 × c_metal	

Step	Calculation
c_metal = 1,255.2 ÷ 3,750 = 0.335 J/g·°C	

Answer: The specific heat is 0.335 J/g·°C. Looking at the table, this is close to copper (0.385) or brass. Not exact due to measurement errors.

Partner talk (1 minute): "Tell your partner: If you double the mass of water, does the heat needed to raise its temperature double? (Yes — q is proportional to m). If you double ΔT, does heat double? (Yes — q is proportional to ΔT)."

SEGMENT 5: Calorimetry — Measuring Calories in Food (12 minutes)

Teacher says: "A calorimeter (kal-oh-RIM-i-ter) is a device that measures heat released or absorbed by a reaction. The same q = mcΔT formula applies."

Calorimetry: The measurement of heat flow.

Food Calories vs. Chemistry Calories

Unit	Definition	Conversion
calorie (cal) lower case	Heat to raise 1 g water by 1°C	1 cal = 4.184 J
Calorie (Cal) upper case (food label)	1 kilocalorie (kcal) = 1000 cal	1 Cal = 4184 J

Teacher: "A food 'Calorie' (with a capital C) is actually 1000 chemistry calories. So when you eat a 200 Calorie snack, your body gets 200,000 chemistry calories of energy!"

Worked Example: Calories in a Peanut

Problem: A peanut is burned under a calorimeter containing 50.0 g of water. The water temperature rises from 22.0°C to 26.5°C. How many calories (cal) and how many food Calories (Cal) are released?

Step 1: Calculate heat gained by water

Step	Calculation
q = m × c × ΔT = 50.0 g × 4.184 J/g·°C × (26.5 - 22.0)°C	
q = 50.0 × 4.184 × 4.5	
q = 50.0 × 18.828 = 941.4 J	

Step 2: Convert Joules to chemistry calories

Step	Calculation
1 cal = 4.184 J	So J ÷ 4.184 = cal
941.4 J ÷ 4.184 = 225 cal	

Step 3: Convert to food Calories (Cal)

Step	Calculation
1 Cal = 1000 cal	225 cal ÷ 1000 = 0.225 Cal

Answer: The peanut released 225 cal (0.225 Cal) — a small peanut has about 5-10 Calories, so this peanut was small or not completely burned.

Worked Example: Hot Pack (Exothermic)

Problem: A disposable hand warmer contains iron powder that oxidizes (rusts) exothermically. The hand warmer contains 50.0 g of material. The temperature rises from 22°C to 45°C. Assume the specific heat is close to water (4.184 J/g·°C). How much heat is released?

Step	Calculation
q = m × c × ΔT = 50.0 × 4.184 × (45 - 22)	
q = 50.0 × 4.184 × 23	
q = 50.0 × 96.232 = 4,811.6 J	

Answer: 4,812 J of heat released (exothermic).

Worked Example: Cold Pack (Endothermic)

Problem: A cold pack contains 100 g of ammonium nitrate and water. The temperature drops from 25°C to 5°C. Assume specific heat ≈ 4.184 J/g·°C. How much heat is absorbed?

Step	Calculation
q = m × c × ΔT = 100 × 4.184 × (5 - 25)	
q = 100 × 4.184 × (-20)	
q = 100 × (-83.68) = -8,368 J	

Answer: 8,368 J absorbed (endothermic — the pack gets cold because it's pulling heat from its surroundings).

> Partner talk (1 minute): "Tell your partner: If a reaction releases 1000 J of heat, is it exothermic or endothermic? (Exothermic — q is negative for the system, but positive for the surroundings)."

SEGMENT 6: Enthalpy and Hess's Law — Adding Reaction Heats (12 minutes)

Teacher says: "Enthalpy (en-THAL-pee, symbol H) is the heat content of a system. The change in enthalpy (ΔH) tells you whether a reaction is exothermic or endothermic."

ΔH (change in enthalpy) = Heat absorbed or released at constant pressure.

Exothermic: ΔH is negative (heat released)

Endothermic: ΔH is positive (heat absorbed)

Signs of ΔH

Reaction Type	ΔH sign	Household Example
Exothermic	Negative ($\Delta H < 0$)	Hand warmer, burning candle
Endothermic	Positive ($\Delta H > 0$)	Cold pack, melting ice

Hess's Law — Adding Reactions

Hess's Law: The total enthalpy change for a reaction is the same, regardless of the pathway. You can add reactions together to find ΔH for a new reaction.

Teacher: "If you know the ΔH for several small steps, you can add them to find ΔH for the overall reaction — even if the overall reaction doesn't happen directly."

Worked Example: Combustion of Carbon to Carbon Dioxide (Two Pathways)

Goal: Find ΔH for: $C(s) + O_2(g) \rightarrow CO_2(g)$

Pathway 1 (Direct): ΔH = -393.5 kJ/mol

Pathway 2 (Two Steps):

$C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)$ $\Delta H_1 = -110.5$ kJ

$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$ $\Delta H_2 = -283.0$ kJ

Add the steps:

Step	Equation	ΔH
Step 1	$C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)$	-110.5 kJ
Step 2	$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$	-283.0 kJ
Add	$C(s) + O_2(g) \rightarrow CO_2(g)$	-393.5 kJ

Answer: Same result! Hess's Law works.

Household Connection: Why Hess's Law Matters

Teacher: "If you can't measure a reaction's heat directly (because it's too slow, too fast, or too dangerous), you can measure heats of smaller reactions and add them. This is how chemists know the energy content of fuels, foods, and explosives."

Partner talk (1 minute): "Tell your partner: If ΔH is negative, is the reaction exothermic or endothermic?" (Exothermic — heat released)

SEGMENT 7: Putting It All Together — Complete Thermodynamics Problem (8 minutes)

Teacher says: "Let's do one complete problem that uses everything from today's lecture."

Problem: A student places 50.0 g of water in a calorimeter at 22.0°C. She adds 5.00 g of ammonium nitrate (NH_4NO_3, molar mass = 80.06 g/mol) and stirs until dissolved. The final temperature is 18.0°C. Assume the solution has the same specific heat as water (4.184 J/g·°C) and that the calorimeter absorbs no heat.

Is this process exothermic or endothermic?

Calculate the heat (q) absorbed by the solution.

Calculate the enthalpy change (ΔH) per mole of NH_4NO_3 (in kJ/mol).

Part 1: Endothermic or Exothermic?

Temperature dropped from 22.0°C to 18.0°C → heat was absorbed from the water → Endothermic.

Part 2: Heat absorbed by solution

Mass of solution = mass water + mass NH_4NO_3 = 50.0 g + 5.00 g = 55.0 g ΔT = T_final - T_initial = 18.0 - 22.0 = -4.0°C

Step	Calculation
q = m × c × ΔT	= 55.0 g × 4.184 J/g·°C × (-4.0°C)
q = 55.0 × 4.184 × (-4.0)	= 55.0 × (-16.736)
q = -920.5 J	(Negative means water lost heat — reaction absorbed it)

Heat absorbed by reaction = +920.5 J

Part 3: ΔH per mole of NH_4NO_3

Step	Calculation
Moles NH_4NO_3 = 5.00 g ÷ 80.06 g/mol	= 0.06245 mol

Step	Calculation
ΔH for 0.06245 mol = +920.5 J	(positive because endothermic)
ΔH per mole = 920.5 J ÷ 0.06245 mol	= 14,740 J/mol
Convert to kJ: 14,740 J ÷ 1000	= +14.7 kJ/mol

Final answers:

Endothermic (ΔT decreased)

q = -920.5 J (water lost heat); reaction absorbed +920.5 J

ΔH = +14.7 kJ/mol (matches literature value for NH_4NO_3 dissolving)

CLOSING — The 60-Second Challenge (5 minutes)

Teacher says: *"Pair up. Person A: 60 seconds — explain the heat equation q = mcΔT and what each variable means. Person B: 60 seconds — calculate the heat needed to raise 100 g of water from 20°C to 30°C (c = 4.184 J/g·°C)."*

Answer for Person B: q = 100 × 4.184 × 10 = 4,184 J = 4.184 kJ.

Final takeaway table (show on screen / read aloud):

You learned...	Household Example
Heat (q) vs. Temperature	Heat = total energy; Temperature = average energy
Specific heat (c) = heat to raise 1g by 1°C	Water: 4.184 J/g·°C (very high)
q = m × c × ΔT	Heat water for tea: 250 g × 4.184 × 78°C = 81.6 kJ
Calorimeter measures heat	Burning peanut: water temperature rise = calories
Food Calorie (Cal) = 1000 chemistry calories	200 Cal snack = 200,000 cal
Enthalpy (ΔH) = heat at constant pressure	ΔH negative = exothermic; ΔH positive = endothermic
Hess's Law = add reaction heats	Combustion of carbon two ways → same ΔH
Water's high specific heat	Car radiators, ocean climate, body temperature

Final line (preview of L2-9): "Next session: Kinetics & Equilibrium (Advanced) — calculating reaction rates, half-lives, and why food spoils faster in summer. See you then."

SUPPLEMENTARY MATERIALS FOR L2-8 (No Grade)

Resource	Household Connection	Description	How to Find It
PhET "Energy Forms and Changes" simulation	Heat transfer	See how heat flows between objects	Search "PhET energy forms and changes"
Calorimetry virtual lab	Food calories	Burn food under water, calculate calories	Search "PhET calorimetry"
Specific heat table	Printable reference	c values for common materials	Search "specific heat table common substances"
Hess's Law interactive	Add reaction heats	Practice adding equations	Search "Hess's Law practice problems"

"This week, look at a nutrition label on a food package. Find the 'Calories' (with a capital C). That's the energy your body gets from that food. Next time, tell us: what food did you look at, and how many Calories per serving?"