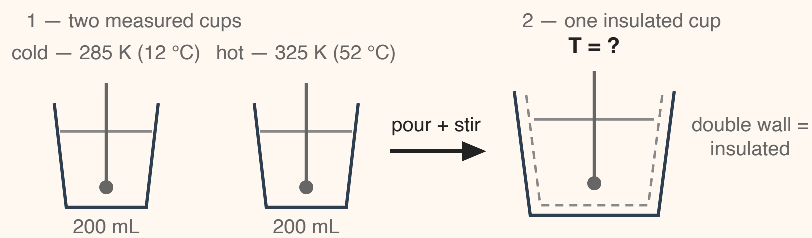
THERMO DAY 5: THERMAL ENERGY TRANSFER & EQUILIBRIUM

WARMUP Two Cups Become One — predict first

Your teacher has two identical insulated cups: 200 mL of cold water at 12 °C (285 K) and 200 mL of hot water at 52 °C (325 K), with a thermometer in each. The teacher pours **both** into a third insulated cup and stirs.



Equal amounts of the same water. Commit to a prediction before the pour.

Prediction — circle one. After stirring, the mixture's thermometer settles at:

(A) close to 325 K — the hot water controls the outcome **(B)** about halfway between, near 305 K **(C)** close to 285 K — the cold water cancels the heat

In one line, why did you pick your prediction?

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WHICH WAY DOES THERMAL ENERGY MOVE?

Day 1's vocabulary carries the whole unit: objects *hold* thermal energy; **heat (Q)** is energy *in transit* across a boundary, driven by a temperature difference. Today's question is the direction and the destination of that transfer.

Direction: the net transfer runs from the higher-temperature system to the lower-temperature system.

Destination: the net transfer shrinks to zero as the two temperatures approach each other. The shared-temperature end state is called **thermal equilibrium**. A thermometer uses this: it reports its *own* temperature once it reaches equilibrium with whatever it touches — that is why you wait for the reading to settle.

QUICK Which Way, and When Does the Net Flow Stop?

(a) A mug of cocoa at 335 K sits in a 290 K room. Heat flows from the ______________ to the ______________, and the net transfer approaches zero when the cocoa's temperature reaches __________ K.

(b) A glass of lemonade at 280 K sits in the same 290 K room. Heat flows from the ______________ to the ______________.

(c) Hours later, the cocoa, the lemonade, and the room air are all at 290 K. Between the cocoa and the lemonade, the net transfer of thermal energy is now ______________.

HOW THE ENERGY GETS ACROSS

THE COLLISION HANDOFF

Zoom in on the boundary between a hot object and a cold one. Molecules on both sides collide at the contact surface. In any single collision, energy can pass in either direction — but averaged over the enormous number of collisions, the faster molecules of the hotter side hand more kinetic energy to the slower molecules of the colder side than they receive back. That average imbalance *is* the heat flow, and it grows with the temperature difference.

At equal temperatures, thermal equilibrium is two-way traffic with equal flow in each direction: the collisions continue, and energy still crosses the boundary both ways — the **net** transfer is what has stopped.

THREE WAYS THERMAL ENERGY TRAVELS

Conduction — molecular collisions pass energy through matter that is in contact. A metal spoon left in soup warms all the way up its handle.

Convection — a moving fluid carries its thermal energy along with it. Water heated at the bottom of a pot rises, and the resulting circulation warms the whole pot.

Radiation — energy travels as electromagnetic waves and needs no matter at all. Sunlight crosses empty space to reach your face.

Conduction and convection require a medium; radiation does not.

QUICK **Name the Mechanism**

Label each transfer **conduction**, **convection**, or **radiation** (the main mechanism):

(a) The handle of a metal spoon standing in hot soup warms up: _______________

(b) A campfire warms your face from two meters away: _______________

(c) A radiator by the window sets up a warm-air loop that heats the far side of the room: _______________

(d) An ice cube resting on a thick aluminum block melts quickly: _______________

How fast does the transfer run? The net rate grows with the temperature gap. A cooling curve is steep at first, when the gap is largest, and flattens as the temperatures close in — the last few kelvins toward equilibrium take the longest. You will measure transfer rates in the upcoming conduction lab.

PREDICTING THE EQUILIBRIUM TEMPERATURE

THE GAS-SAMPLE TOOLKIT

Internal (thermal) energy counts every molecule's microscopic kinetic *and* potential energy. For the monatomic ideal gases in today's problems, the potential-energy share is zero, so the total is all translational KE:

$$U = N \cdot \tfrac{3}{2} k_B T$$

Today's containers are **rigid** — no boundary moves, so no work is done on either gas. Heat is the only energy crossing. For two samples in contact, isolated from everything else, **energy lost by the hot sample = energy gained by the cold sample**, so the total U is fixed:

$$N_1 T_1 + N_2 T_2 = (N_1 + N_2)\, T_f$$

(The $\tfrac{3}{2} k_B$ multiplies every term, so it cancels.) The equilibrium temperature is the **molecule-weighted average** of the starting temperatures, in kelvin.

WE DO — Equal Bulbs

Two identical rigid bulbs each hold N atoms of helium: one at 445 K, the other at 295 K. The bulbs are placed in contact and insulated from everything else.

(a) Equal amounts: $T_f = \dfrac{T_1 + T_2}{2} = \dfrac{445\ \text{K} + 295\ \text{K}}{2} =$ __________ K

(b) Units check: on average, each atom of the 445 K bulb loses $\tfrac{3}{2} k_B \, \Delta T = \tfrac{3}{2}(1.38 \times 10^{-23}\ \text{J/K})(\_\_\_\_\ \text{K}) =$ ___________ J. Where does that energy go?

WE DO — Three-to-One

A rigid tank holding 3.0×10^{22} argon atoms at 505 K is placed in contact with a rigid tank holding 1.0×10^{22} argon atoms at 345 K; the pair is insulated from everything else.

(a) Find the equilibrium temperature T_f of the two tanks (weighted average — carry units).

(b) Find the thermal energy the cold tank's gas gains: $E = \tfrac{3}{2} k_B N_2 (T_f - T_2)$.

(c) Check the books: does the hot tank's gas lose the same amount?

YOU DO — Equal Amounts of Argon

Two rigid tanks each hold 2.0×10^{22} argon atoms, one at 355 K and one at 485 K. They are placed in contact and insulated from everything else. Before computing: will T_f sit at the midpoint of the two starting temperatures? Then find T_f, carrying units.

When one side is enormous: in $T_f = \frac{N_1 T_1 + N_2 T_2}{N_1 + N_2}$, if N_2 dwarfs N_1, the weighted average lands essentially on T_2. A room, a lake, or a stirred water bath acts as a **reservoir**: it pins the final temperature at its own, while its own reading barely moves.

PRACTICE

1 Juice Bottle in a Classroom

A chilled juice bottle at 275 K sits on a desk in a 296 K classroom. **(a)** Heat flows from the _______________ to the _______________. **(b)** The bottle's final temperature = __________ K. **(c)** In one line: why doesn't the classroom's temperature drop noticeably while the bottle warms?

2 Two Neon Samples

Two rigid containers each hold 5.0×10^{21} neon atoms, one at 315 K and one at 535 K. They are placed in contact and insulated from everything else. **(a)** Find the equilibrium temperature of the pair. **(b)** Which container's atoms *lost* average translational kinetic energy while the pair equilibrated, and how do you know?

3 Unequal Tanks

A rigid tank of 6.0×10^{22} argon atoms at 470 K is placed in contact with a rigid tank of 2.0×10^{22} argon atoms at 330 K, insulated from everything else. Find the equilibrium temperature of the two tanks (carry units through the weighted average).

4 Energy on the Move

Two rigid flasks each hold 4.0×10^{21} helium atoms, one at 510 K and one at 320 K. They are placed in contact and insulated from everything else. **(a)** Find the equilibrium temperature of the pair. **(b)** Find the thermal energy transferred from the hot flask's gas to the cold flask's gas by the time equilibrium is reached (carry units).

5 Fix the Claim

On a winter morning a student grabs a metal railing with a bare hand and says: *"The cold flowed out of the railing into my hand."* Rewrite the student's claim in 2–3 sentences so that the **direction** of the energy transfer, the **mechanism** that carries it, and the condition for the transfer to end are each stated correctly.