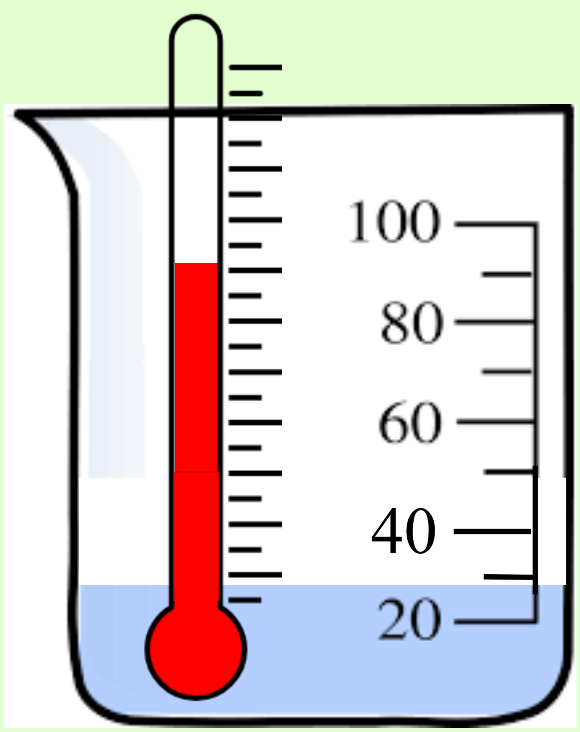
Thermochemistry

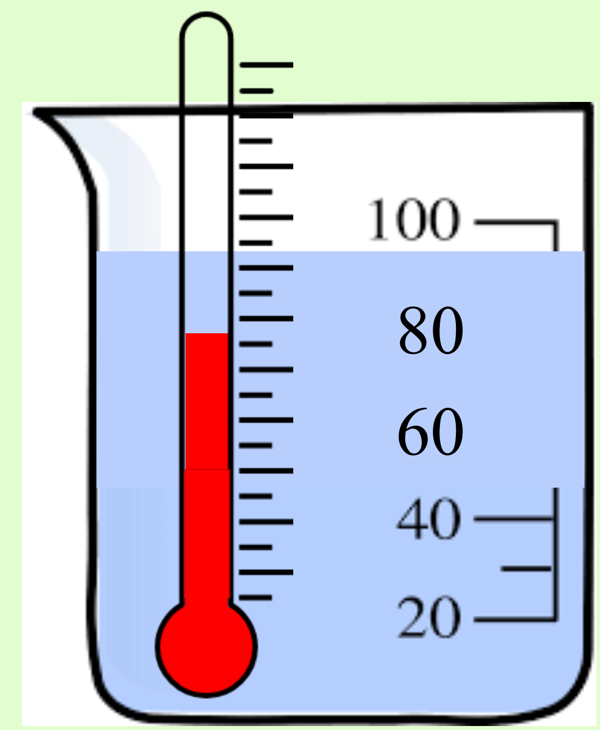
Heat Energy

Temp Changes
and Phase Changes

Which water is hotter?

1. Left
2. Right

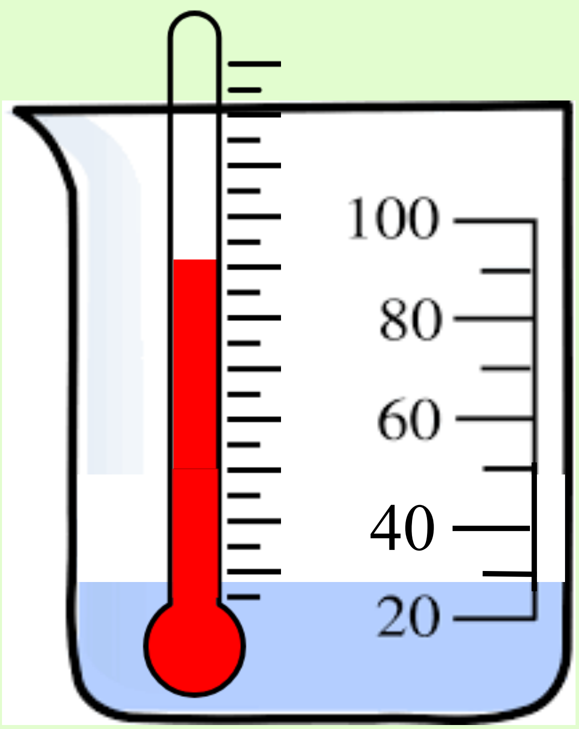


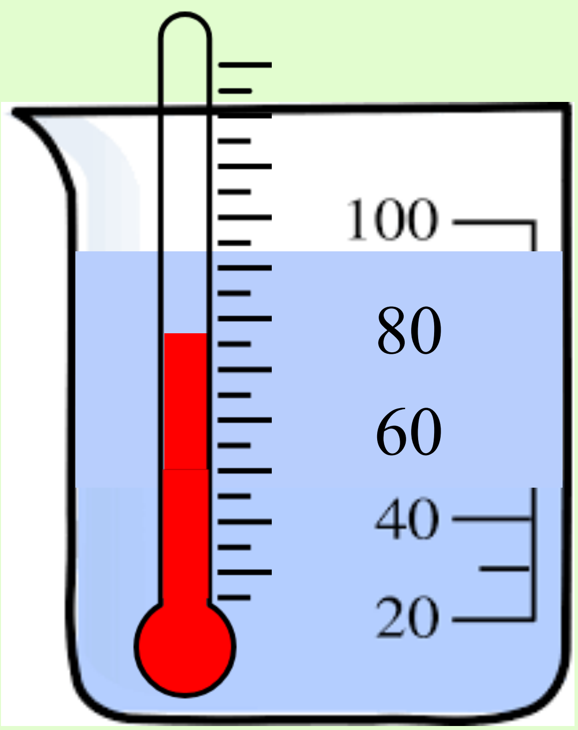


Which water is hotter?

1. Left
2. Right

Hotness and coldness are words that we use to describe temperature.

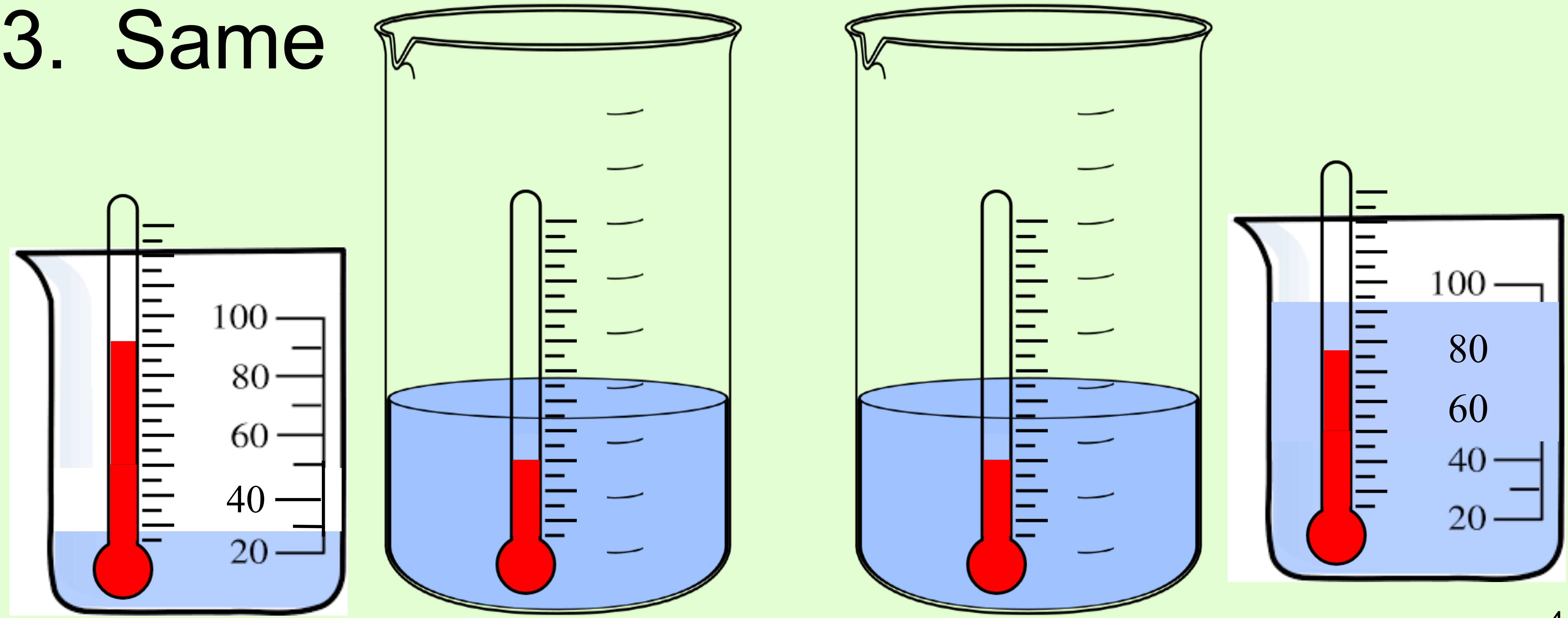




Which beaker will combine with the center beaker of water to end at a higher temperature?

1. Left
2. Right
3. Same

Temp of big beakers are same and are below both the left and right beakers



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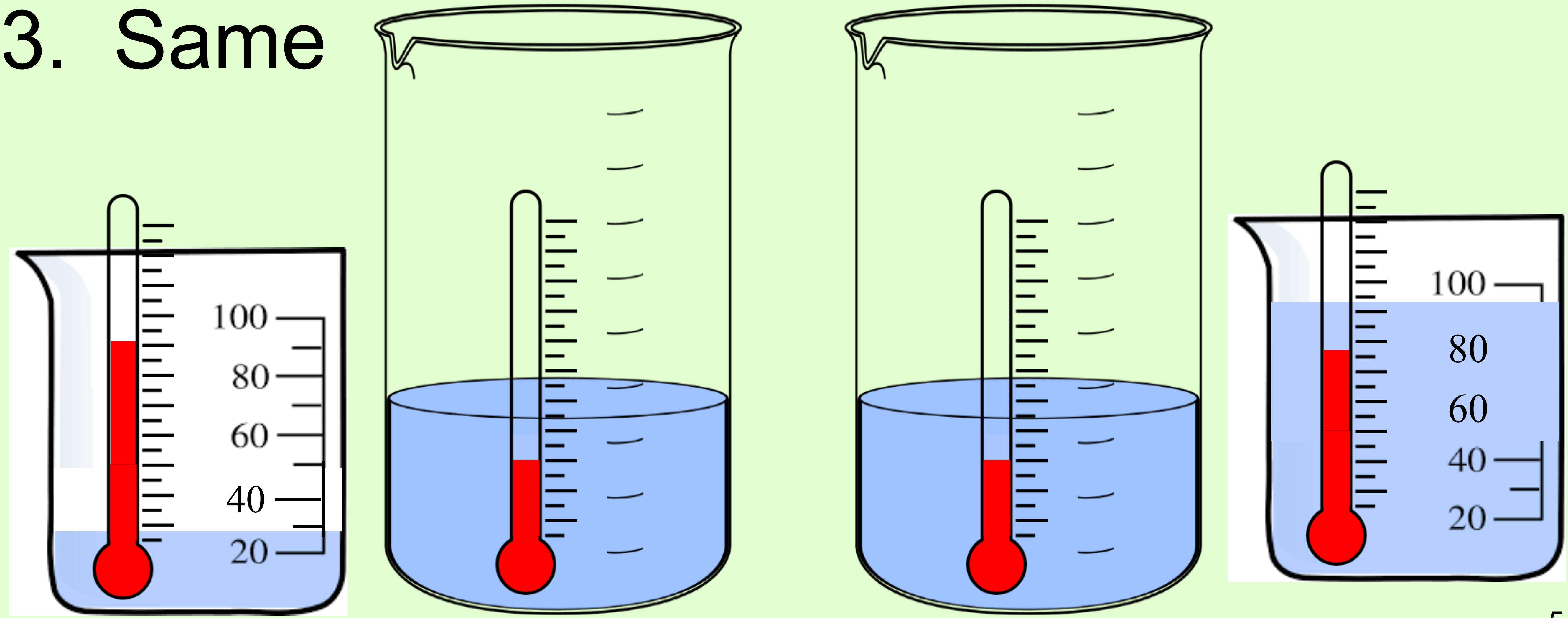
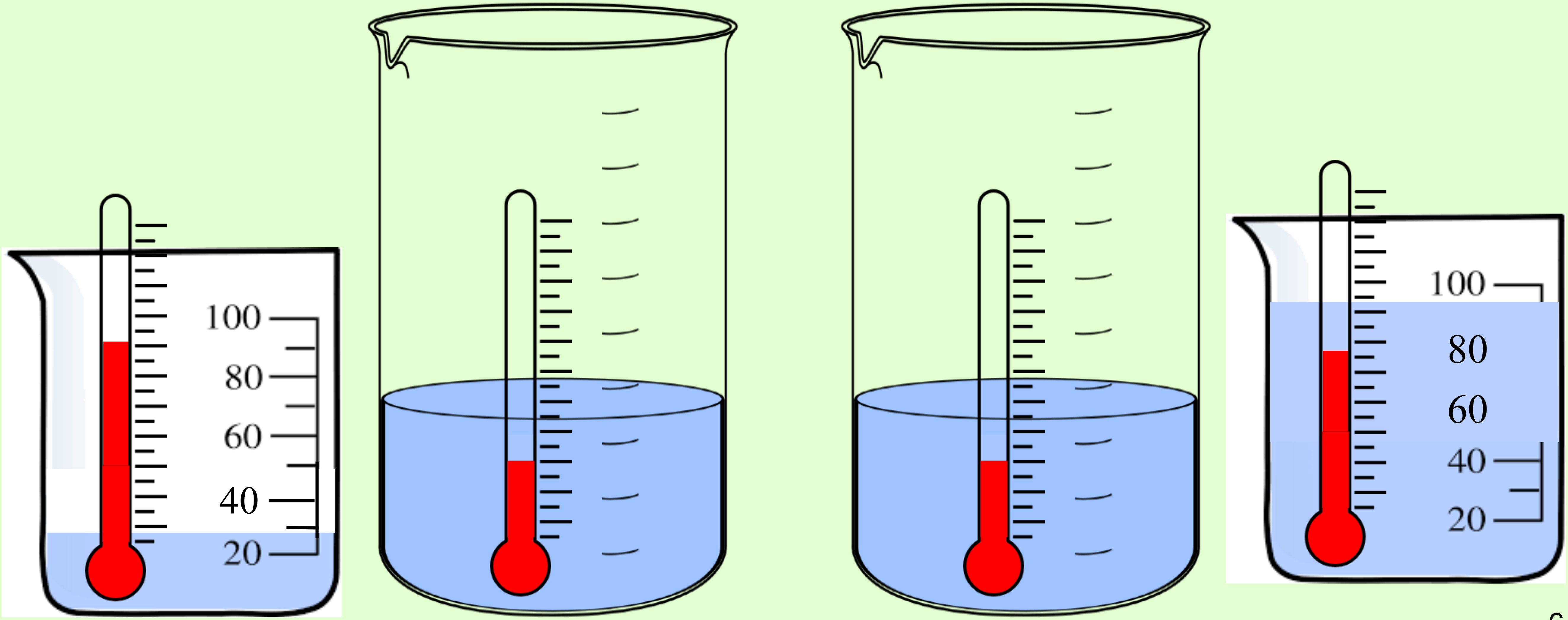


Which beaker of water transferred more heat?

1. Left
2. Right
3. Same

Temp of big beakers are same and are below both the left and right beakers

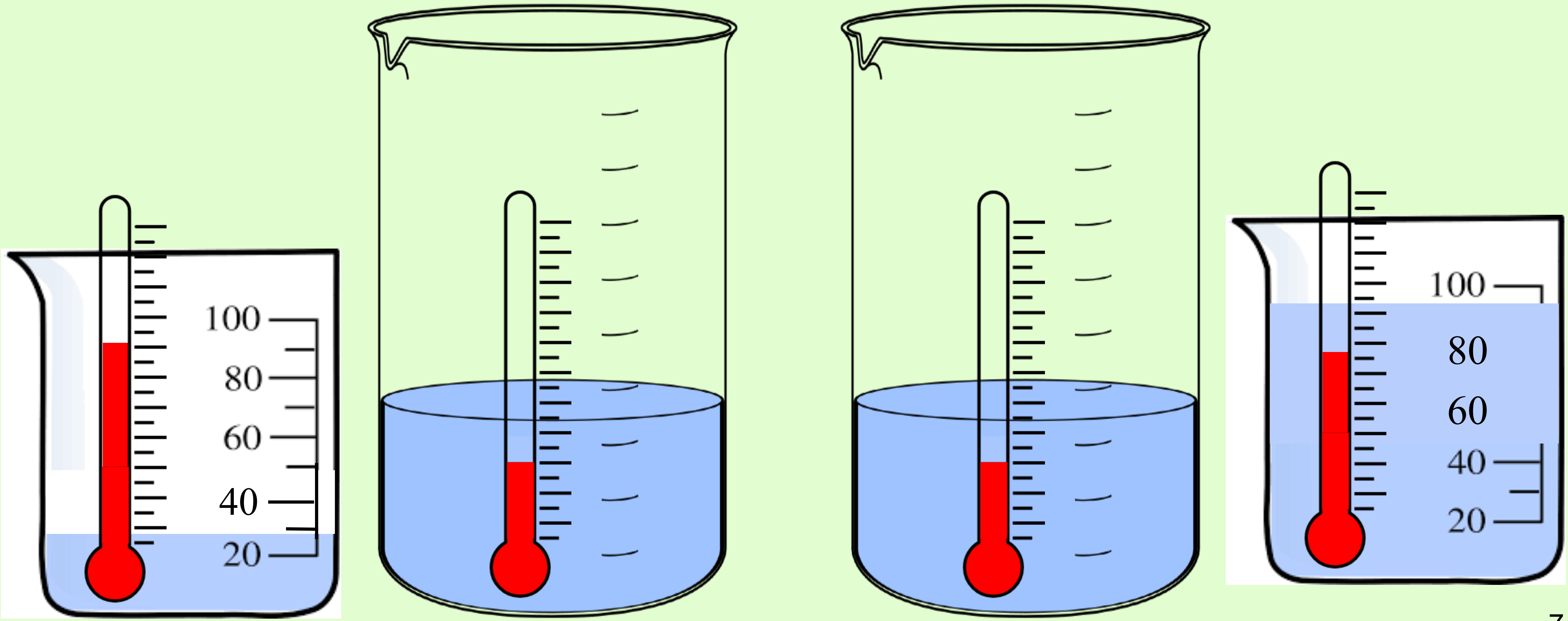


Which beaker of water transferred more heat?

1. Left
2. Right
3. Same

Amount of heat transferred is caused by both temperature **and** mass of the material.

Temp of big beakers are same and are below both the left and right beakers



Mixing equal quantities of hot and cold water in a perfectly insulated container, aka calorimeter, the final temperature of the mixture should be

1. above the hot temperature
2. below the cold temperature
3. exactly in the middle between the two temperatures
4. closer to the hot temperature
5. closer to the cold temperature
6. not enough information to make some of the judgments previously stated

Mixing equal quantities of hot and cold water, the final temperature of the mixture should be *(Select all that apply. Be prepared to comment.)*

3. between the two temperatures - exactly in the middle

- (or just slightly below the middle temperature since some heat will be lost to the foam cup and the thermometer.)

- We call this final temperature
  ★ Thermal Equilibrium

- What’s equal is the temperature of all the water

Mixing more cold water with less hot water at in an insulated container, the final temperature (*thermal equilibrium*) of the mixture should be

(Select all that apply. Be prepared to comment.)

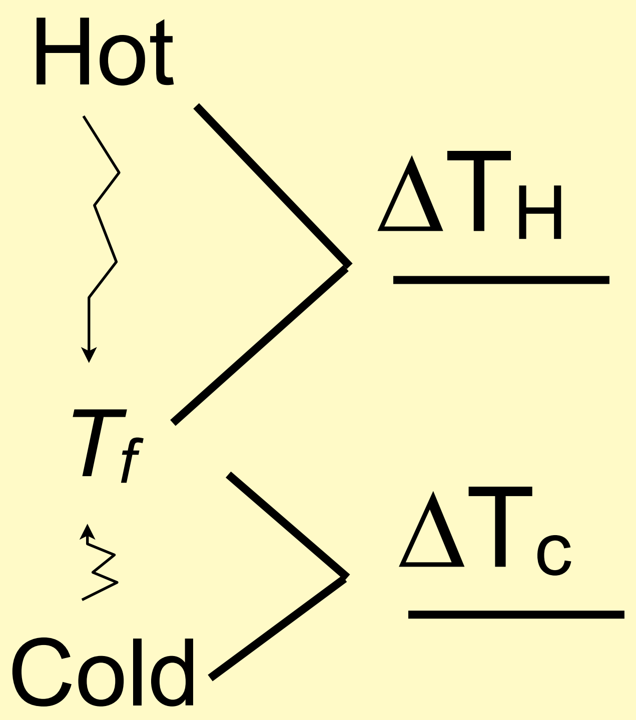
1. above the hot temperature
2. below the cold temperature
3. exactly in midway between the two temperatures
4. closer to the hot temperature
5. closer to the cold temperature
6. not enough information to make some of the judgments previously stated

Mixing more cold water with less hot water at in an insulated container, the final temperature (*thermal equilibrium*) of the mixture should be

(Select all that apply. Be prepared to comment.)

5. closer to the cold temperature, because the larger mass of water has a higher ***heat capacity***.

Let's make a Temperature Diagram

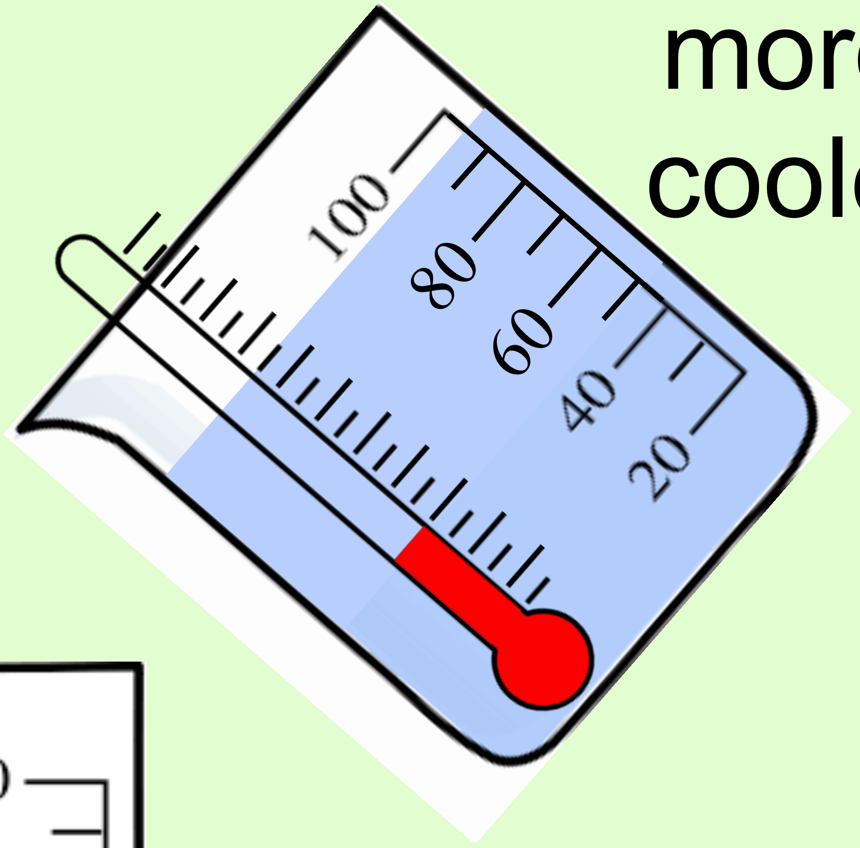


This time Thermal Equilibrium is not halfway in the middle.
So what's equal? The temp of all the water molecules are the same.

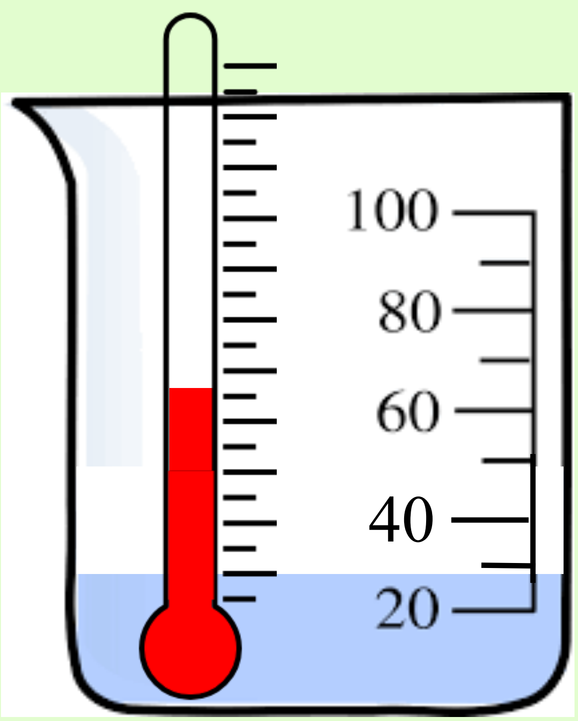
Tiny Lab

1. Take mass of each amount of water
2. Take temp of each water
3. Pour water together
4. Record final temp
5. Back to seats

more mass
cooler temp



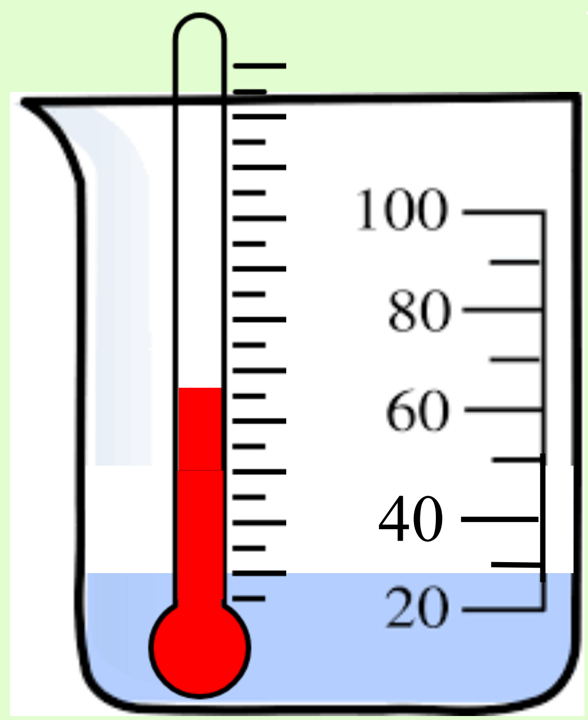
less mass
higher temp

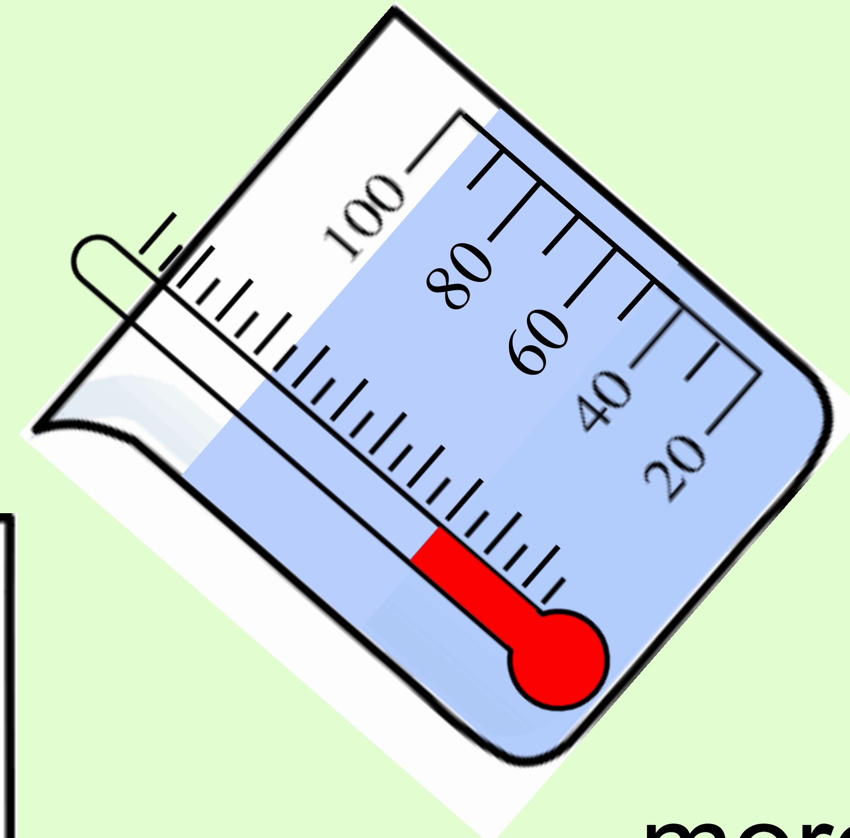


ERROR in our Tiny Lab

1. In what ways may error have occurred in yesterday's lab?
2. In what ways should we be more careful when we run another trial?

less mass
higher temp





more mass
cooler temp

My mother in-law comes over for a swim and complains the pool is cold

- I tell her to hold on.... and run inside to heat some water in the tea kettle........

- The water in the pool and water from the tea kettle will reach **thermal equilibrium**
- Thermal equilibrium does not mean "in the middle" it means "same temperature"

The pool has a higher **heat capacity**, C, than the tea kettle's heat capacity.

Temperature and Heat
They are *not* the same thing

- Temperature: measures kinetic energy.
  - ✓ is proportional to the speed of molecules
  - ✓ measures “hotness” or “coldness”
  - ✓ tells us the direction that heat will flow
  - ✓ is measured in degrees, ºC, K, ºF
- Heat: the exchange of thermal energy caused by a temperature difference.
  - ✓ is a quantity of thermal energy (being transferred)
  - ✓ can only be measured when it is transferred
  - ✓ measured in Joules, J (calories, Calories (food), BTU)

We need an Energy Unit

- I thought NS&E you used the calorie
- A calorie is the amount of thermal energy required to change the temperature of 1 g of water by 1º C
- The food Calorie is actually a kilocalorie

Nutrition Facts
Serving Size 1 oz. (28g/About 32 chips)
Servings Per Container 3

Amount Per Serving

Calories 160	Calories from Fat 90
	% Daily Value*
Total Fat 10g	**16%**
Saturated Fat 1.5g	**7%**
Trans Fat 0g	

In chemistry we will use the Joule

- A physicist would define a Joule this way…
- A joule is defined as the kinetic energy possessed by a 2 kg mass moving at a speed of 1 meter per second.

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(2kg)\left(\frac{1m}{1s}\right)^2 = \frac{1\ kg\ m^2}{s^2} = 1\ Joule$$

- In chemistry, thermally, 1 Joule is the amount of heat required to change the temperature of ~0.25 g of water by 1ºC.
- Or 4.186 Joules will change 1 g of liquid water 1ºC

Specific Heat Capacity, c

A measure of the intrinsic capacity of a substance to absorb heat.

- *c*, the quantity of heat required to change 1 g of a substance by 1°C

$$c = \frac{q}{m\Delta T} = \frac{J}{g^{o}C}$$

- the specific heat capacity of liquid water
  - ✓ c_{water}, is 4.186 J/g°C

We will commonly use this equation rearranged

$$q = mc\Delta T$$

Using q = mcΔT

How many kilojoules of energy are required to change the temperature of 36 g of water from 5.0ºC to 65ºC?

Send an answer with 2 sig figs $c_w = 4.186 J / gºC$

Using q = mcΔT

How many kilojoules of energy are required to change the temperature of 36 g of water from 5ºC to 65ºC?

$$c_w = 4.186\, J/g^{\circ}C$$

$$q = Amount \times c_w \times \Delta T$$

$$q = 36 g \times \frac{4.186 J}{g^{\circ}C} \times \left(65^{\circ}C - 5^{\circ}C\right)$$

$$9{,}000 J \qquad 9.0 kJ$$

Sign of q + or – ?

- Of course energy is positive, however we need a way to distinguish if energy is coming or going
- Energy in, Endothermic
  - ✓ We give the quantity a positive sign.
- Energy out, Exothermic
  - ✓ We give the quantity a negative sign.

Determining T_{final}

Determine the final temperature of the water when 200. g of water at 11.0ºC is mixed with 150. g of hot water with a temperature of 90.0ºC.

send in an answer with 3 sig figs.

$$q_{lost} = q_{gained}$$

$$-\left(m_{hw} \times c_{w} \times \left(T_{fhw} - T_{ihw}\right)\right) = m_{cw} \times c_{w} \times \left(T_{fcw} - T_{icw}\right)$$

Determining T_{final}

Determine the starting temperature of the hot water when 128 g of water at 11ºC is mixed with 95 g of hot water and the final temperature is 28ºC.

send in an answer with 2 sig figs.

$$q_{lost} = q_{gained}$$

$$-\left(m_{hw} \times c_{hw} \times \left(T_{fhw} - T_{ihw}\right)\right) = m_{cw} \times c_{cw} \times \left(T_{fcw} - T_{icw}\right)$$

Determining T_{final}

Determine the starting temperature of the hot water when 128 g of water at 11ºC is mixed with 95 g of water and the final temperature is 28ºC.

$$-Amount \times c_w \times \Delta T = Amount \times c_w \times \Delta T$$

$$-\left[\left(95g\right)\left(4.18 J/g^{\circ}C\right)\left(\Delta T\right)\right] = \left(128g\right)\left(4.18 J/g^{\circ}C\right)\left(28^{\circ} - 20^{\circ}\right)$$

$$-\left(95\right)\left(\Delta T\right) = \left(1024\right)$$

$$\Delta T = 10.8^{\circ}C \qquad T_{start}\ 28^{\circ}C + 10.8^{\circ}C$$

$$T_{start} = 29^{\circ}C$$

Specific Heat Capacity, c

A measure of the intrinsic capacity of a substance to absorb heat.

- As you may have guessed, the amount of heat needed to change a substance's temperature may vary from substance to substance.
- *c*, the quantity of heat required to change 1 g of a substance by 1ºC

$$c = \frac{q}{m \Delta T} = \frac{J}{g\,^{\circ}C}$$

We will commonly use this equation rearranged

$$q = mc\Delta T$$

- the specific heat capacity of liquid water
  - ✓ c_{water}, is 4.18 J/gºC
- the specific heat capacity of ethanol
  - ✓ $c_{ethanol}$, is 2.46 J/gºC

Mixing 50. g of *alcohol* at 20.ºC with 50. g of hot water at 80.ºC in an insulated container, the final temperature (*thermal equilibrium*) of the mixture should be

(Select all that apply. Be prepared to comment.)

1. above the hot temperature
2. below the cold temperature
3. exactly in midway between the two temperatures
4. closer to the hot temperature
5. closer to the cold temperature
6. not enough information to decide on the statements above

Mixing 50. g of alcohol at 20.ºC with 50. g of hot water at 80.ºC in an insulated container, the final temperature (*thermal equilibrium*) of the mixture should be

(Select all that apply. Be prepared to comment.)

6. not enough information to make some of the judgments previously stated

- You are correct in thinking there will be a *difference* in the "energy-capacity" of alcohol compared to water.

The really big assumption in this unit:

To calculate energy coming or going, we will need to **assume** that the amount of heat lost will equal the amount of heat gained.

$$\text{Heat lost} = \text{Heat gained}$$

$$-q_{lost} = q_{gained}$$

$$-Amount \times c \times \Delta T = Amount \times c \times \Delta T$$

$$\Delta T = T_{final} - T_{initial}$$

- By convention, energy lost from a system will be negative, and energy gained by a system will be positive, thus we must include a negative sign in order to set energy lost equal to energy gained.
- the energy will be equal but opposite in sign.

Let's reconsider the previous problem with cool alcohol and warm water, and calculate:

50.0 g of cold alcohol at 20.0ºC with 50.0 g of hot water at 80.0ºC Calculate the thermal equilibrium temperature

The really big assumption:

$$\text{Heat lost} = \text{Heat gained}$$

$$-q_{lost} = q_{gained}$$

$$-Amount \times c \times \Delta T = Amount \times c \times \Delta T$$

$$\Delta T = T_{final} - T_{initial}$$

- Let's do the algebra…. $c_{ethanol}$, is 2.46 J/gºC

50.0 g of cold ethanol at 20.0ºC with 50.0 g of hot water at 80.0ºC. Calculate the thermal equilibrium temperature.

$$\Delta T_w = T_{final} - T_{initial}$$

$$\Delta T_a = T_{final} - T_{initial}$$

80º

T_f

20º

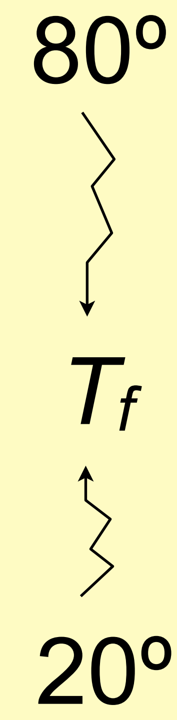
Thermal Equilibrium
Same temperature for
both alcohol and water

Let's set T_f equal to x

$$-Amount \times c \times \Delta T = Amount \times c \times \Delta T$$

$$-\left[\left(50.0\right)\left(4.18 J / g^{\circ}C\right)\left(x - 80^{\circ}\right)\right] = \left(50 g\right)\left(2.46 J / g^{\circ}C\right)\left(x^{\circ} - 20^{\circ}\right)$$

50.0 g of cold ethanol at 20.0ºC with 50.0 g of hot water at 80.0ºC. Calculate the thermal equilibrium temperature.



$$-Amount \times c \times \Delta T = Amount \times c \times \Delta T$$

$$\Delta T = T_{final} - T_{initial}$$

$$-\left[(50.0)(4.18 J/g^{\circ}C)(x-80)\right] = (50g)(2.46 J/g^{\circ}C)(x^{\circ}-20^{\circ})$$

$$-(x-80)\left(\frac{4.18}{2.46}\right) = (x^{\circ}-20^{\circ})$$

$$136^{\circ} - 1.7x^{\circ} = x - 20^{\circ}$$

$$156 = 2.7x$$

$$x = 57.8^{\circ}$$

Suppose you are cold weather camping (5ºC) and you decide to bring some objects into your sleeping bag for extra warmth.
Near the campfire, you heat up a gallon jug of water and a big rock of equal size, both reaching a temperature of 75ºC. (Your body is 37ºC)
If you could bring only one into your sleeping bag, which one should you choose to keep you the warmest through the night?

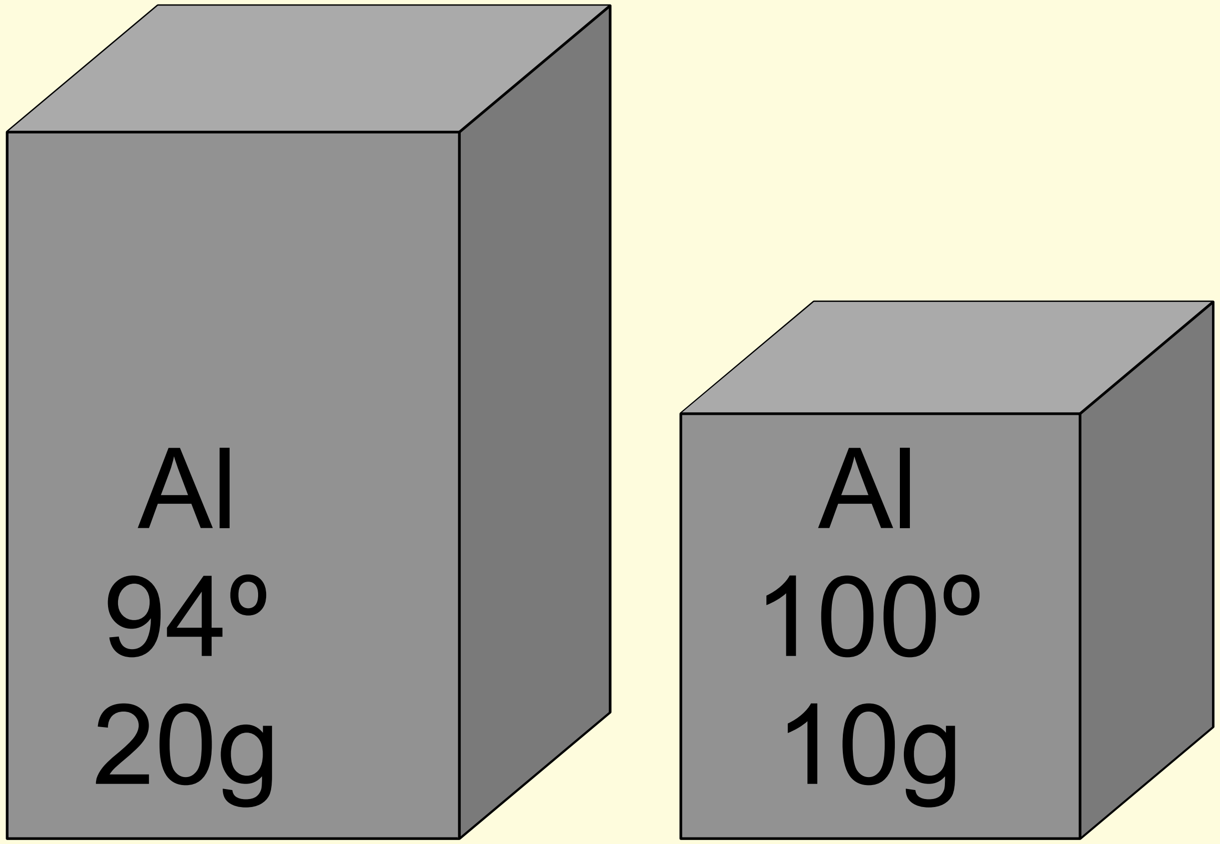
1. Water jug
2. Rock

Suppose you are cold weather camping and you decide to bring some objects into your sleeping bag for extra warmth.
Near the campfire, you heat up a jug of water and a big rock of equal mass, both reaching a temperature of 43ºC.
If you could bring only one into your sleeping bag, which one should you choose to keep you the warmest through the night?

1. Water jug
2. Water has higher specific heat capacity, c_W, and as it cools to thermal equilibrium with you, the water will release more energy per gram per degree.
3. Rock

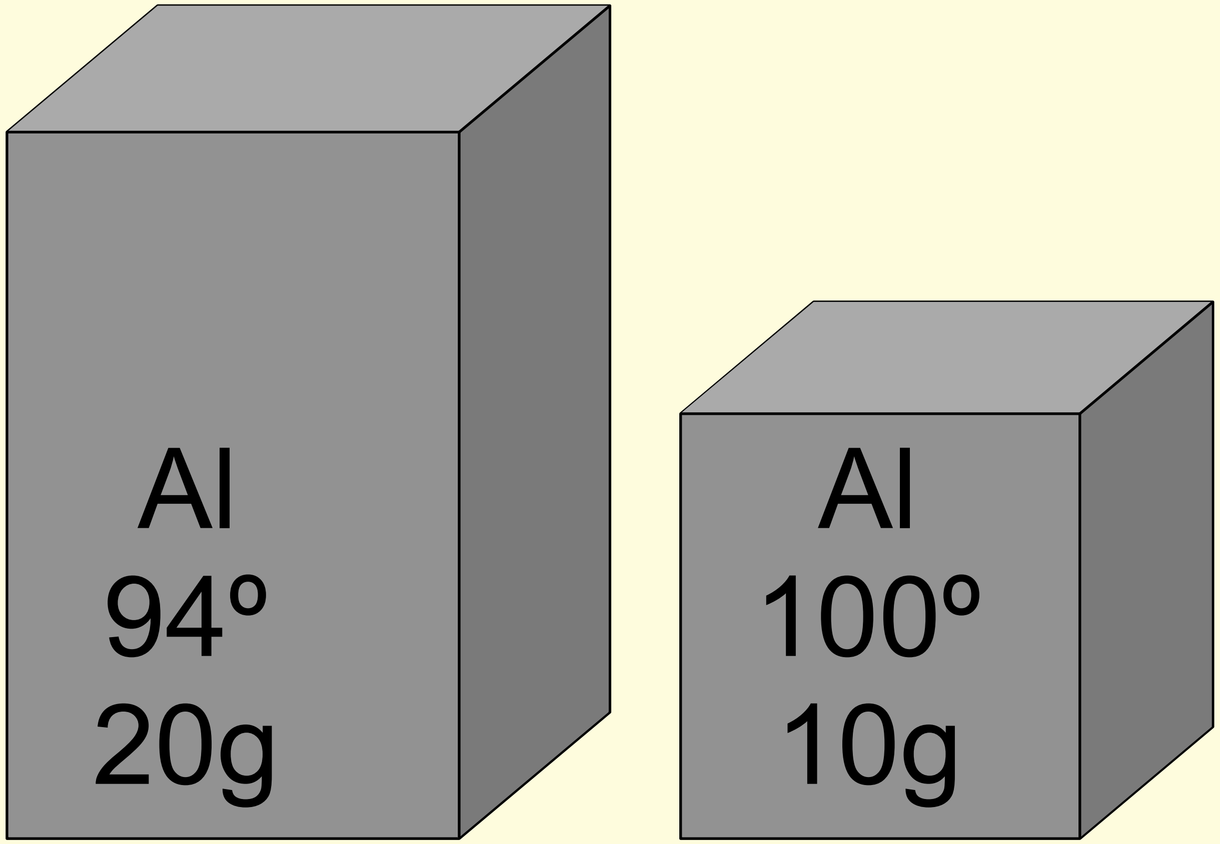
Which block is hotter?

1. Bigger block
2. Smaller block
3. Same



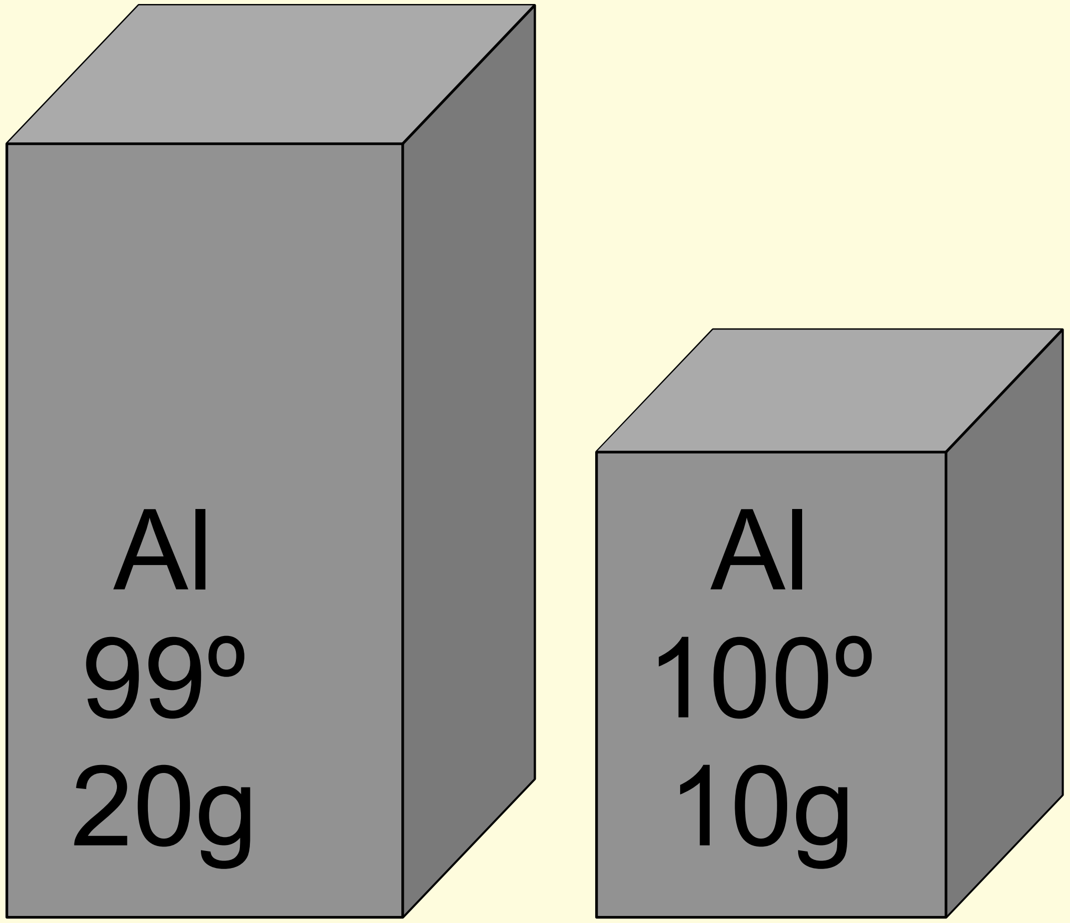
Which block is hotter?

1. Bigger block
2. Smaller block
- The smaller block is at a higher temperature, and temp is a measure of hotness and coldness.
3. Same



Which block has thre ability to transfer more thermal energy?

1. Bigger block
2. Smaller block
3. Same

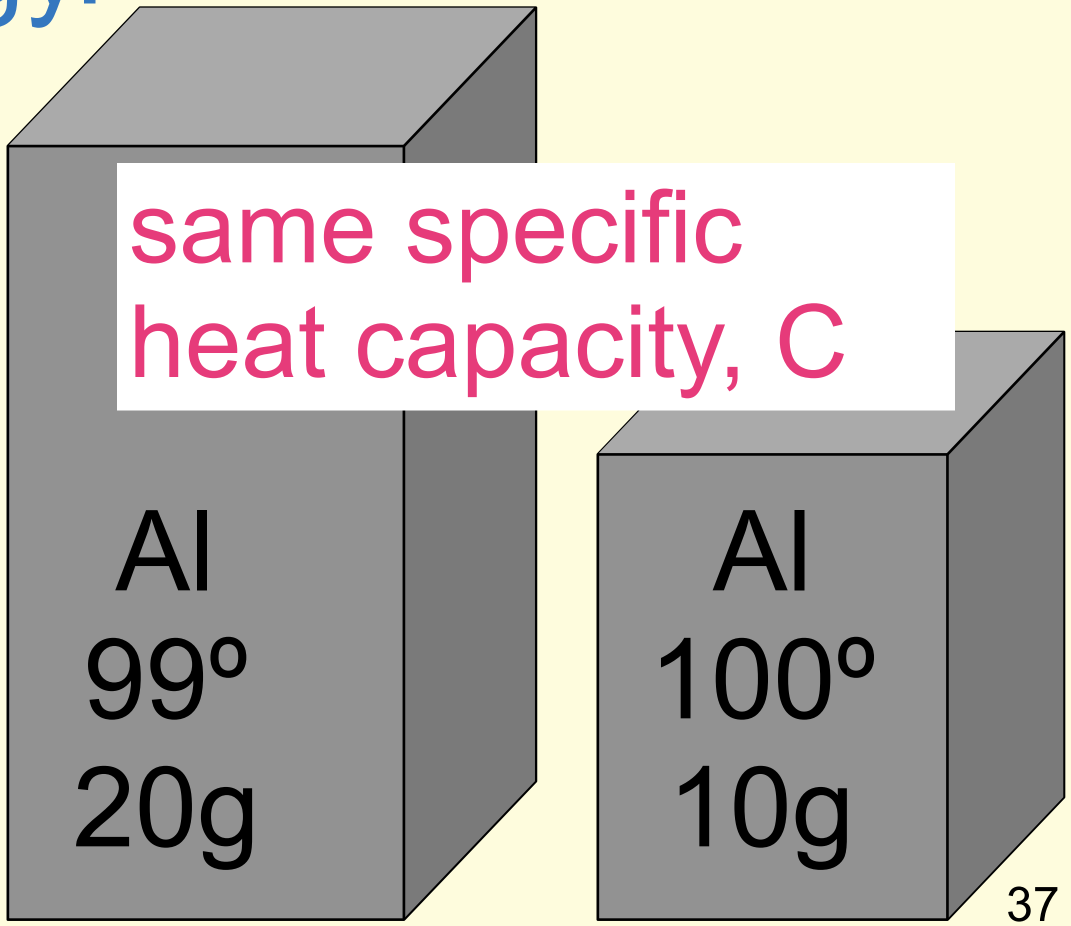


Which block has thre ability to transfer more thermal energy?

1. Bigger block, even though it is slightly cooler.
   - Just as a big pile of wood, would transfer more heat (when burned). The large block would also transfer more heat. If you dropped both blocks in equal amounts of cold water, the larger block would heat the water up much more – thus, in a sense, it contains more energy.
2. Smaller block
3. Same

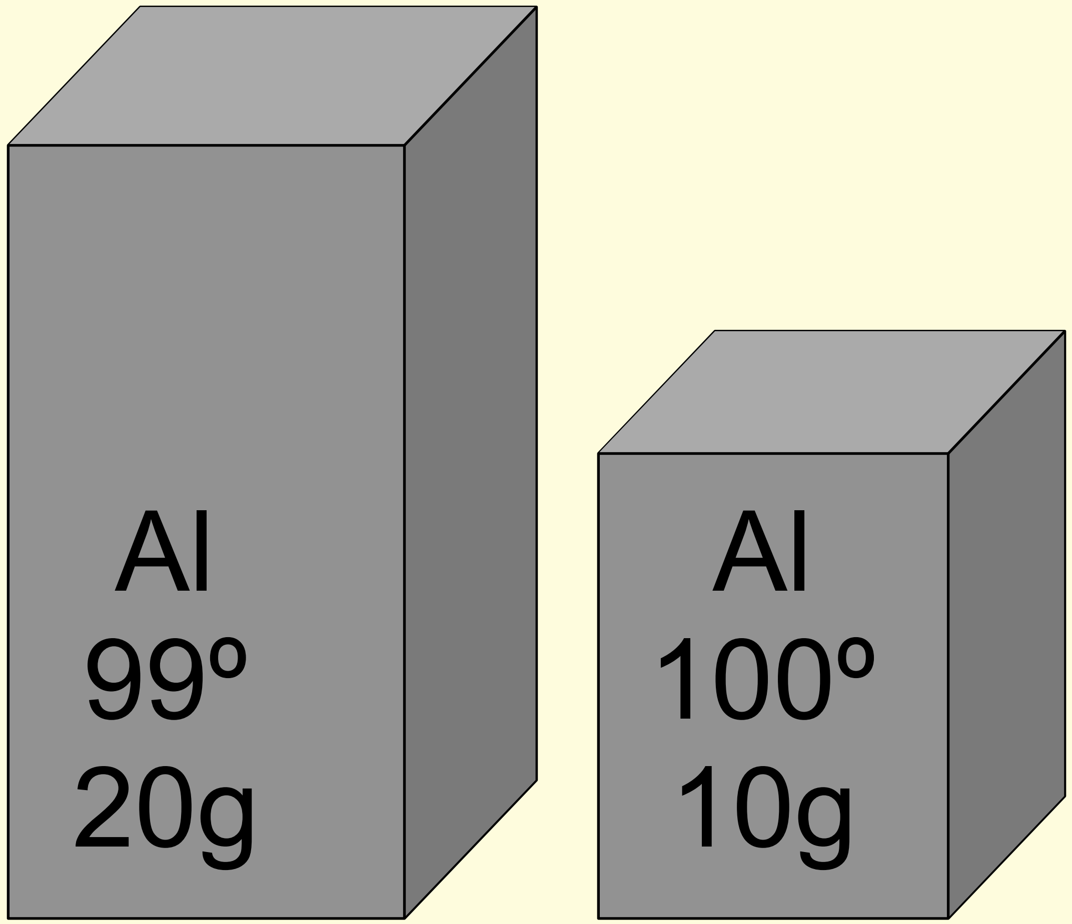
Even though it is at a lower temperature, the bigger block has a higher heat capacity, C.

$$C = \frac{\#\,Joules}{^{\circ}C}$$



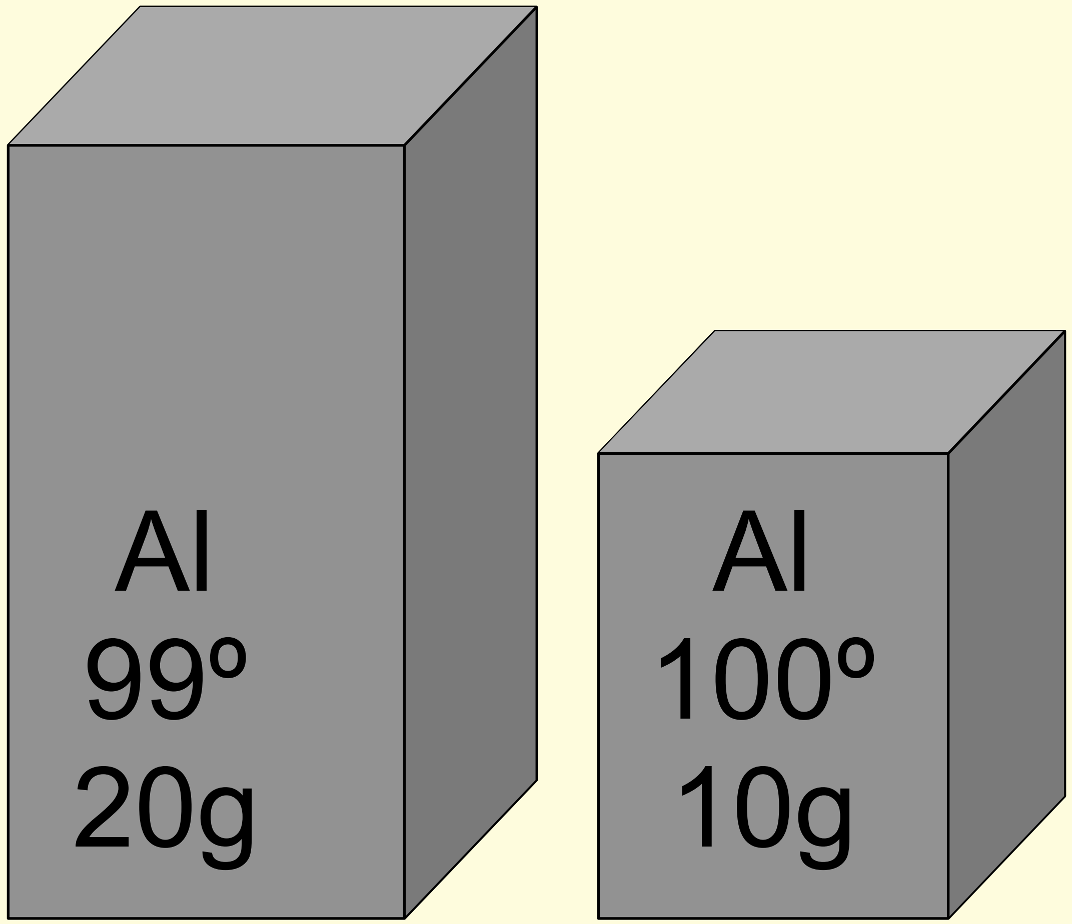
In which direction would heat flow in order to reach thermal equilibrium?

1. from big block to small block
2. from small block to big block
3. impossible to determine



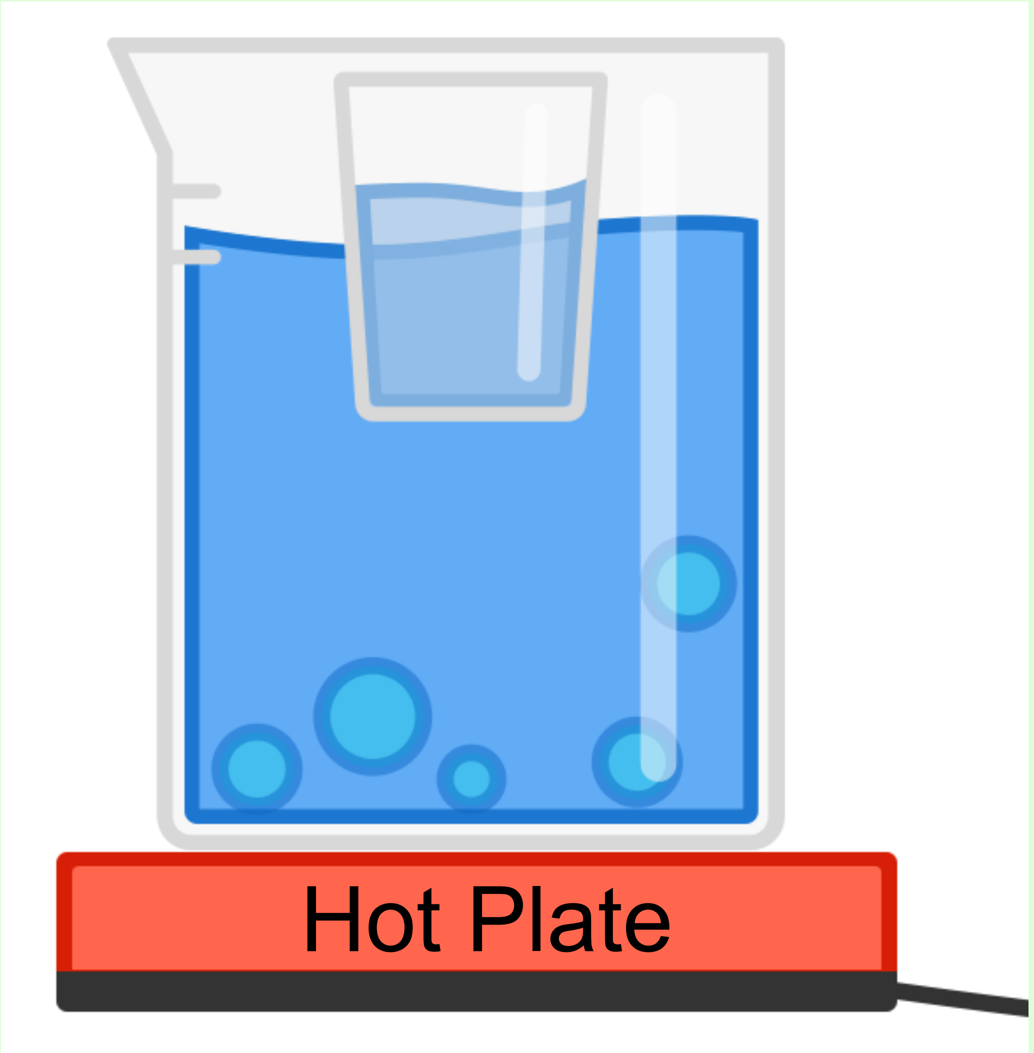
In which direction would heat flow in order to reach thermal equilibrium?

1. from big block to small block
2. from small block to big block
3. The Second Law of Thermodynamics tells us (among other things):
   Heat will always flow from hot to cold – never in the opposite direction.
4. impossible to determine



A cup of warm water is suspended in a large beaker of boiling water. Will the water in the cup ever boil? 1 - Yes, 2 - No

Assume that the large beaker never runs out of water.

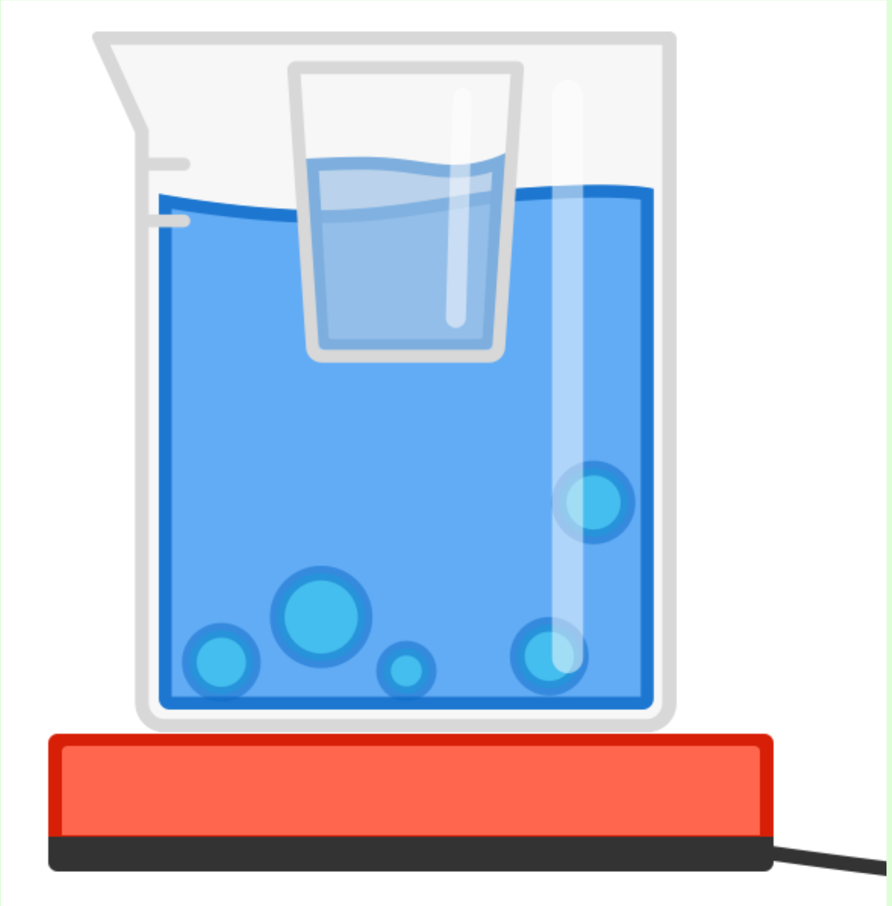


Yes, the hot plate is turned on

A cup of warm water is suspended in a large beaker of boiling water. Will the water in the cup ever boil? NO

Assume that the pot never runs out of water.

- The boiling water in the large pot will bring the cup of water to 100ºC (at 1 atm)
- At which point the temp of the pot and temp of cup will be at the same temperature.
- No more heat will transfer to the cup to provide the $\Delta H_{vaporization}$ - the heat required to liberate the water molecules from the liquid to the gas phase.



LAD C.1

Specific Heat Capacity of Various Metals

LAD C1 – Heat Capacity of Various Metals

Let's make some measurements of the specific heat capacity of various metals, by dropping hot metals into cool water and measuring the temp changes.

We will use 4.18 J/gºC as the specific heat capacity of water.

1. What are we calculating?

$$-Amount_m \times \boxed{c_m} \times \Delta T_m = Amount_w \times c_w \times \Delta T_w$$

2. What do we need to measure?
   - Set up a data table on lined paper   Old School!!!

The really big assumption:

Heat lost = Heat gained

−heat lost by hot = heat gained by cold

$-q_{hot} = q_{cold}$

$$-Amount_m \times c_m \times \Delta T_m = Amount_w \times c_w \times \Delta T_w$$

LAD C.1 Temp Organizer

T_H ______

ΔT_H _________

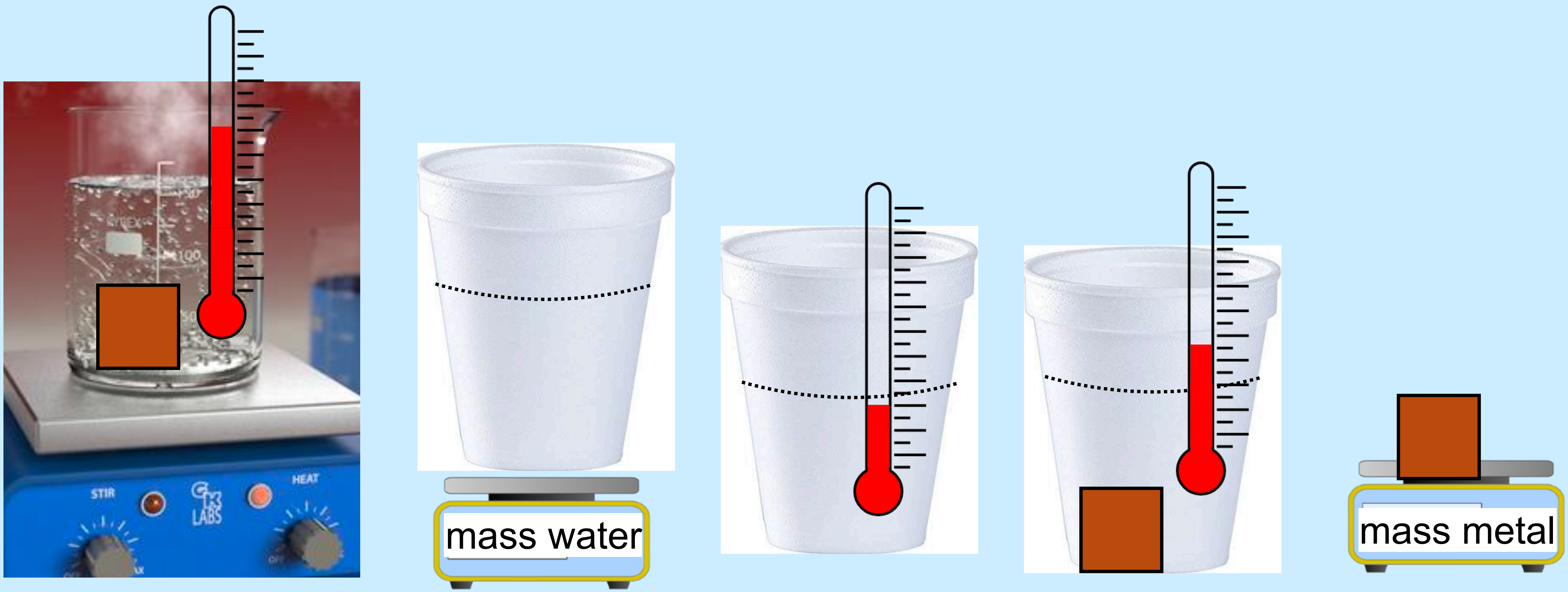
T_{equil} ______

ΔT_C _________

T_C ______

$$\Delta T = T_{final} - T_{initial}$$

Lab set-up / procedure – Error Analysis



Temperature Organizer

T_{metal} ______

ΔT_{metal} ______

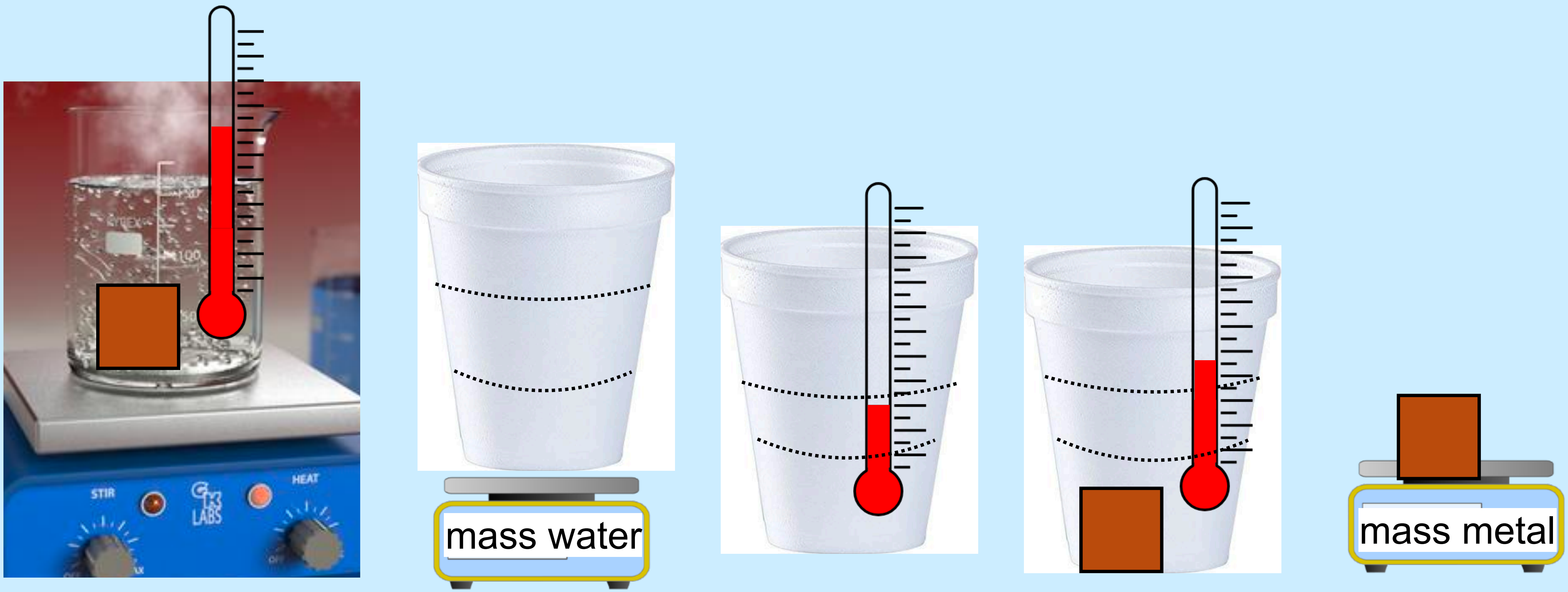
T_{final} ______

ΔT_{water} ______

T_{water} ______

$$\frac{m_w c_w \Delta T_w}{-\left(m_m \Delta T_m\right)} = c_m$$

Specific Heat Capacity, an Intensive property



Temperature Organizer

T_{metal} ______

ΔT_{metal} ______

T_{final} ______

ΔT_{water} ______

T_{water} ______

$$\frac{m_w c_w \Delta T_w}{-\left(m_m \Delta T_m\right)} = c_m$$

What units could be on q?

Select all that apply.

1. J
2. kJ
3. kJ/Kelvin
4. kJ/g^{o}C
5. J/g
6. J/gKelvin
7. kJ/mg^{o}C
8. kJ/mg
9. J/^{o}C

What units could be on q?

Select all that apply.

1. J
2. kJ
3. kJ/Kelvin
4. kJ/gºC
5. J/g
6. J/gKelvin
7. kJ/mgºC
8. kJ/mg
9. J/ºC

just energy   # J

specific heat capacity, c
What units could be on c?

Select all that apply.

1. J
2. kJ
3. kJ/Kelvin
4. kJ/g^{o}C
5. J/g
6. J/gKelvin
7. kJ/mg^{o}C
8. kJ/mg
9. J/^{o}C

specific heat capacity, c
What units would be appropriate for c?
Select all that apply.

1. J
2. kJ
3. kJ/K
4. kJ/g°C
5. J/g
6. J/gK
7. kJ/mg°C
8. kJ/mg
9. J/°C

$$\frac{energy}{amount \bullet degree} \qquad \frac{\# J}{1g \bullet 1^{\circ}C}$$

Phase change constants, $\Delta H_{phase\ change}$

What units could be on a ΔH?

Select all that apply.

1. J
2. kJ
3. kJ/Kelvin
4. kJ/g^{o}C
5. J/g
6. J/gKelvin
7. kJ/^{o}C
8. kJ/mg
9. J/^{o}C

Enthalpy, ΔH

What units would be appropriate for ΔH?

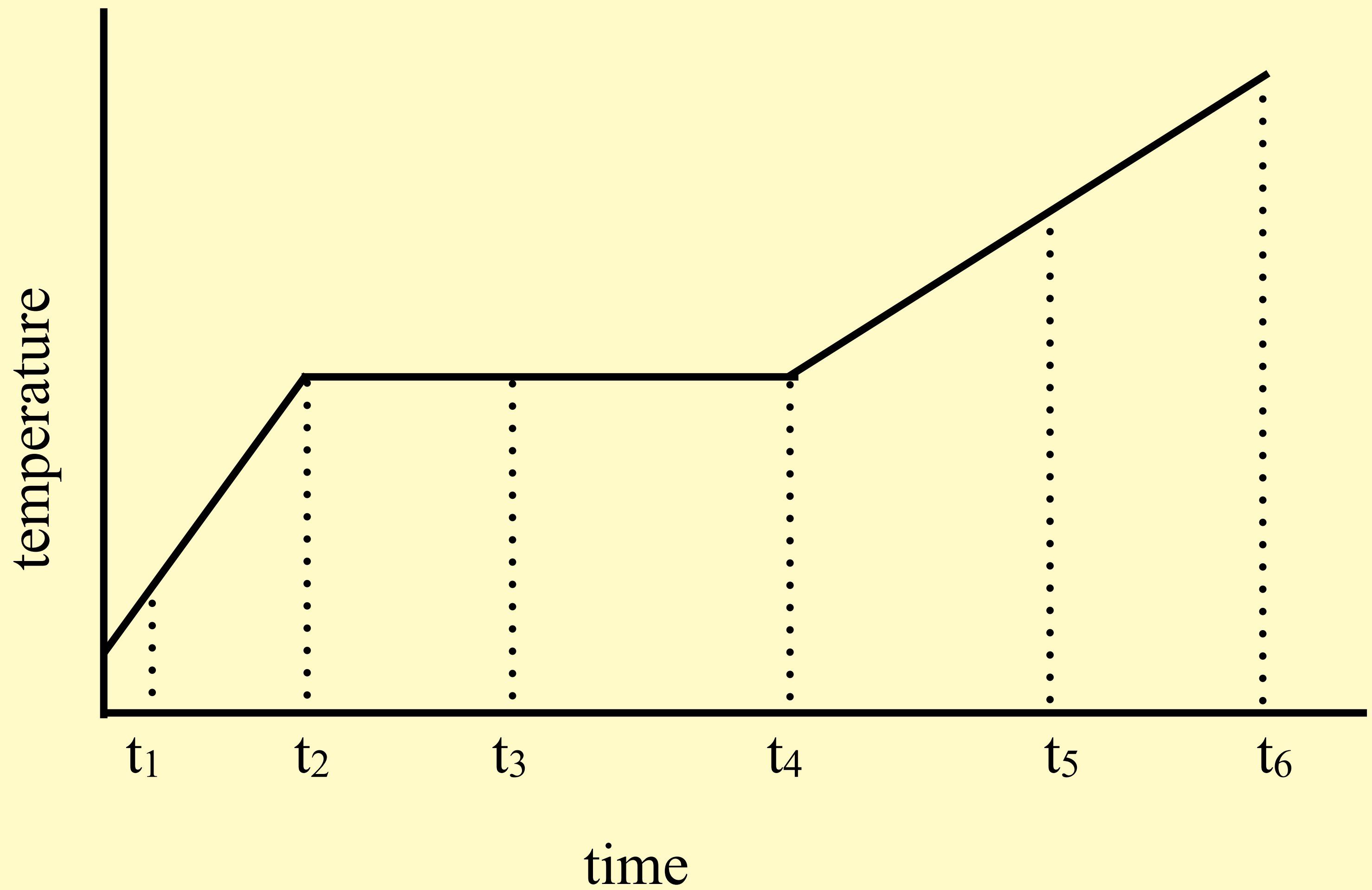
Select all that apply.

1. J
2. kJ
3. kJ/K
4. kJ/g°C
5. J/g
6. J/gK
7. kJ/°C
8. kJ/mg
9. J/°C

$$\frac{energy}{amount} \qquad \frac{\# J}{1g}$$

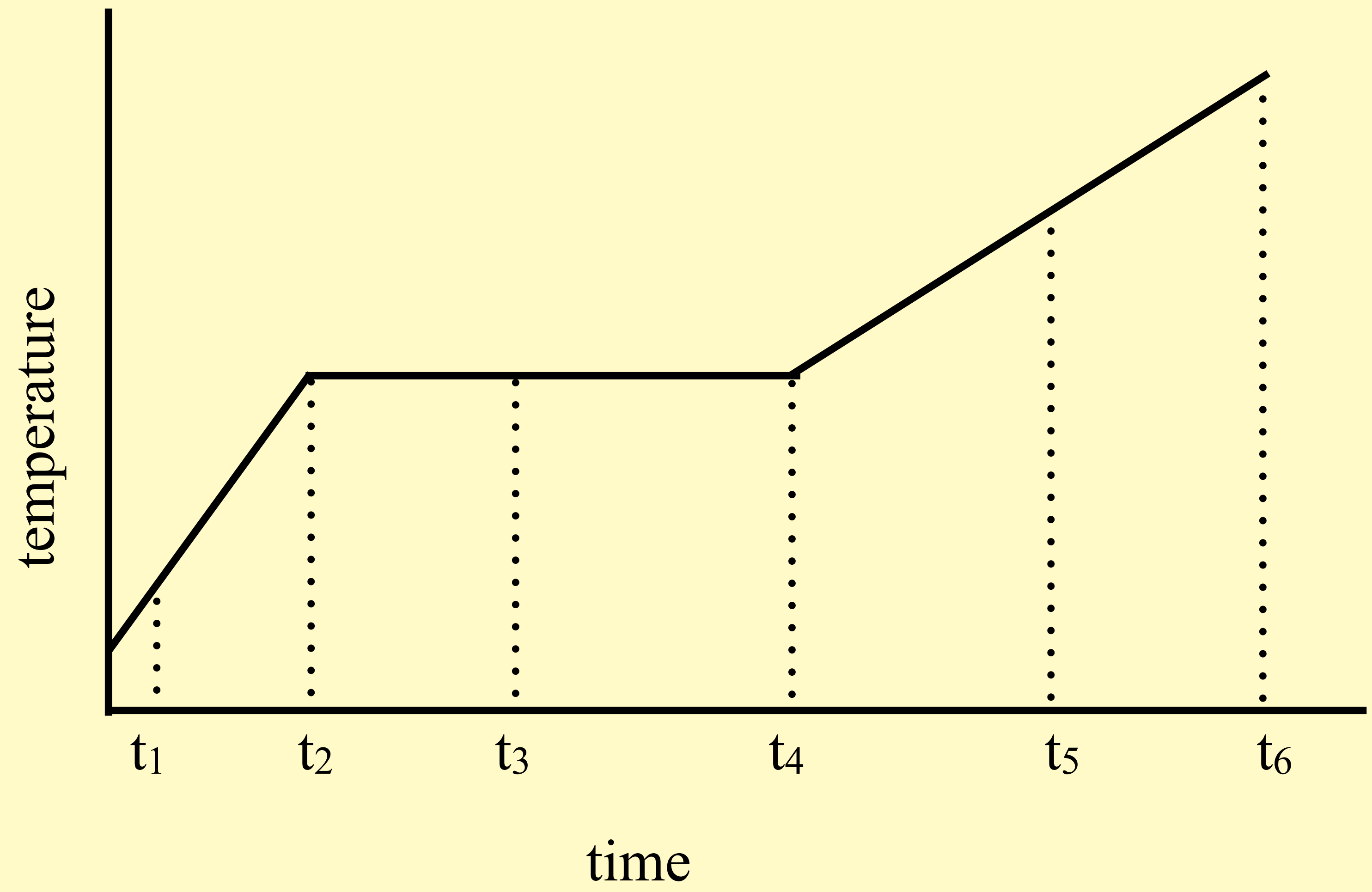
The substance is at its *normal* boiling point (temperature) at which time(s)? *Select all that apply.*

1. t_1
2. t_2
3. t_3
4. t_4
5. t_5
6. t_6
7. The time at which this substance boils cannot be determined without more information.



The substance is at its normal boiling point (temperature) at which time? *Select all that apply.*

1. t_1
2. t_2
3. t_3
4. t_4
5. t_5
6. t_6
7. The time at which this substance boils cannot be determined without more information.

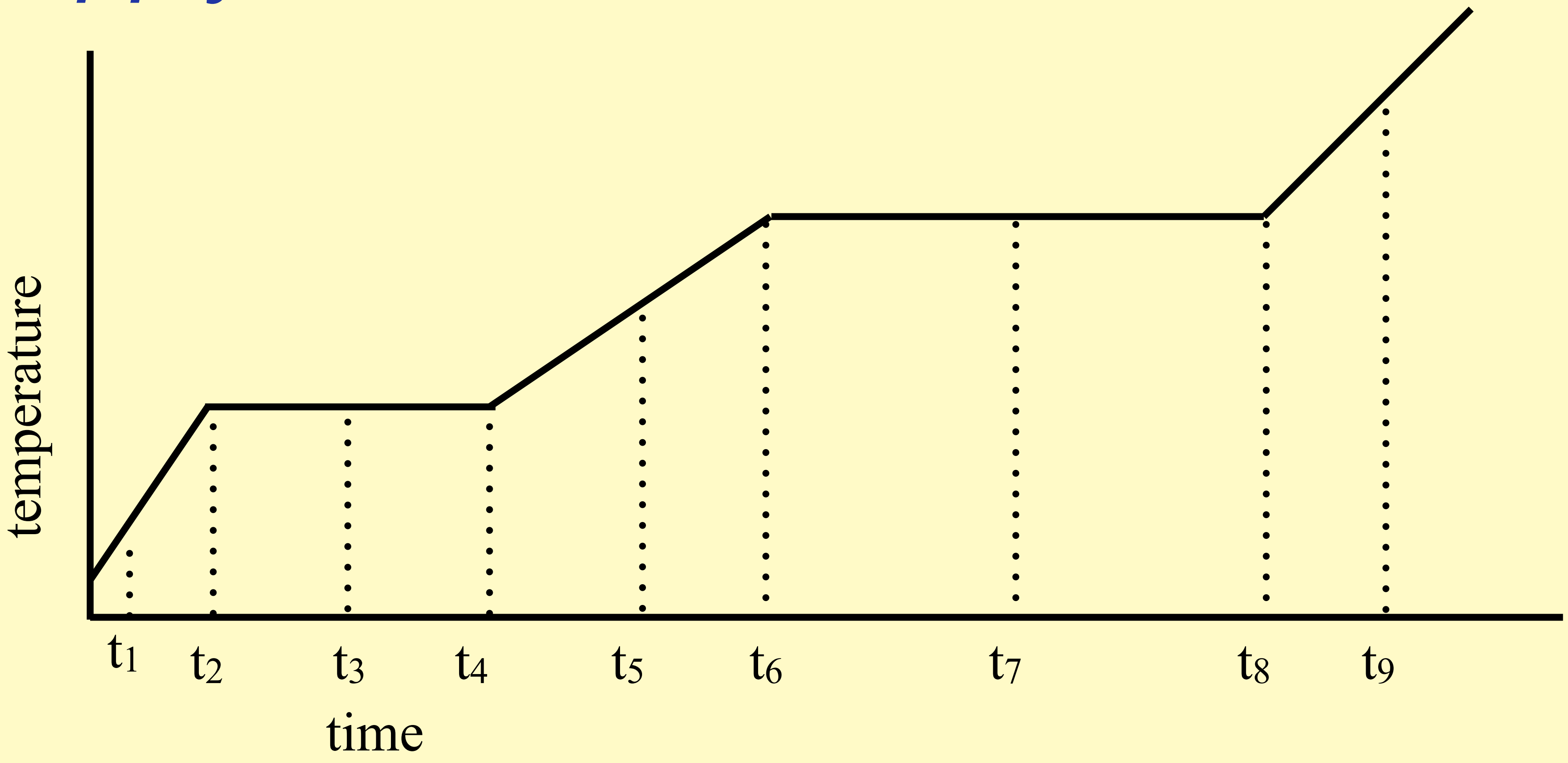


- We can not tell if the plateau is melting or boiling

The substance is at its normal boiling point at what time(s)?

Select all that apply.

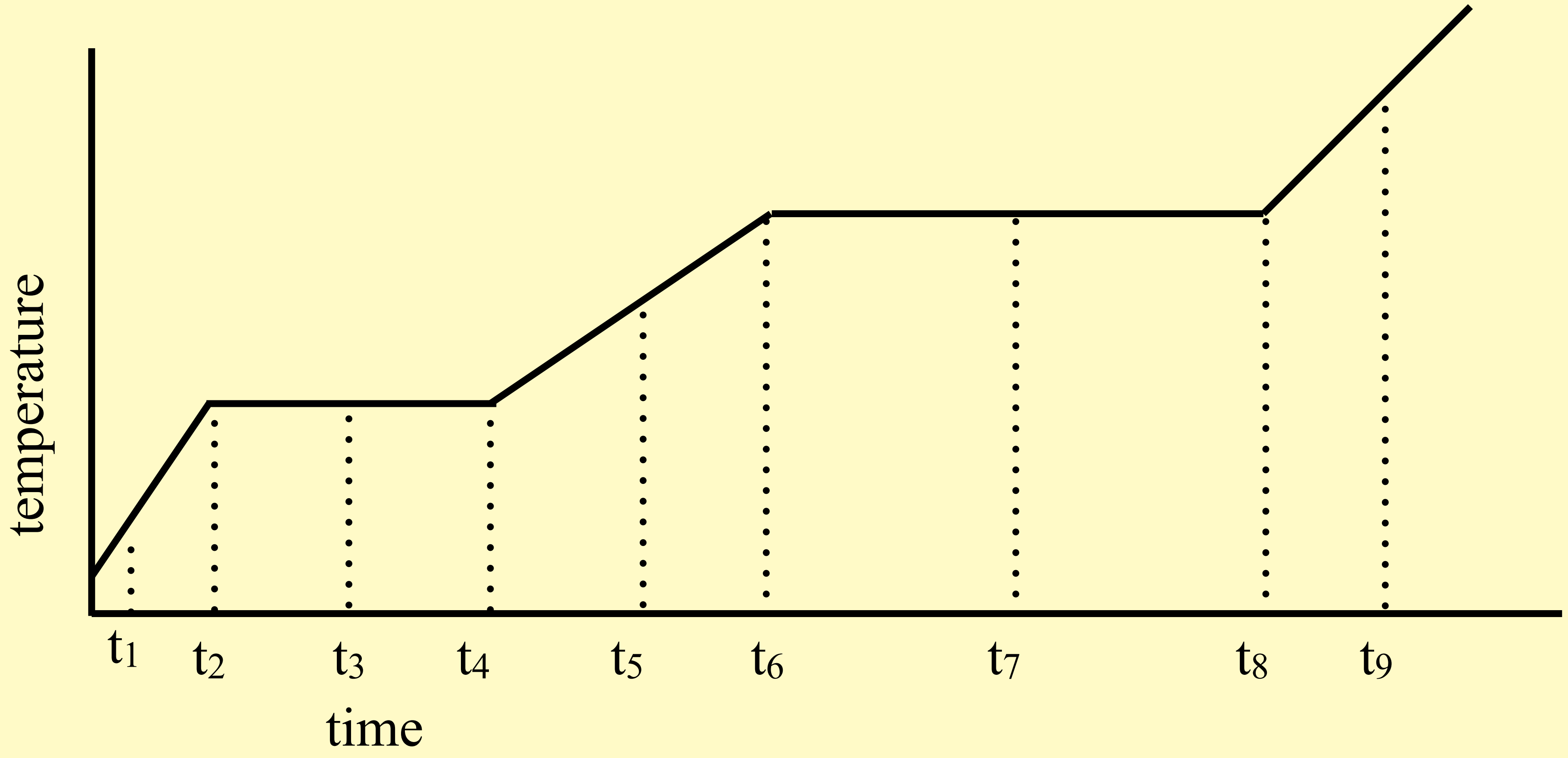
1. t_1
2. t_2
3. t_3
4. t_4
5. t_5
6. t_6
7. t_7
8. t_8
9. t_9



The substance is at its normal boiling point at what time(s)?

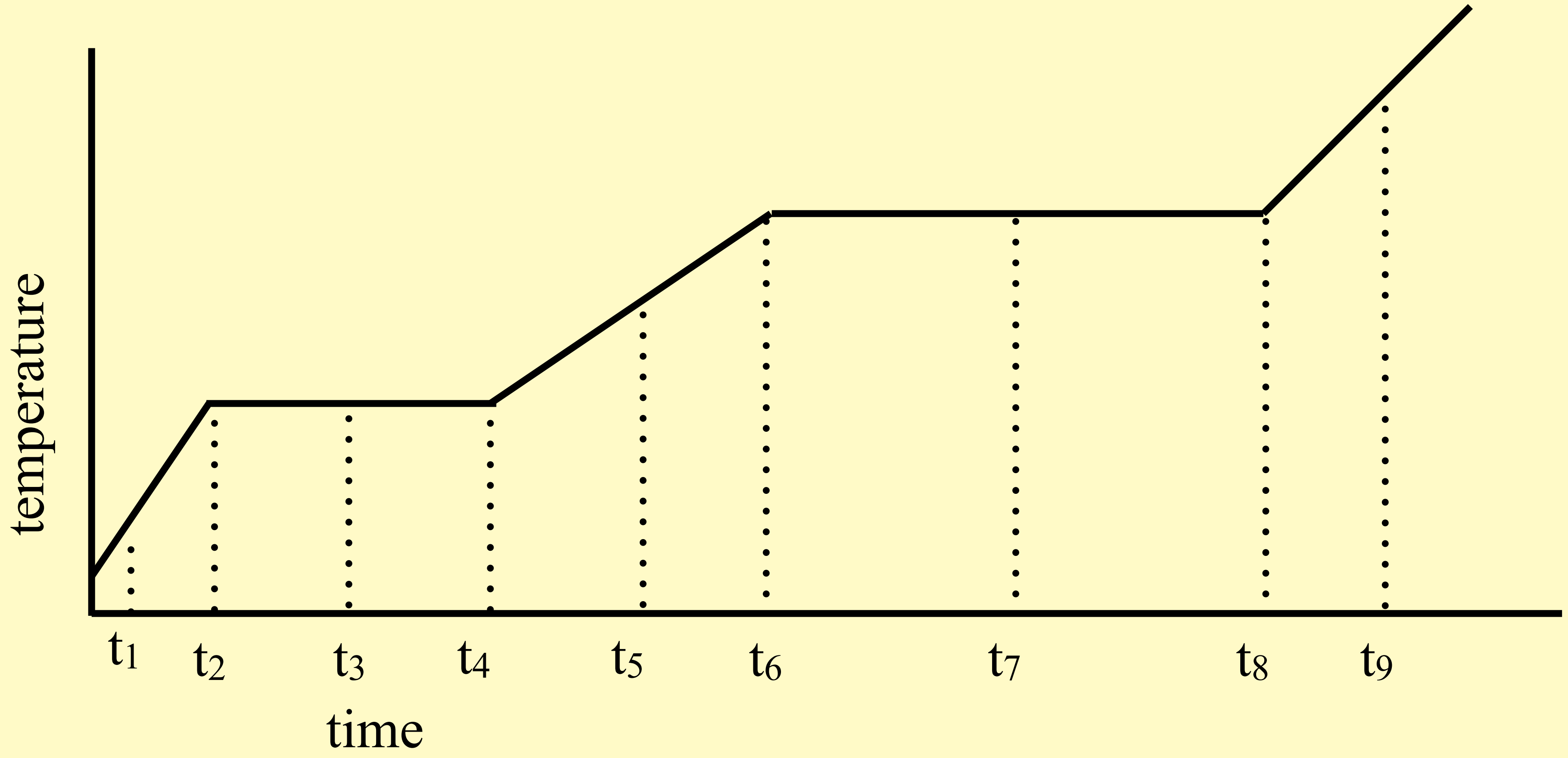
Select all that apply.

1. t_1
2. t_2
3. t_3
4. t_4
5. t_5
6. t_6
7. t_7
8. t_8
9. t_9



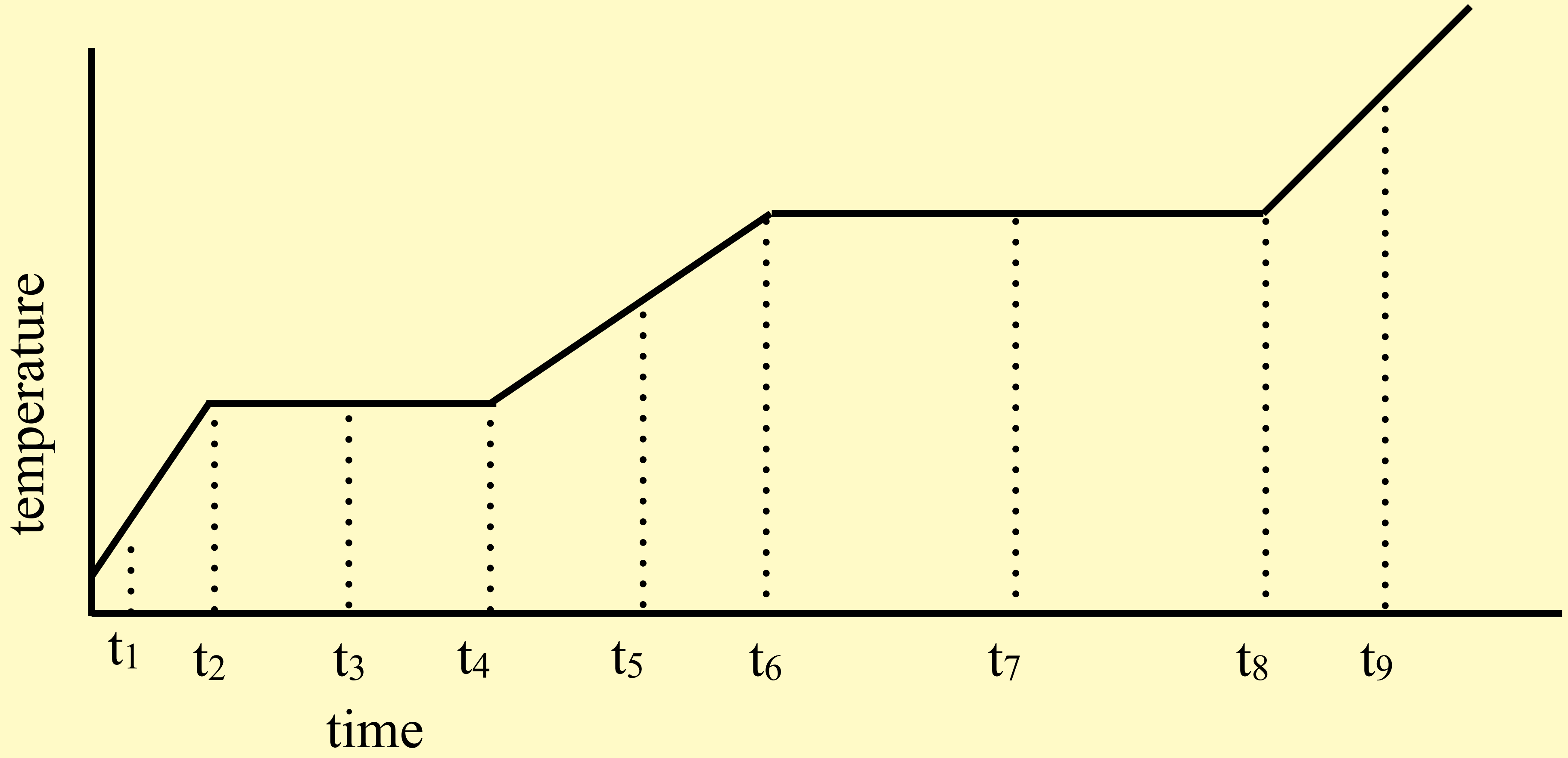
If you were calculating the total energy gained by this substance during the heating process, you would be using the ΔH_{fusion} at which time(s)?

1. t_1
2. t_2
3. t_3
4. t_4
5. t_5
6. t_6
7. t_7
8. t_8
9. t_9



If you were calculating the total energy gained by this substance during the heating process, you would be using the ΔH_{fusion} at which time?

1. t_1
2. t_2
3. t_3
4. t_4
5. t_5
6. t_6
7. t_7
8. t_8
9. t_9



Sketch a cooling graph that represents H_2O from 80ºC to -15ºC

Label the following items

1. 0ºC
2. freezing
3. potential energy changing
4. kinetic energy changing

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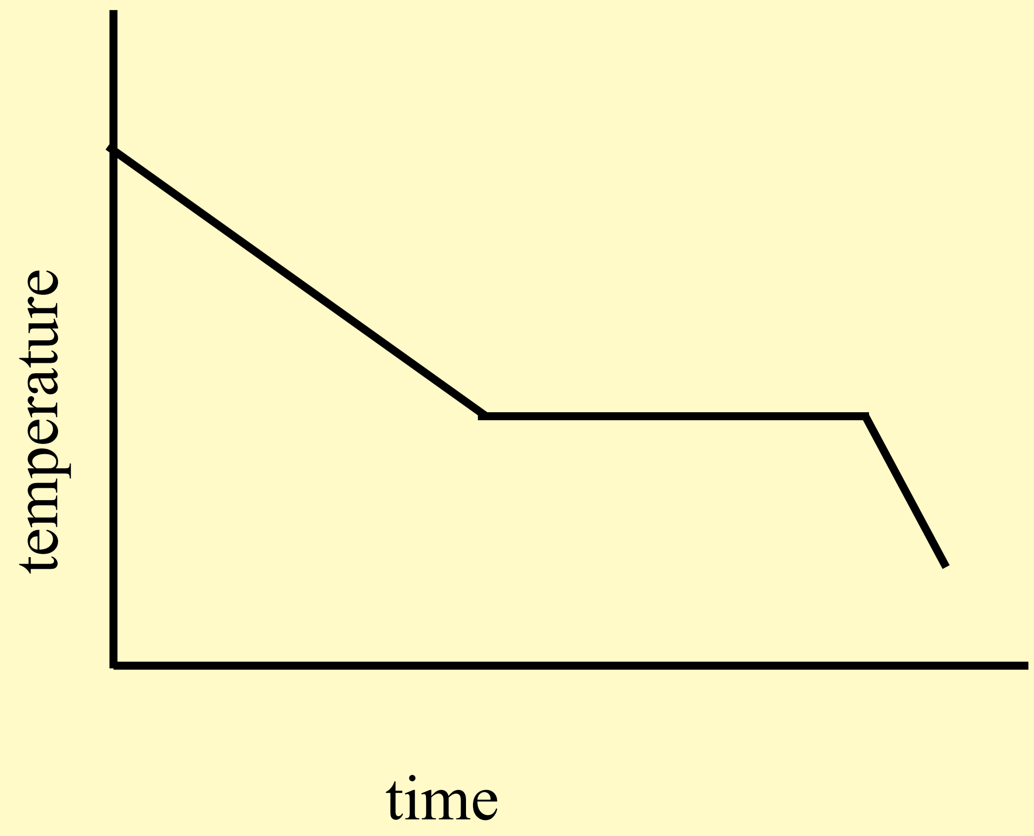
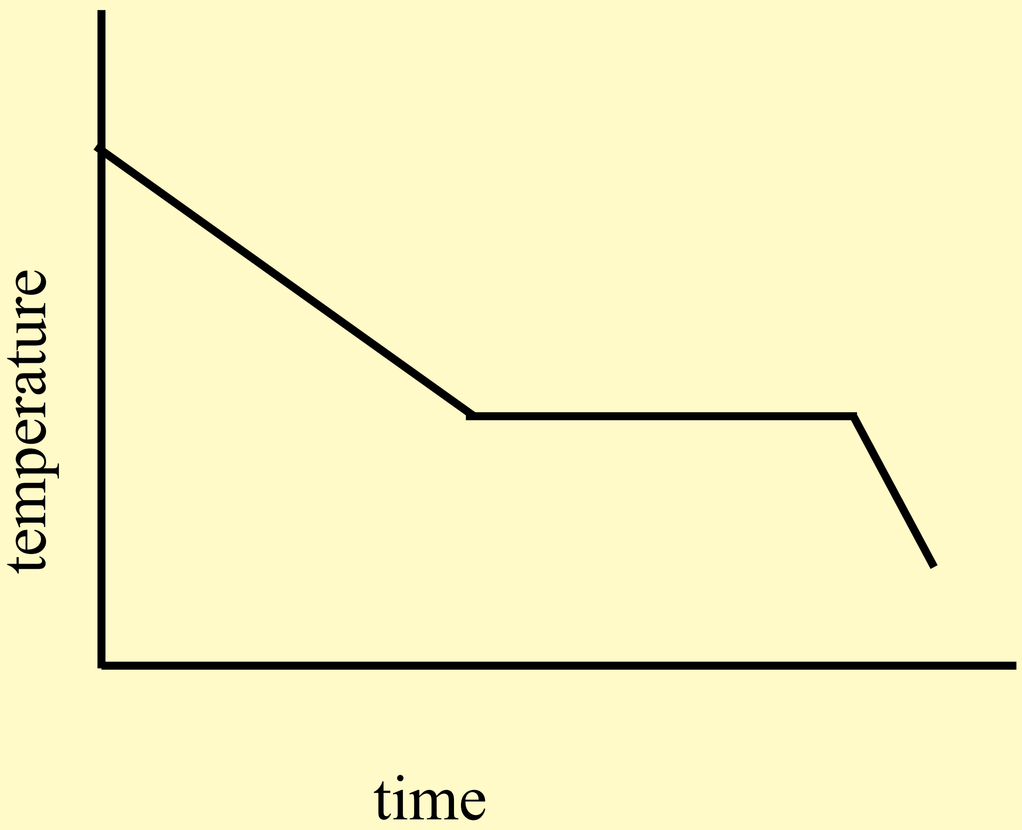


Back the graph up to steam at 120ºC to -15ºC

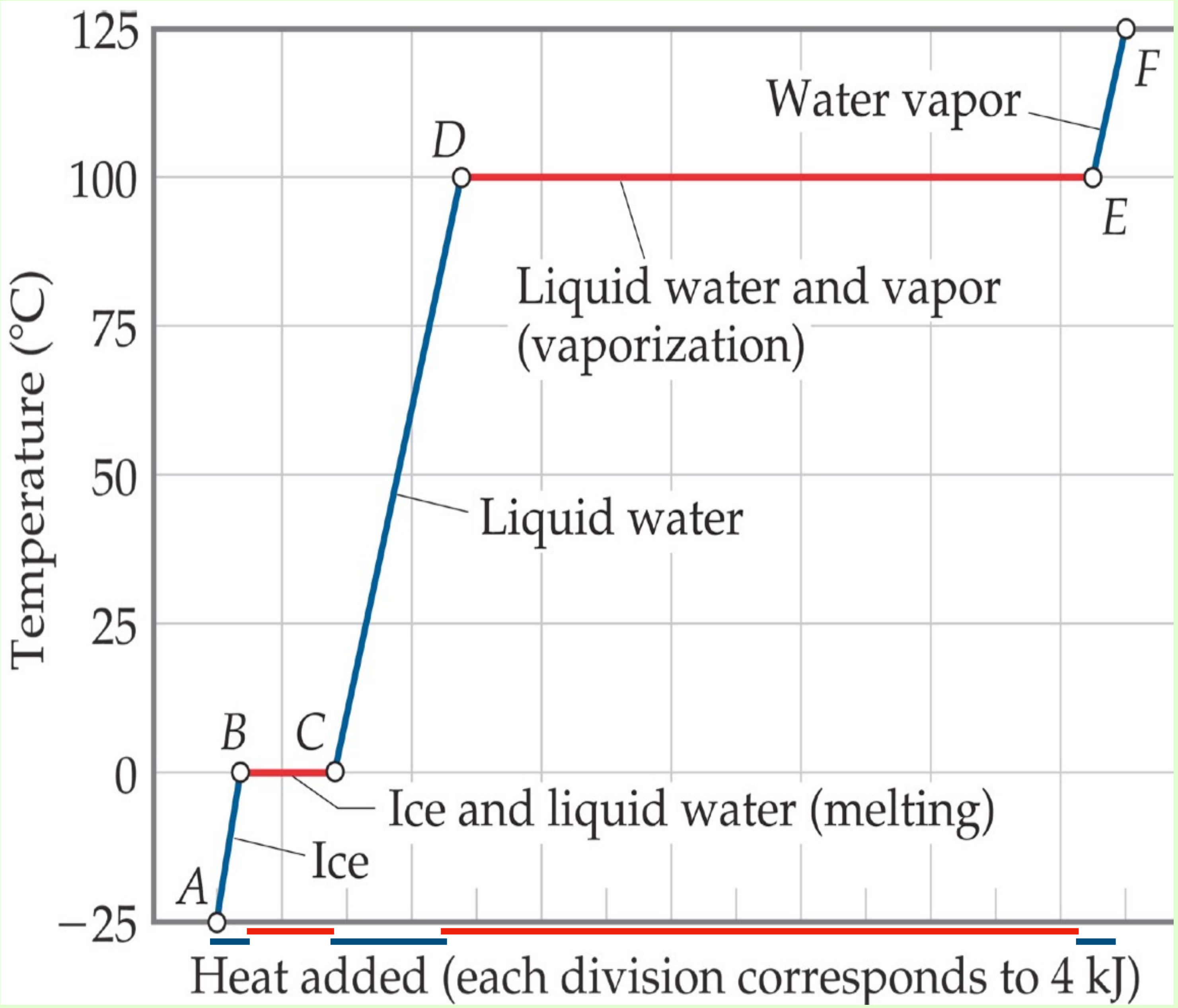
Label the following items

1. 0ºC
2. freezing
3. potential energy changing
4. kinetic energy changing



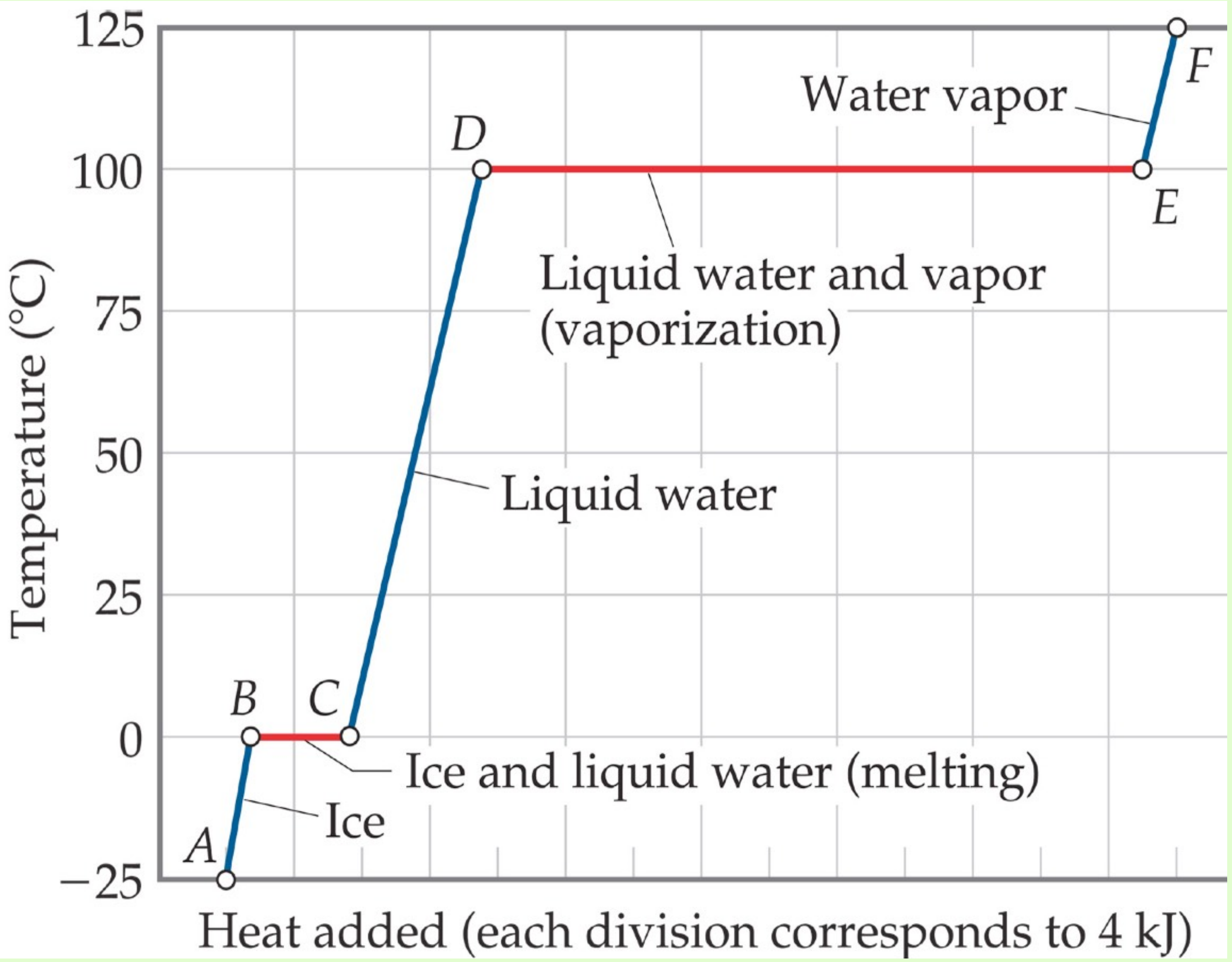
Heating a Substance from Solid to Gas

- What formulas to calculate q for each section of the graph?
- Slope of the vertical sections?
- Length of the plateaus?



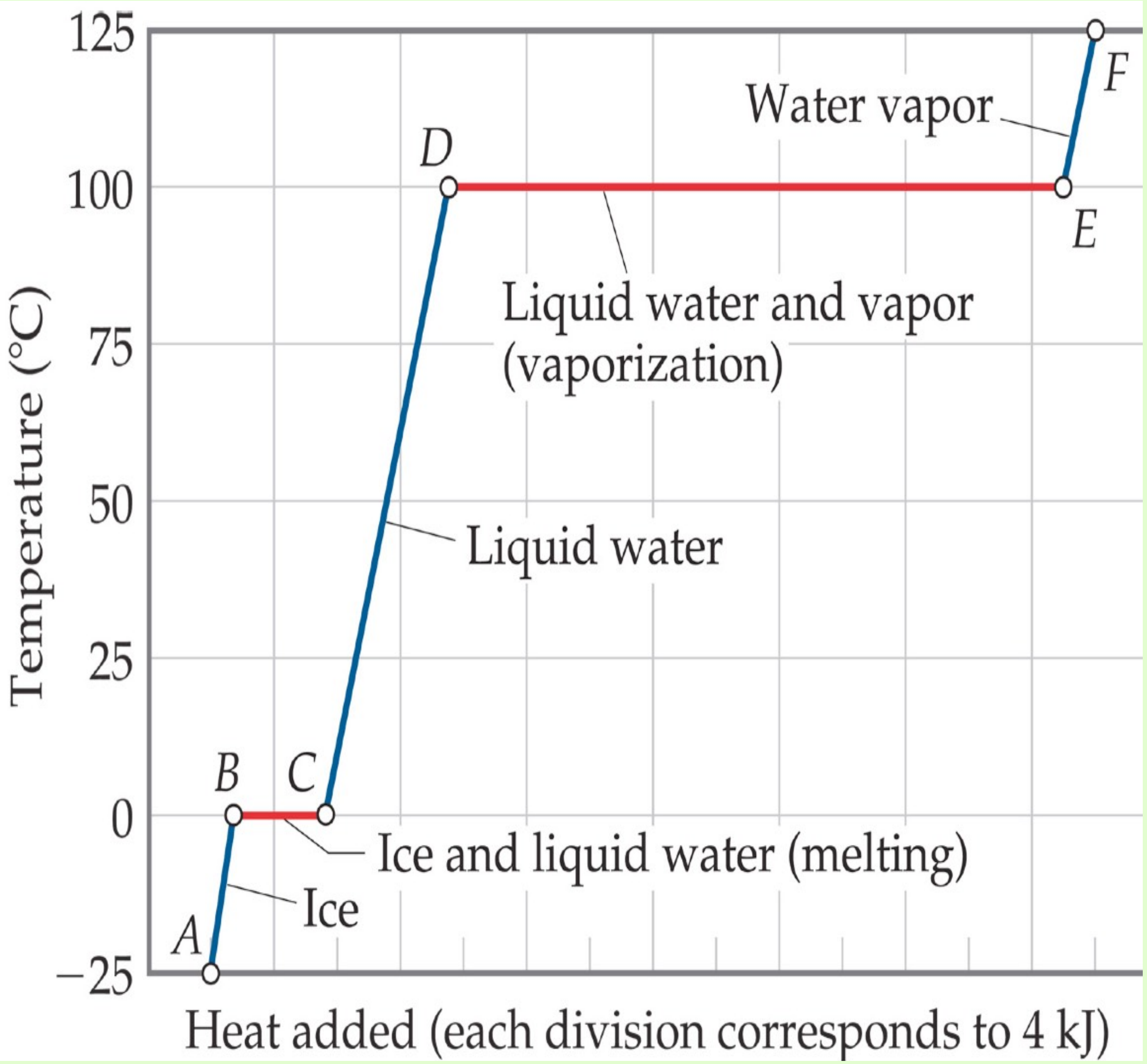
Heating a Substance from Solid to Gas

- Let's use your pink sheets to calculate
- ΔH for melting/ freezing
- ΔH for boiling/ condensing
- What does the length of the plateau tell us about the magnitude of these two ΔH values?



Heating a Substance from Solid to Gas

- Calculate the energy required to completely evaporate 15 g of ice at −25ºC
- ΔH_{fusion} 334 J
- $\Delta H_{vaporization}$ 2261 J
- c of $H_2O_{(L)}$ 4.18 J/gºC
- c of $H_2O_{(g)}$ 1.79 J/gºC
- c of $H_2O_{(s)}$ 2.1 J/gºC



Calculation Energy for Temperature Changes and Phase Changes

- Temperature changes
  - » Heat = amount x c x ΔT
- Phase changes
  - » Heat = $\Delta H_{phase\ change}$ x amount
    - ✓ ΔH_{fusion}
      - ◉ Solid → Liquid or Liquid → solid
    - ✓ $\Delta H_{vaporization}$
      - ◉ Liquid → Gas or Gas → Liquid

That’s all for now