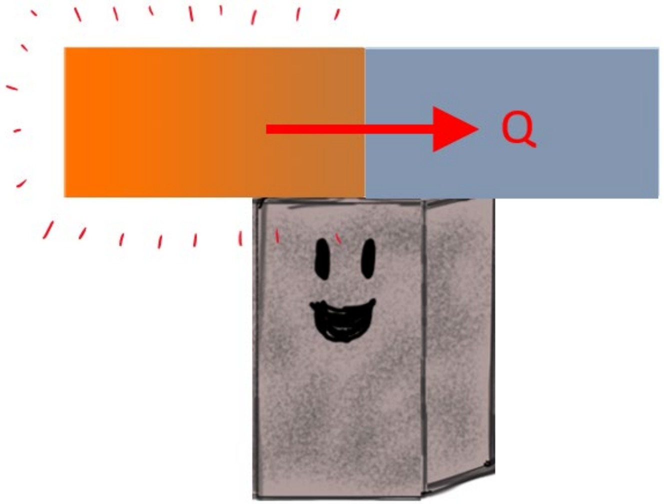
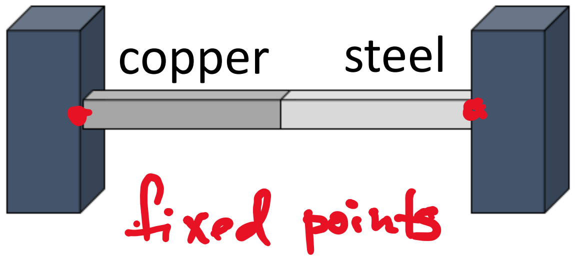


Lecture 8.
Heat

Last Time:

$\Delta L_1 + \Delta L_2 = 0$

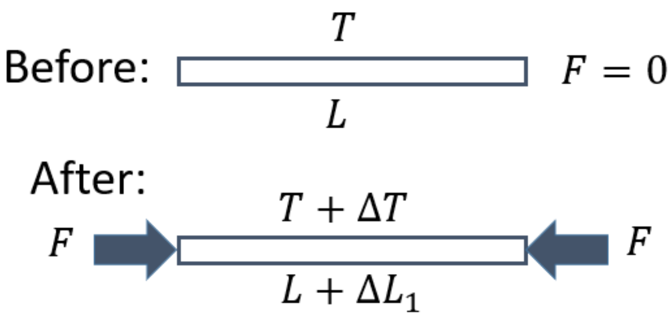


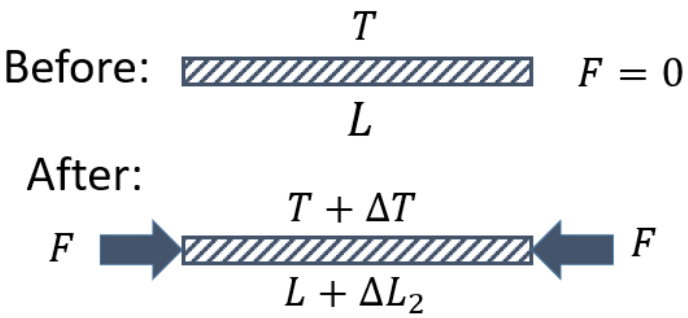
T: 20 °C => 40 °C

$F_{\text{from wall}} = ?$

Step 3: Equations

- For each part, write an equation relating the change in length to the changes in temperature and forces





One of them is positive, one negative

$$\Delta L_1 = \alpha_1 L \Delta T - \frac{F}{A}\frac{L}{Y_1} \qquad \Delta L_2 = \alpha_2 L \Delta T - \frac{F}{A}\frac{L}{Y_2}$$

F is positive, the signs express compression

Step 4

- Collect equations and solve for unknowns

A. $F = 3.4 \times 10^1 N$

B. $F = 6.5 \times 10^2 N$

C. $F = 8.2 \times 10^3 N$

D. $F = 9.1 \times 10^4 N$

E. Something else

Step 4

- Collect equations and solve for unknowns

$$\Delta L_1 + \Delta L_2 = 0 \qquad (1)$$

$$\Delta L_1 = \alpha_1 L \Delta T - \frac{F}{A}\frac{L}{Y_1} \qquad (2)$$

$$\Delta L_2 = \alpha_2 L \Delta T - \frac{F}{A}\frac{L}{Y_2} \qquad (3)$$

A. $F = 3.4 \times 10^1 N$

B. $F = 6.5 \times 10^2 N$

C. $F = 8.2 \times 10^3 N$

D. $F = 9.1 \times 10^4 N$

E. Something else

- Plug (2) and (3) into (1):

$$\alpha_1 L \Delta T + \alpha_2 L \Delta T - \frac{F}{A}\frac{L}{Y_1} - \frac{F}{A}\frac{L}{Y_2} = 0$$

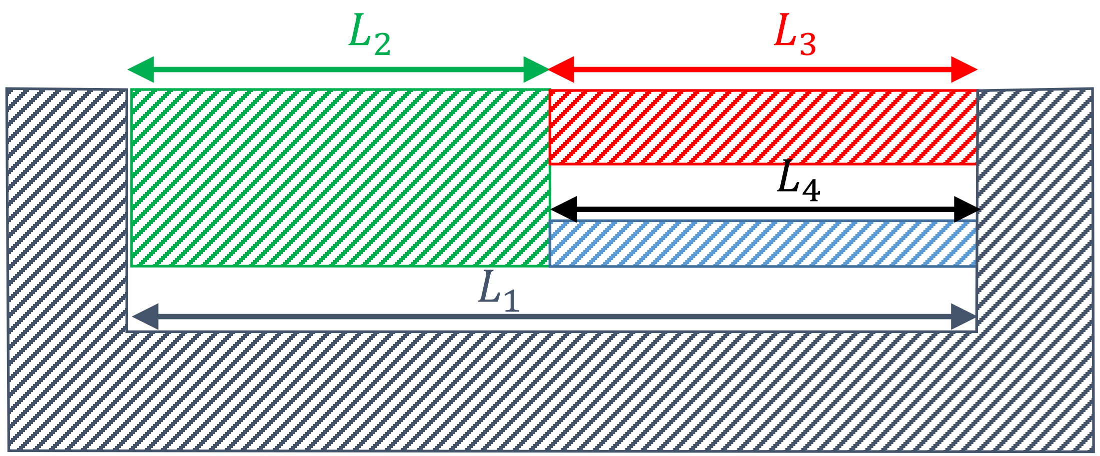
- Isolate terms with F:

$$\frac{FL}{A}\left(\frac{1}{Y_1} + \frac{1}{Y_2}\right) = (\alpha_1 + \alpha_2) L \Delta T$$

- Solve:

$$F = \frac{(\alpha_1 + \alpha_2) A \Delta T}{\left(\frac{1}{Y_1} + \frac{1}{Y_2}\right)} = 8.2 \times 10^3 N$$

If this system is heated, what constraints must be satisfied by the four quantities ΔL_1, ΔL_2, ΔL_3, and ΔL_4? (all objects are attached to each other and cannot separate)



A. $\Delta L_1 + \Delta L_2 + \Delta L_3 + \Delta L_4 = 0$

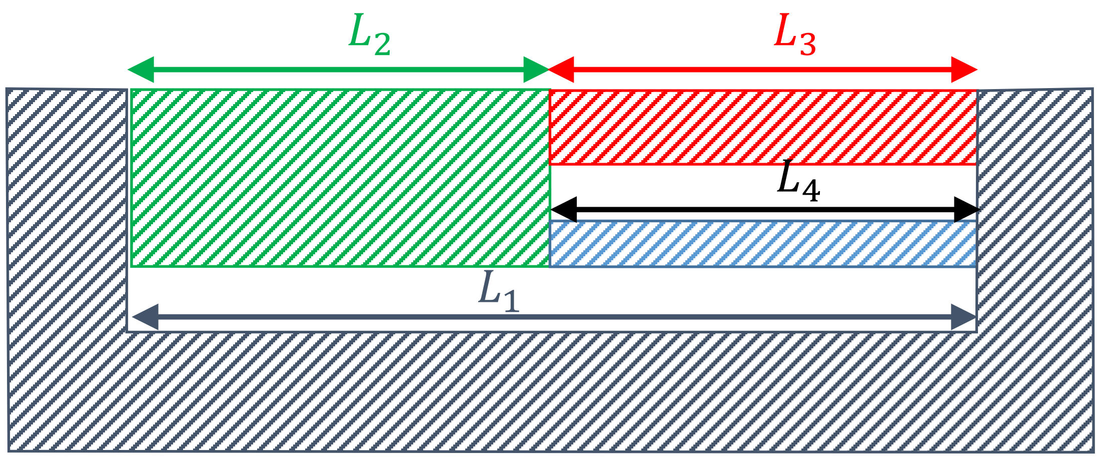
B. $\Delta L_1 = \Delta L_2 + \Delta L_3 = \Delta L_2 + \Delta L_4$

C. $\Delta L_2 + \Delta L_3 = 0 = \Delta L_2 + \Delta L_4$

D. (a) and (b)

E. (b) and (c)

If this system is heated, what constraints must be satisfied by the four quantities ΔL_1, ΔL_2, ΔL_3, and ΔL_4? (all objects are attached to each other and cannot separate)



A. $\Delta L_1 + \Delta L_2 + \Delta L_3 + \Delta L_4 = 0$

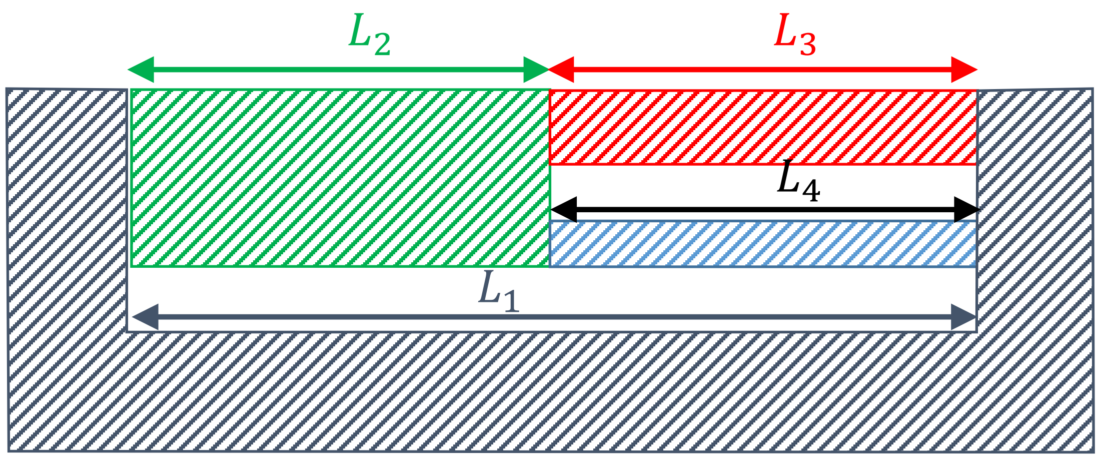
B. $\Delta L_1 = \Delta L_2 + \Delta L_3 = \Delta L_2 + \Delta L_4$

C. $\Delta L_2 + \Delta L_3 = 0 = \Delta L_2 + \Delta L_4$

D. (a) and (b)

E. (b) and (c)

If this system is heated, what relations do we have between the compressive forces F_2, F_3 and F_4 on the green, red, and ~~black~~ blue objects?



A. $F_2 + F_3 + F_4 = 0$

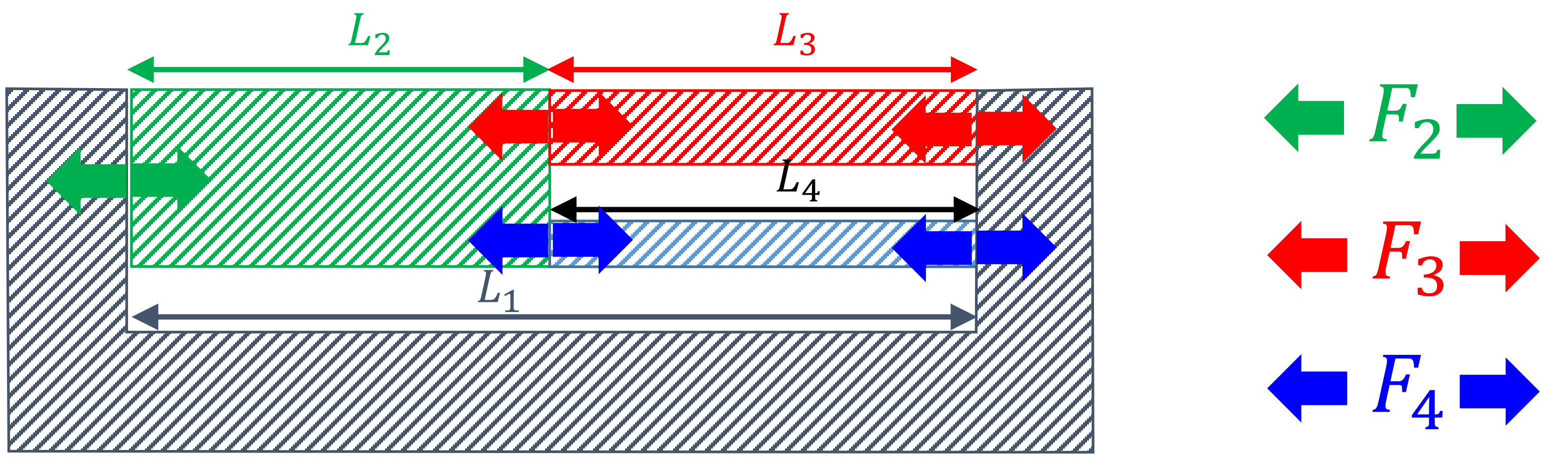
B. $F_2 = F_3 = F_4$

C. $F_2 = F_3 + F_4$

D. $F_3 = F_4$

E. Help!

If this system is heated, what relations do we have between the compressive forces F_2, F_3 and F_4 on the green, red, and ~~black~~ blue objects?



A. $F_2 + F_3 + F_4 = 0$

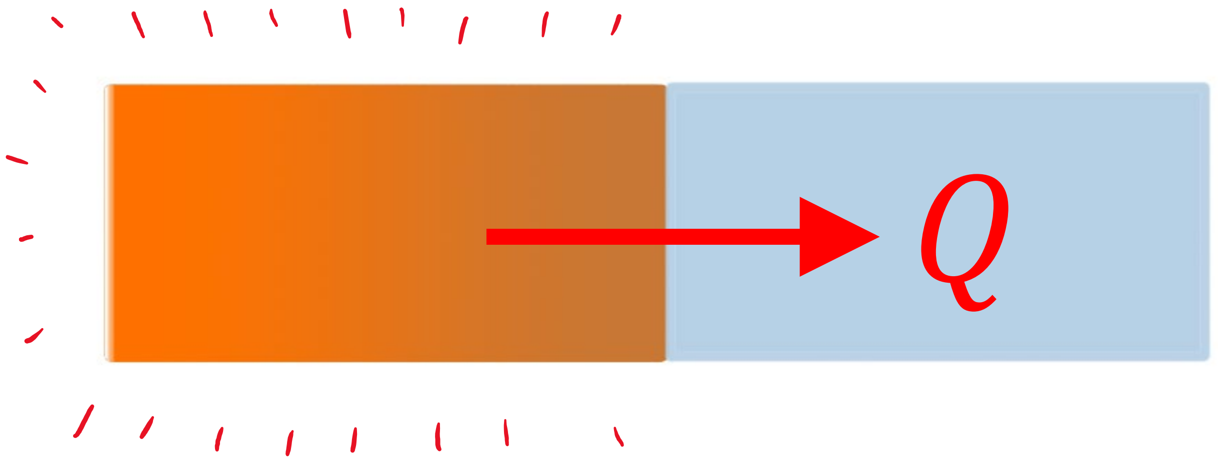
B. $F_2 = F_3 = F_4$

C. $F_2 = F_3 + F_4$ ✓

D. $F_3 = F_4$

E. Help!

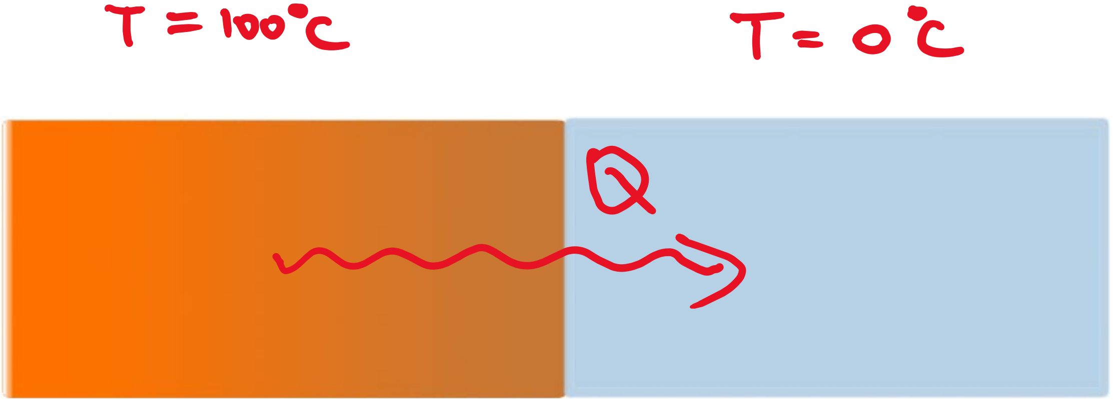
Heat



Q = heat: amount of energy transferred due to temperature differences

- Q is energy!!! Measured in Joules (J)
- T is temperature (NOT energy); measured in degrees Celsius (^{o}C) or kelvin (K)

Two objects with the same mass are put in thermal contact and insulated from their environment. If the initial temperatures are 100 ^{o}C and 0 ^{o}C, the final equilibrium temperature will be



A. 50 ^{o}C

B. Somewhere between 0 ^{o}C and 100 ^{o}C, but not necessarily 50 ^{o}C

C. Not necessarily between 0 ^{o}C and 100 ^{o}C

Two objects <u>with the same mass</u> are put in thermal contact and insulated from their environment. If the initial temperatures are 100 ^{o}C and 0 ^{o}C, the final equilibrium temperature will be

- Heat flows from the hotter object to the cooler object
- Temperature of the hot object decreases and the cold object increases, until they are the same temperature, somewhere between 0^{o} C and 100^{o} C
- Not necessarily 50^{o} C since <u>some materials require more energy for a given temperature change</u>

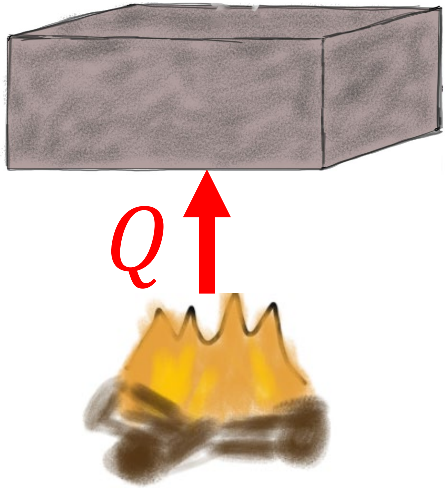
A. 50 ^{o}C

B. Somewhere between 0 ^{o}C and 100 ^{o}C, but not necessarily 50 ^{o}C

C. Not necessarily between 0 ^{o}C and 100 ^{o}C

Specific heat

- Heat required to raise the temperature of a material of mass m is determined by its specific heat, c:



1kg   1K

$$\boxed{Q = m\,c\,\Delta T}$$

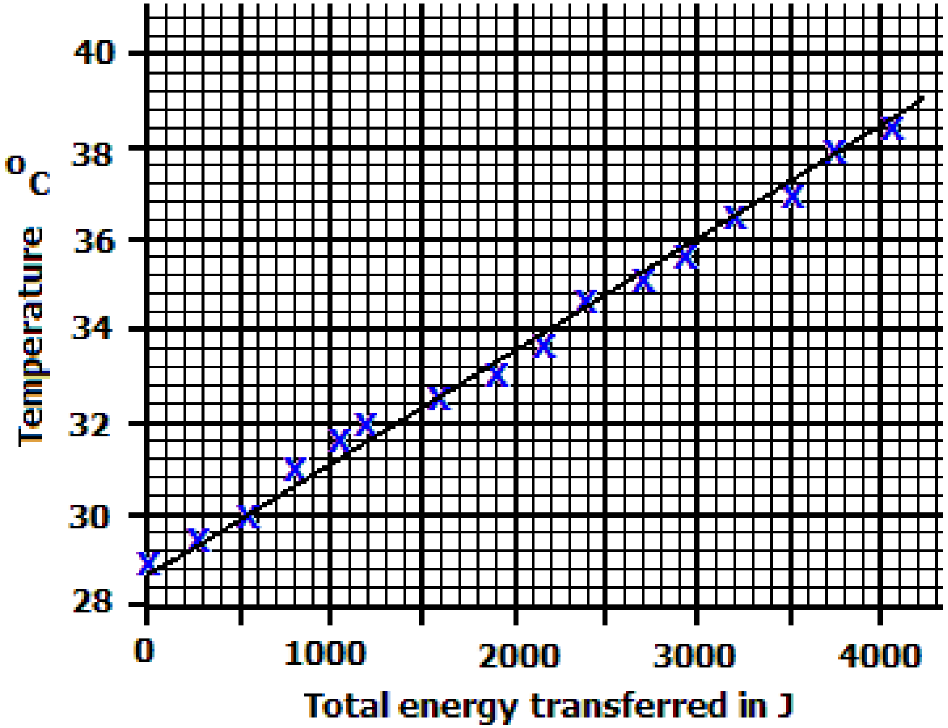
- Q = heat added
- m = mass
- c = specific heat
- ΔT = change in temperature

- c is a measure of the energy required to heat 1 kg of material by 1 K (material constant!)
- Units of c are $\frac{\mathrm{J}}{\mathrm{kg}\cdot\mathrm{K}}$

Q: Heat is added to two kilograms of a liquid, and data for the temperature vs energy transfer is shown. If we took data for another liquid with the same mass but a larger specific heat, the slope of this graph would be

A. Larger
B. Smaller
C. The same
D. Any of the above are possible.

$$\boxed{Q = m\, c\, \Delta T}$$



Extra: What is the specific heat of the original liquid?

Q: Heat is added to two kilograms of a liquid, and data for the temperature vs energy transfer is shown. If we took data for another liquid with the same mass but a larger specific heat, the slope of this graph would be

A. Larger

B. Smaller ✓

C. The same

D. Any of the above are possible.

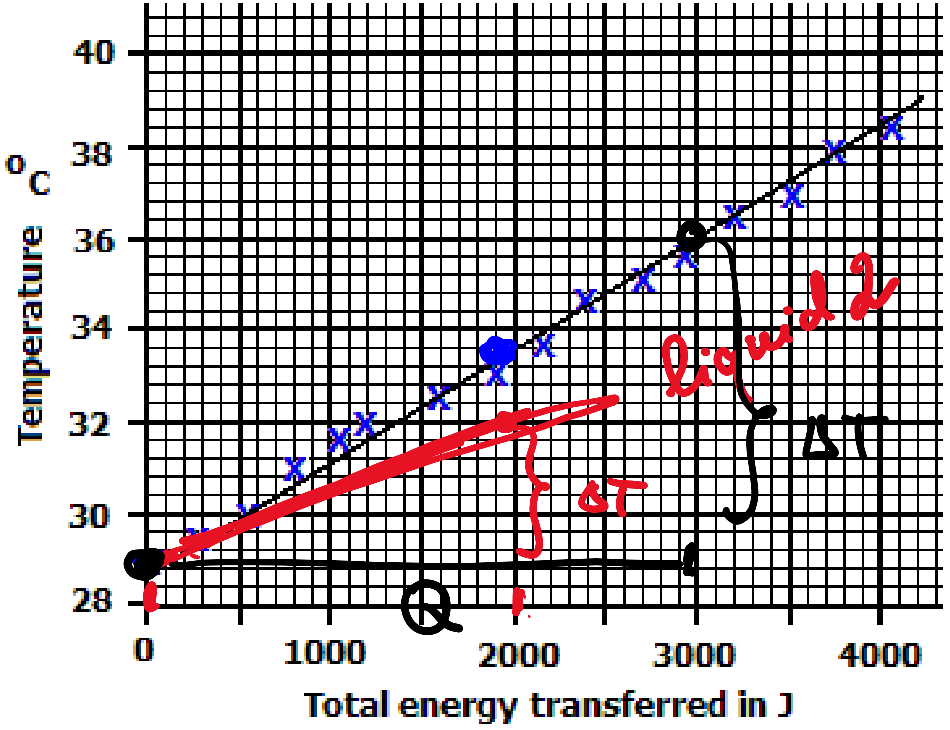
fix

$$\boxed{Q = m\, c\, \Delta T}$$

$$c = \frac{Q}{m\,\Delta T}$$

↪ 2 kg

Smaller ΔT for same Q, so smaller slope (rise/run)



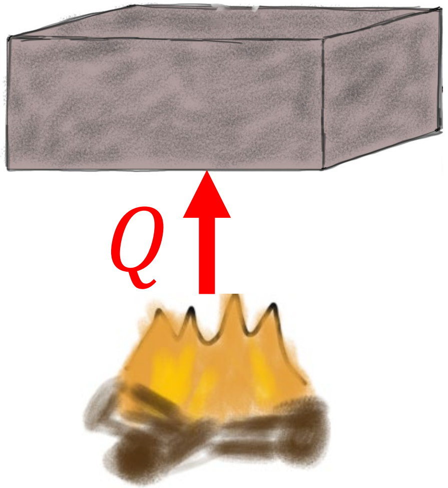
Extra: What is the specific heat of the original liquid?

$$c \approx \frac{3000}{2 \cdot 7} \approx 200\,\frac{\mathrm{J}}{\mathrm{kg} \cdot \mathrm{K}}$$

Molar heat capacity

1 mole = $6 \cdot 10^{23}$ particles

- Heat required to raise the temperature of n moles of a substance is determined by its molar heat capacity, C:



specific heat

$$Q = m\,c\,\Delta T$$

or:

$$Q = n\,C\,\Delta T$$

molar heat capacity

- n = # of moles
- C = molar heat capacity (also called 'molar specific heat')

➢ c in $\frac{\mathrm{J}}{\mathrm{kg \cdot K}}$: energy required to heat 1 kg of material by 1 K

➢ C in $\frac{\mathrm{J}}{\mathrm{mol \cdot K}}$: energy required to heat 1 mole of material by 1 K

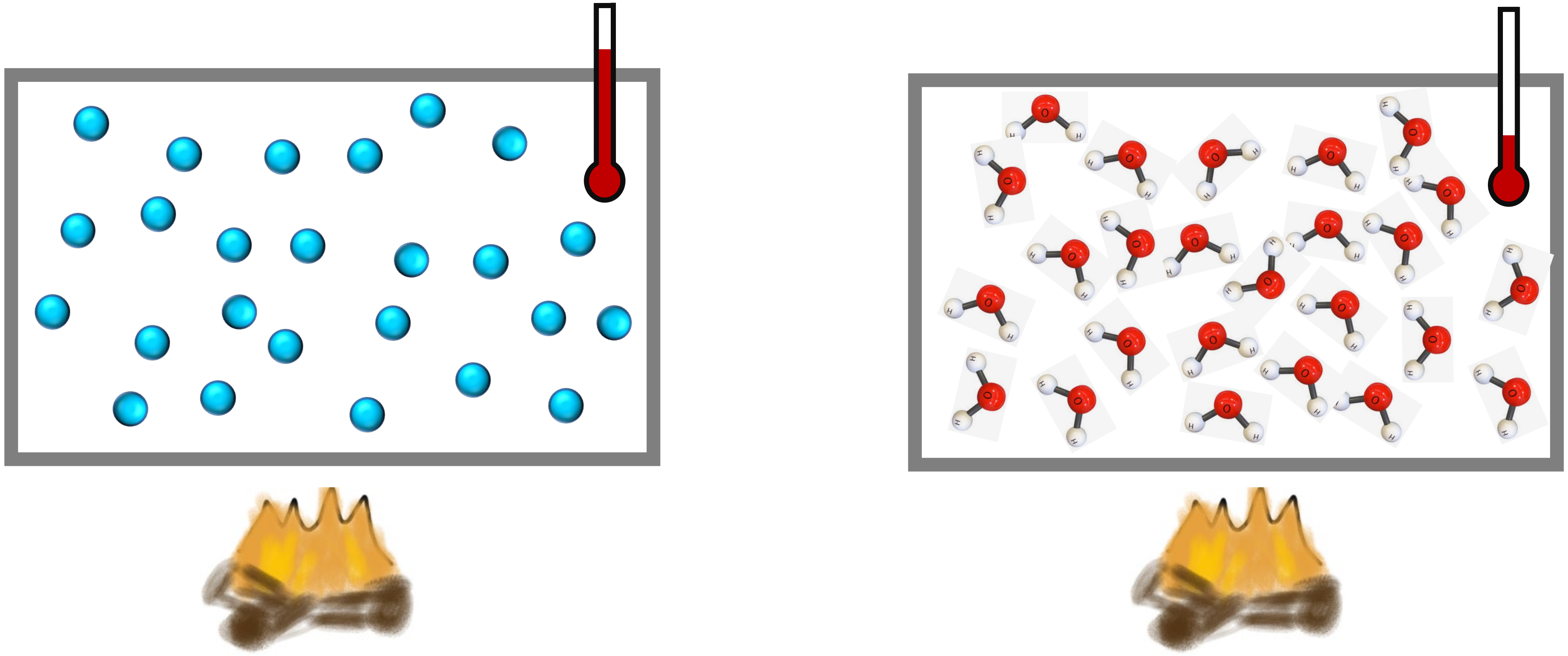
Specific Heat values

Table 17.3 Approximate Specific Heats and Molar Heat Capacities (Constant Pressure)

Substance	Specific Heat, c ($J/kg \cdot K$)	Molar Mass, M (kg/mol)	Molar Heat Capacity, C ($J/mol \cdot K$)
Aluminum	910	0.0270	24.6
Beryllium	1970	0.00901	17.7
Copper	390	0.0635	24.8
Ethanol	2428	0.0461	111.9
Ethylene glycol	2386	0.0620	148.0
Ice (near 0°C)	2100	0.0180	37.8
Iron	470	0.0559	26.3
Lead	130	0.207	26.9
Marble ($CaCO_3$)	879	0.100	87.9
Mercury	138	0.201	27.7
Salt (NaCl)	879	0.0585	51.4
Silver	234	0.108	25.3
Water (liquid)	4190	0.0180	75.4

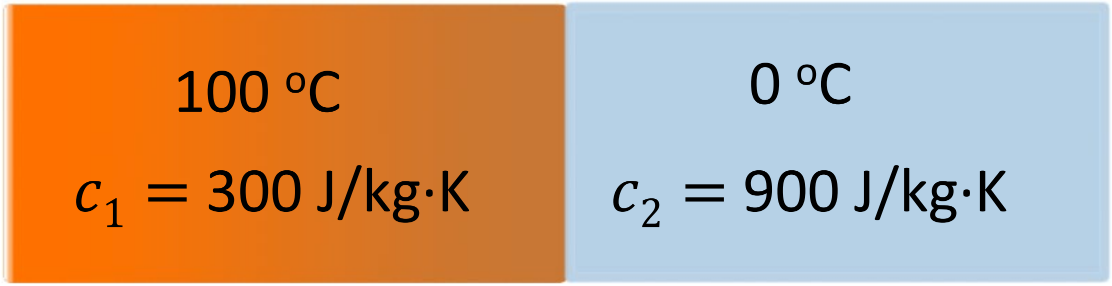
Why is heat capacity larger for some materials?

- Temperature is proportional to average kinetic energy of molecules



- For more complicated materials, part of energy added goes to rotations/vibrations, etc…, so it takes more Q to increase their kinetic energy (= rise temperature)

Q: Two objects with the same mass are put in thermal contact but insulated from their environment. If the initial temperatures are 100 ºC and 0 ºC, and the specific heats are $c_1 = 300$ J/kg·K and $c_2 = 900$ J/kg·K, calculate the final equilibrium temperature.



$0°C < T < 100°C$ $T = ?$

Hint: isolate the parts and think of what is happening to each part separately. Draw a picture and label it.

$$\boxed{Q = m\,c\,\Delta T}$$

Step 1: System

- Visualize what will happen
- Draw a before/after picture
- Gives names to known & unknown quantities & label diagram
- Understand which quantities are changing and which are fixed

- Next: for each part, determine how much heat was added

Step 1: System

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- Draw a before/after picture
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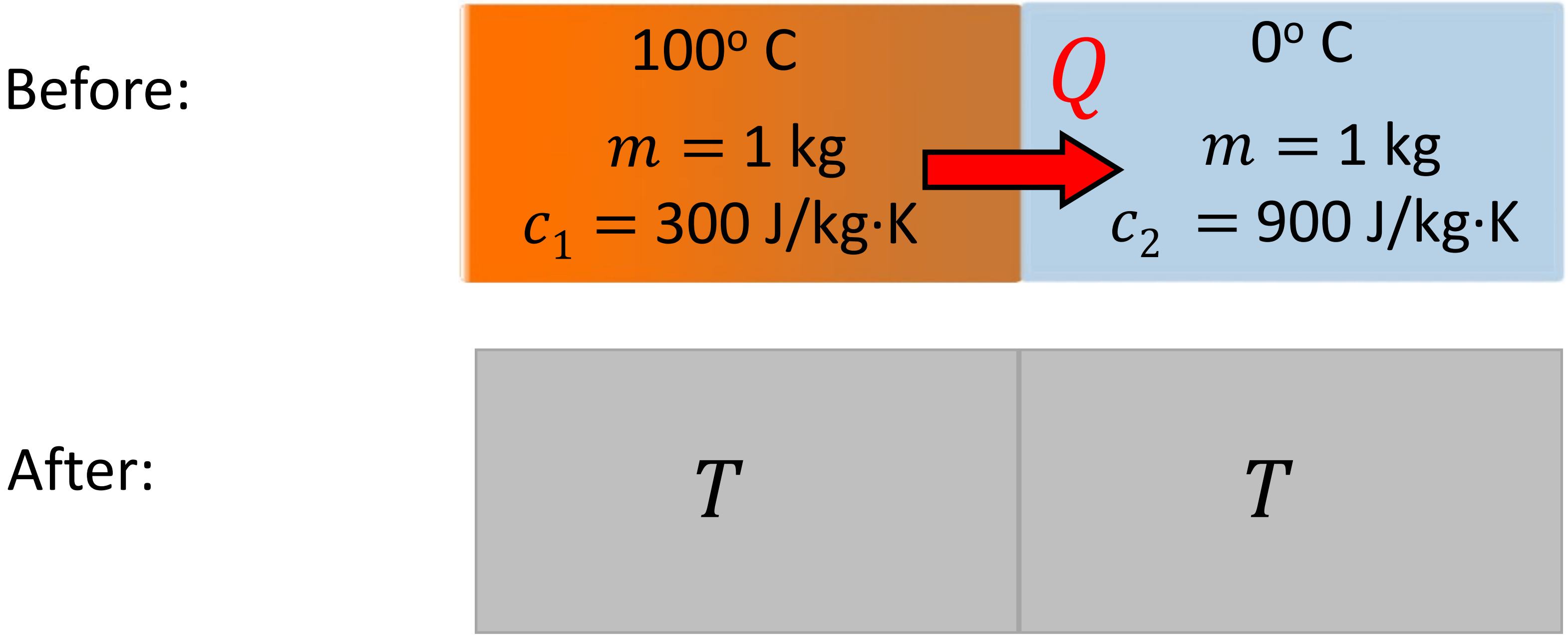


Heat given off by 1st is equal to heat received by 2nd

We want to find T

- Next: for each part, determine how much heat was added

Step 2: Parts of the system

- Isolate the parts of the system
- For each part, draw a before/after picture

Step 2: Parts of the system

- Isolate the parts of the system
- For each part, draw a before/after picture

Before:

$T_1 = 100\ ^{\circ}\mathrm{C}$

$m = 1$ kg

$c_1 = 300$ J/kg·K

Transferred heat: $Q_1 < 0$

After:

T

Before:

$T_1 = 0\ ^{\circ}\mathrm{C}$

$m = 1$ kg

$c_2 = 900$ J/kg·K

Tranferred heat: Q_2

After:

T

$Q_2 > 0$

$$\boxed{Q = m\, c\, \Delta T}$$

- How are Q_1 and Q_2 related?

$$Q_1 + Q_2 = 0$$

- $Q > 0$ if T increases (heat received)
- $Q < 0$ if T decreases (heat spent)

Step 3: Equations

- For each part, write an equation relating the change in length to the changes in temperature and forces

$$\boxed{Q = m\,c\,\Delta T}$$

Step 3: Equations

- For each part, write an equation relating the change in length to the changes in temperature and forces

no forces here! :)

Q: For the object initially at 100 ºC, transferred heat is:

Before: $T_1 = 100$ ºC, $m = 1$ kg, $c_1 = 300$ J/kg·K $\quad T_i$

Transferred heat: Q_1

After: T $\quad T_f$

A. $Q_1 = 300$ J/K · T

B. ~~$Q_1 = 300$ J/K · 100 ºC~~

C. $\boxed{Q_1 = 300 \text{ J/K} \cdot (T - 100\,^\circ\text{C}) \cdot 1 \text{ kg}}$

D. ~~$Q_1 = 300$ J/K · (100 ºC – T)~~

E. $Q_1 = 300$ J/K · (T + 100 ºC)

$$\Delta T = T_f - T_i$$

$$Q_1 + Q_2 = 0$$

Q: What is Q_2?

$$\Delta T = T_{f,2} - T_{i,2} =$$

$$\boxed{Q_2 = m c_2 (T - 0\,^\circ\text{C}) = 900 \cdot 1 \cdot T = 900\,T} \quad [\text{J}]$$

$$\boxed{Q = m\,c\,\Delta T}$$

Step 3: Equations

- For each part, write an equation relating the change in length to the changes in temperature and forces

Before: $T_1 = 100$ ºC, $m = 1$ kg, $c_1 = 300$ J/kg·K

Transferred heat: Q_1

After: T

Q: For the object initially at 100º C, transferred heat is:

A. $Q_1 = 300$ J/K · T

B. $Q_1 = 300$ J/K · 100 ºC

C. $Q_1 = 300$ J/K · (T – 100 ºC) ✓

D. $Q_1 = 300$ J/K · (100 ºC – T)

E. $Q_1 = 300$ J/K · (T + 100 ºC)

$$\Delta T = T_f - T_i$$

$Q_1 = m\, c\, \Delta T$ (NOTE: $\Delta T = T_F - T_I$)

$m = 1$ kg

$c_1 = 300$ J/kg·K

$\Delta T = (T - 100^\circ\text{ C})$

Q_1 is negative (hotter object loses heat)

Q: What is Q_2?

$$Q_2 = m\, C_2\, (T - 0\,^oC) > 0$$

$$\boxed{Q = m\, c\, \Delta T}$$

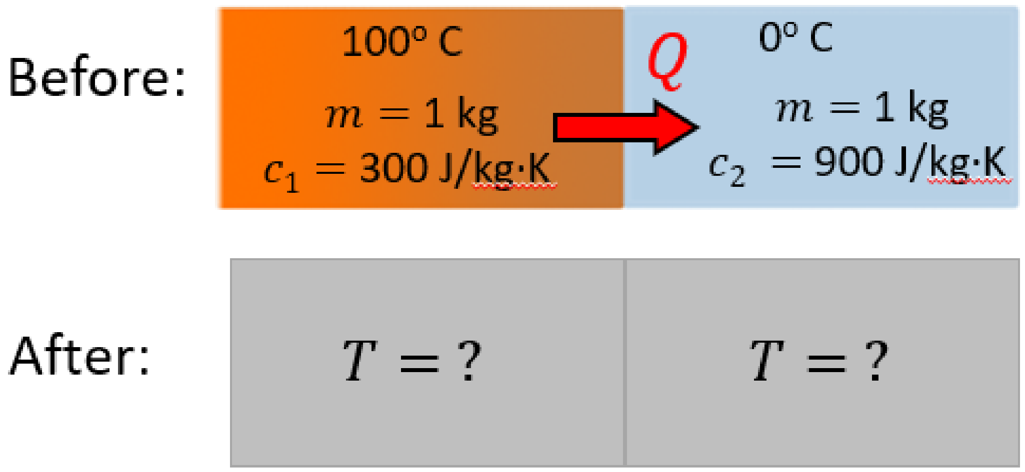
Step 4

- Collect equations and solve for unknowns

$$\boxed{Q = m\,c\,\Delta T}$$

Step 4

- Collect equations and solve for unknowns



- We have:

$Q_1 = 300\ \text{J/K} \cdot (T - 100^\circ\ \text{C})$ - negative

$Q_2 = 900\ \text{J/K} \cdot (T - 0^\circ\ \text{C})$ - positive

- How are Q_1 and Q_2 related? Why?

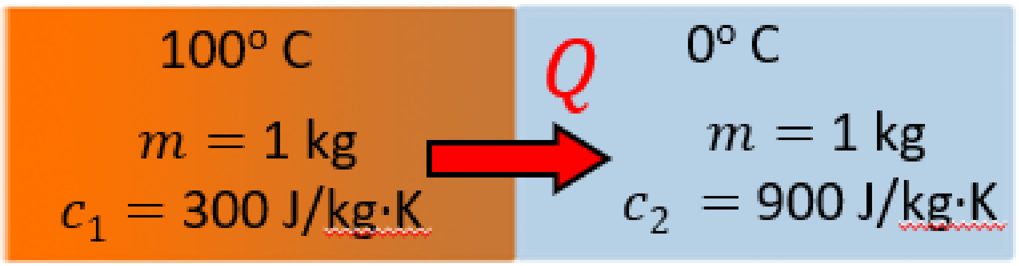
Energy conservation! Heat given off by 1st is equal to heat received by 2nd

$$Q_1 + Q_2 = 0$$

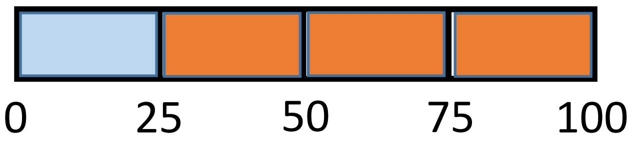
$$1200\,\frac{J}{K} \cdot T - 30{,}000\,J = 0 \quad \Rightarrow \quad T = 25^o C$$

$$\boxed{Q = m\,c\,\Delta T}$$

Same problem done very quickly



- Intuitively: c_2 is $3 \times c_1$, so same magnitude of heat will cause 1/3 of the temperature change
- 25° is 1/3 of 75° and these add to 100° C



- General solution for the final temperature:

$$\boxed{Q = m\, c\, \Delta T}$$

const ×3↑ ×3↓

$$T = \left(\frac{m_1 c_1}{m_1 c_1 + m_2 c_2}\right) T_1 + \left(\frac{m_2 c_2}{m_1 c_1 + m_2 c_2}\right) T_2$$

Weighted average of T_1 and T_2