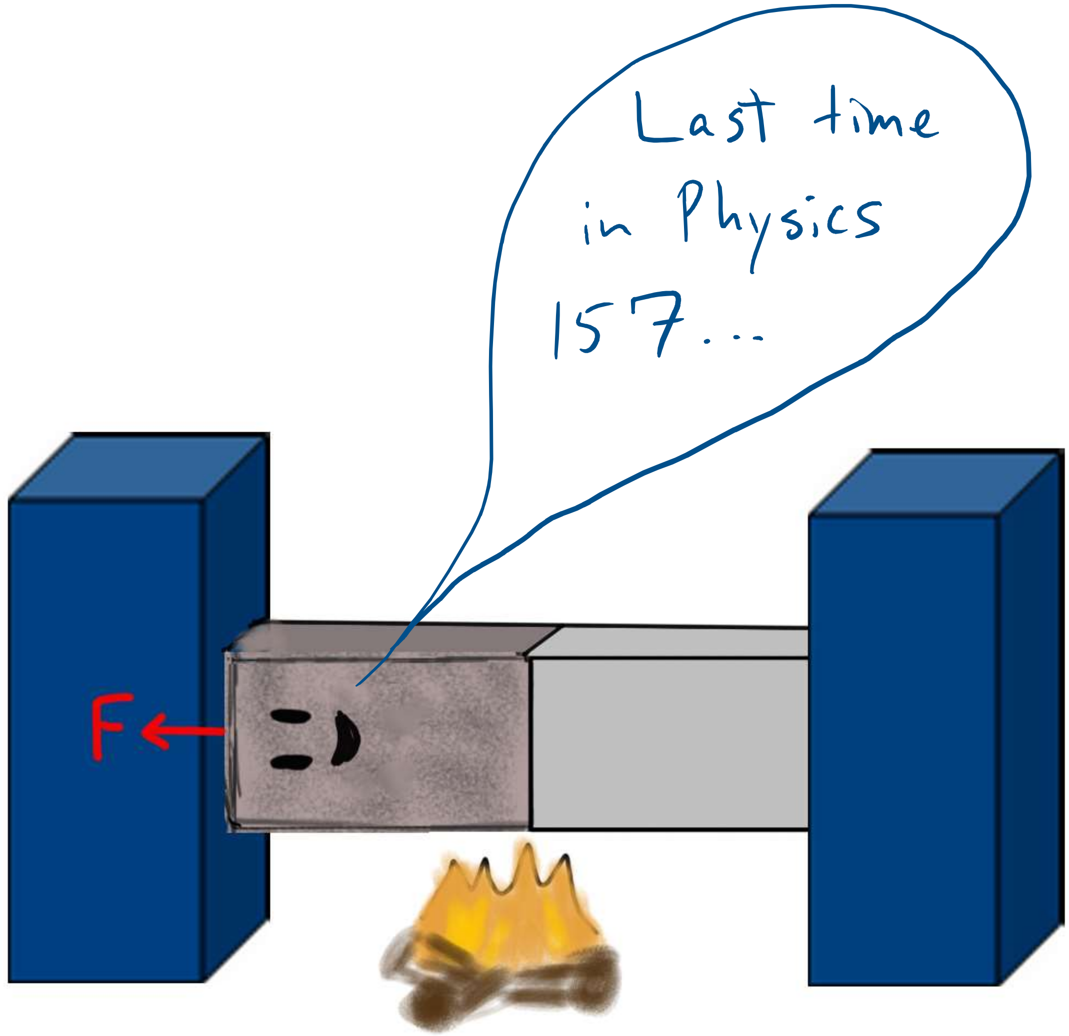
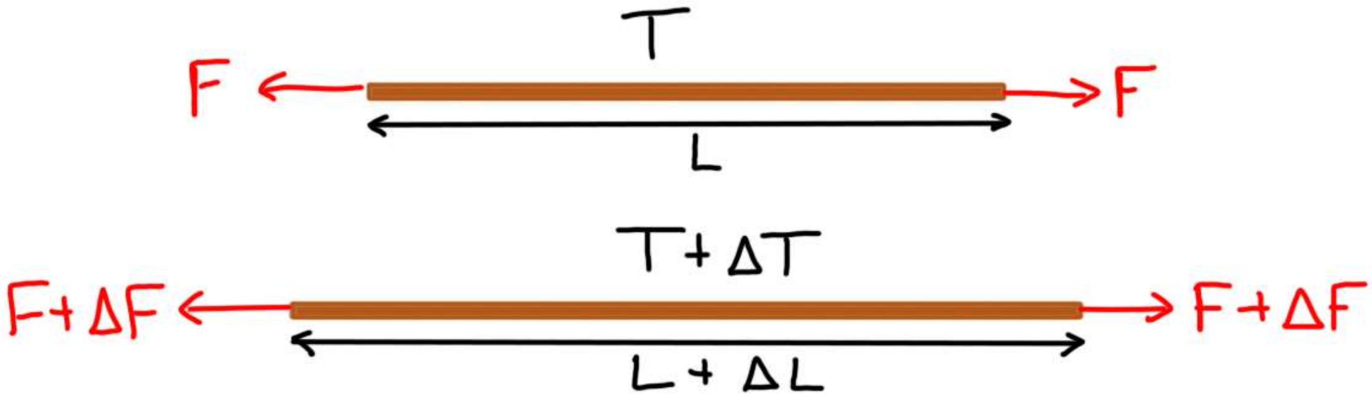
Learning Goals

- Identify the relation between stresses and changes of length for various parts of a multipart structure undergoing thermal expansion
- Explain what is meant by heat
- For objects of equal mass in thermal contact, to explain why the temperature changes of the two objects need not be the same when heat flows from one to the other
- Deduce the specific heat / heat capacity of a system of known mass from a graph of temperature vs energy added. Explain how this heat capacity is related to the slope of such a graph
- Provide a microscopic reason why certain materials have a larger molar specific heat than other materials



Last time in Physics 157...
F

NET CHANGE IN LENGTH



$$\Delta L = \Delta L_T + \Delta L_F$$

$$\Delta L_T = \alpha L \Delta T$$

from stress/strain formula

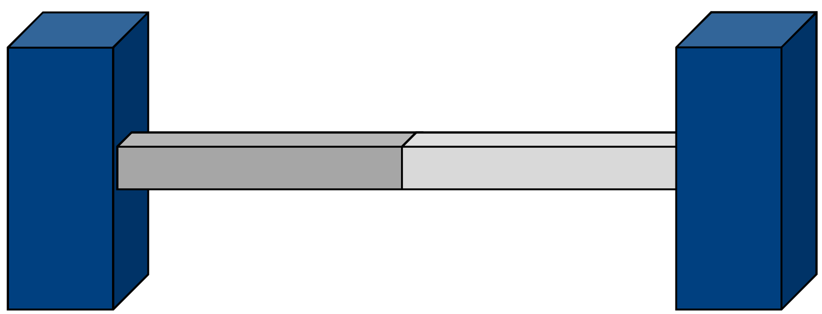
$$\Delta L_F = \frac{1}{Y} L \frac{\Delta F}{A}$$

This applies to each part of a system

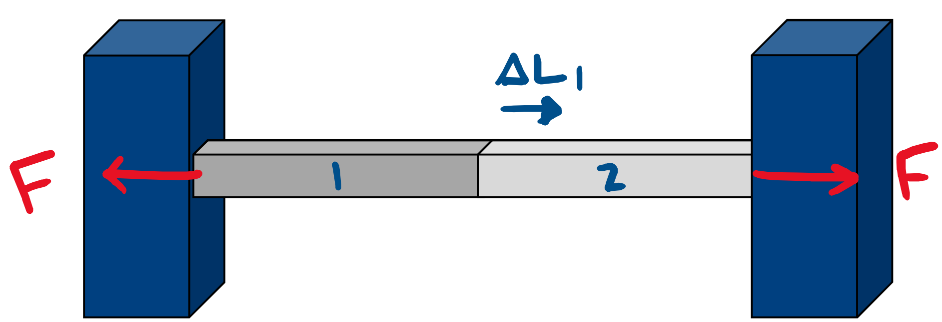
Stressed Rods

A compound bar consisting of a copper rod with a length of 1 m and cross-section area of 2.00 cm^2 placed end to end with a steel rod with length 1m and cross-section area 2.00 cm^2. The compound rod is placed between two rigid walls. Initially there is no stress in the bars at room temperature 20^o C.

Find the force on each wall at 40^o C.



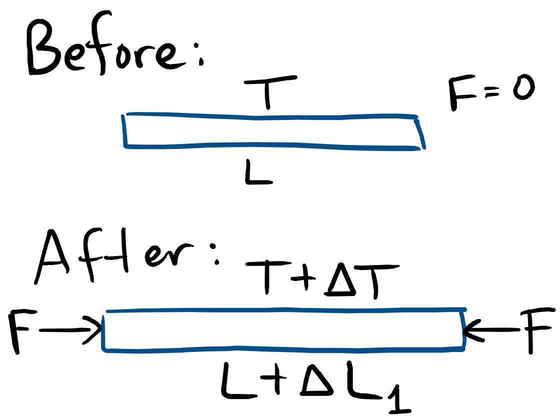
$\alpha_{steel} = 12 \times 10^{-6}\ K^{-1}$, $\alpha_{copper} = 17 \times 10^{-6}\ K^{-1}$,
$Y_{steel} = 200 \times 10^{9}\ N\ m^{-2}$, $Y_{copper} = 110 \times 10^{9}\ N\ m^{-2}$

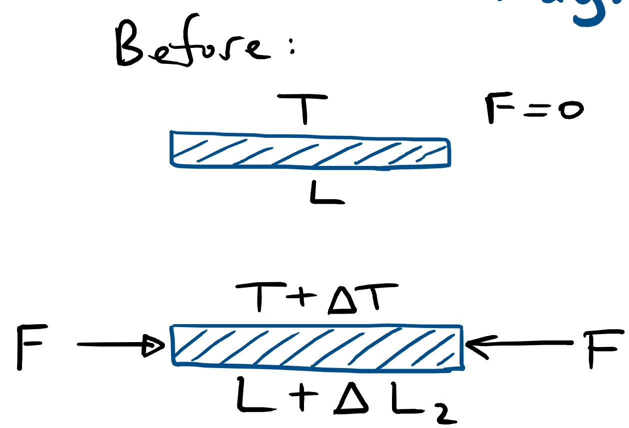


rigid ends:

$$\Delta L_1 + \Delta L_2 = 0$$

Newton's Laws: all forces have magnitude F





Length change from ΔT and ΔF for each part:

$$\Delta L_1 = \alpha_1 L \Delta T - \frac{F}{A} \cdot \frac{L}{Y_1}$$

$$\Delta L_2 = \alpha_2 L \Delta T - \frac{F}{A} \cdot \frac{L}{Y_2}$$

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

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

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

$$\Big\downarrow \text{ solve for } F$$

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

If you find it annoying to use your calculator...

web address

https://sagecell.sagemath.org

SageMathCell

type in your constants

Type some Sage code below and press Evaluate.

```
alpha1 = 12*10^(-6)
alpha2 = 17*10^(-6)
Y1 = 200*10^9
Y2 = 110*10^9
DT = [redacted]20
A = 2.0*10^(-4)
A*DT*(alpha1 + alpha2)/(1/Y1 + 1/Y2)
```

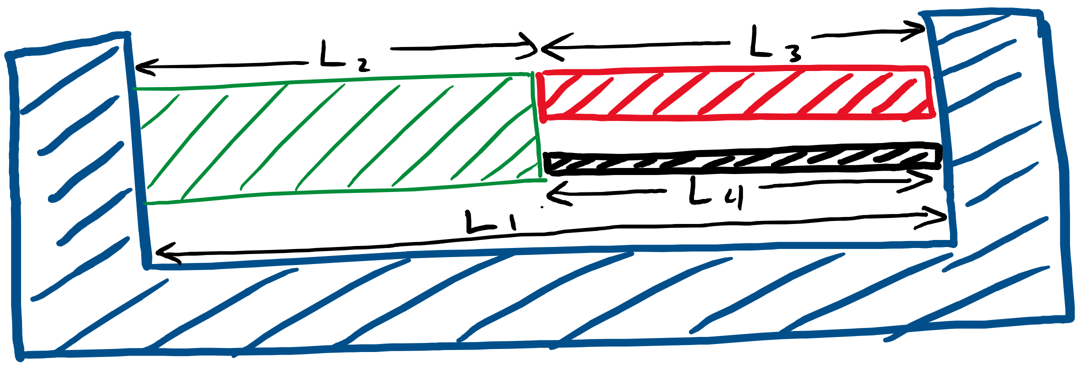
type in your formula

Evaluate

click

```
[redacted]8232.25806451613
```

answer

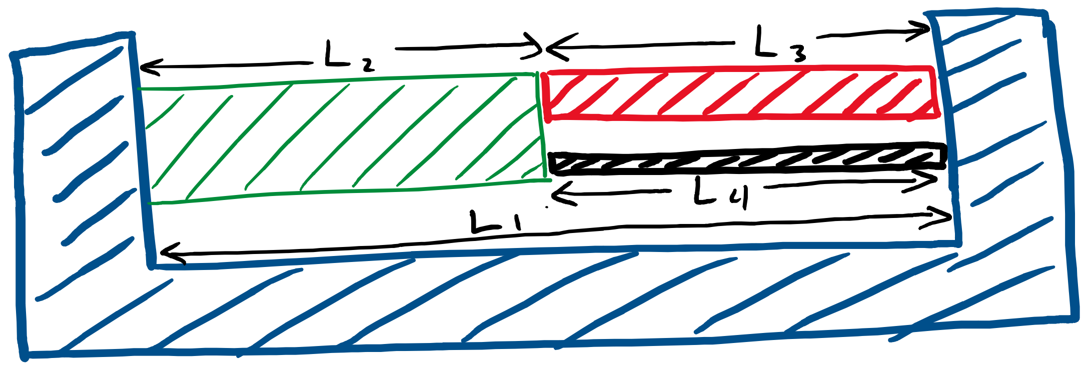


The structure shown has various parts all made of different materials.

1)If the system is heated, what constraints must be satisfied by the four quantities ΔL_1, ΔL_2, ΔL_3, and ΔL_4?

2) After heating, the green, red, and black objects have compressive forces F_2, F_3, and F_4 acting on their ends. What is the relation between the magnitude of these forces?

Click A if you are done number 1
Click B if you are done number 1 and 2
Click C if you are stuck



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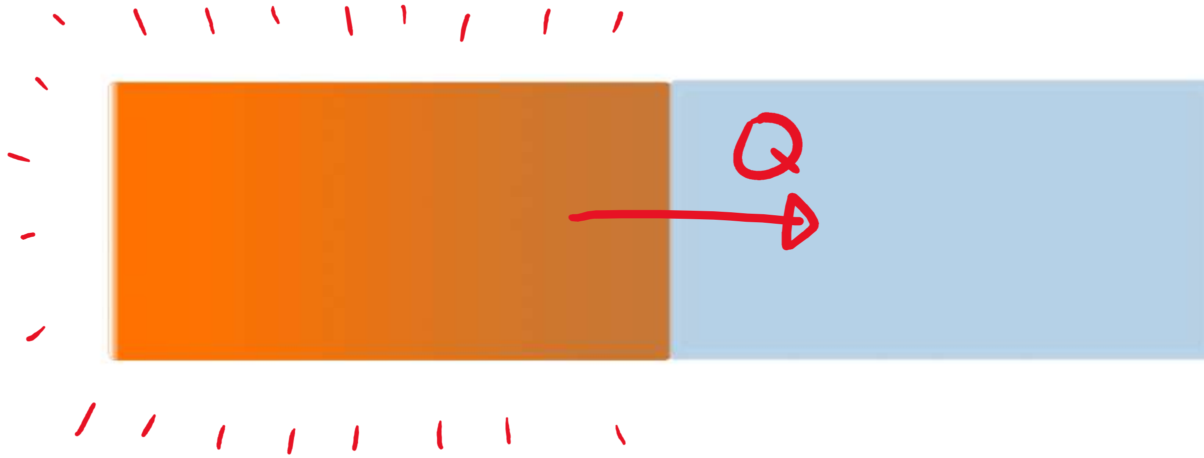
HEAT:



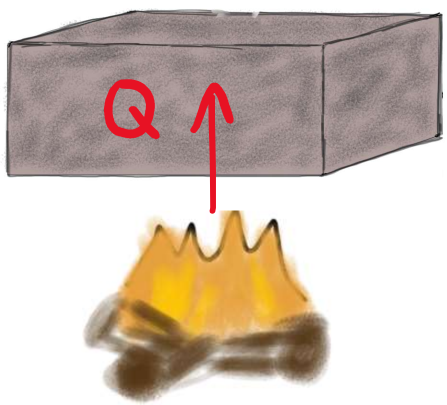
Q = heat : amount of energy transfered due to temperature differences

(Joules)

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

A) Somewhere between 0^{o}C and 100^{o}C but not necessarily 50^{o}C
B) 50^{o}C
C) Not necessarily between 0^{o}C and 100^{o}C

Heat required to raise the temperature of a material determined by its SPECIFIC HEAT c :



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

heat added

mass

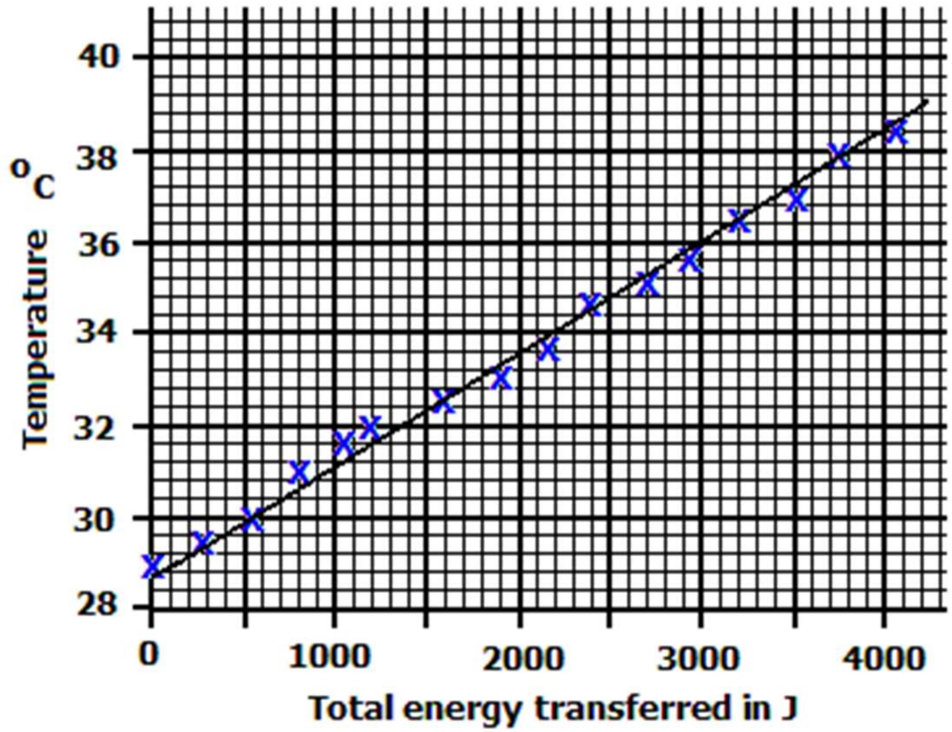
change in temperature

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

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.



EXTRA: what is the specific heat of the original liquid?

$$Q = mc\Delta T$$

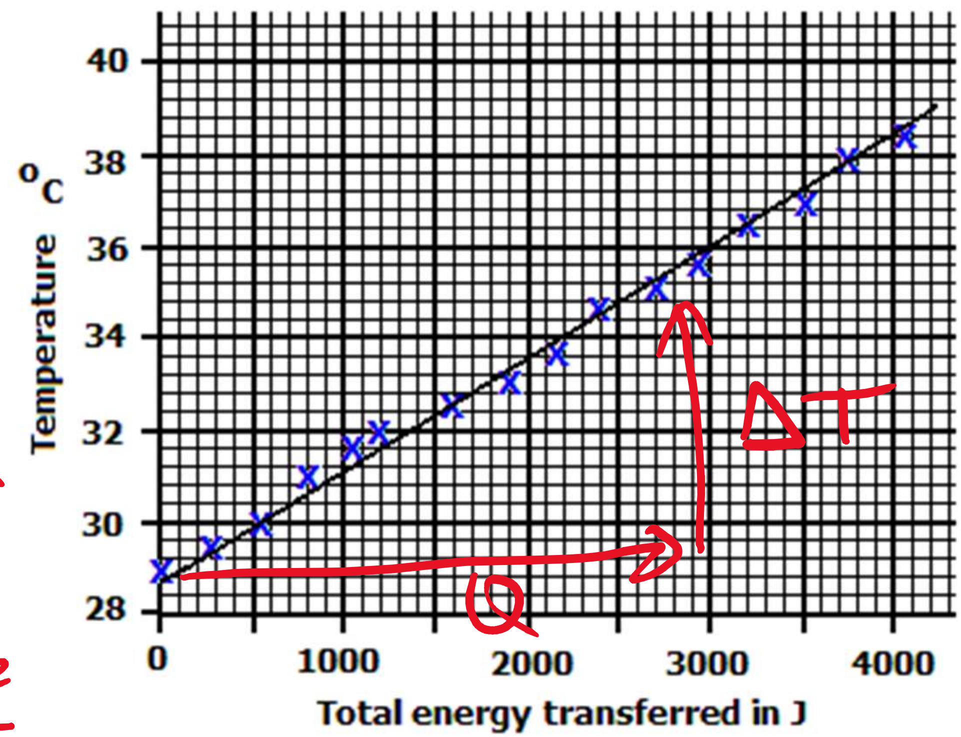
Heat is added to two kilograms of a liquid, and data for the temperature vs energy transfer is shown.

If we took data for another liquid with the same mass but a larger specific heat, the slope of this graph would be

Smaller ΔT for same Q

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

$\therefore$ smaller $\frac{\text{rise}}{\text{run}}$

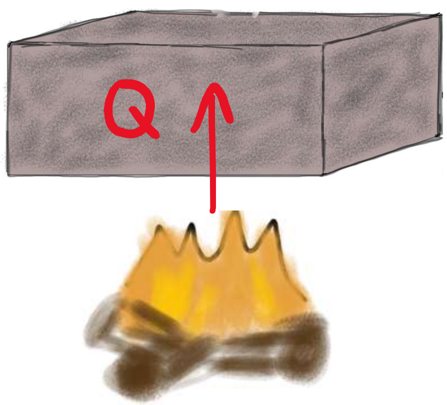


EXTRA: what is the specific heat of the original liquid?

$c \approx \frac{3000}{7.2} \approx 200$ J/kg K

$\boxed{Q = mc\,\Delta T}$

Heat required to raise the temperature of a material determined by its SPECIFIC HEAT c:



mass

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

OR:

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

moles

MOLAR SPECIFIC HEAT
= MOLAR HEAT CAPACITY

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

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

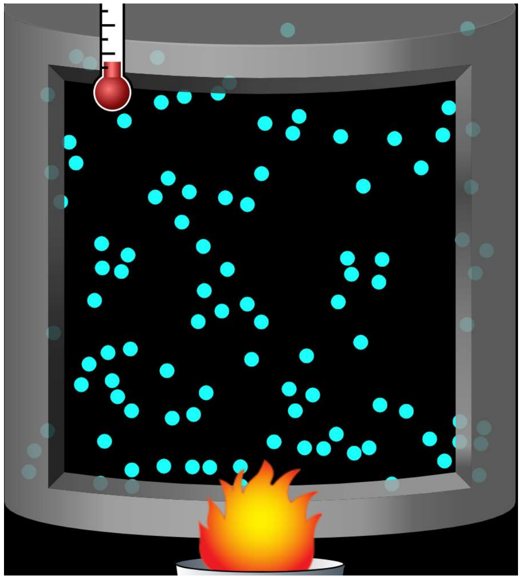
Specific heat values

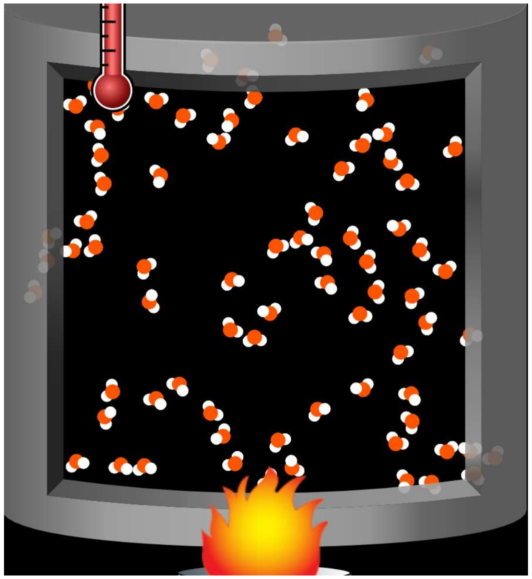
Table 17.3 Approximate Specific Heats and Molar Heat Capacities (Constant Pressure)

Substance	Specific Heat, c (J/kg · K)	Molar Mass, M (kg/mol)	Molar Heat Capacity, C (J/mol · 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 higher for some materials?

temperature proportional to average kinetic energy of molecules





for more complicated materials, part of added energy added goes to rotations/vibrations etc..., so it takes more Q to increase the kinetic energy.

From PHET: states of matter simulation, https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html