Clicker: If 0.2mm diameter nylon fishing line is good for catching fish up to 2kg, what thickness of line would you need to catch a 50kg fish?

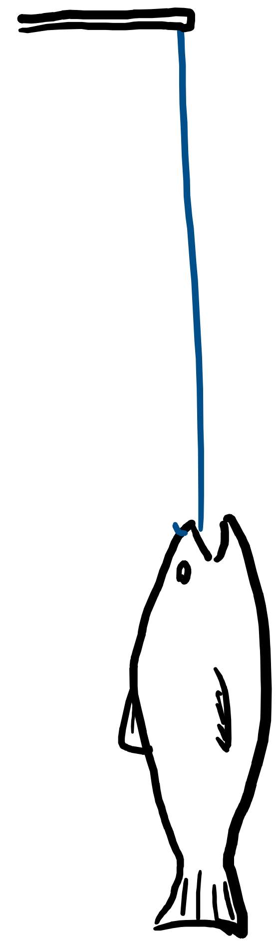
A) 0.5mm

B) 1mm

C) 2mm

D) 5mm

E) 300mm



EXTRA: By roughly how much would 1m of 0.2mm diameter line be stretched by a 2kg fish?

(Y_{nylon} = 3 GPa)

G = giga = 10^9

$$\boxed{\frac{F}{A} = Y\frac{\Delta L}{L_0}}$$

Clicker: If 0.2mm diameter nylon fishing line is good for catching fish up to 2kg, what thickness of line would you need to catch a 50kg fish?

F is 25x before
to get equivalent "safe" stretching,
need A 25x before
so diameter 5x before.

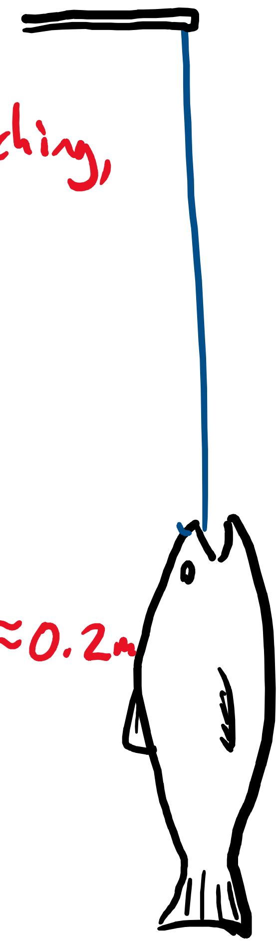
A) 0.5mm

B) 1mm

C) 2mm

D) 5mm

E) 300mm



$$\Delta L \approx \frac{1m}{3\times10^9}\cdot\frac{20N}{\pi\cdot(10^{-4}m)^2} \approx 0.2m$$

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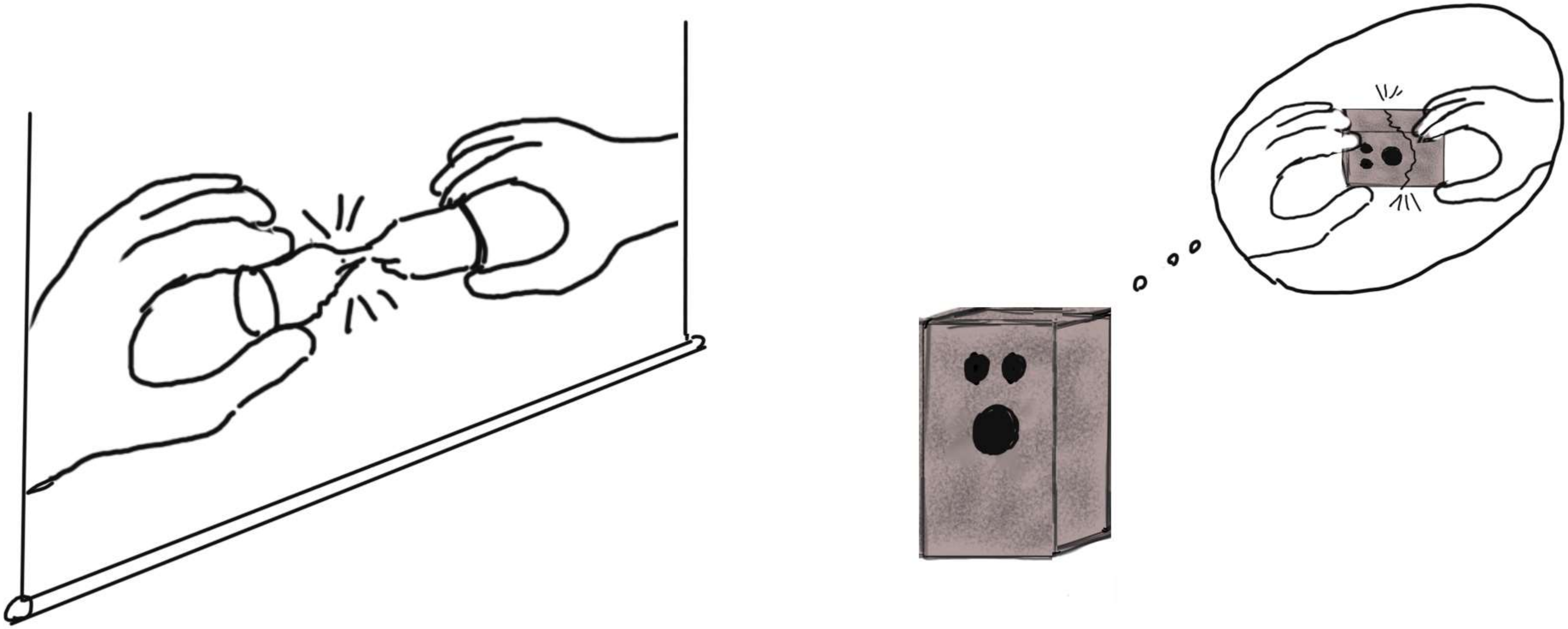


Last time in
physics 157...

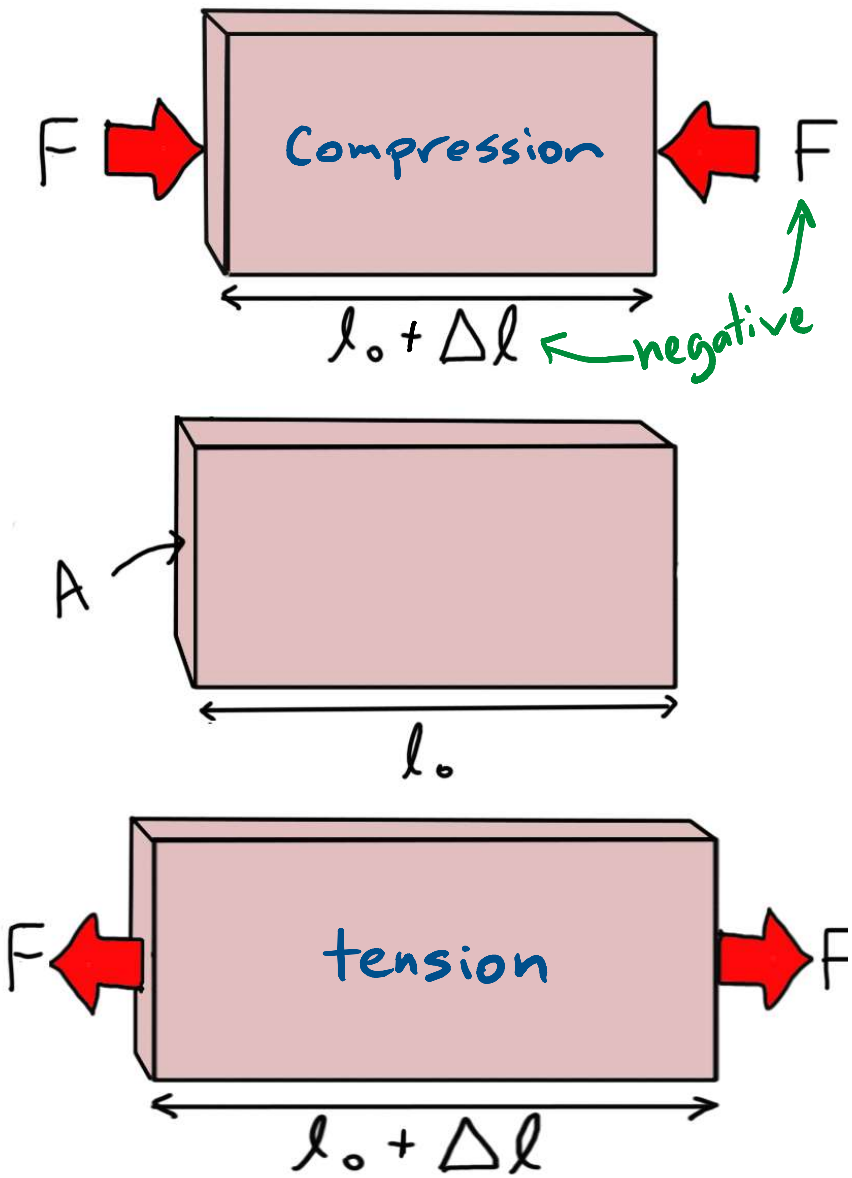
Stress & Strain

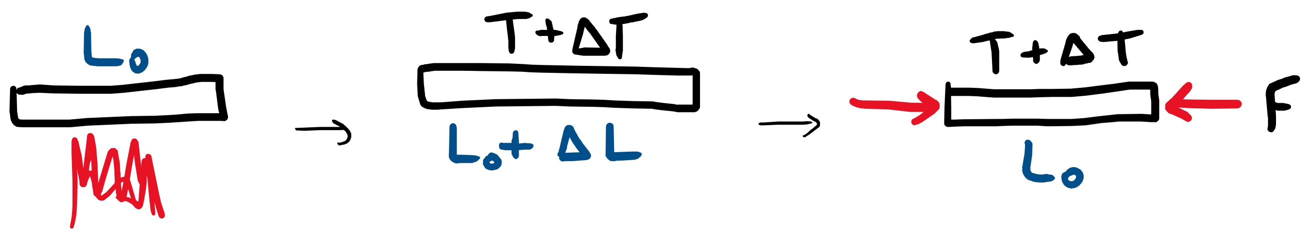
$$\frac{F}{A} = Y \frac{\Delta \ell}{\ell_0}$$

sign of F:

- positive for tension
  ||
  pulling

- negative for compression
  ||
  pushing





A steel rod of length L_0 is heated by temperature ΔT.

How much stress (force per unit area) is required to compress the rod back to its original length?

Write an answer in terms of ΔT and the parameters Y, α, L_0 for the rod.

Click A if you have an answer, B if you are stuck.

thermal expansion:

$$\boxed{\Delta L = \alpha L_0 \Delta T}$$

stress vs strain:

$$\boxed{\frac{F}{A} = Y \frac{\Delta L}{L_0}}$$

A steel rod of length L_0 is heated by temperature ΔT and expands. How much stress (force per unit area) is required to compress the rod back to its original length?

Write an answer for the magnitude of F/A in terms of Y, α, L_0, and ΔT.

A) $Y \alpha L_0 \Delta T$

B) $Y \alpha \Delta T$

C) $Y L_0 \Delta T$

D) $\alpha L_0 \Delta T$

E) $Y \alpha L_0$

A steel rod of length L_0 is heated by temperature ΔT and expands. How much stress (force per unit area) is required to compress the rod back to its original length?

Write an answer in terms of Y, α, L_0, and ΔT.

A) $Y \alpha L_0 \Delta T$

$\boxed{\text{B) } Y \alpha \Delta T}$

C) $Y L_0 \Delta T$

D) $\alpha L_0 \Delta T$

E) $Y \alpha L_0$

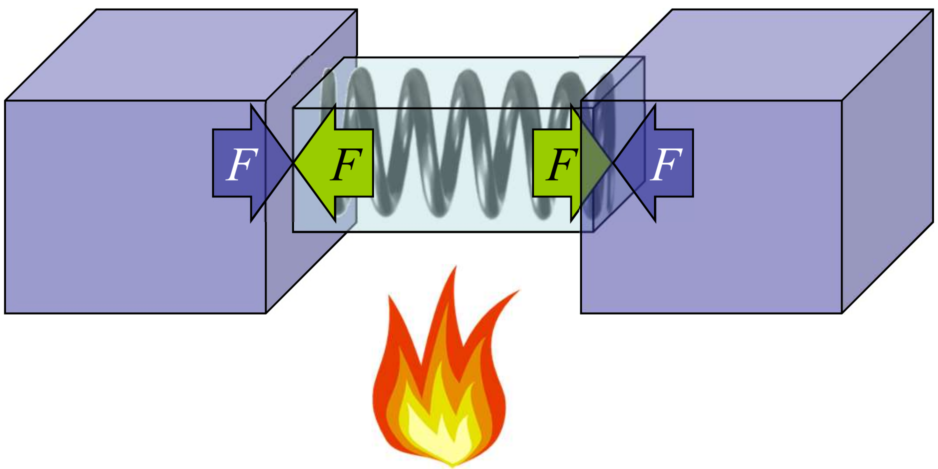
Change in length under heating is:

$$\Delta L = \alpha L_0 \Delta T$$

To reverse this change, need $\frac{F}{A} = Y \cdot \frac{\Delta L}{L_0}$

$$\Rightarrow \frac{F}{A} = Y \cdot \alpha \cdot \Delta T$$

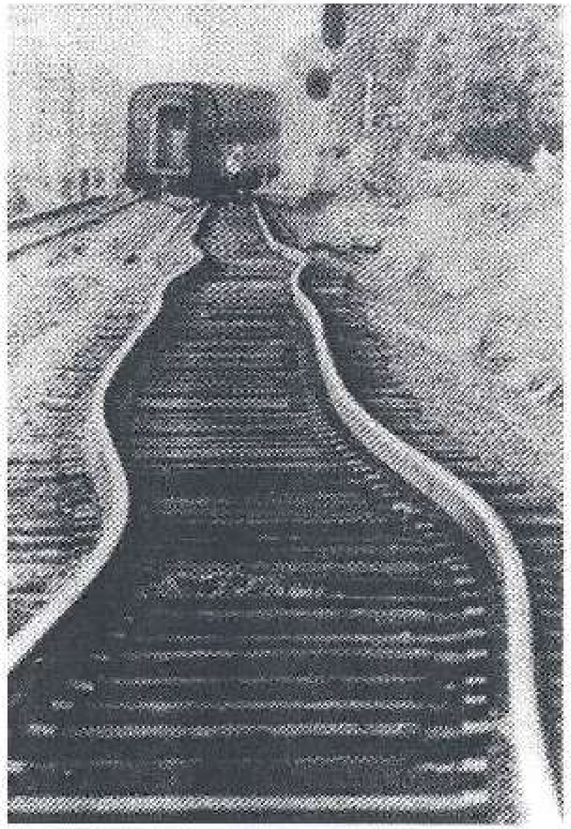
THERMAL STRESS : forces on a material preventing expansion/contraction due to heating/cooling



$$\frac{F}{A} = -Y\alpha\,\Delta T$$

stress on material (compression for ΔT +ve)

* assumes zero change in length *



Clicker: 10m long steel train rails are laid end to end on a winter day (0 ºC). If the engineer forgot to leave gaps for thermal expansion, roughly how much force is generated at the ends of each rail due to thermal stress when the temperature reaches 30 ºC?

Cross sectional area of rail: 0.01m²

$Y_{steel} = 20 \times 10^{10}\ Pa$

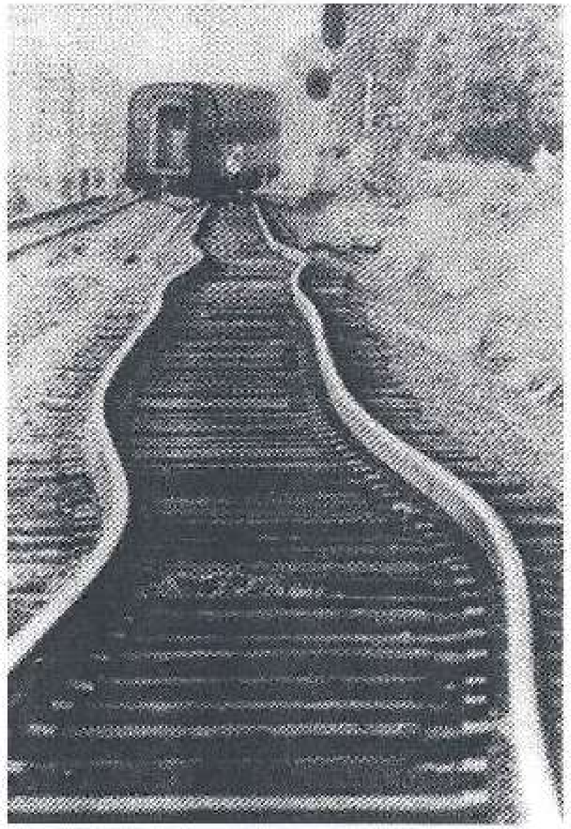
$\alpha_{steel} = 1.2 \times 10^{-5}\ K^{-1}$

A) 700 N B) 7,000 N C) 70,000 N

D) 700,000 N E) 7,000,000 N

$$\boxed{\frac{F}{A} = -Y\alpha\,\Delta T}$$

EXTRA: How much gap should have been left?



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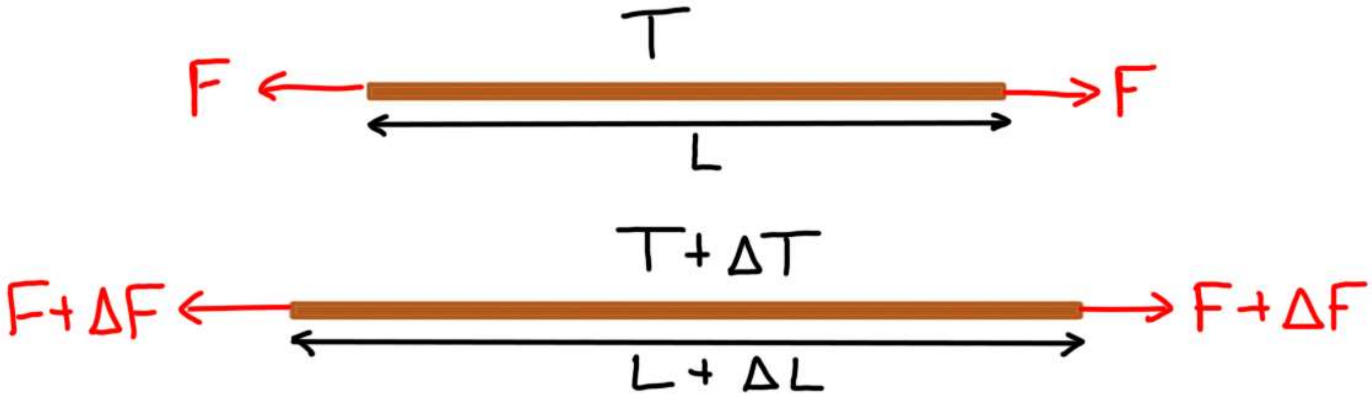
$$\boxed{\frac{F}{A} = -Y\alpha\,\Delta T}$$

$F \approx 10^{-2} \times 2\times10^{11} \times 1.2\times10^{-5} \times 30 \approx 7\times10^{5}$

EXTRA: How much gap should have been left? $\Delta L = \alpha L_0 \Delta T \approx 3.6\ mm$


fully loaded
Boeing 737
AIR CANADA
rail



Clicker: a copper wire under a tension force of F and at temperature T initially has a length L. If we heat up the wire by ΔT and also change the tension force by ΔF, by how much does the length of the wire change?

Hint: treat the change in length from thermal expansion and the change in length from the force increase separately

Clicker: a copper wire under a tension force of F and at temperature T initially has a length L. If we heat up the wire by ΔT and also change the tension force by ΔF, by how much does the length of the wire change?

Thermal expansion:

$$(\Delta L)_T = \alpha L \Delta T$$

Mechanical stretching:

$$\frac{\Delta F}{A} = Y \frac{(\Delta L)_F}{L} \Rightarrow \Delta L_F = \frac{\Delta F}{A} \cdot \frac{L}{Y}$$

Total expansion:

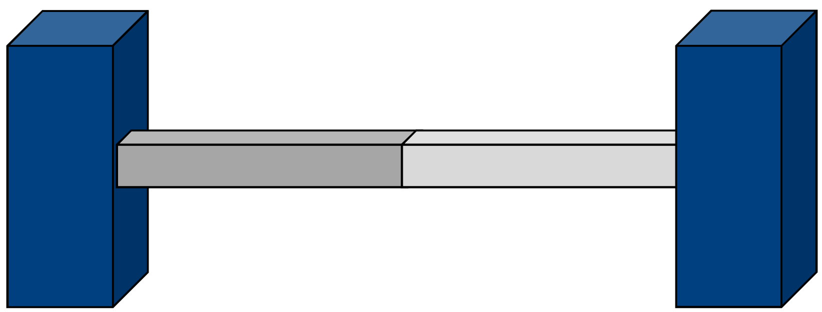
$$\boxed{\begin{aligned} \Delta L &= (\Delta L)_T + (\Delta L)_F \\ \Rightarrow \Delta L &= \alpha L \Delta T + \frac{L}{Y} \cdot \frac{\Delta F}{A} \end{aligned}}$$

A harder problem:

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° C.

Find the force on each wall at 40° C.



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

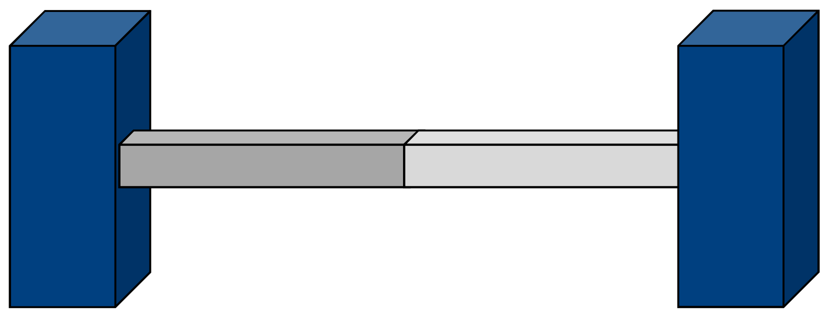
STEP 1 : visualize what will happen. Draw a before/after picture. Give names to known + unknown quantities + label diagram. Understand which quantities are changing and which quantities are fixed.

Clicker: As the system is heated, we expect that

A) Both rods will increase in length

B) Both rods will stay the same length

C) One rod will get longer and the other rod will get shorter



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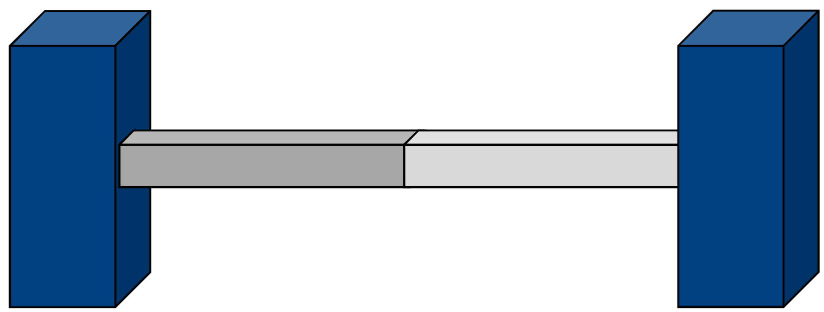
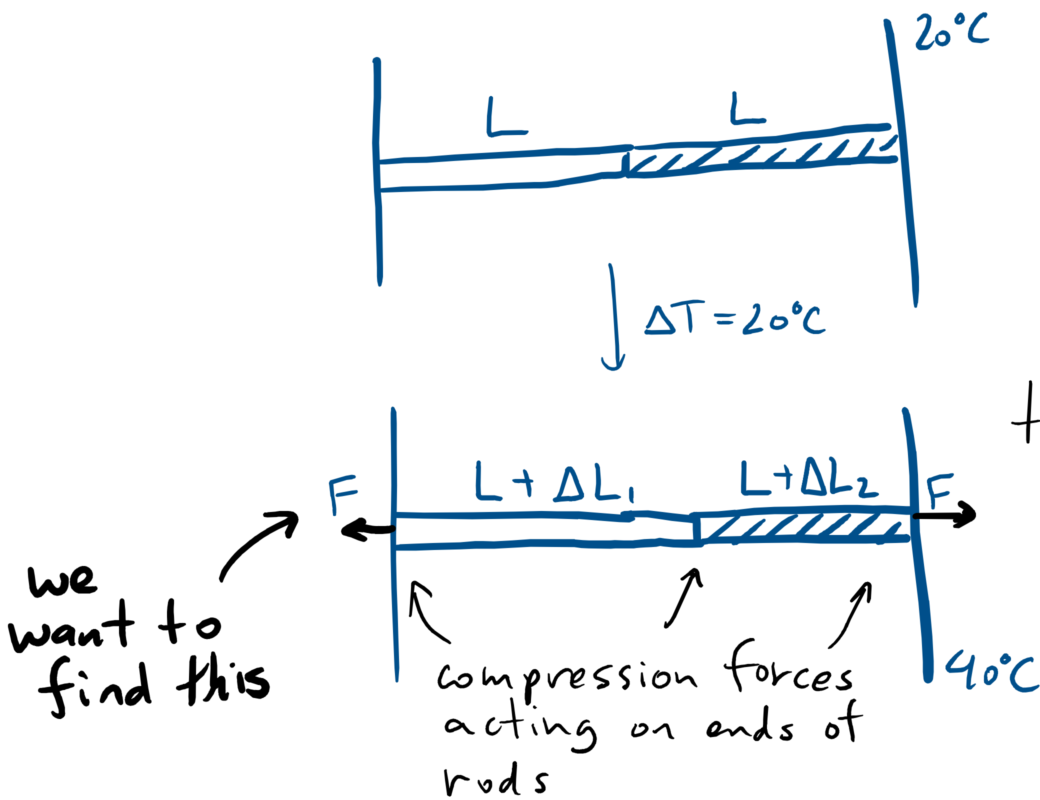


rigid walls, so
B or C

but different
materials so
will likely
change relative
length

STEP 1: visualize what will happen. Draw a before/after picture. Give names to known + unknown quantities + label diagram. Understand which quantities are changing and which quantities are fixed.



total length is fixed

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

STEP 2: Isolate the parts of the system. For each part, draw before/after free body diagrams making use of Newton's Laws to relate forces.

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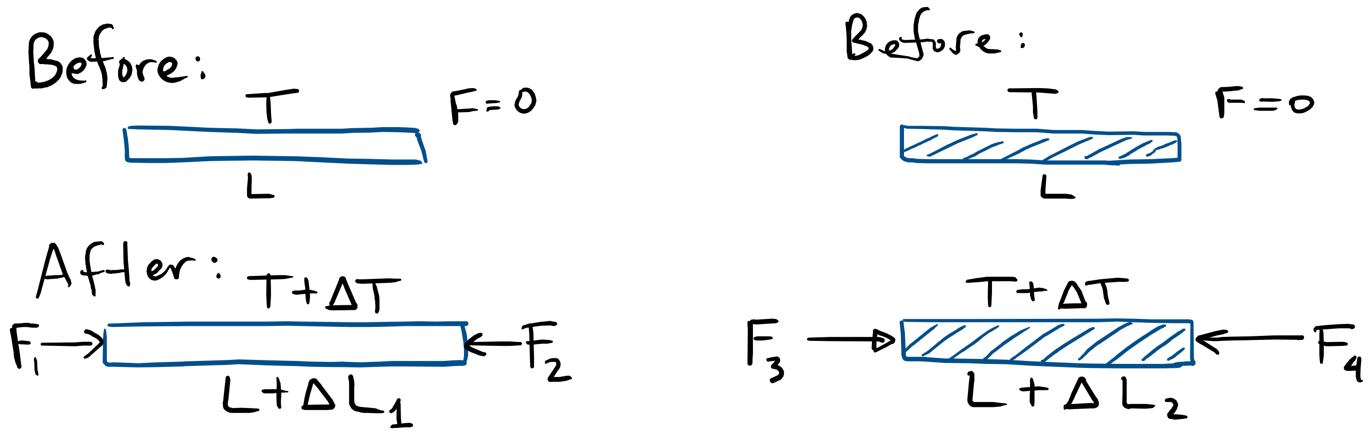
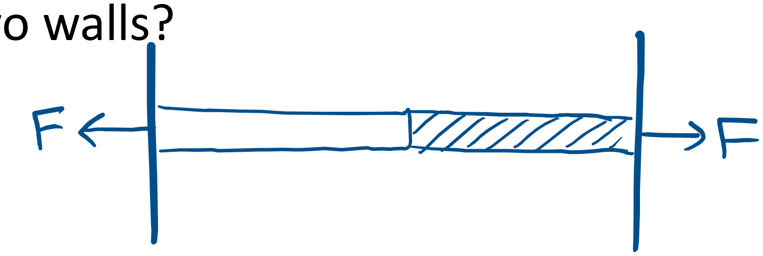


Question: What are F_1, F_2, F_3 and F_4 in terms of F, the magnitude of the forces on the two walls?



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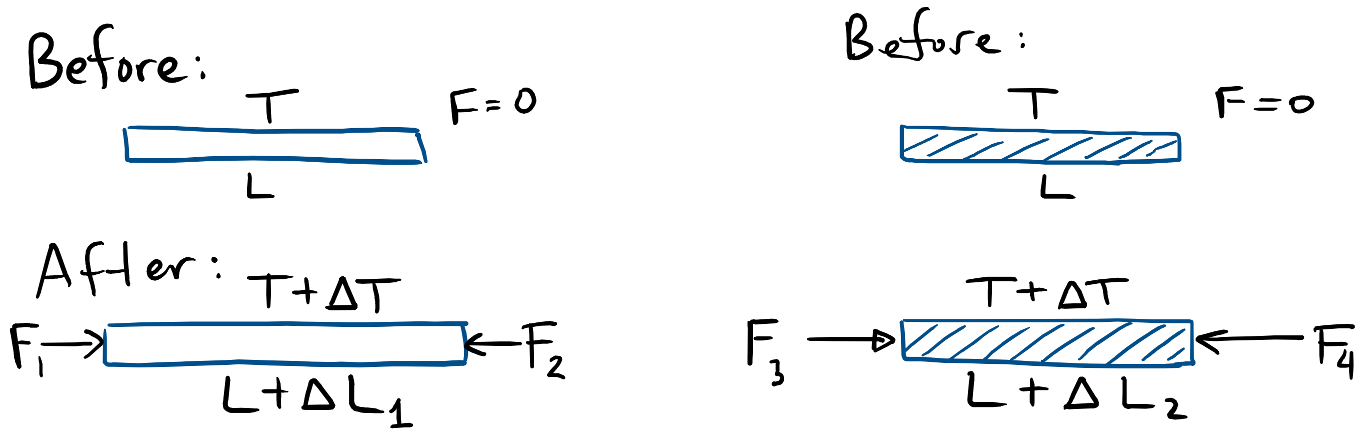

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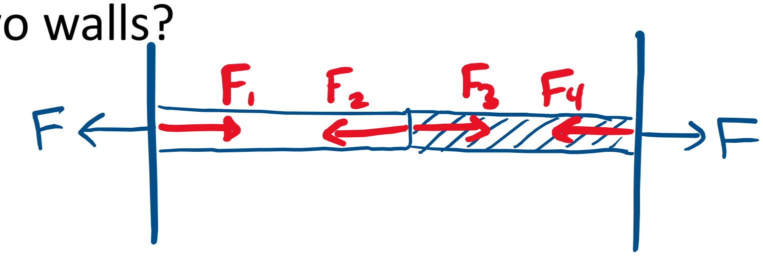


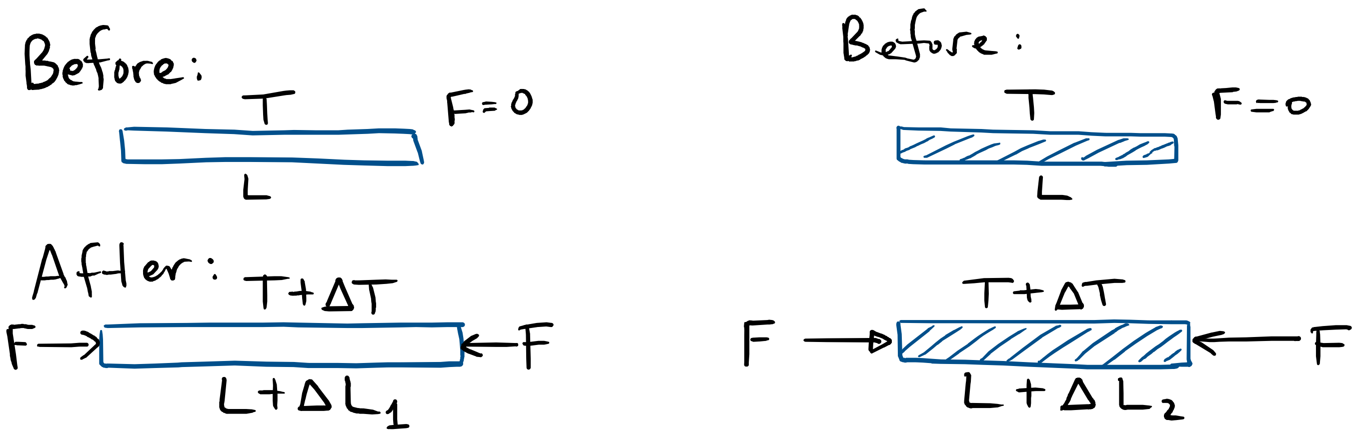
$F_1 = F$: Newton's 3rd.

$F_2 = F_1$: left bar not accelerating

$F_3 = F_2$: Newton's 3rd

$F_4 = F_3$: right bar not accelerating

STEP 3: For each part, write an equation relating the change in length to the changes in temperature and forces.



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

$$\Delta L_2 = \alpha_1 L \Delta T - \frac{F}{A} \cdot \frac{L}{Y_2}$$

check that signs make sense with our interpretation of F as a positive number

STEP 4: collect equations + solve for unknowns

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

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

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

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:

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

Solve:

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