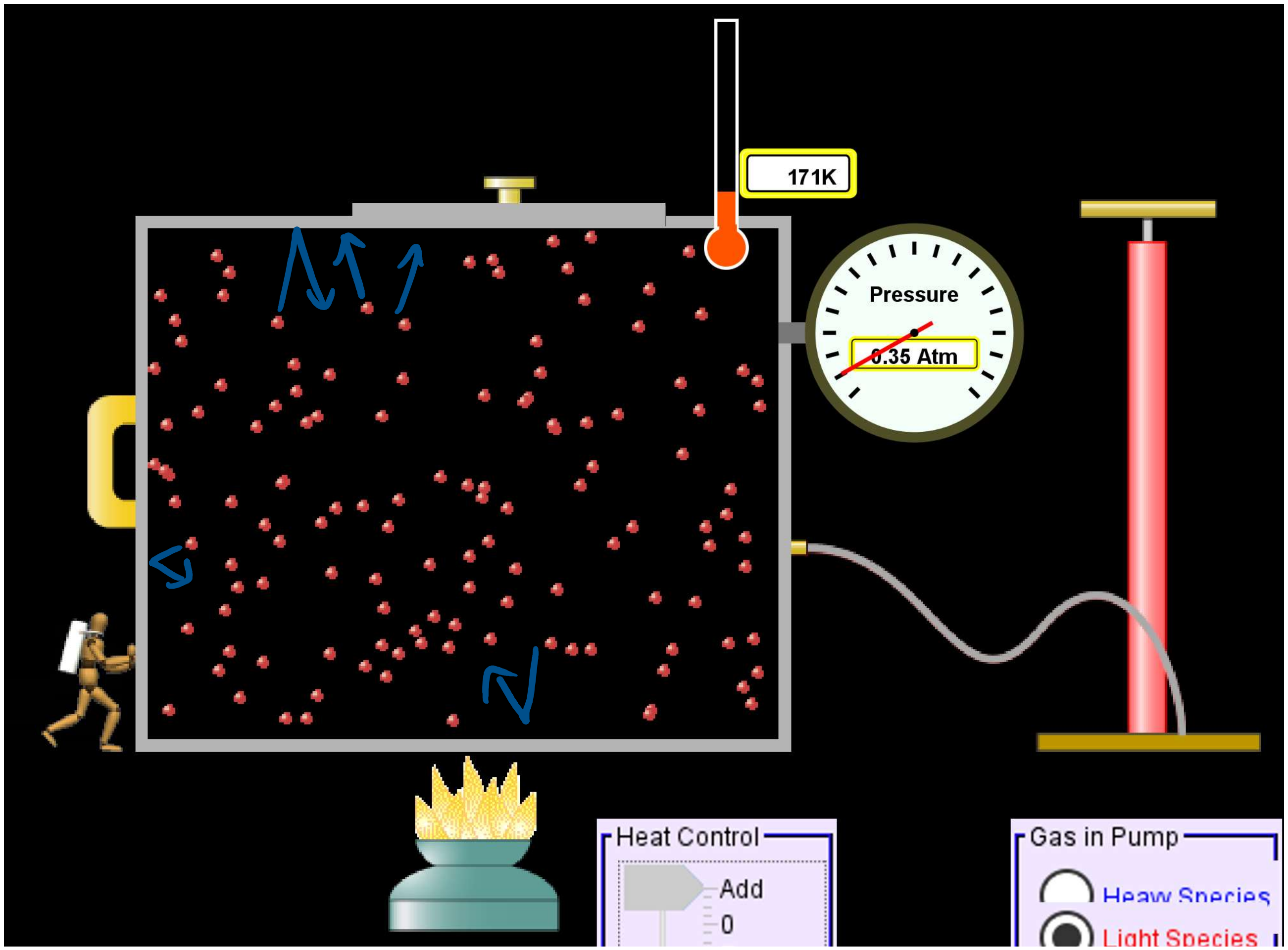
Learning Goals

- Explain how the Kelvin scale is defined
- Describe the difference between a linear relationship and a proportional relationship
- Explain why different thermometers might be more appropriate in different situations (e.g. to measure the temperature of a small volume of liquid)
- Convert between Kelvin and Celsius temperatures
- Calculate the pressure in a constant volume gas thermometer at some temperature given the pressure at another temperature. Calculate the temperature given the pressure of an ideal gas thermometer and the pressure at some other temperature
- For an object made of some material, to calculate the changes in length that object undergoes in response to changes in temperature, given the initial length and thermal expansion coefficient

Simulation of an ideal gas: pressure is from the molecules hitting the wall!



As we heat the gas, the molecules move faster so pressure increases.

Gas properties PHET from U. Colorado

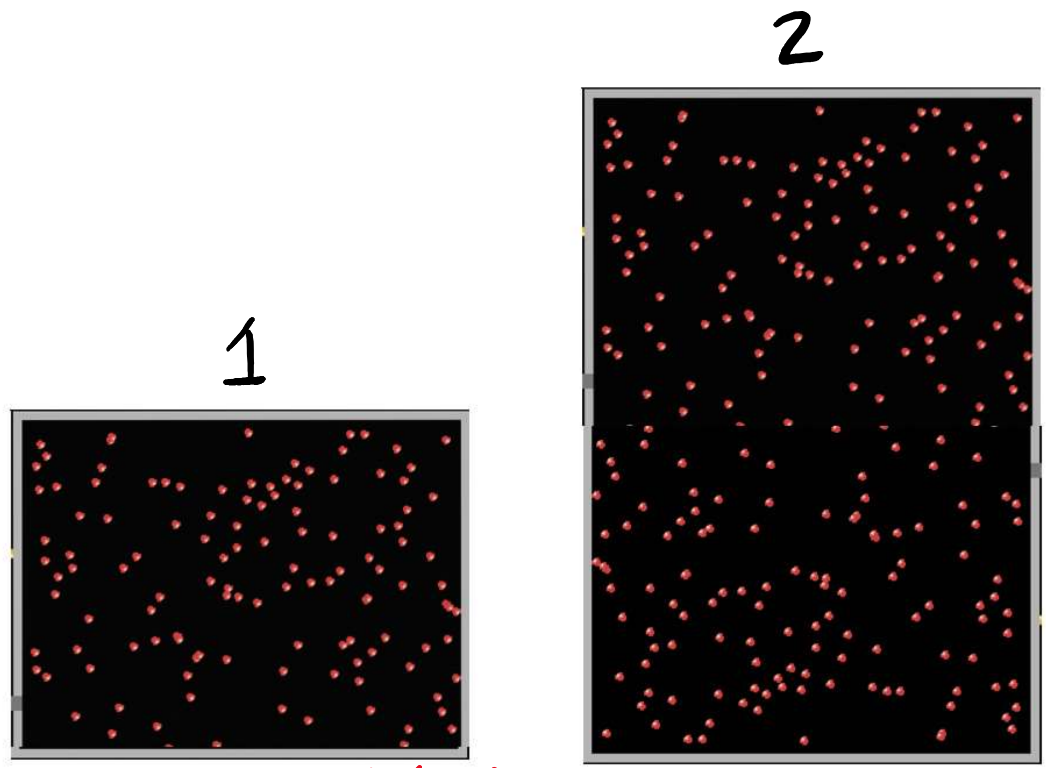
Clicker question: In the picture below, box 2 is twice the height as box 1, with twice the number of molecules, moving at the same average speed. Compared to the pressure on the left wall of box 1, the pressure on the left wall in box 2 will be

A) the same.

B) half.

C) double.

D) None of the above.



EXTRA: if we double the average speed of the molecules, give TWO reasons why pressure would increase.

$$P = \frac{F}{A}$$

Clicker question: In the picture below, box 2 is twice the height as box 1, with twice the number of molecules, moving at the same average speed. Compared to the pressure on the left wall of box 1, the pressure on the left wall in box 2 will be

A) the same.

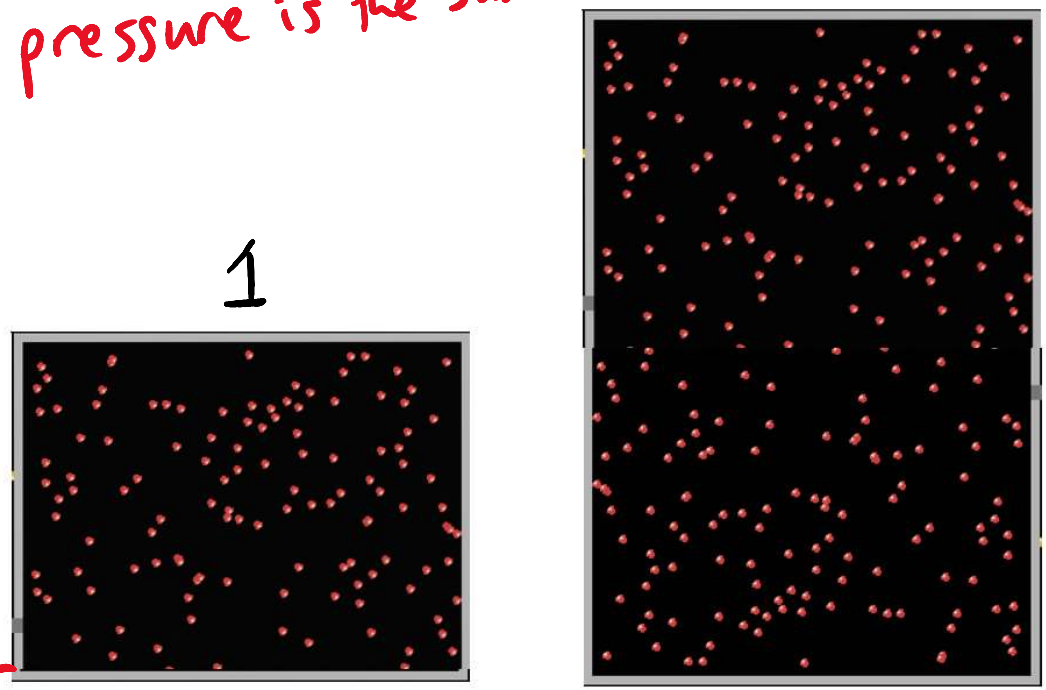
Force is double, but area is also double, so pressure is the same

B) half.

C) double.

D) None of the above.

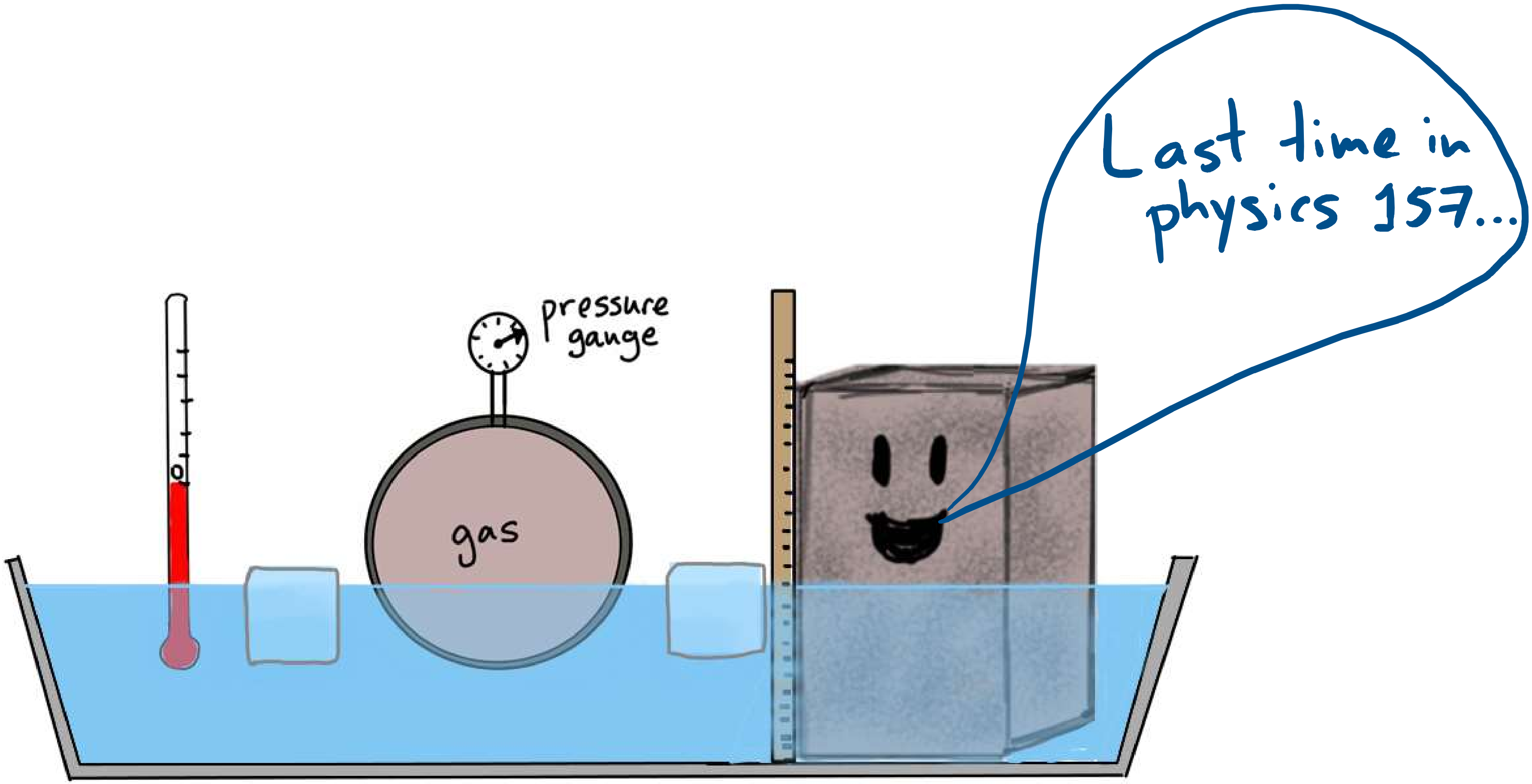
1 2



EXTRA: faster molecules

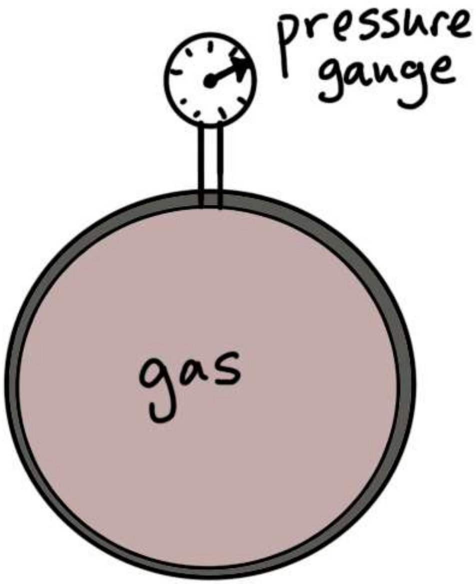
more frequent collisions

more impact per collision



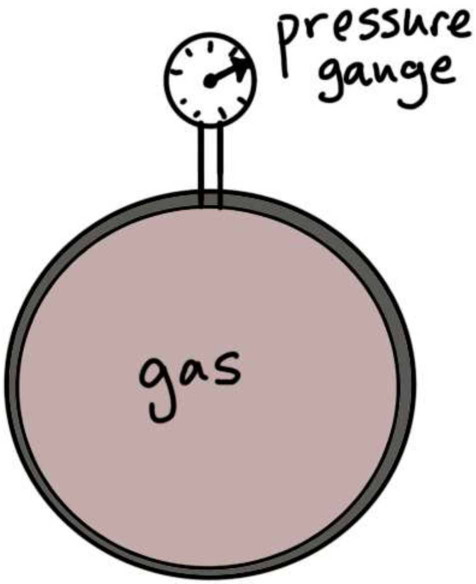
pressure gauge
gas
0
Last time in physics 157...

Defining temperature using constant volume gas thermometer



P = Force on walls per unit area

constant volume gas thermometer:



constant
volume
gas thermometer:

Define Kelvin scale by:

$$T = \text{const.} \times P$$

depends on
particular thermometer

will discuss calibration
later

pressure

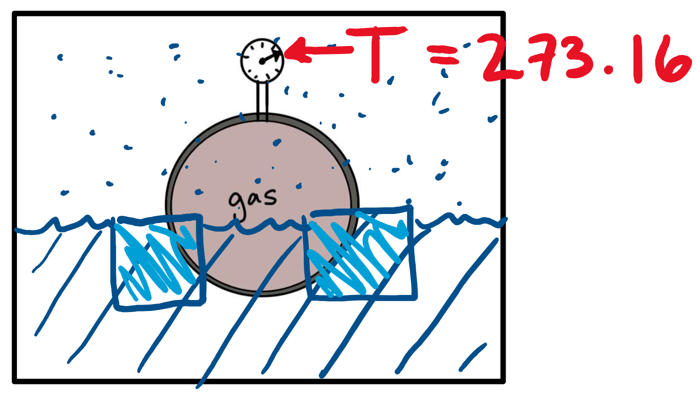
Define Kelvin scale by:

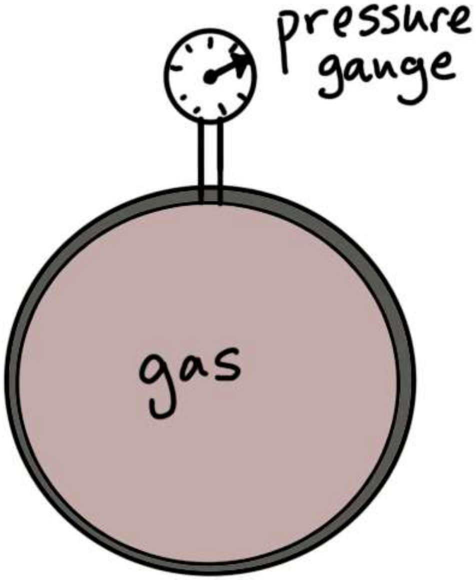
$$T = \underbrace{\text{const.}}_{\text{depends on particular thermometer}} \times \underbrace{P}_{\text{pressure}}$$

and

$$T = 273.16\,\text{K}$$

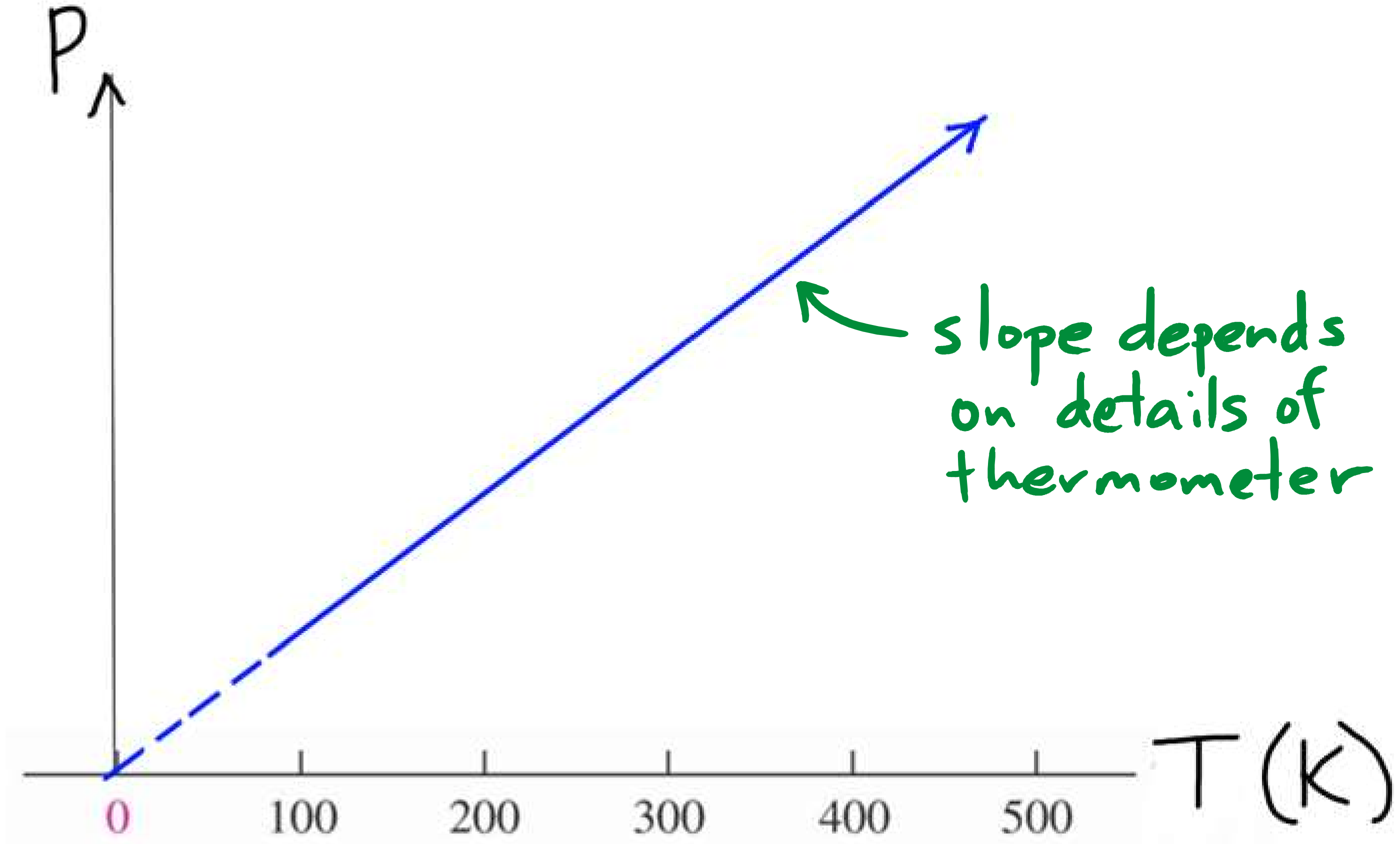
at triple point of water





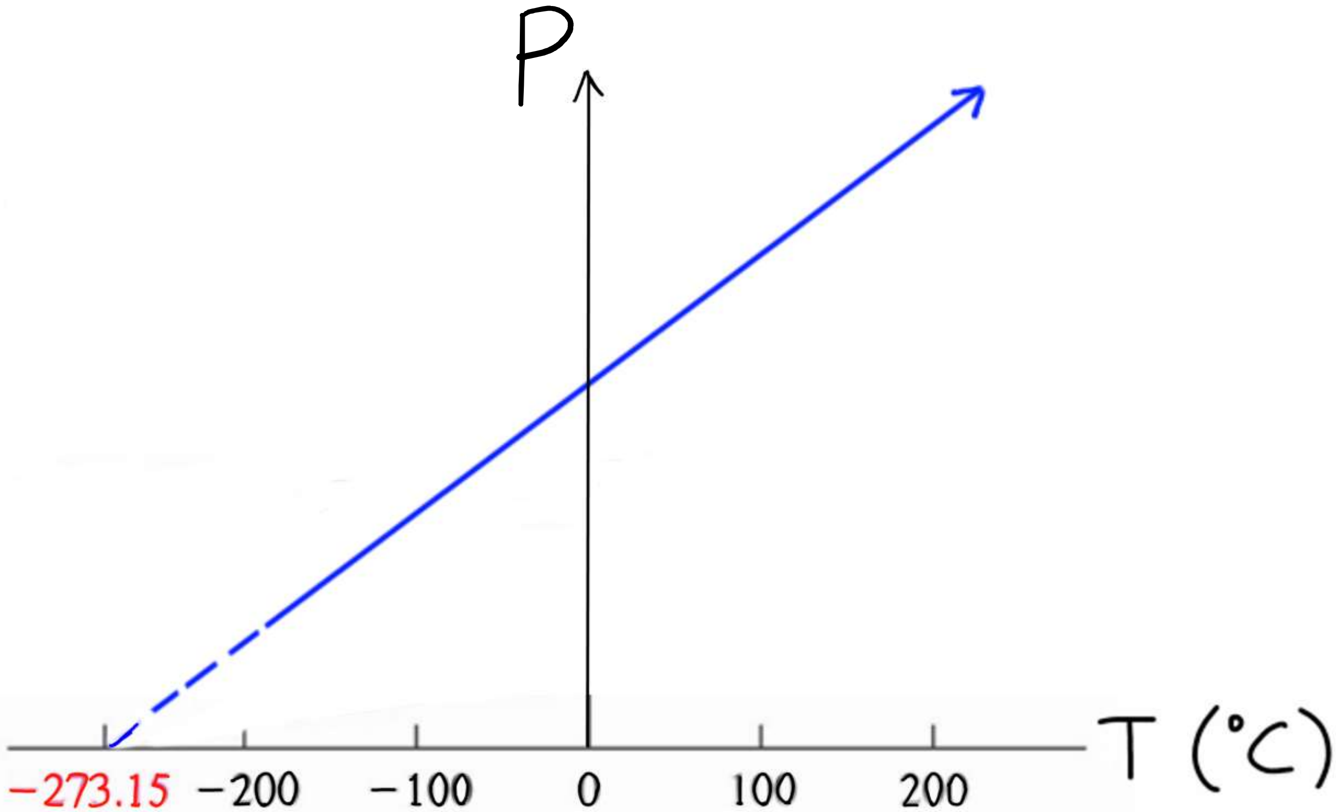
constant volume gas thermometer:

Pressure vs Kelvin temperature for constant volume gas thermometers



Kelvin scale: P is PROPORTIONAL to T : $P = m \cdot T$

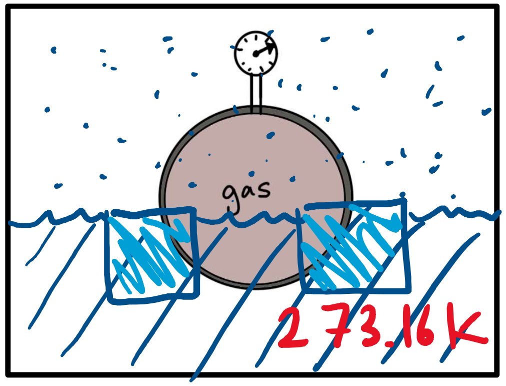
Pressure vs Celcius temperature for constant volume gas thermometers



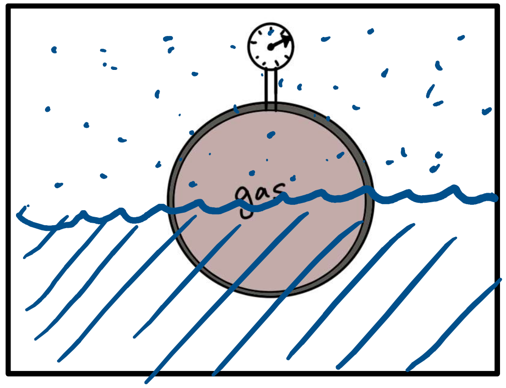
Celcius scale: P is LINEAR in T_c $\quad P = mT_c + b$

$$\star \; T_K = T_c + 273.15 \; \star$$

Clicker question: An ideal gas thermometer is calibrated by placing it in equilibrium with water at its triple point. The pressure reads 50kPa. The same thermometer is placed in equilibrium with another container of water. If the pressure reads 100kPa, we can say that the temperature of the water is



A) 136.58K
B) 273.16K
C) 546.32K
D) 373.00K
E) We need to know the constant of proportionality between T and P to answer this.



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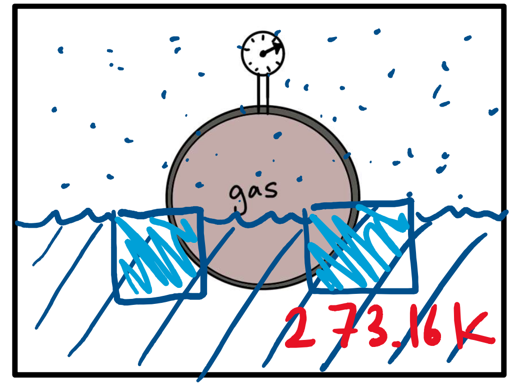


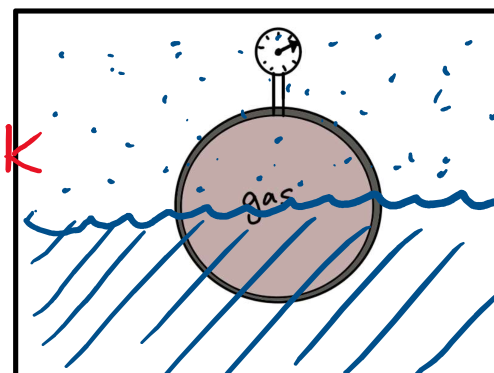
A) 136.58K
B) 273.16K
C) 546.32K
D) 373.00K
E) We need to know the constant of proportionality between T and P to answer this.

$T = \text{const} \times P$

these are equivalent ways to state that T is proportional to P

means $\frac{T_2}{T_1} = \frac{P_2}{P_1} = 2$

so $T_2 = 2 \cdot 273.16\text{K} = 546.32\text{K}$



if $T = c \cdot P$ then:

$T_1 = cP_1 \quad T_2 = cP_2 \quad \text{so } \frac{T_1}{T_2} = \frac{P_1}{P_2}$

Clicker: A $0.010 m^3$ rigid container of gas has a pressure of 1.0kPa at 20.0ºC. The pressure at 120.0ºC is closest to:

A. 0.2 kPa
B. 1.3 kPa
C. 3.0 kPa
D. 6.0 kPa
E. There is not enough information to answer.

$$T_{\text{Celcius}} \text{ defined as } T_{\text{Kelvin}} + 273.15$$

$$T_{\text{Fahrenheit}} \text{ defined as } \frac{9}{5} T_{\text{Celcius}} + 32$$

Clicker: A $0.010m^3$ rigid container of gas has a pressure of 1.0kPa at 20.0ºC. The pressure at 120.0ºC is closest to:

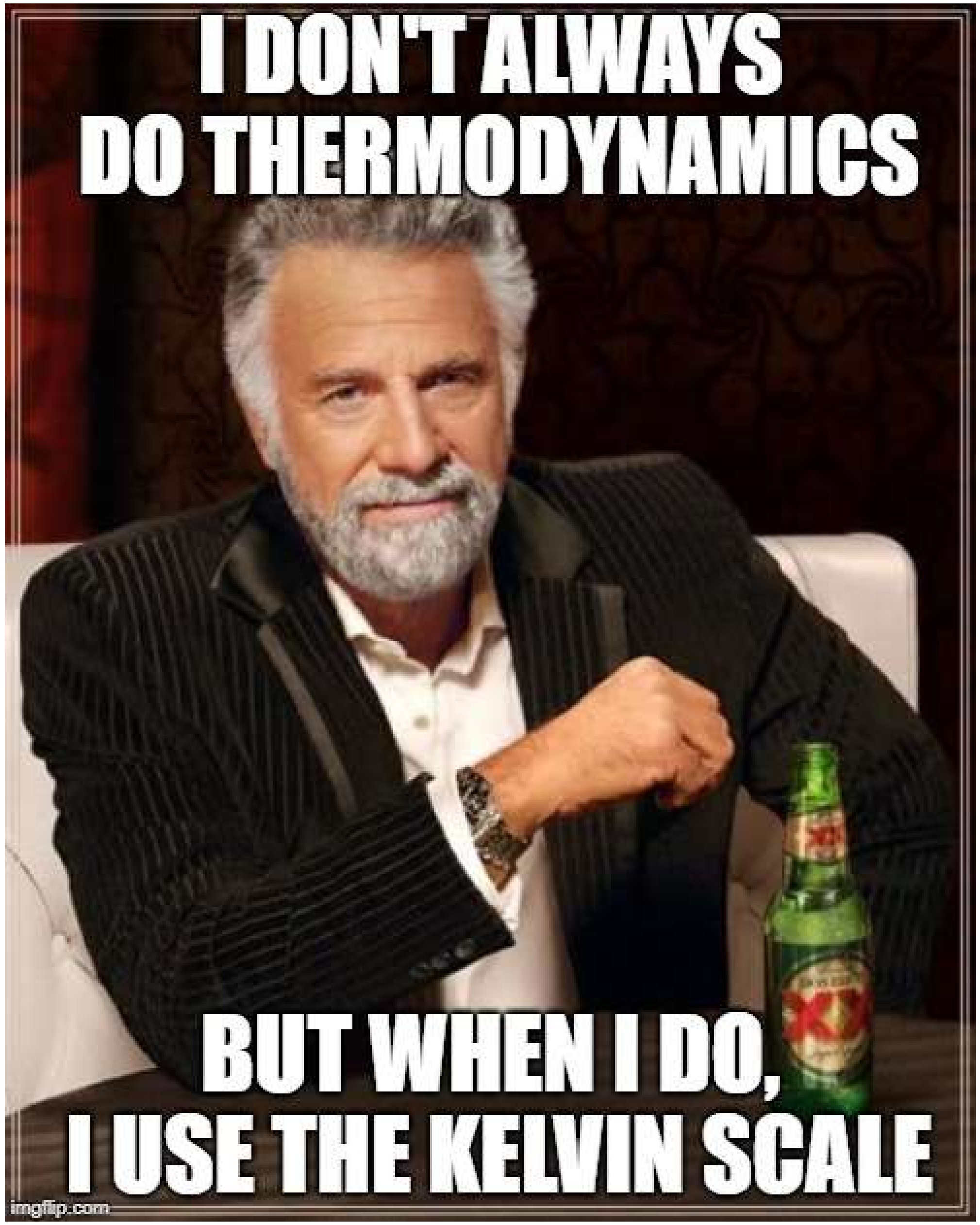
$$\frac{P_2}{P_1} = \frac{(T_{kelvin})_2}{(T_{kelvin})_1} \approx \frac{4}{3}$$

$// \; T_c + 273.15$

A. 0.2 kPa
B. 1.3 kPa
C. 3.0 kPa
D. 6.0 kPa
E. There is not enough information to answer.

so $P_2 \approx \frac{4}{3} P_1$

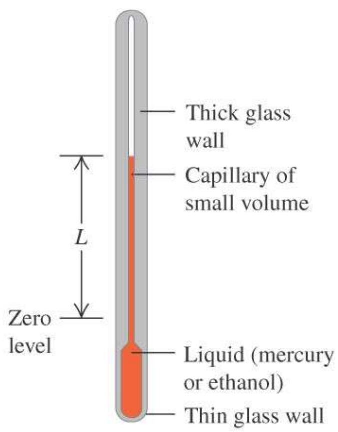
T is not proportional to P if we use the Celcius scale!


I DON'T ALWAYS
DO THERMODYNAMICS
BUT WHEN I DO,
I USE THE KELVIN SCALE
imgflip.com

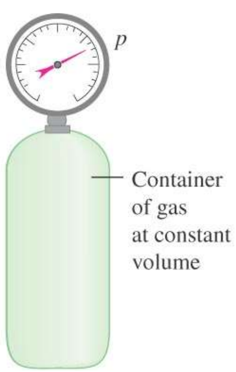
Thermometers

Liquid or gas thermometers

(a) Changes in temperature cause the liquid's volume to change.



(b) Changes in temperature cause the pressure of the gas to change.



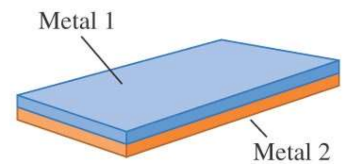
Digital

IR (infrared)

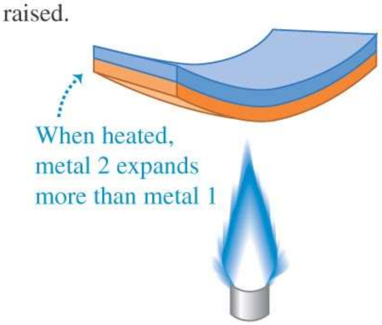
this one doesn't need to be in equilibrium with the sample

Bimetal

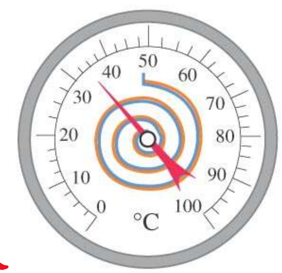
(a) A bimetallic strip



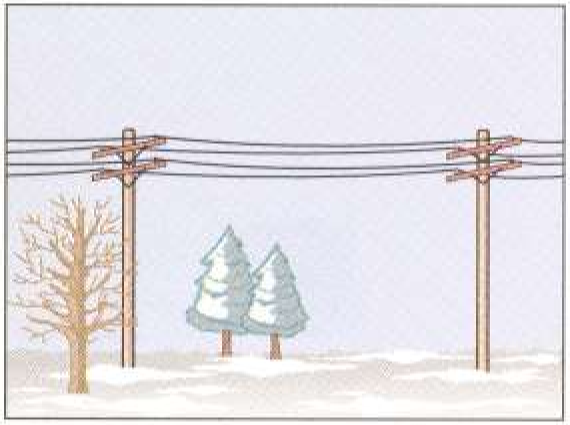
(b) The strip bends when its temperature is raised.



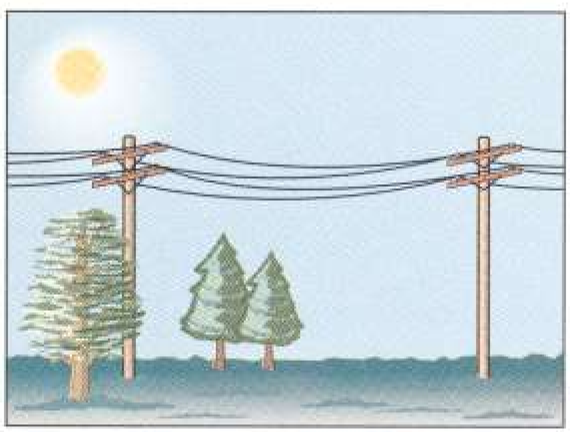
(c) A bimetallic strip used in a thermometer

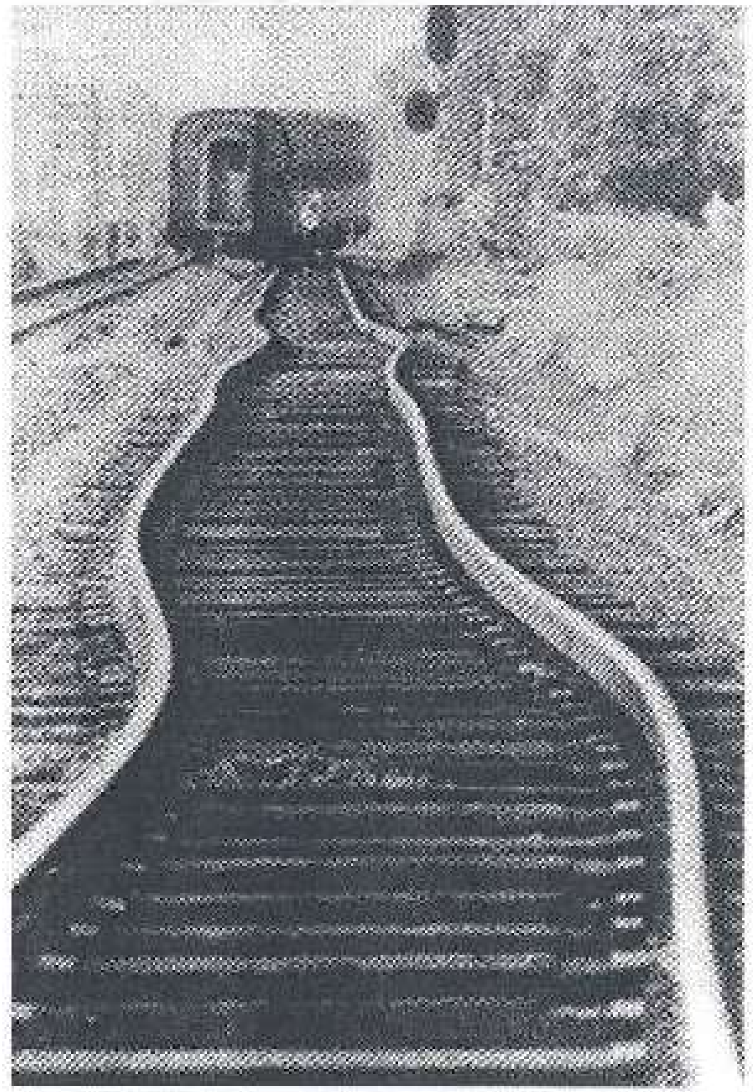


Thermal expansion

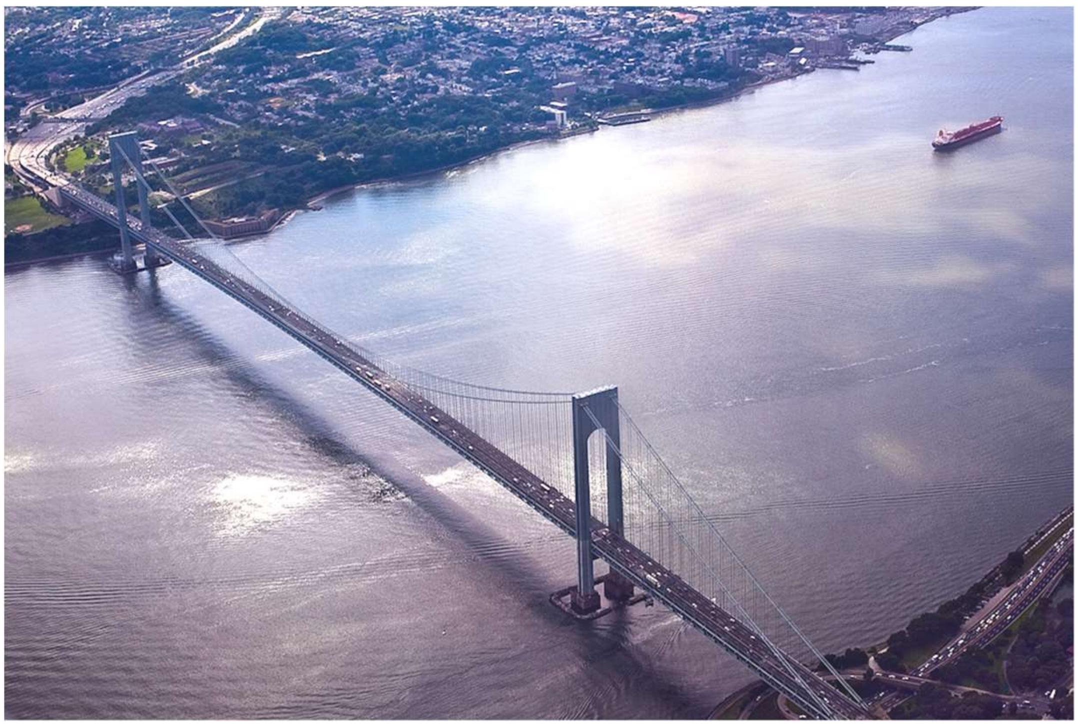


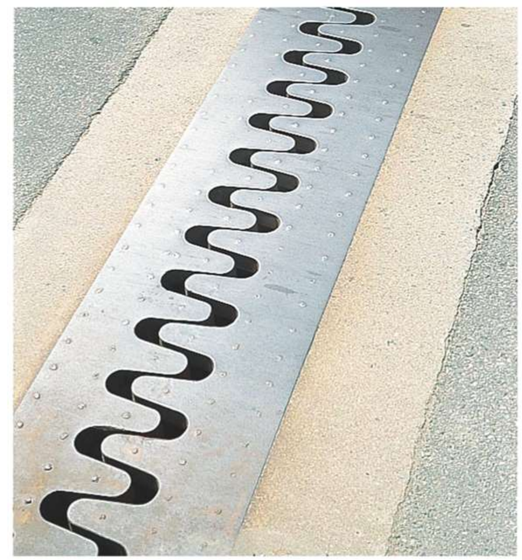
(a)



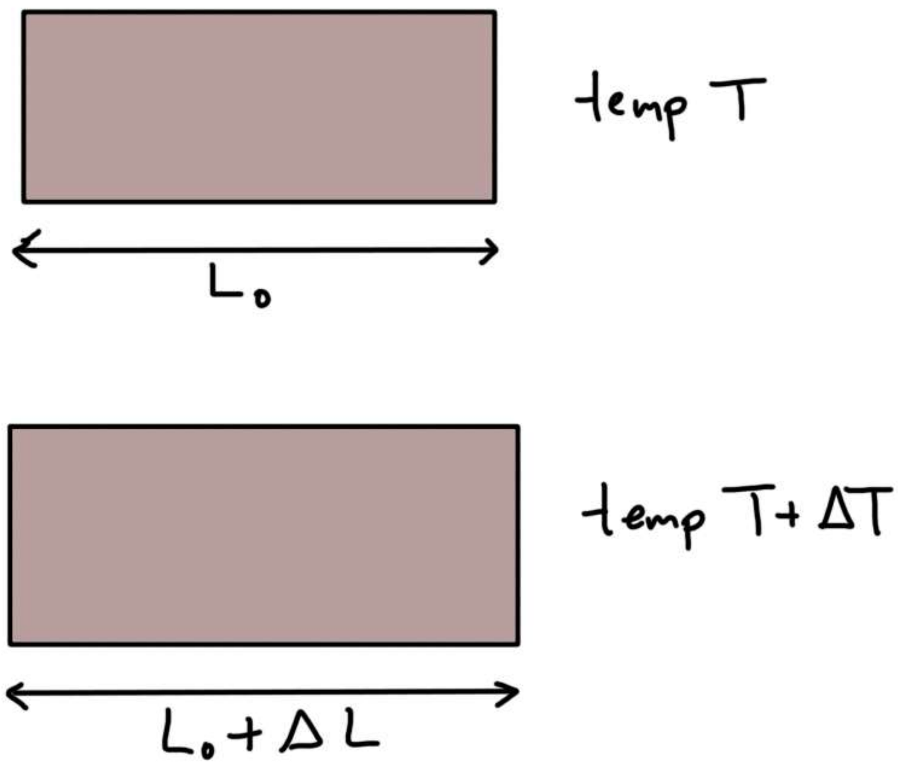


Thermal expansion





Thermal expansion:



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

coefficient of linear expansion

- assumes $\frac{\Delta L}{L}$ is small
- α can depend on T

Thermal expansion:
Verrazano Narrows Bridge

How much longer will the bridge deck be during the summer compared to the winter?

(center span ~1300m, think order of magnitude)

A. 5mm
B. 5cm
C. 50cm
D. 5m
E. 50m


Photo credit: Tom Giebel, cc licence

$\alpha \sim 1 \cdot 10^{-5}\ K^{-1}$

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

Thermal expansion: Verrazano Narrows Bridge

changes in K are same as changes in °C

How much longer will the bridge deck be during the summer compared to the winter?

(center span ~1300m, think order of magnitude)

we only need to be accurate within a factor of 10

A. 5mm
B. 5cm
C. 50cm
D. 5m
E. 50m

$\Delta T = 50\,C^\circ = 50\,K$

(−15°C winter
35°C summer)

$L_0 = 1300\,m \approx 10^3\,m$

$\alpha = 10^{-5}\,K^{-1}$

Photo credit: Tom Giebel, cc licence

$\alpha \sim 1 \cdot 10^{-5}\,K^{-1}$

$\Delta L \approx 10^{-5} \times 10^3\,m \times 50 = 0.5\,m$

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

Extra clicker question: At 200K, the pressure of a (nearly) ideal gas in a sealed fixed volume container is 50kPa. The container is now placed in an oven and the pressure is observed to increase to 100kPa. The temperature of the oven is

A) 100K

B) 200K

C) 300K

D) 400K

E) We need to know the constant of proportionality between T and P to answer this.

Clicker question: At 200K, the pressure of a (nearly) ideal gas in a sealed fixed volume container is 50kPa. At 400K, the pressure will be

$$T = \text{const} \cdot P$$

A) 25kPa

means $\frac{P_2}{P_1} = \frac{T_2}{T_1} = 2$

B) 50kPa

C) 100kPa

so $P_2 = 2 \cdot 50\text{kPa} = 100\text{kP}$

D) we need to know the constant of proportionality between T and P to answer this

We say T is directly proportional to P