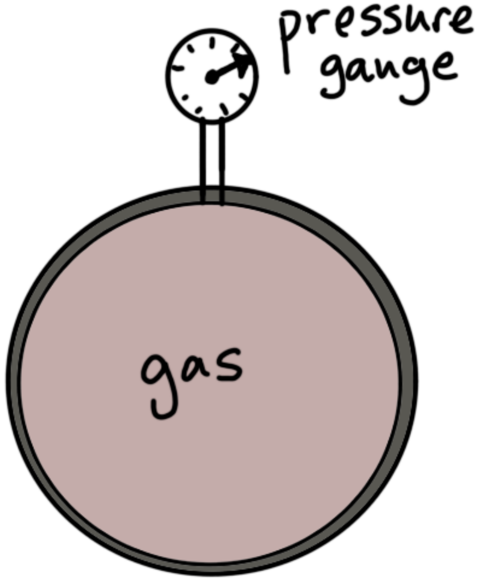
Lecture 3.

Thermometers and Temperature scales.

Pressure.

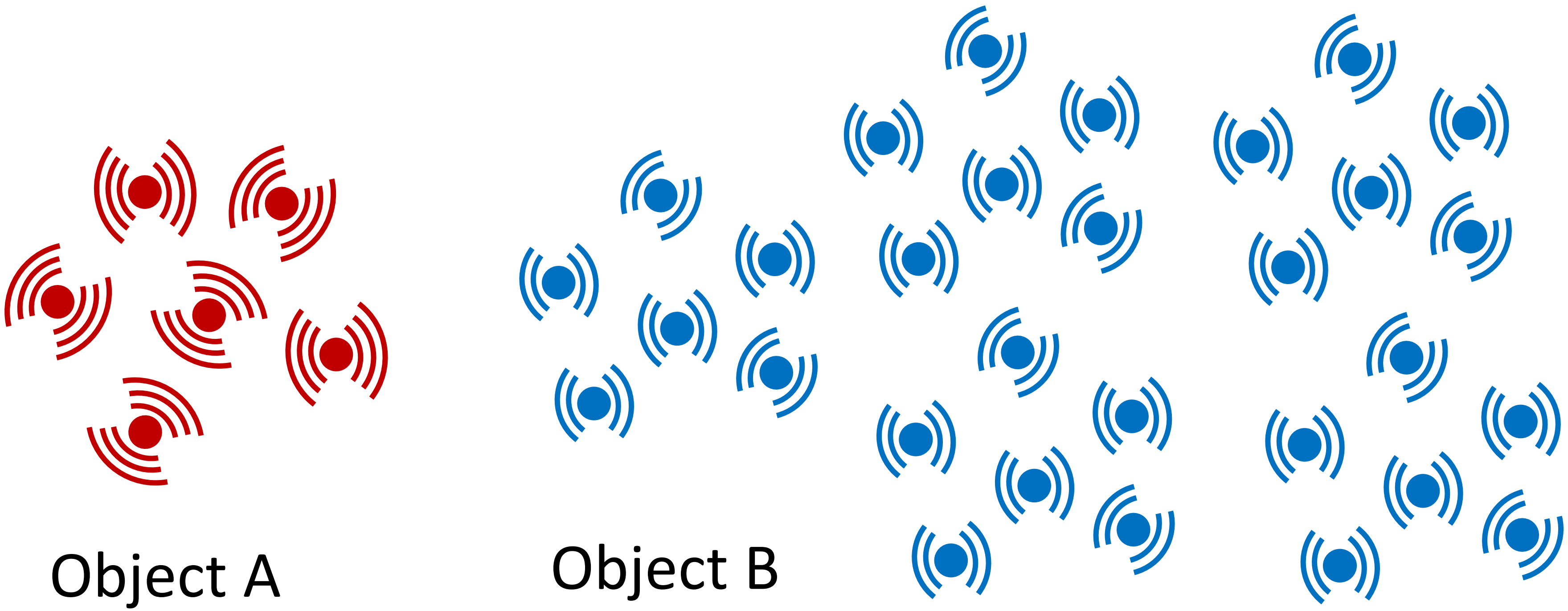


Q: Two objects (each initially in equilibrium) are put into thermal contact, and the pair is thermally insulated from its environment. If heat is observed to flow from object A to object B we can say that:

Last time

A. Object A initially had more energy than object B

B. Object A initially had a higher temperature than object B

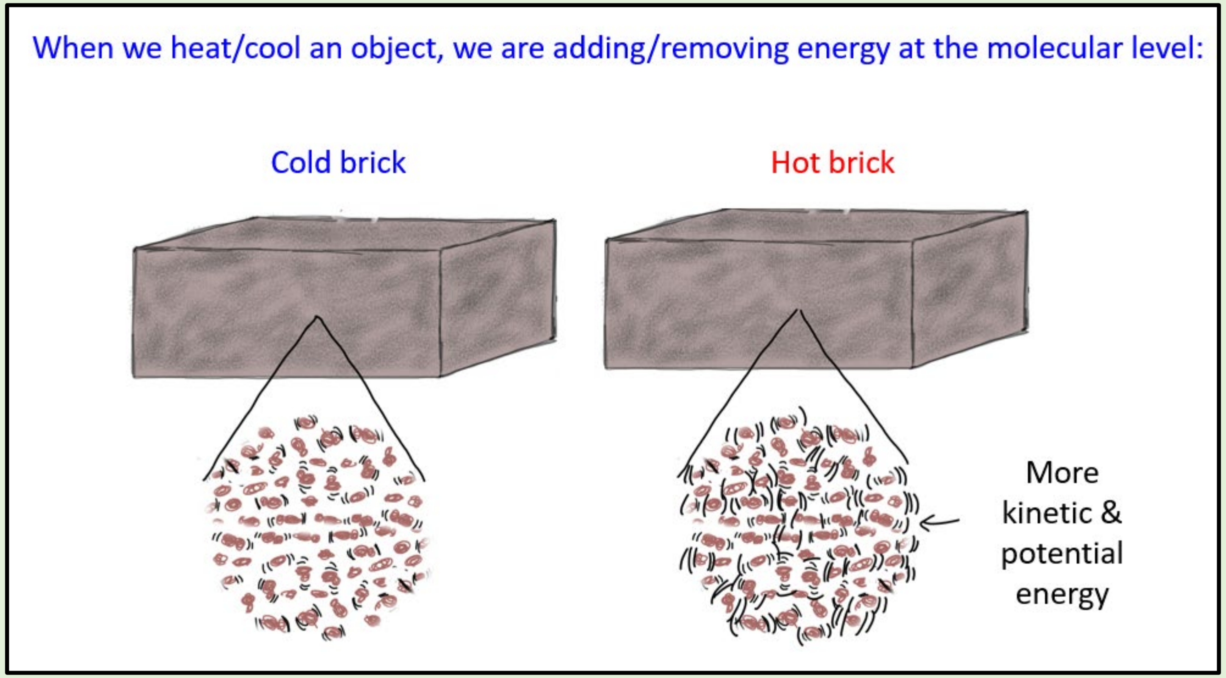


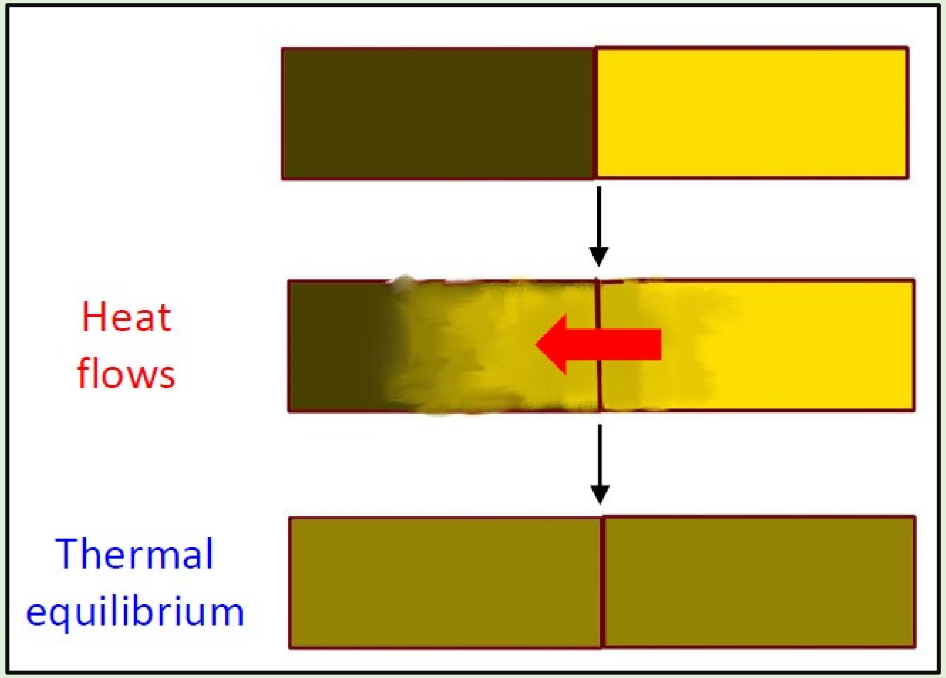
Intensive

Temperature: always from hotter to colder.

Energy: extensive (additive) quantity.

Last time





- Next goal: Assign a value to the temperature!

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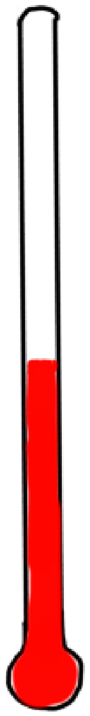
- How?
- We can assign a numerical value for different temperatures by using some temperature dependent macroscopic property of a standard object (e.g., volume of liquid in a tube)

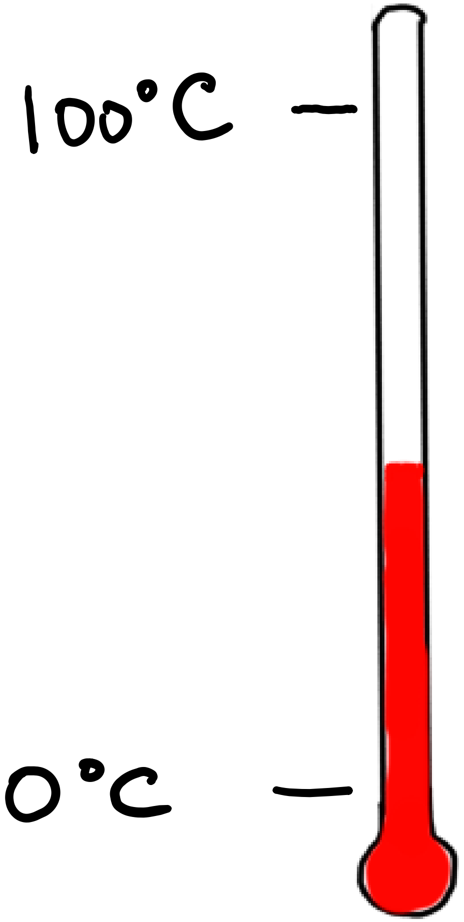


1 2 3 4 5 6 7 8 9 10

Let us explore the fact that liquids expand when heated, and shrink when cooled.

Assume that you have a liquid thermometer with no marking. Can you measure temperature, in degrees Celsius, in your room using it?

- Method:

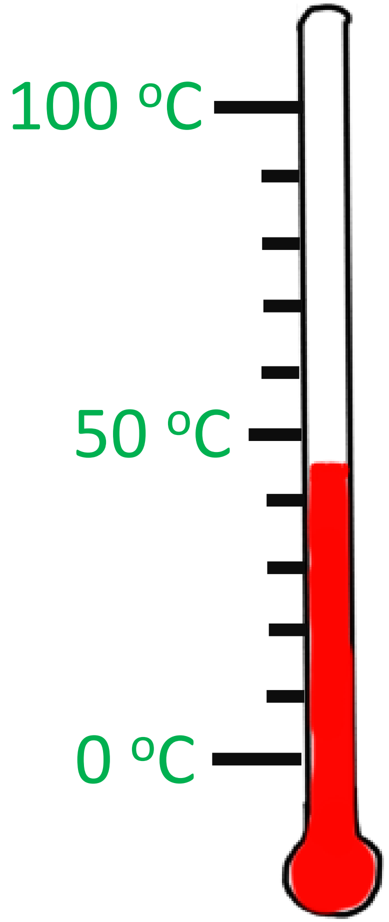


Let us explore the fact that liquids expand when heated, and shrink when cooled.

Assume that you have a liquid thermometer with no marking. Can you measure temperature, in degrees Celsius, in your room using it?

- Method:
  - ➢ $T = 0\ ^oC$: Freezing point of water
  - ➢ $T = 100\ ^oC$: Boiling point of water
  - ➢ Linear scale in between!

- Anybody here raised in the US? What would you do?



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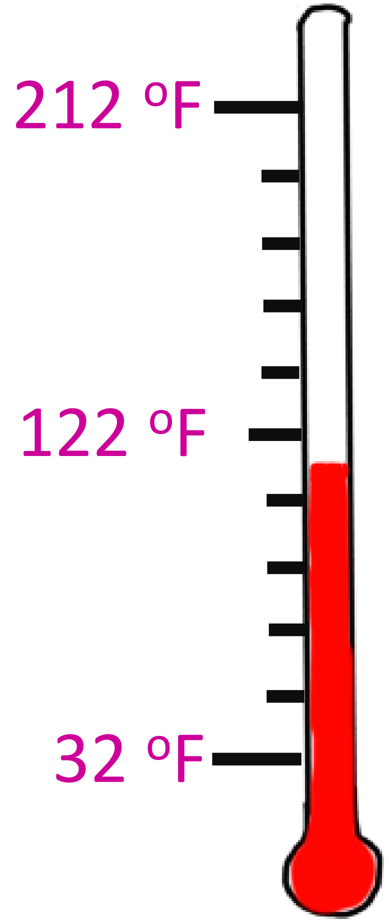


- Method:
  - T = 32 ^oF: Freezing point of water
  - T = 212 ^oF: Boiling point of water
  - Linear scale in between!

- Conversion:
  - $100\ ^oC = 180\ ^oF \quad \Rightarrow \quad 1\ ^oC = 1.8\ ^oF = 9/5\ ^oF$
  - $0\ ^oC = 32\ ^oF$

Celsius and Fahrenheit temperature scales

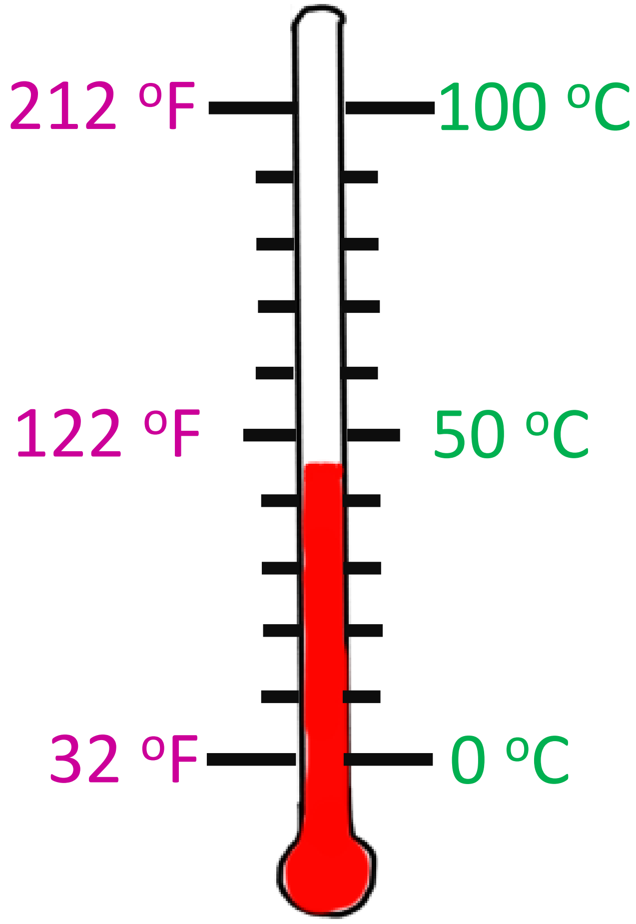
Example: 150 °C to °F ??

- 1 °C = 1.8 °F = 9/5 °F
- 0 °C = 32 °F

$$150\,°C = 0\,°C + 150\,°C =$$

$$= 32\,°F + 150\,°C\,\frac{9/5\,°F}{1\,°C} =$$

$$= \left(32 + 150 \cdot \frac{9}{5}\right)°F$$



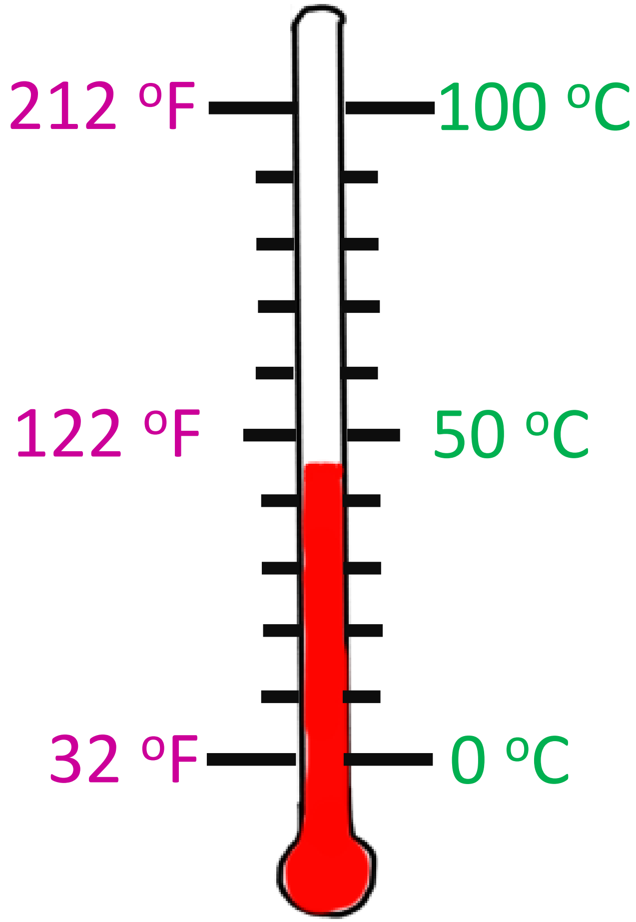
$$T_F = 32 + \frac{9}{5}\,T_C$$

$$T_C = \frac{5}{9}\left(T_F - 32\right)$$

Celsius and Fahrenheit temperature scales

- Will you get exact temperature? Are you assuming anything?

  - Experimental: Human error, not in equilibrium, impurities in water, altitude, …
  - ✓ Model: Liquid expansion may not be linear with temperature!

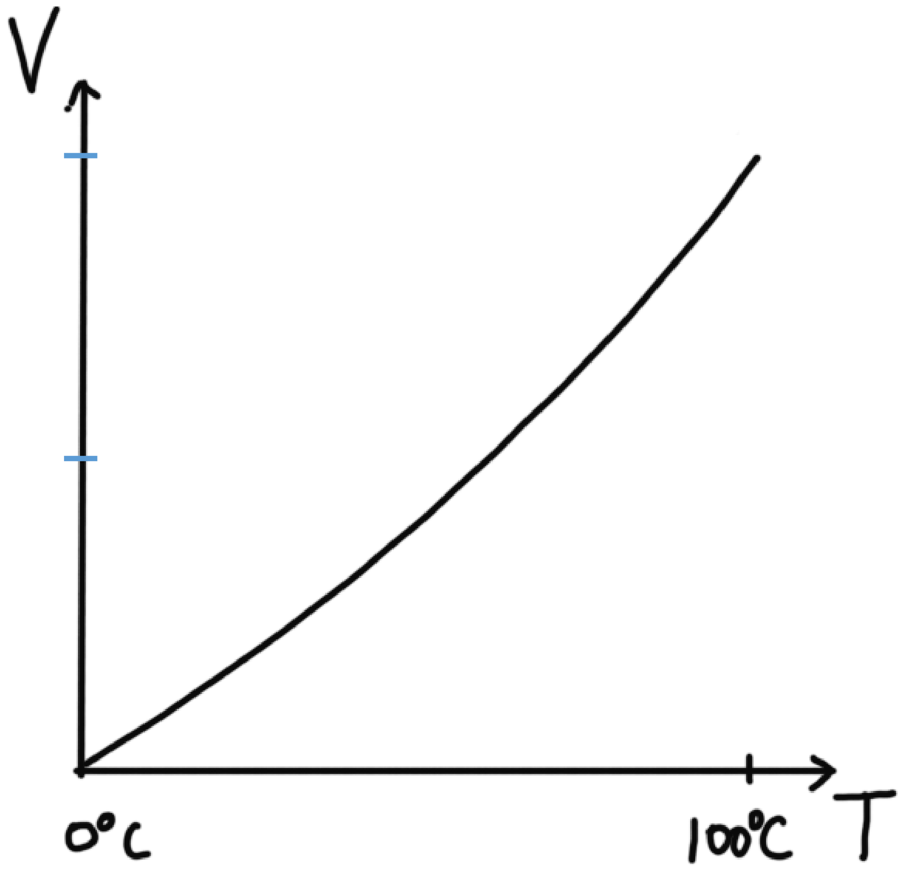


$$T_F = 32 + \frac{9}{5}\,T_C$$

$$T_C = \frac{5}{9}(T_F - 32)$$

Q: The graph shows the volume vs temperature relationship for a sample of mercury. For a mercury thermometer with equally spaced temperature markings, if the thermometer reads 50 ^{o}C, the actual temperature is:

A. Exactly 50 ^{o}C
B. A bit higher than 50 ^{o}C
C. A bit lower than 50 ^{o}C



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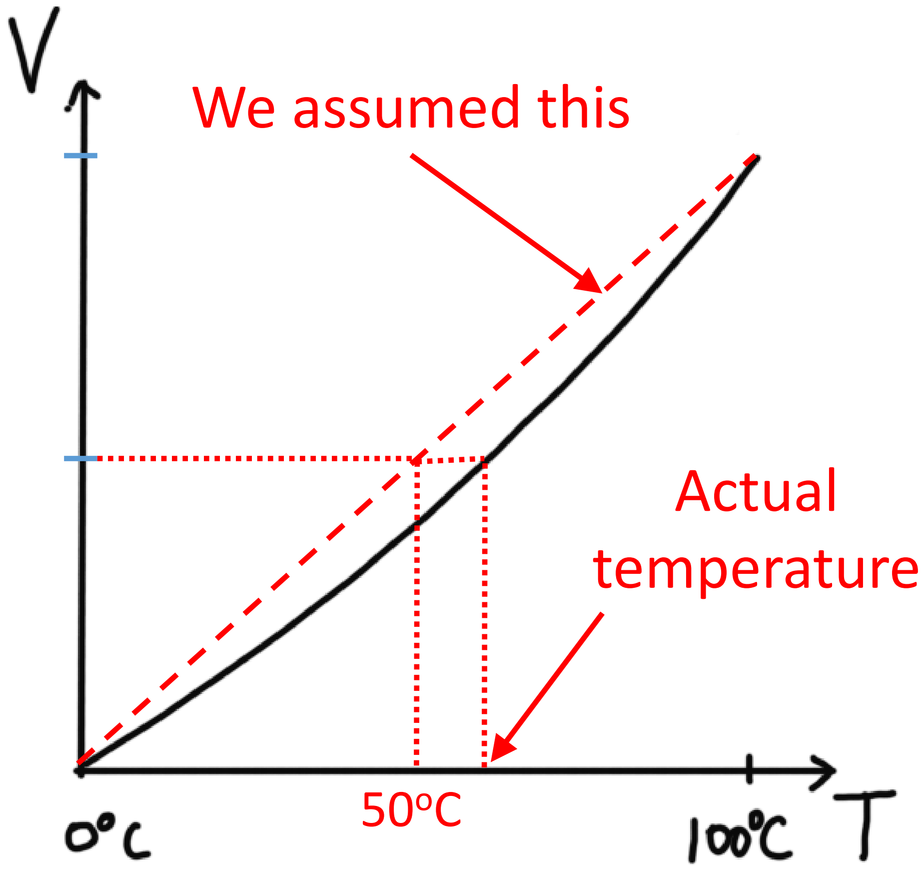
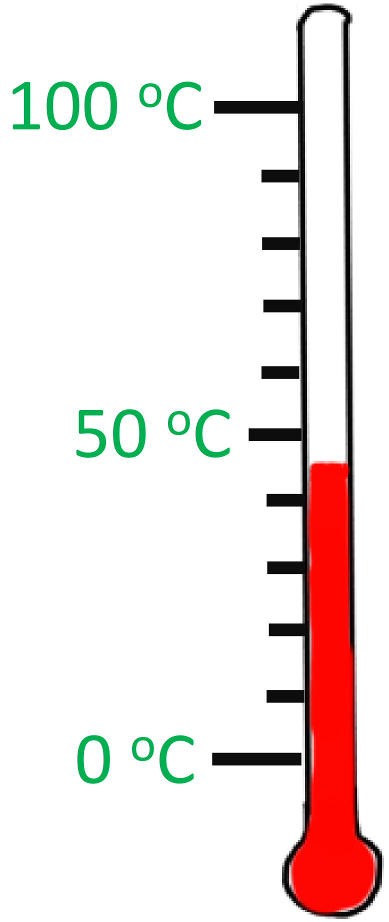


Interpolation between two reference temperatures

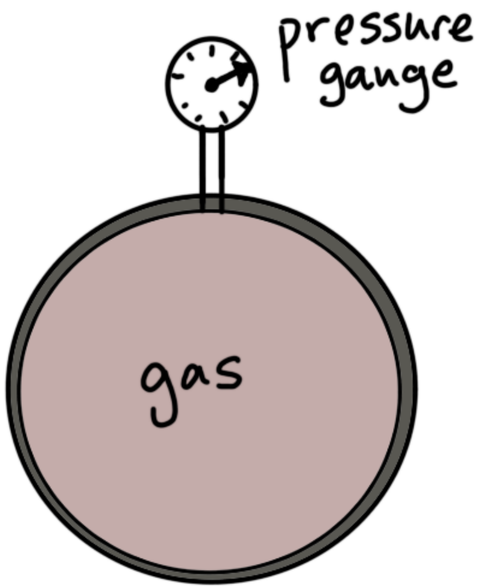
- The linear interpolation of temperature between the two reference temperatures, based on thermal expansion of some substance, is purely phenomenological.
  - ➢ It is NOT an exact law of nature.

- As a result, temperature measurement by the above method becomes (slightly) material dependent.
  - ➢ Not suited for precision measurement of temperature.

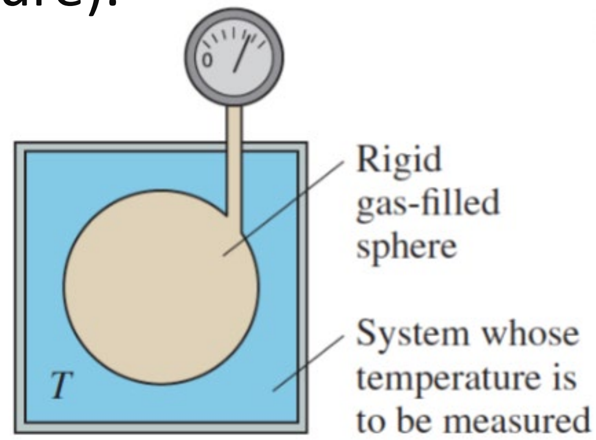
- How can we do better?



Let us then explore the fact that gases expand when heated.

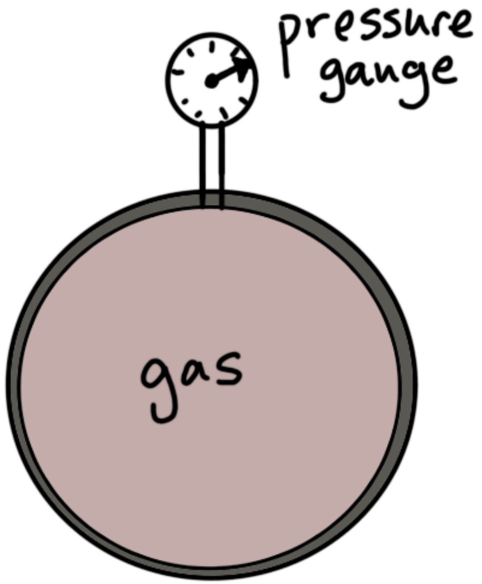


- Why gases?
- An ideal gas is a gas of point-like particles which do not interact with each other (possible: elastic collisions)
- Ideal gas approximation works very well at low density & not too low temperature
- Instead of looking at how the volume increases when the gas is heated, we will look at changes in pressure for fixed volume (easier to measure).
- Gas-based thermometer:



➢ We need to recall what pressure is.

Pressure



Constant volume gas thermometer

Pressure = Force on a surface (e.g., a wall) per unit area:

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

S.I. Unit of Pressure: Pascal = N/m^2

Q: The air pressure in the room is about 100 kPa. The force of the air on the top of your head (say 10 cm by 10 cm) is similar to the downward force from:

$k = 10^3$

A. a 100 g mass
B. a 1 kg mass
C. a 10 kg mass
D. a 100 kg mass
E. a 1000 kg mass

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

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B. a 1 kg mass
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$$\begin{aligned} F &= PA \\ &= 100{,}000 \text{ Pa} \times 0.01\, m^2 \\ &= 1{,}000\, N \end{aligned}$$

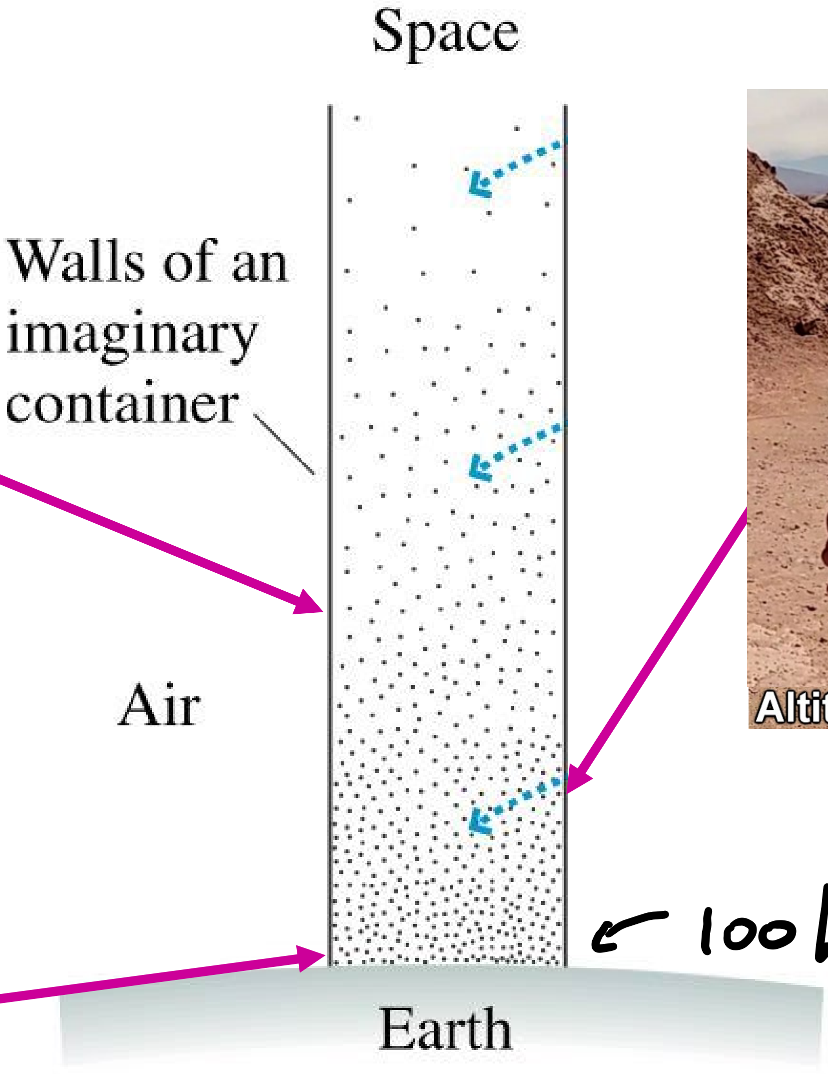
Same as from a 100 kg mass:

$$F = mg \sim 1{,}000\, N$$

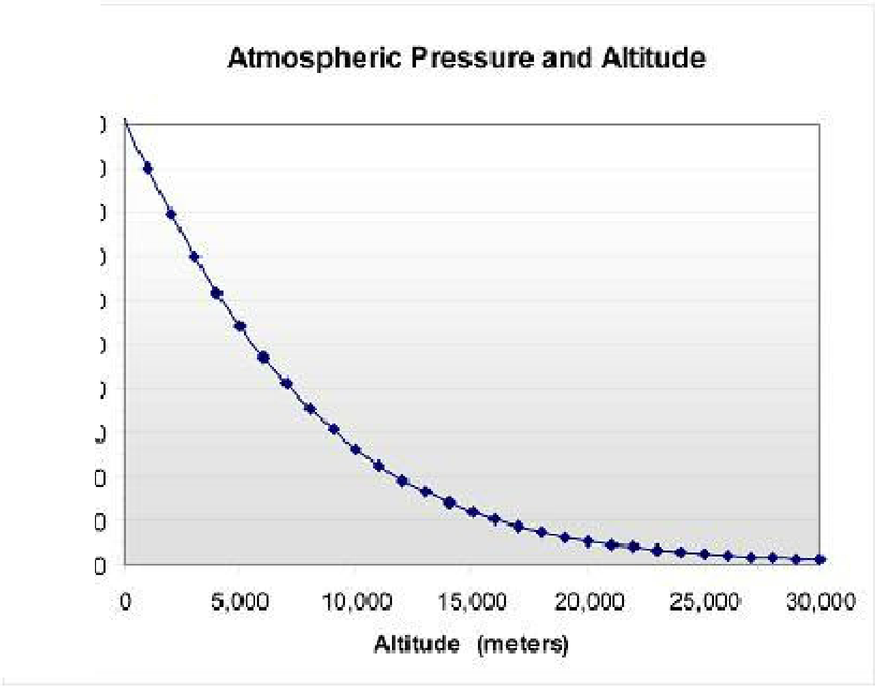
Atmospheric pressure

Why an empty plastic bottle sealed at the altitude of 5 km gets compressed when brought to the sea level?

Atmospheric pressure

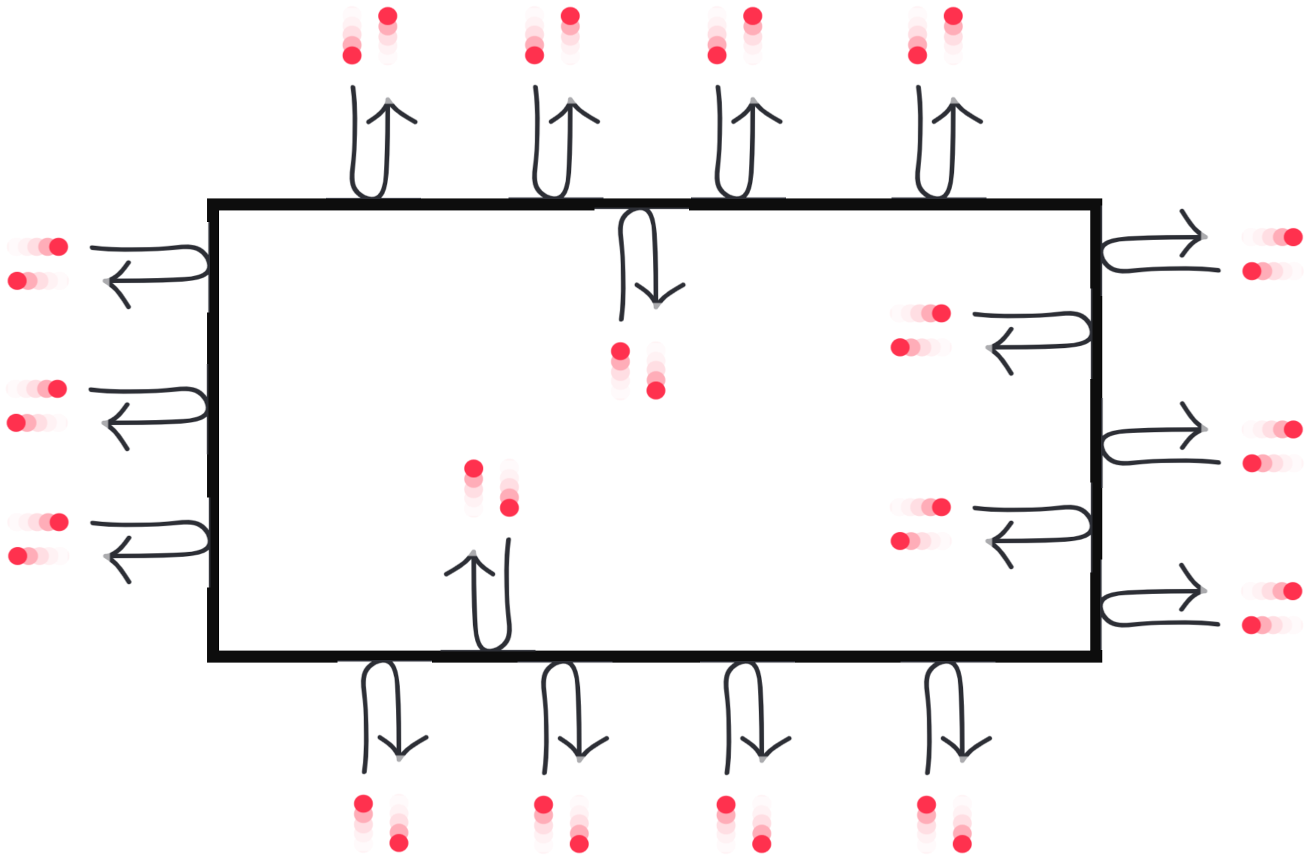


Atmospheric pressure as a function of altitude:



Pressure

- Why does the bottle become squeezed like that?
- We need to look at the microscopic picture of pressure

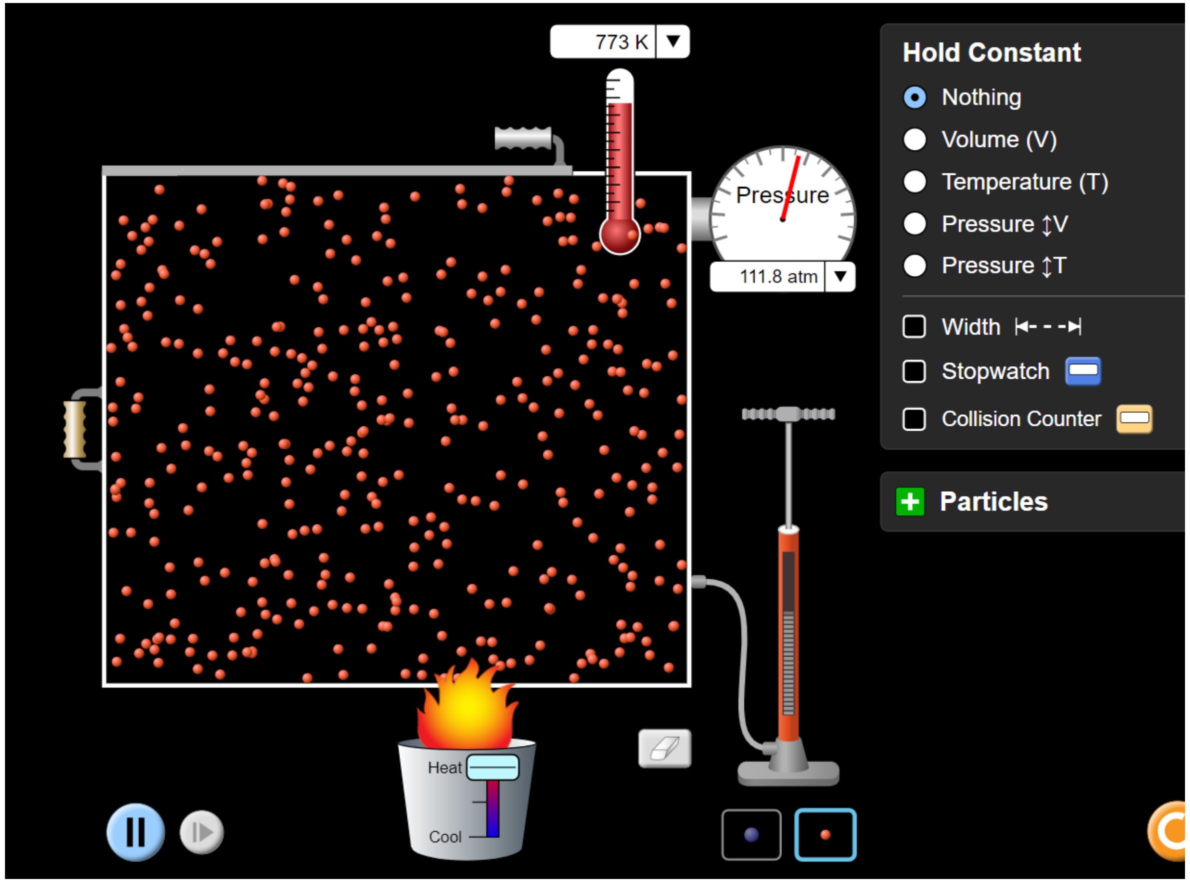


- Gas particles bounce against the walls and push on them (pressure!)

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

- More molecules outside – more pressure from the air outside the bottle.

Simulation of an ideal gas



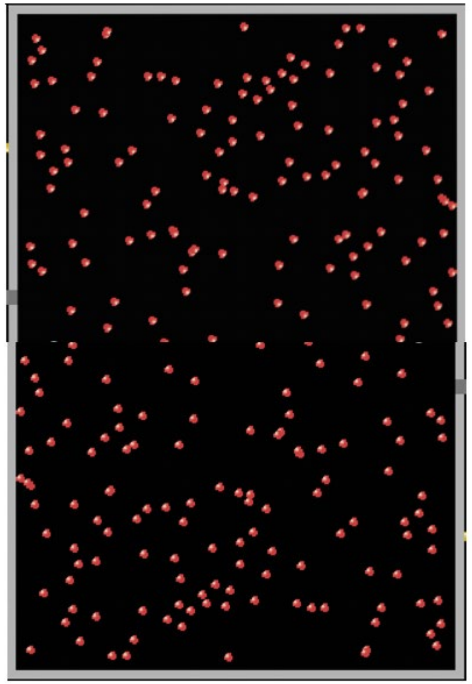
Gas properties PHET from U. Colorado

https://phet.colorado.edu/en/simulation/gas-properties

- Pressure is from the molecules hitting the wall: each collision of a gas molecule with the wall imparts momentum.
- As we heat the gas, the molecules move faster, so pressure increases

Remember that, microscopically, the temperature (the measure of supplied heat) is directly related to the speed of the molecules.

Q: If we double the average speed of the molecules, give two reasons why pressure would increase

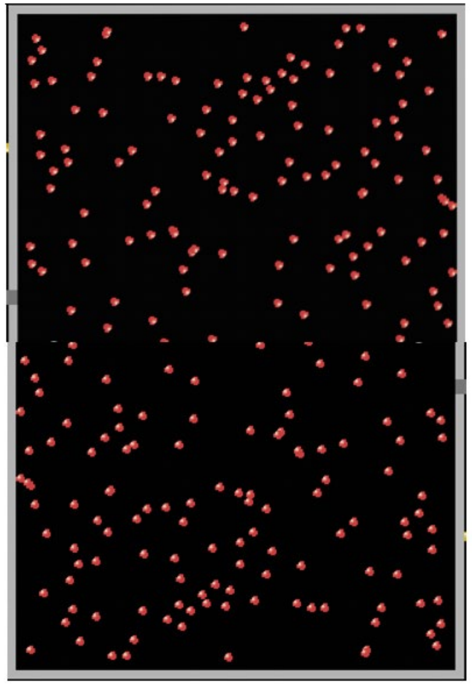


Q: If we double the average speed of the molecules, give two reasons why pressure would increase

1) More impact per collision

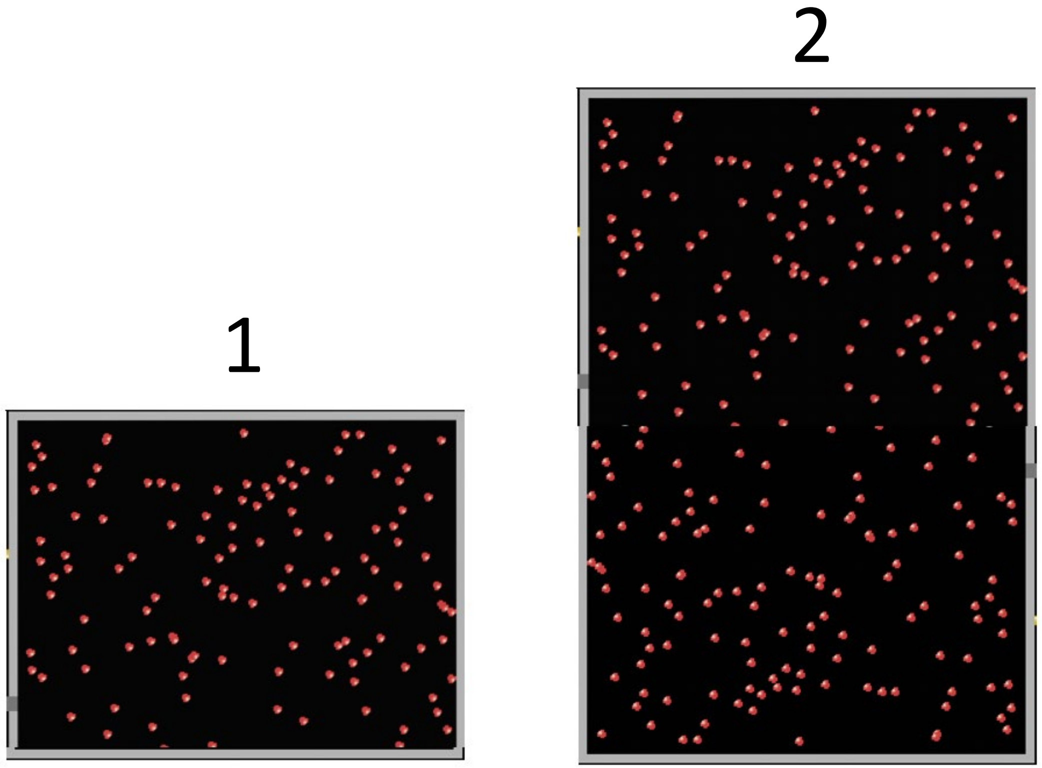
2) More frequent collisions

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



Q: In the picture below, box 2 is twice the height of 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 is:

A. the same
B. half
C. double
D. none of the above



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A. the same ✓

B. half

C. double

D. none of the above

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

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