1. Mass of a helium atom is $m_{He}=7\times10^{-27}$ kg. How much time (in average) it would take for He atom to fly through this lecture hall?

Here we need to estimate values!

Room temperature $T_{room} \sim 28°C = 300K$

$$\left\langle \frac{mv^2}{2} \right\rangle = k_B T \Rightarrow v_{He} \sim \sqrt{\frac{2k_BT}{m_{He}}} \approx 770\,m/s$$

$$t_{He} = \frac{L_{room}}{v_{He}} \approx \frac{30m}{770\,m/s} \approx 0.04s = 40\,ms$$

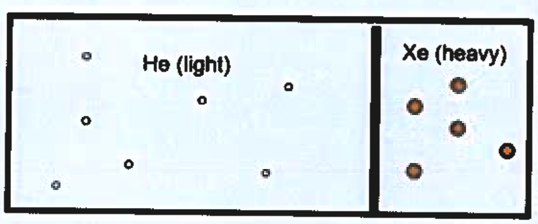
2. Xe atoms are approximately 30 times heavier than He. How much time (in average) it would take for Xe atom to fly through this lecture hall?

Two atoms at the same temperature have the same kinetic energy

$$v_{Xe} = \sqrt{\frac{2k_BT}{m_{Xe}}} = v_{He}\sqrt{\frac{m_{He}}{m_{Xe}}} = 140\,m/s$$

$$t_{Xe} = \sqrt{\frac{m_{Xe}}{m_{He}}}\, t_{He} \approx 0.2s = 200\,ms$$

The two gasses are at the same temperature and same number of atoms. If the divider between them is free to move, is its position shown correctly? 0



- Yes, He must occupy bigger volume since its atoms move faster
- No, Xe must occupy bigger volume since its heavier atoms push the divider more
- No, two gases should be equal and be satisfied with an equal amount of space.

A Divider is in equilibrium if pressure values of the two compartments are the same

$P_{He} = P_{Xe}$

$T_{He} = T_{Xe}$

$N_{He} = N_{Xe}$

since for each gas

$$PV = Nk_BT$$

$$V_{He} = V_{Xe}$$

A cowboy fires a silver bullet (c_{silver}=234J/kg·°C) with a muzzle speed of 400m/s into the pine wall of a saloon. Assume all the internal energy generated by the impact remains with the bullet. What is the temperature change of the bullet?

Kinetic energy of the bullet is completely transfered to heat

$$\frac{\cancel{m}v^2}{2} = Q = c_{silver} \cdot \cancel{m} \cdot \Delta T \qquad \Delta T = \frac{v^2}{2c_{silver}} = \frac{(400\,m/s)^2}{2 \cdot 234\,J/kg \cdot °C}$$

$$\Delta T = 341°C$$

Silver melts at $T_{melt} = 962°C$, we should be fine here assuming no melting

Modern rifles have much higher exit speed, for example 800m/s. What is the final temperature (and state) of the bullet in this case? Assume its temperature was 40 °C before the impact.

Higher speed ⟶ higher T.

Assuming no melting $\Delta T = \frac{(800\,m/s)^2}{2\,c_{silver}} = 1364°C$

must account for intermediate melting

$L_{silver} = 104\,kJ/kg = 1.04 \cdot 10^5\,J/kg$

c_{silver} is the same for both liquid and solid.

More accurate calculation of energy balance

$$\frac{\cancel{m}v^2}{2} = \underbrace{c_{silver}\,\cancel{m}\,(T_{melt} - T_{ini})}_{\text{solid heating}} + \underbrace{L_{silver} \cdot \cancel{m}}_{\text{melting}} + \underbrace{c_{silver} \cdot \cancel{m}\,(T_{fin} - T_{melt})}_{\text{liquid heating}}$$

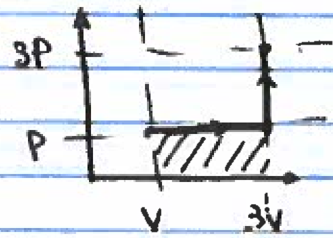
We can only combine two terms since c_{silver} is the same

$$\frac{v^2}{2} = \underbrace{c_{silver}\,(T_{fin} - T_{ini})} + L_{silver}$$

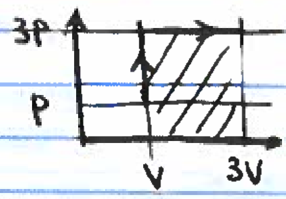
$$\Delta T = \frac{\frac{v^2}{2} - L_{silver}}{c_{silver}} = 923°C$$

$T_{fin} = 40°C + 923°C = 963°C$, 1°C above melting point

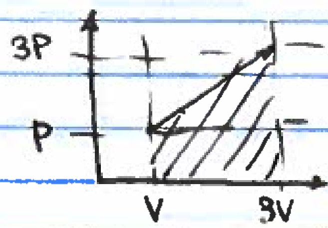
Example: ideal gas is warmed slowly so that it goes from (P, V) to $(3P, 3V)$. How much work is done in each case?

① 

$$W_1 = P(3V - V) = 2PV$$

② 

$$W_2 = 3P \cdot 2V = 6PV$$

③ 

$$W_3 = 2P \cdot 2V = 4PV$$

Change in the internal energy is the same in all three cases

$$\Delta E_{int} = E_2 - E_1 = \frac{3}{2}\underbrace{Nk_BT_2}_{9PV} - \frac{3}{2}\underbrace{Nk_BT_1}_{PV} = 12\,PV$$

Clearly, the amount of heat needed for each scenario is different

First law of thermodynamics

The change ~~of~~ in the internal energy of the system $\Delta E_{int} = Q - W$

where Q is heat exchange
W is work done by the system
(basically, energy conservation)

So we can calculate the amount of heat as $Q = \Delta E_{int} + W$

① $Q_1 = \Delta E_{int} + W_1 = 14PV$
② $Q_2 = \Delta E_{int} + W_2 = 18PV$
③ $Q_3 = \Delta E_{int} + W_3 = 16PV$