Homework MME 4501 – MASE 6402

Problem 1. 23 grams of hydrogen are contained in 0.33 liters, what is the pressure when the temperature is 21 °C?

SOLUTION.

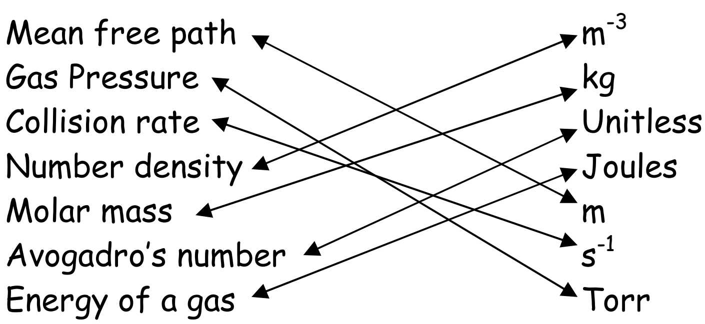
P = mRT/MV = (23 g)(83.14 mbar L mol^{-1} K^{-1})(294 K)/((0.33 L)(1 g mol^{-1})) = 1703614 mbar

Or

P = mRT/MV = (23 g)(83.14 mbar L mol^{-1} K^{-1})(294 K)/((0.33 L)(1 g mol^{-1})) = 1703614 mbar

---

Problem 2. Relate the physics concepts of the left with the proper units on the right



Problem 3. Consider the equation discussed in the notes for the rate of arrival: Using such an equation as a starting point produce a new expression, such that the multiplicative constant allows the use of units of mmHg for pressure, Kelvin degree for temperature and molecular units for mass.

SOLUTION.

Let us start with the basic equations to make all more understandable:

$$r = \frac{1}{4} n \langle \mathrm{v} \rangle$$

$$
\begin{aligned}
&; \text{consider that:} \\
&R = 83.14 mbar \\
&\quad = N_A k, \\
&k = 1.38 \times 10^{-23} J/K, \\
&M = N_A m, \\
&P = nkT, \\
&dyne = g\ cm^2 s^2, \\
&J = kg\ m^2 s^2, \\
&1J = 1 \times 10^7 dyne, \\
&1Pa = 7.5 \times 10^{-3} Torr, \\
&1Torr = 1.333 mbar, \\
&N_A = 6.02 \times 10^{23} mol^{-1}.
\end{aligned}
$$

$$= \frac{1}{4} n \left(\frac{8RT}{\pi m N_A} \right)^{1/2}$$

$$= \frac{1}{4} \frac{P}{kT} \left(\frac{8RT}{\pi m N_A} \right)^{1/2}$$

$$= \frac{1}{4} \frac{P}{kT} \left(\frac{8kN_A T}{\pi m N_A} \right)^{1/2}$$

$$= P \left(\frac{1}{kT\pi 2m} \right)^{1/2}$$

$$= \frac{P}{T^{1/2} m^{1/2}} \left(\frac{1}{2\pi k} \right)^{1/2}$$

$$= \frac{P N_A^{1/2}}{T^{1/2} M^{1/2}} \left(\frac{1}{2\pi k} \right)^{1/2}$$

$$= \frac{P}{T^{1/2} M^{1/2}} \left(\frac{N_A}{2\pi k} \right)^{1/2}$$

$$= \frac{P}{T^{1/2} M^{1/2}} \left(6.9428 \times 10^{45} \right)^{1/2} \text{; has to convert J to dyne,}$$

$$= \frac{P}{T^{1/2} M^{1/2}} 8.3323 \times 10^{22} \text{; has to convert J to dyne}$$

$$= \frac{P}{T^{1/2} M^{1/2}} \left(\frac{100Pa}{1mbar} \right) \frac{\left(\frac{1000g}{1kg} \right) \left(\frac{100cm}{1m} \right)}{\left(\frac{1 \times 10^4 cm^2}{1\mathrm{m}^2} \right)} 2.6349 \times 10^{19} \ \frac{1}{\mathrm{cm}^2 s} \text{; with M in g/mol, P in mbar and T in K,}$$

$$= \frac{P}{T^{1/2} M^{1/2}} 2.6349 \times 10^{22} \ \frac{1}{\mathrm{cm}^2 s} \text{; assuming P in mbar, T in K and M in g/mol.}$$

Thus the result yields particles per s, per cm^2, using the variables for P, T and M as indicated above. This expression can be directly compared to the one in the notes, "lecture_preliminaries.ppt", slide 13.

Problem 4. For the particular case of nitrogen at room temperature and a pressure of 10^{-9} Torr, what is the rate of arrival?

SOLUTION.

If we assume that nitrogen dissociative adsorption, then we can take the molar mass as 14 g/mol:

$$
\begin{aligned}
r &= \frac{P}{T^{1/2}M^{1/2}} 2.6349\times10^{22} \quad \frac{1}{\mathrm{cm}^2 s} \\
&= \frac{1.333\times10^{-9}\, mbar}{(300K)^{1/2}(14 g/mol)^{1/2}} 2.6349\times10^{22} \quad \frac{1}{cm^2 s} \\
&= 5.419\times10^{11} \frac{1}{cm^2 s}
\end{aligned}
$$

Remember that 1 Torr = 1.333 mbar. If adsorption is not dissociative then we take M=28g/mol, and r yields: 3.825×10^{11} cm^{-2} s^{-1}.

Problem 5. How long would it take for nitrogen at 10^{-9} Torr to produce a monolayer coverage? Assume that a monolayer is about $1\text{x}10^{15}$ atoms/cm^2, and that the structure of the surface does not play a major role; although in practice it actually does. **(25 points)**

SOLUTION.

$$
\begin{aligned}
t &= \frac{\gamma}{r} \\
&= \frac{1.0\times10^{15}\, atoms\cdot cm^{-2}}{5.419\times10^{11}\, atoms\cdot cm^{-2} s^{-1}} \\
&= 1.845\times10^{3}\ s = 0.51 hr,
\end{aligned}
$$

where γ represents a monolayer coverage value. The above result corresponds to dissociative adsorption, without it, t = 0.72 hr.
