Marks 6

- A champagne bottle is filled with 750 mL of wine, leaving 10.0 mL of air at atmospheric pressure when it is sealed with a cork. After fermentation, the pressure inside the bottle is 6.0 atm at 20 °C. Assume that the gas produced is entirely CO_2 and that its solubility in the wine is the same as in water. What mass of CO_2 has been produced by the fermentation?
  Data: The mole fraction solubility of CO_2 in water is 7.1×10^{-4} at 293 K and 1.0 atm.

The molar mass of H_2O is (16.00 (O) + 2 × 1.008 (H)) g mol^{-1} = 18.016 g mol^{-1}. Assuming that the wine is entirely water with a density of 1.0 g mL^{-1}, the bottle contains 750 g of water or:

$$\text{number of moles of water} = \frac{\text{mass}}{\text{molar mass}} = \frac{750\text{ g}}{18.016\text{ g mol}^{-1}} = 41.67\text{ mol}$$

The mole fraction of CO_2 in water, X_{CO_2}, is given by:

$$X_{CO_2} = \frac{n_{CO_2(aq)}}{n_{CO_2(aq)} + n_{H_2O(l)}} = \frac{n_{CO_2(aq)}}{n_{CO_2(aq)} + (41.67\text{ mol})} = 7.1 \times 10^{-4}$$

Hence, the number of moles of CO_2 in the wine *before* fermentation(1.0 atm) is given by:

$$n_{CO_2(aq)} = (7.1 \times 10^{-4})(n_{CO_2(aq)} + 41.67)$$

$$= 7.1 \times 10^{-4} n_{CO_2(aq)} + (7.1 \times 10^{-4} \times 41.67)$$

$$n_{CO_2(aq)}(1.0 - 7.1 \times 10^{-4}) = (7.1 \times 10^{-4} \times 41.67)$$

$$n_{CO_2(aq)} = 0.0296\text{ mol}$$

***After* fermentation, the pressure is 6.0 atm so $n_{CO_2(aq)}$ = 6.0 × 0.0296 mol. The number of moles of CO_2 produced by the fermentation and dissolved in the wine is therefore:**

$$n_{CO_2(aq)} = (6.0 - 1.0) \times 0.0296\text{ mol} = 0.148\text{ mol}$$

The increase in air pressure of 5.0 atm is due to extra CO_2(g). As 1 atm = 101.3 kPa, P = (5.0 × 101.3) kPa = 506.5 kPa. The volume of air = 10.0 mL = 0.0100 L = = 1.00 × 10^{-5} m^3. Using the ideal gas equation, $PV = nRT$, the number of moles of CO_2(g) is:

$$n_{CO_2(g)} = \frac{PV}{RT} = \frac{(5.065 \times 10^5\text{ Pa})(1.00 \times 10^{-5}\text{ m}^3)}{(8.314\text{ m}^3\text{ Pa K}^{-1}\text{ mol}^{-1})((20+273)\text{K})} = 0.00208\text{ mol}$$

Overall:

$$n_{CO_2} = n_{CO_2(aq)} + n_{CO_2(g)} = (0.148 + 0.002)\text{ mol} = 0.150\text{ mol}$$

The molar mass of CO_2 is (12.01 (C) + 2 × 16.00 (O)) g mol^{-1} = 44.01 g mol^{-1}. Hence, the mass of CO_2 produced by fermentation is given by:

$$\text{mass} = \text{number of moles} \times \text{molar mass}$$

$$= (0.150\text{ mol}) \times (44.01\text{ g mol}^{-1}) = 6.6\text{ g}$$

Answer: **6.6 g**

ANSWER CONTINUES ON THE NEXT PAGE

After the bottle has been opened and all of the bubbles have been released, what volume of CO_2 has escaped? Assume all the CO_2 produced escapes.

When the cork is released, the pressure returns to 1.0 atm. The amount of CO_2 that will remain dissolved is therefore, from above, $n_{CO_2(aq)}$ = 0.0296 mol.

The amount of CO_2 which escapes is therefore:

$$n_{CO_2(g))} = (0.150 - 0.0296)\text{ mol} = 0.120\text{ mol}$$

At 1.0 atm = 101.3 kPa, this will occupy a volume:

$$V = \frac{nRT}{P} = \frac{(0.120\text{ mol})(8.314\text{ m}^3\text{ Pa K}^{-1}\text{ mol}^{-1})((20+273)\text{K})}{(1.013 \times 10^5\text{ Pa})}$$

$$= 2.9 \times 10^{-3}\text{ m}^3 = 2.9\text{ L}$$

Answer: **2.9×10^{-3} m^3 = 2.9 L**