Answers to Exercise 9.7
Ideal and Nonideal Gases

1.

(a) Generally, a gas will behave ideally when its density is low (as in air).

When a gas behaves ideally,

- the volume occupied by gas atoms/molecules is negligible and
- the atoms/molecules do not experience significant intermolecular forces.

If either of the above statements is false, the gas must be treated as a nonideal gas.

(b) (i) *a* is larger for water because water is polar and can hydrogen bond whereas silane is nonpolar and cannot hydrogen bond. As such, we expect the intermolecular forces between water molecules to be stronger than those between silane molecules. Since *a* corrects for the effect of intermolecular forces, it is larger for the more polar water.

(ii) *b* is larger for silane because silane is a larger molecule than water. Silicon is a larger atom than oxygen, and it has four hydrogen atoms attached instead of two. Since *b* corrects for the volume occupied by gas molecules, it is larger for the larger silane.

(c) **Step 1: Convert temperature into Kelvin**

$T = 25 + 273.15 = 298.15\ K = 298\ K$

This value only has 3 sig. fig. because 25 ℃ has no decimal places; however, we will still use 298.15 K in the calculation to minimize rounding error.

Step 2: Calculate pressure if gas behaves ideally

$PV = nRT$

$$P = \frac{nRT}{V} = \frac{(2.5\ mol)\left(8.314\ 462\frac{Pa\cdot m^3}{mol\cdot K}\right)(298.15\ K)}{2.5\ m^3} = 2.48 \times 10^4 Pa \times \frac{1\ bar}{10^5\ Pa} = 0.248\ bar$$

Step 3: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

Step 4: Answer the follow-up question

This answer corresponds to a low density gas. (For reference, atmospheric pressure is approximately 1 bar. So, this pressure is lower than atmospheric pressure.) As such, I would expect this gas to behave ideally.

When we set this question on a midterm, a lot of students wasted a lot of time doing the calculation using the van der Waals equation and comparing the numbers. While that does indeed show that the ideal gas law gives a value that is "good enough" in this situation, it's not an effective use of time. If you understand the material thoroughly, you can avoid doing things like that. (The fact that only about 2" was given to answer the question should also have suggested that we were not looking for a massive calculation.)

2. A 5.00 L flask contains 450 g CH_4 at 0 °C. Use the van der Waals equation of state to predict the pressure in this flask.

The van der Waals parameters for CH_4 are $a = 0.2303 \frac{Pa \cdot m^6}{mol^2}$ and $b = 4.31 \times 10^{-5} \frac{m^3}{mol}$.

16. **Step 1: Convert temperature into Kelvin**

$T = 0 + 273.15 = 273.15\ K = 273\ K$

This value only has 3 sig. fig. because 0 ℃ has no decimal places; however, we will still use 273.15 K in the calculation to minimize rounding error.

Step 2: Convert volume into m^3

$V = 5.00\ L \times \frac{1\ m^3}{1000\ L} = 5.00 \times 10^{-3}\ m^3$

Step 3: Calculate moles of CH_4

$M_{CH_4} = 12.011 \frac{g}{mol} + 4\left(1.0079 \frac{g}{mol}\right) = 16.0426 \frac{g}{mol}$

$n_{CH_4} = 450\ g \times \frac{1\ mol}{16.0426\ g} = 28.1\ mol$

Step 4: Calculate pressure using van der Waals equation

$\left(P + a\frac{n^2}{V^2}\right)(V - b \cdot n) = nRT$

$P = \frac{nRT}{V - b \cdot n} - a\frac{n^2}{V^2}$

$P = \frac{(28.1\ mol)\left(8.314\ 462 \frac{Pa \cdot m^3}{mol \cdot K}\right)(273.15\ K)}{(5.00 \times 10^{-3}\ m^3) - \left(4.31 \times 10^{-5} \frac{m^3}{mol}\right)(28.1\ mol)} - \left(0.2303 \frac{Pa \cdot m^6}{mol^2}\right)\frac{(28.1\ mol)^2}{(5.00 \times 10^{-3}\ m^3)^2}$

$P = (1.6804119 \times 10^7 Pa) - (7.25 \times 10^6 Pa)$

$P = 9.6 \times 10^6 Pa \times \frac{1\ bar}{10^5\ Pa} = 96\ bar$

Step 5: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

This is a really high pressure, but it's a lot of gas in a small container so it might be reasonable. This pressure is lower than what we'd get using the ideal gas law (127 bar) – which is what we expect for most gases when they behave nonideally. (Exceptions being very small and nonpolar like He.)