2021

AP® CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

Inside:

Free Response Question 7

☑ Scoring Guideline

☑ Student Samples

☑ Scoring Commentary

Question 7: Short Answer — 4 points

(a) For the correct calculated value: **1 point**

Accept one of the following:

- $0.325 \text{ mol } O_2 \times \dfrac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 10.4 \text{ g } O_2$

  $D = \dfrac{m}{V} = \dfrac{10.4 \text{ g}}{7.95 \text{ L}} = 1.31 \text{ g/L}$

- $D = \dfrac{m}{V} = \dfrac{P(MM)}{RT} = \dfrac{(1.0 \text{ atm})(32.00 \text{ g/mol})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(298 \text{ K})} = 1.31 \text{ g/L}$

(b) For the correct answer and a valid justification: **1 point**

Accept one of the following:

- *No, the density of the gas remains constant because P, R, and T remain constant AND the mass and volume of O_2 decrease proportionately.*
- *A mathematical justification is shown below.*

$$D = \frac{m}{V} = \frac{n \text{ moles of } O_2 \times \text{molar mass of } O_2}{\frac{nRT}{P}} = \frac{P \times (\text{molar mass of } O_2)}{RT}$$

(c) For a valid explanation: **1 point**

Accept one of the following:

- *As the gas cools, the average kinetic energy (speed) of the O_2 molecules decreases. The molecules rebound with less energy when they collide with each other and the walls of the container. The spacing between particles decreases, causing the volume occupied by the gas to decrease.*

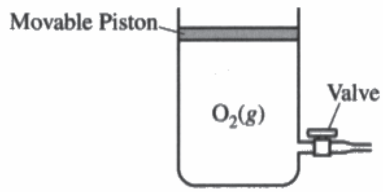
- *As the gas cools, the average kinetic energy (speed) of the O_2 molecules decreases. The molecules rebound with less energy when they collide with each other and the walls of the container. The only way for the molecules to maintain a constant rate of collisions with the walls of the container (maintaining a pressure of 1.00 atm) is for the volume of the gas to decrease.*

(d) For a valid explanation: **1 point**

The ideal gas law assumes that gas particles do not experience interparticle attractions. As a real gas cools further, the intermolecular forces have greater effect as the average speed of the molecules decreases, resulting in inelastic collisions. To maintain a gas pressure of 1.00 atm, the volume must decrease to accommodate more collisions with less energy.

Total for question 7 — 4 points

Begin your response to **QUESTION 7** on this page.



7. A student investigates gas behavior using a rigid cylinder with a movable piston of negligible mass, as shown in the diagram above. The cylinder contains 0.325 mol of $O_2(g)$.

(a) The cylinder has a volume of 7.95 L at 25°C and 1.00 atm. Calculate the density of the $O_2(g)$, in g/L, under these conditions.

$$0.325 \text{ mols } O_2 \cdot \frac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = \frac{10.4 \text{ g } O_2}{7.95 \text{ L } O_2} = \boxed{1.31 \frac{g}{L}}$$

Density =

(b) Attempting to change the density of the $O_2(g)$, the student opens the valve on the side of the cylinder, pushes down on the piston to release some of the gas, and closes the valve again. The temperature of the gas remains constant at 25°C. Will this action change the density of the gas remaining in the cylinder? Justify your answer.

No, it shouldn't. Since the gas is uniformly distributed throughout the container, pushing the piston down and releasing some gas changes volume and mass proportionately. Since the piston is not restored to its original state, the density is constant.

Continue your response to **QUESTION 7** on this page.

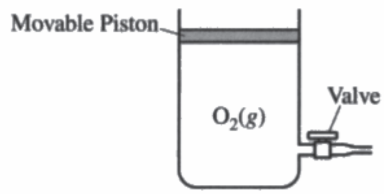
(c) The student tries to change the density of the $O_2(g)$ by cooling the cylinder to $-55°C$, which causes the volume of the gas to decrease. Using principles of kinetic molecular theory, explain why the volume of the $O_2(g)$ decreases when the temperature decreases to $-55°C$.

The speed of O_2 decrease and their force against container walls decreases; since this outward pushing energy is decreased, the volume decreases with it.

(d) The student further cools the cylinder to $-180°C$ and observes that the measured volume of the $O_2(g)$ is substantially smaller than the volume that is calculated using the ideal gas law. Assume all equipment is functioning properly. Explain why the measured volume of the $O_2(g)$ is smaller than the calculated volume. (The boiling point of $O_2(l)$ is $-183°C$.)

At -180°C, the molecules of O_2 begin experiencing intramolecular forces between themselves and other molecules, reducing their volume by forming attractions that bring them closer together.

Begin your response to **QUESTION 7** on this page.



7. A student investigates gas behavior using a rigid cylinder with a movable piston of negligible mass, as shown in the diagram above. The cylinder contains 0.325 mol of $O_2(g)$.

(a) The cylinder has a volume of 7.95 L at 25°C and 1.00 atm. Calculate the density of the $O_2(g)$, in g/L, under these conditions.

~~$PV = nRT$~~

~~$V = \frac{nRT}{P}$~~

$0.325 \text{ mol } O_2 \times \frac{32 \text{ g } O_2}{1 \text{ mol } O_2} = 10.4 \text{ g } O_2$

$d = \frac{10.4 \text{ g } O_2}{7.95 \text{ L}} \rightarrow 1.308$

$\boxed{\text{density: } 1.31 \text{ g/L } O_2}$

(b) Attempting to change the density of the $O_2(g)$, the student opens the valve on the side of the cylinder, pushes down on the piston to release some of the gas, and closes the valve again. The temperature of the gas remains constant at 25°C. Will this action change the density of the gas remaining in the cylinder? Justify your answer.

decrease volume
decrease mols

This action will not change the density because this action decreases both the volume and mass of gas in the container. Since both decreased the same amount/ for the same amount of time, the density won't change.

Continue your response to **QUESTION 7** on this page.

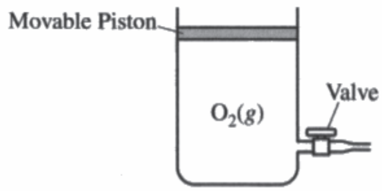
(c) The student tries to change the density of the $O_2(g)$ by cooling the cylinder to $-55°C$, which causes the volume of the gas to decrease. Using principles of kinetic molecular theory, explain why the volume of the $O_2(g)$ decreases when the temperature decreases to $-55°C$.

The volume of O_2 decreases when the temperature decreases because of the equation $PV=nRT$. Since ~~volume~~ the temperature decreased, the volume must also increase ~~becaus~~ in order to keep the equation equal.

(d) The student further cools the cylinder to $-180°C$ and observes that the measured volume of the $O_2(g)$ is substantially smaller than the volume that is calculated using the ideal gas law. Assume all equipment is functioning properly. Explain why the measured volume of the $O_2(g)$ is smaller than the calculated volume. (The boiling point of $O_2(l)$ is $-183°C$.)

The measured volume of O_2 is smaller than the calculated volume because the calculated volume pertains to a gas that's "ideal", while the real measured volume is for a real gas, which is why the measured volume is smaller.

Begin your response to **QUESTION 7** on this page.



7. A student investigates gas behavior using a rigid cylinder with a movable piston of negligible mass, as shown in the diagram above. The cylinder contains 0.325 mol of $O_2(g)$.

(a) The cylinder has a volume of 7.95 L at 25°C and 1.00 atm. Calculate the density of the $O_2(g)$, in g/L, under these conditions.

$D = \frac{m}{V}$ $D = \frac{11.264\,g}{7.95\,L}$

$\frac{.0.325 \text{ mol } O_2}{} \times \frac{32.00 g O_2}{1 \text{ mol}}$

$= 11.264$ g

$\boxed{D = 1.416 \text{ g/L}}$

(b) Attempting to change the density of the $O_2(g)$, the student opens the valve on the side of the cylinder, pushes down on the piston to release some of the gas, and closes the valve again. The temperature of the gas remains constant at 25°C. Will this action change the density of the gas remaining in the cylinder? Justify your answer.

NO. because if the mass goes down so does the volume. They are proportionate.

Continue your response to **QUESTION 7** on this page.

(c) The student tries to change the density of the $O_2(g)$ by cooling the cylinder to $-55°C$, which causes the volume of the gas to decrease. Using principles of kinetic molecular theory, explain why the volume of the $O_2(g)$ decreases when the temperature decreases to $-55°C$.

Since the gas is getting cooled, it is condensing and becoming smaller. The volume then decreases.

(d) The student further cools the cylinder to $-180°C$ and observes that the measured volume of the $O_2(g)$ is substantially smaller than the volume that is calculated using the ideal gas law. Assume all equipment is functioning properly. Explain why the measured volume of the $O_2(g)$ is smaller than the calculated volume. (The boiling point of $O_2(l)$ is $-183°C$.)

It is slowly approaching its boiling point which means it is forming a precipitate and condensing.

Question 7

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 7 involves a sample of O_2 inside a container with a movable piston. In part (a), the student must calculate the density of the gas based upon its mass and volume (SPQ-1.A, 5.F). Part (b) asks whether releasing some of the gas from the container will change the density of the gas, and to justify the answer (SAP-7.A, 2.B). The volume of the gas decreases upon cooling, and part (c) asks the student to explain this observation in terms of kinetic molecular theory (SAP-6.A, 4.C). Part (d) requires an explanation for why the measured volume of O_2 gas deviates from that predicted by the ideal gas law at low temperature (SAP7.C, 4.C).

Sample: 7A
Score: 3

In part (a), the point was earned for correctly calculating the mass of $O_2(g)$ from the moles and the molar mass and then calculating the density of the $O_2(g)$ as 1.31 g/L using the appropriate mass and volume. In part (b), the point was earned for indicating that the density did not change and that releasing some gas decreases volume and mass proportionately. In part (c), the point was earned for formulating a response that was focused on particle behavior based upon a postulate from the kinetic molecular theory. The response included a statement that links the decrease in temperature to a decrease in speed of O_2 gas phase molecules, to a decrease in the force of the molecules striking the walls of the container. This results in an initial decrease in pressure which is compensated for by a decrease in volume. In part (d), no point was earned because the response does not make clear that at low temperature, intermolecular forces become more effective at causing inelastic collisions and reducing the number of particles that collide. In order to maintain a pressure of 1.00 atm at –180°C, the volume must decrease to maintain a constant rate of collisions in less volume. Also, the response erroneously states that molecules of O_2 begin experiencing "intramolecular forces" when the proper term to use is "intermolecular forces."

Sample: 7B
Score: 2

In part (a), the point was earned for correctly calculating the mass of O_2 (g). In part (b), the point was earned for stating that the density of the O_2 gas would not change and indicating that the mass and volume "decreased the same amount/for the same amount of time," thus implying a similar rate of change, which indicates proportionality. In part (c), the point was not earned because the response does not include components of the kinetic molecular theory and less energetic collision of particles at the lower temperature. The response includes a discussion of the gas equation (volume is proportional to temperature), which does not address the prompt. In part (d), the point was not earned because the response does not discuss the fact that real gases have a contribution of intermolecular forces of attraction at low temperature. Intermolecular forces of attraction are a factor in slowing the average speed of molecules, resulting in a decrease in volume. The response does identify that the measured volume is for real gases and the calculated volume is for ideal gases, but the response does not explain why the measured volume is smaller than the calculated volume.

Sample: 7C
Score: 1

In part (a), the point was not earned because the response shows 0.325 mole O_2 multiplied by 32.00 g O_2/1 mol yields 11.264 g, which is incorrect. The incorrect value of mass caused the value of the reported density to be incorrect. In part (b), the point was earned for correctly stating "No", the density will not change and that "if the mass goes down so does the volume" and "They are proportionate." In part (c), the point was not earned because the statement that the gas "is condensing and becoming smaller" indicates that the gas is becoming a liquid at –180°C and 1.00 atm pressure, which is incorrect. Also, a kinetic molecular theory explanation is not included.

Question 7 (continued)

In part (d), the point was not earned because the reason offered for a decrease in volume is that the gas is "forming a precipitate and condensing." This statement indicates that the gas is becoming a solid and a liquid at –180°C and 1.00 atm, which is incorrect. In addition, the response does not include a discussion of the influence an increased effectiveness of intermolecular forces acting on O_2 gas phase molecules has on molecular speed and molecular collisions.