Student #: _____ Student Name: _____

# AP PHYSICS 2: THERMODYNAMICS

**Directions:** Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and place the letter of your choice in the corresponding box on the student answer sheet.

**Note:** To simplify calculations, you may use $g = 10\,\text{m/s}^2$ in all problems.

1. Air is made up primarily of nitrogen and oxygen. In an enclosed room with a constant temperature, which of the following statements is correct concerning the nitrogen and oxygen gases?
   (A) The nitrogen gas molecules have a higher average kinetic energy than the oxygen gas molecules.
   (B) The nitrogen gas molecules have the same average kinetic energy as the oxygen gas molecules.
   (C) The nitrogen gas molecules have a lower average kinetic energy than the oxygen gas molecules.
   (D) More information is necessary to compare the average kinetic energies of the two gases.

2. Air is made up primarily of nitrogen and oxygen. In an enclosed room with a constant temperature, which of the following statements is correct concerning the nitrogen and oxygen gases?
   (A) The nitrogen gas molecules have a higher velocity than the oxygen gas molecules.
   (B) The nitrogen gas molecules have the same velocity as the oxygen gas molecules.
   (C) The nitrogen gas molecules have a lower velocity than the oxygen gas molecules.
   (D) It is impossible to compare the velocity of the two gases without knowing the temperature of the air and the percentage of nitrogen and oxygen in the room.

3. When using the ideal gas law, $PV = nRT$,
   (A) $P$ can be gauge pressure
   (B) $N$ can be in kilograms
   (C) $T$ can be in degrees Celsius
   (D) none of the above

4. For ideal gases, the ratio $PV/T$ is
   (A) equal to Avogadro's number
   (B) equal to Boltzmann's constant
   (C) independent of the number of molecules
   (D) independent of the chemical nature of the molecules

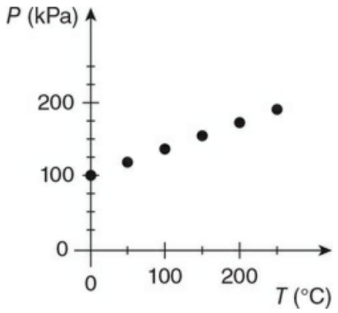
5. The volume of an ideal gas at constant pressure is proportional to its
   (A) Fahrenheit temperature
   (B) Celsius temperature
   (C) Absolute temperature
   (D) Molar mass

6. In an experiment, a gas is confined in a cylinder with a movable piston. Force is applied to the piston to increase the pressure and change the volume of the gas. Each time the gas is compressed, it is allowed to return to a room temperature of 20 °C. The data gathered from the experiment is shown in the table. What should be plotted on the vertical and horizontal axes so the slope of the graph can be used to determine the number of moles of gas in the cylinder?

| **Pressure** $10^5$ Pa | **Volume** $10^{-3}$ m$^3$ |
|---|---|
| 1.0 | 25 |
| 1.5 | 17 |
| 1.8 | 14 |
| 2.2 | 11 |
| 2.6 | 9.6 |
| 3.3 | 7.6 |

   (A) $P$ and $V_2$
   (B) $P$ and $V$
   (C) $P$ and $V^{1/2}$
   (D) $P$ and $1/V$

7. In an experiment, a sealed container with a volume of 100 ml is filled with hydrogen gas. The container is heated to a variety of temperatures, and the pressure is measured. The data from the experiment is plotted in the figure. Which of the following methods can be used to determine additional information regarding the gas? Select two answers.




(A) The slope can be used to calculate the number of atoms in the gas.
(B) The area under the graph can be used to calculate the work done by the gas.
(C) The vertical axis can be used to calculate the force the gas exerts on the container.
(D) The $x$-intercept can be used to estimate the value of absolute zero.

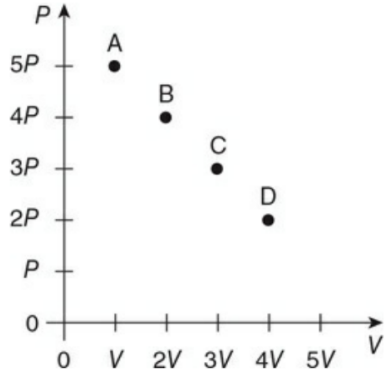
8. Two identical rooms are connected by an open door. The temperature in one room is greater than the temperature in the other. Which room contains the most gas molecules?

(A) The warmer room.
(B) The colder room.
(C) The number of gas molecules will be the same in both rooms.
(D) It is impossible to determine without more information.

9. On a hiking trip in the mountains, where the air temperature is cool and has a lower concentration of oxygen, you seal an empty water bottle. You return to your home near sea level where the air temperature is warm and has a higher concentration of oxygen. You notice that the sealed bottle appears partially crushed. Which of the following would contribute to the decrease in volume of the bottle?

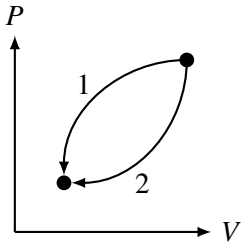
(A) The change in temperature
(B) The change in atmospheric pressure
(C) The change in oxygen concentration
(D) The change in temperature, pressure, and oxygen concentration

10. The figure shows the pressure and volume of a gas at four different states. Which of the following correctly ranks the temperature of the gas at the different states?



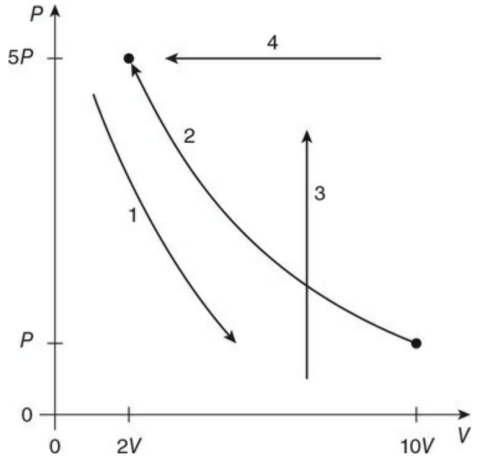

(A) $T_A > T_B > T_C > T_D$
(B) $T_B = T_C > T_A = T_D$
(C) $T_C > T_B = T_D > T_A$
(D) $T_D > T_C > T_B > T_A$

11. Which of the following is correct concerning the two processes shown in the figure?




(A) $\Delta U_1 = \Delta U_2$ and $W_1 = W_2$
(B) $\Delta U_1 = \Delta U_2$ and $W_1 > W_2$
(C) $\Delta U_1 > \Delta U_2$ and $W_1 = W_2$
(D) $\Delta U_1 > \Delta U_2$ and $W_1 \geq W_2$

12. The figure shows four samples of gas being taken through four different processes. Process 1 is adiabatic. In which process is heat being transferred to the gas sample from the environment?



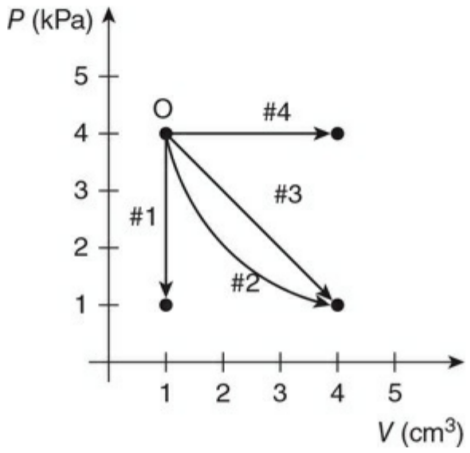

(A) 1
(B) 2
(C) 3
(D) 4

13. Two sealed cylinders holding different gases are placed one on top of the other so heat can flow between them. Cylinder A is filled with hydrogen. Cylinder B is filled with helium moving with an average speed that is half that of the hydrogen atoms. Helium atoms have four times the mass of hydrogen atoms. Which of the following best describes the transfer of heat between the two containers by conduction?

(A) Net heat flows from cylinder A to cylinder B, because heat flows from higher kinetic energy atoms to lower kinetic energy atoms.
(B) Net heat flows from cylinder B to cylinder A, because heat flows from higher kinetic energy atoms to lower kinetic energy atoms.
(C) There is no net heat transfer between the two cylinders, because both gases have the same average atomic kinetic energy.
(D) There is no net heat transfer between the two cylinders, because heat conduction requires the movement of atoms between the cylinder, and the cylinders are sealed.

**Questions 14 and 15**

A gas beginning at point O on the graph can be taken along four paths to different ending conditions.



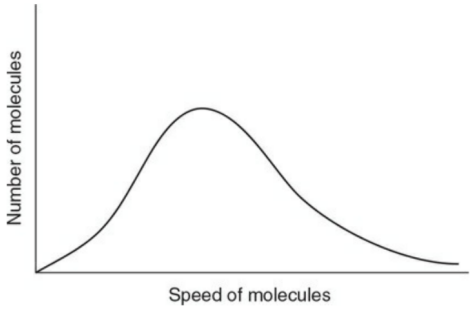

14. Which of the following are the same for processes 2 and 3? *Select two answers.*

(A) $Q$
(B) $\Delta T$
(C) $\Delta U$
(D) $W$

15. Along which of the paths is the most thermal energy removed from the gas?

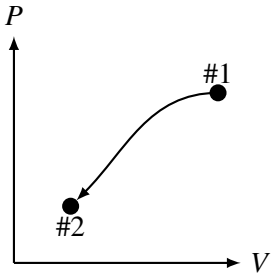
(A) 1
(B) 2
(C) 3
(D) 4

16. The graph shows the distribution of speeds for one mole of hydrogen at temperature $T$, pressure $P$, and volume $V$. How would the graph change if the sample was changed from one mole hydrogen to one mole of argon at the same temperature, pressure, and volume?




(A) The peak will shift to the left
(B) The peak will shift upward and to the left
(C) The peak will shift to the right
(D) The peak will shift downward and to the right

17. The graph shows the pressure and volume of a gas being taken from state #1 to state #2. Which of the following correctly indicates the sign of the work done by the gas, and the change in temperature of the gas?




| | **Work done** | **$\Delta$ Temperature** |
|---|---|---|
| (A) | + | + |
| (B) | + | − |
| (C) | − | + |
| (D) | − | − |

18. What is the volume of one mole of ideal gas at 300 K and at standard atmospheric pressure?

(A) 23.21
(B) 24.11
(C) 24.61
(D) 25.71

19. A fixed mass of oxygen ($O_2$, molecular mass 32 g/mol) is contained in a cylinder whose volume is 2.80 liters. The pressure is 148 atm when the temperature is 23 °C. Find the mass of oxygen in the cylinder.

(A) 20 g
(B) 80 g
(C) 140 g
(D) 280 g
(E) 546 g

20. A tire is filled with air at 15 °C to a gauge pressure of $2.2 \times 10^5$ Pa. If the tire reaches a temperature of 38 °C, what will the new gauge pressure be inside it?

(A) $2.4 \times 10^2$ Pa
(B) $3.4 \times 10^3$ Pa
(C) $2.4 \times 10^5$ Pa
(D) $6.0 \times 10^7$ Pa
(E) $8.0 \times 10^9$ Pa

21. A fixed mass of an ideal gas having a volume of 2500 $cm^3$ at 20 °C and absolute pressure of 65 atm expands until its volume is 4000 $cm^3$ and its absolute pressure is 45 atm. Find its new temperature.

(A) 20 °C
(B) 42.3 °C
(C) 51.6 °C
(D) 61.8 °C
(E) 80 °C

22. A fixed mass of an ideal gas is in a container with a constant volume. By what factor will the pressure change if the absolute temperature is tripled?

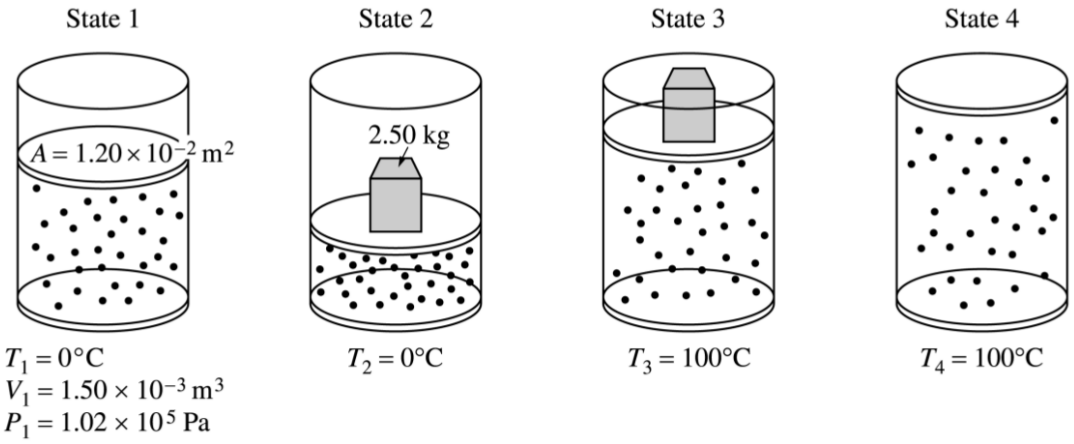
(A) 1/9
(B) 1/3
(C) 3
(D) 9

23. If the pressure of gas is doubled and the temperature is constant, then the volume is what factor times the original?

(A) 2
(B) 1/2
(C) 1/4
(D) 4

**AP PHYSICS 2: Thermodynamics of Gases**
**SECTION II**
**4 Questions**

**Directions:** Answer all questions. The parts within a question may not have equal weight. All final numerical answers should include appropriate units. Credit depends on the quality of your solutions and explanations, so you should show your work. Credit also depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should clearly indicate which part of a question your work is for.




Note: Figure not drawn to scale.

1. A cylinder is fitted with a freely movable piston of area $1.20 \times 10^{-2}$ m$^2$ and negligible mass. The cylinder below the piston is filled with a gas. At state 1, the gas has volume $1.50 \times 10^{-3}$ m$^3$, pressure $1.02 \times 10^5$ Pa, and the cylinder is in contact with a water bath at a temperature of 0 °C. The gas is then taken through the following four-step process.

   - A 2.50 kg metal block is placed on top of the piston, compressing the gas to state 2, with the gas still at 0 °C.
   - The cylinder is then brought in contact with a boiling water bath, raising the gas temperature to 100 °C at state 3.
   - The metal block is removed and the gas expands to state 4 still at 100 °C.
   - Finally, the cylinder is again placed in contact with the water bath at 0 °C, returning the system to state 1.

   (a) Determine the pressure of the gas in state 2.

   (b) Determine the volume of the gas in state 2.

   (c) Indicate below whether the process from state 2 to state 3 is isothermal, isobaric, or adiabatic.

   ____ Isothermal ____ Isobaric ____ Adiabatic

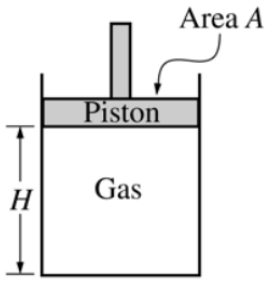
   Explain your reasoning.

(d) Is the process from state 4 to state 1 isobaric?

____Yes ____ No

Explain your reasoning.

(e) Determine the volume of the gas in state 4.

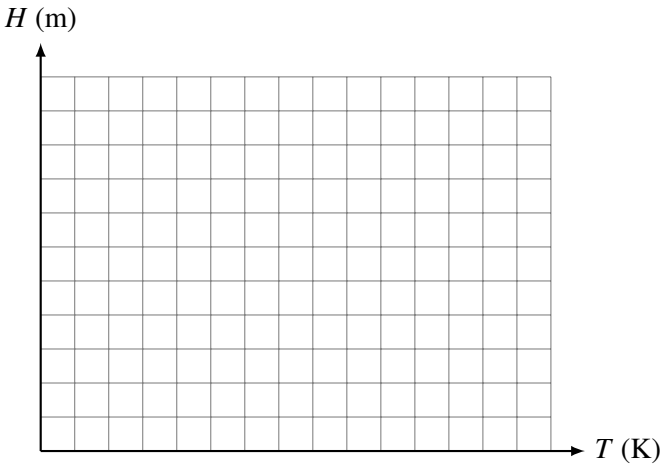



2. An experiment is performed to determine the number $n$ of moles of an ideal gas in the cylinder shown above. The cylinder is fitted with a movable, frictionless piston of area $A$. The piston is in equilibrium and is supported by the pressure of the gas. The gas is heated while its pressure $P$ remains constant. Measurements are made of the temperature $T$ of the gas and the height $H$ of the bottom of the piston above the base of the cylinder and are recorded in the table below. Assume that the thermal expansion of the apparatus can be ignored.

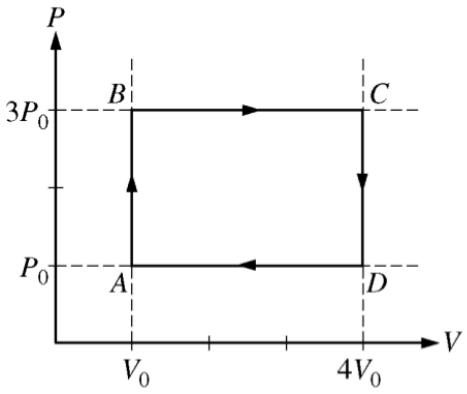
| $T$ (K) | $H$ (m) |
|---|---|
| 300 | 1.11 |
| 325 | 1.19 |
| 355 | 1.29 |
| 375 | 1.37 |
| 405 | 1.47 |

(a) Write a relationship between the quantities $T$ and $H$, in terms of the given quantities and fundamental constants, that will allow you to determine $n$.

(b) Plot the data on the axes below so that you will be able to determine $n$ from the relationship in part (a). Label the axes with appropriate numbers to show the scale.



(c) Using your graph and the values $A = 0.027\,\text{m}^2$ and $P = 1.0\,\text{atm}$, determine the experimental value of $n$.




3. A sample containing three moles of an ideal gas is taken through a series of equilibrium states, as represented by the closed path $ABCDA$ in the diagram above.

(a) i. Rank the temperatures at the 4 labeled points from least to greatest, using 1 for the lowest temperature. If two or more points have the same temperature, give them the same ranking.

____ A ____ B ____ C ____ D

ii. Determine the temperature $T_D$ at point $D$ in terms of $P_0$, $V_0$, and fundamental constants, as appropriate.

(b) Indicate all segments of the path $ABCDA$, if any, for which the work done by the gas is positive. If the work done by the gas is not positive for any of the segments, then check "None".

____ AB ____ BC ____ CD ____ DA ____ None

Justify your answer.

(c) In process $AB$, is the energy transferred to the gas by heating positive, negative, or zero?

____ Positive ____ Negative ____ Zero

Justify your answer.

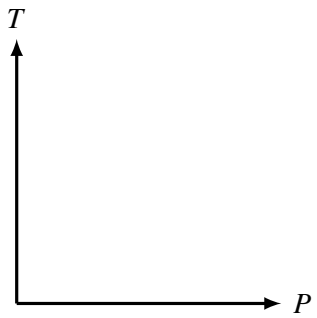
(d) Derive an expression for the net work done on the gas during the entire process $ABCDA$. Express your answer in terms of $P_0$, $V_0$, and fundamental constants, as appropriate.

4. You wish to determine the relationship between gas pressure and temperature.

   (a) List the items you would use to perform this investigation.

   (b) Draw a simple picture of the lab setup, and outline the experimental procedure you would use to gather the necessary data. Indicate the measurements to be taken and how the measurement will be used to obtain the data needed. Make sure your outline contains sufficient detail so that another student could follow your procedure.

   (c) On the axis, sketch the line or curve that you predict will represent the results of the data gathered in this experiment.



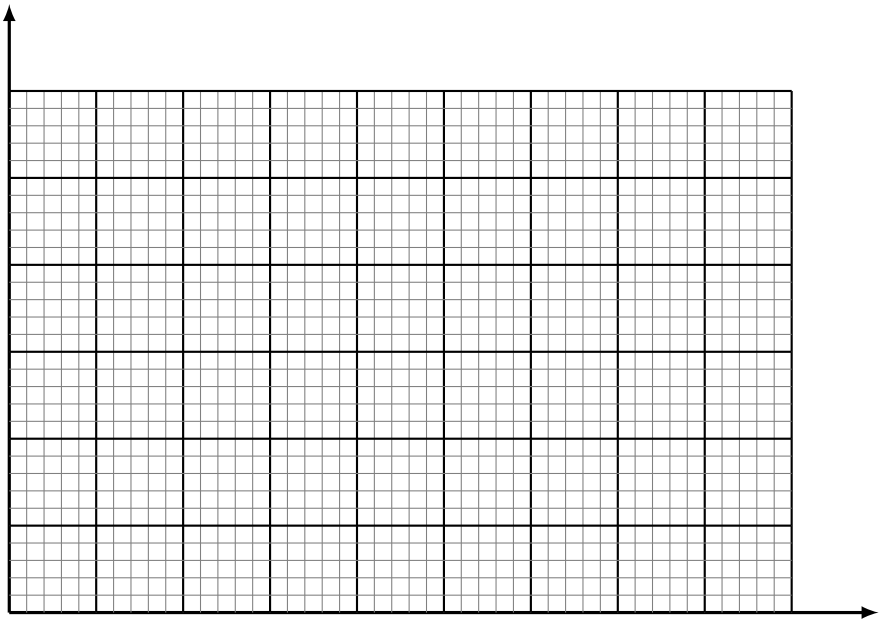

   (d) Explain how you could use your results to estimate the value of absolute zero.

You are given the following set of data acquired in a gas laboratory experiment and asked to determine the relationship between pressures and volume for the gas.

| Trial | Temperature (K) | Volume (ml) | Pressure (kPa) |
|---|---|---|---|
| 1 | 270 | 500 | 8,979 |
| 2 | 270 | 1,000 | 4,490 |
| 3 | 270 | 2,000 | 2,245 |
| 4 | 270 | 5,000 | 898 |
| 5 | 300 | 1,000 | 4,988 |
| 6 | 300 | 2,000 | 2,494 |
| 7 | 300 | 5,000 | 998 |
| 8 | 320 | 1,000 | 5,321 |
| 9 | 320 | 5,000 | 1,064 |
| 10 | 350 | 500 | 11,640 |
| 11 | 350 | 5,000 | 1,164 |
| 12 | 370 | 500 | 12,305 |
| 13 | 370 | 2,000 | 3,076 |
| 14 | 370 | 3,000 | 1,230 |
| 15 | 370 | 6,000 | 769 |

(e) Which subset of the data would be most useful in creating a graph to determine the relationship between gas pressure and volume? Explain why the trials you selected are the most useful.

(f) Plot the subset of data you chose on the graph, being sure to label the axes. Draw a line or curve that best represents the relationship between the variables.



(g) What can you conclude from your line or curve about the relationship between volume and pressure?