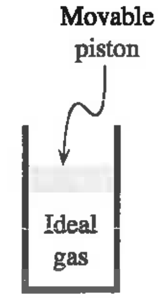
I. Pressure



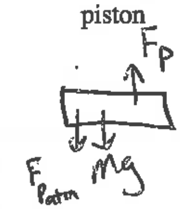
A cylinder contains an ideal gas that is at room temperature. The cylinder is sealed with a piston of mass *M* and cross-sectional area *A* that is free to move up or down without friction. No gas can enter or leave the cylinder. The piston is at rest. Atmospheric pressure (*i.e.*, the pressure of the air surrounding the cylinder) is P_o.

A. In the space provided, draw a free-body diagram for the piston.

Make sure the label for each force indicates:

- the type of force,
- the object on which the force is exerted, and
- the object exerting the force.

Free-body diagram for piston



B. In the space provided, draw an arrow to indicate the direction of the net force on the piston. If the net force is zero, state so explicitly.

Net force on piston

zero

C. Is the force exerted on the piston by the gas *inside* the cylinder *greater than, less than,* or *equal to* the force exerted on the piston by the air *outside* the cylinder? Explain.

greater, to compensate for mg

Write an equation that relates all the forces on your free-body diagram. (*Hint:* How are these forces related to the net force?)

$\Sigma F = 0 = F_p - mg - F_{P_{atm}}$

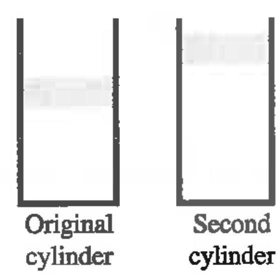
D. Is the pressure of the gas in the cylinder *greater than, less than,* or *equal to* atmospheric pressure? Explain.

greater, to compensate for mg

Determine the value of the pressure of the gas in the cylinder in terms of the given quantities. (*Hint:* Which of the forces that act on the piston can you use to find the pressure of the gas?)

$P = \frac{mg + P_{atm}A}{A}$

E. A second cylinder contains a different sample of ideal gas at room temperature, as shown at right. The two cylinders and their pistons are identical.



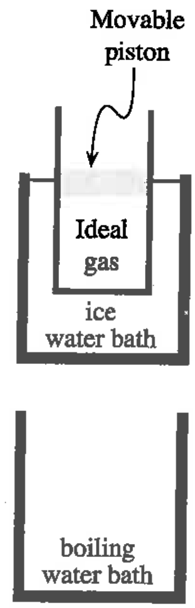
Is the pressure of the gas in the second cylinder *greater than, less than,* or *equal to* the pressure in the cylinder above? If you cannot tell, state so explicitly. Explain.

Equal. The equation from part D does not depend on volume

⇨ Check your answer with a tutorial instructor before you continue.

II. Pressure and temperature

A. A cylinder of the type described in section I contains a fixed amount of gas. Initially, it is in thermal equilibrium with an ice-water bath. The pressure, volume, and temperature of the gas are $P_{initial}$, $V_{initial}$, and $T_{initial}$, respectively.



The cylinder is then removed from the ice water and placed into boiling water. After the system has come to thermal equilibrium with the boiling water the pressure, volume, and temperature are P_{final}, V_{final}, and T_{final}.

1. Is T_{final} *greater than, less than,* or *equal to* $T_{initial}$?

   $T_f > T_i$

2. Is P_{final} *greater than, less than,* or *equal to* $P_{initial}$? Explain.

   $P_f = P_i$ See Equation D on previous page.

   Is your answer consistent with your answer to part D of section I? If not, resolve any inconsistencies.

   Yes

3. Is V_{final} *greater than, less than,* or *equal to* $V_{initial}$? Explain.

   $V_f > V_i$ since $V = \frac{NkT}{P}$ and N & P are constant

   Is your answer consistent with the ideal gas law *(i.e.,* the relationship $PV = nRT$)? If not, resolve any inconsistencies.

   Yes

B. In the process you considered in part A above, which variables are held constant and which are allowed to change? Explain how you can tell.

constant N, P
change T, V

C. Consider the following student dialogue.

Student 1: *"According to the ideal gas law, the pressure is proportional to the temperature. Since I increased the temperature of the gas, the pressure must go up."*

Student 2: *"That's right. Since no gas entered or left the system, the volume did not change. So the pressure must have increased."*

Do you agree with either of the students? Explain your reasoning.

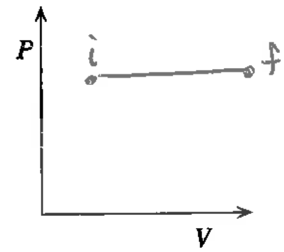
No P is constant, V changes

➪ Check your reasoning with a tutorial instructor before you continue.

III. *PV* diagrams

Ideal gas processes are often represented graphically. For instance, a ***PV diagram*** is a graph of pressure *versus* volume for a given sample of gas. A single point on the graph represents simultaneously measured values of pressure and volume. These values define a *state* of the gas.

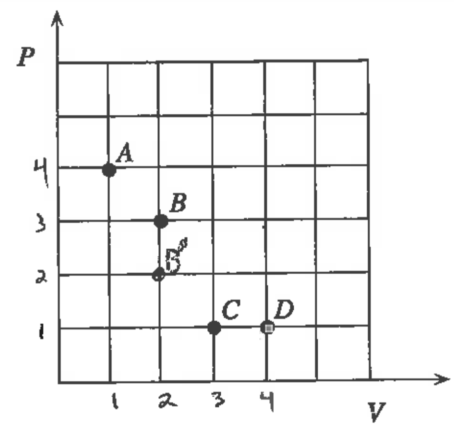
A. Sketch the process described in section II on the *PV* diagram provided. Label the initial and final states of the gas.



Is your sketch consistent with your answer in part B of section II? Explain.

Yes

B. The same sample of ideal gas is used for a new experiment. The pressure and volume of the gas are measured at several times. The values of *P* and *V* are recorded on the diagram shown at right.



1. Rank the temperatures of the gas in states *A*, *B*, *C*, and *D* from largest to smallest. If any two temperatures are the same, state so explicitly.

$T_B > T_A = T_D > T_C$

6 4 4 3

2. Is your ranking consistent with the ideal gas law?

✓

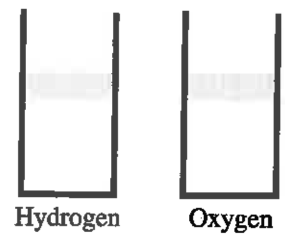
3. Is it possible for the gas to be in a state in which it has the same volume as in state *B* and the same temperature as in state *A*? If so, mark the location of the state on the *PV* diagram. If not, explain why not.

B' : $2 \times 2 = 4 = 4 \times 1$

⇨ Check your reasoning with a tutorial instructor before you continue.

IV. Avogadro's number

A. Two identical cylinders of the type described above contain hydrogen and oxygen, respectively. Both cylinders have been in the same room for a long time. Their pistons are at the same height.



1. Compare the volumes of the gases in the two cylinders. Explain.

   $V_{H_2} = V_{O_2}$

2. Compare the temperatures of the gases in the two cylinders. Explain.

   $T_{H_2} = T_{O_2}$

3. Compare the pressures in the two cylinders. Explain.

   $P_{H_2} = P_{O_2}$ since both pressures counteract $mg + P_{atm}$

4. Compare the number of moles in the two cylinders. Explain.

   $\frac{N_{H_2}}{N_{O_2}} = \frac{PV/kT_{H_2}}{PV/kT_{O_2}} = 1$

   Is your answer consistent with the ideal gas law?

   ✓.

B. A student looks up the molar masses and finds the values 2 $\frac{g}{mol}$ (for H_2) and 32 $\frac{g}{mol}$ (for O_2).

1. Give an *interpretation* of these two numbers. (*Note:* A formula is not considered an interpretation.)

   H_2: proton + proton O_2: $(8p + 8n) + (8p + 8n)$

2. Compare the masses of the gas samples in the two containers. Explain.

   $M_{O_2} = 16\, M_{H_2}$

C. Consider the following student discussion.

Student 1: *"Since hydrogen molecules are so much smaller than oxygen molecules, there should be more of them in the same volume."*

Student 2: *"No, since n = 2 for hydrogen, and n = 32 for oxygen, there must be more oxygen molecules."*

Find the flaws in the statements of both students. Explain.

$N_{O_2} = N_{H_2}$

⇨ Check your reasoning with a tutorial instructor.