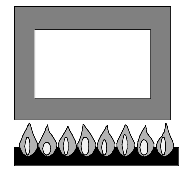
PhyzSpringboard: PV Processes

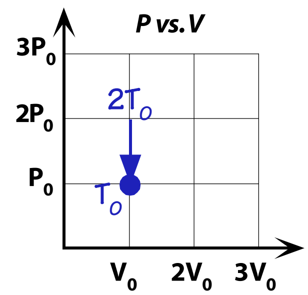
When keeping track of thermodynamic processes and cycles that occur in a sample of gas, it is useful to use graphs of pressure vs. volume.

BASIC PROCESSES

1. Consider a closed container of gas. It encloses a certain volume of gas (V_0) at a certain pressure (P_0) and a certain temperature (T_0).



a. Plot that point on the graph shown to the right.



b. If the gas were heated, what would happen to its volume and pressure? Describe what would happen and show the result on the plot.

Volume remains constant, pressure increases.

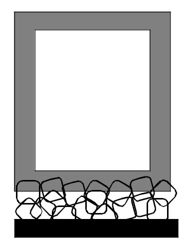
c. What became of the heat added?

It increased the internal energy.

d. What happened to the temperature of the gas? (Suppose the pressure in the gas went to $2P_0$.) Label both temperatures at the corresponding points on the graph.

Temperature increased from T_0 to $2T_0$.

2. Consider a closed container of gas. It encloses a certain volume of gas ($2V_0$) at a certain pressure ($2P_0$).



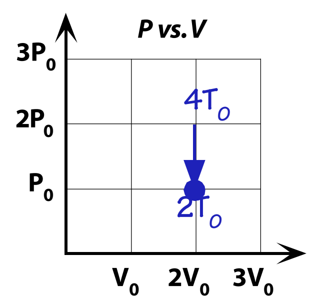
a. Plot that point on the graph shown to the right.

b. If the gas were cooled, what would happen to its volume and pressure? Describe what would happen and show the result on the plot.

Volume remains constant, pressure decreases.

c. What decreased in equal measure with the heat removed?

Internal energy.



d. What happened to the temperature of the gas? (What was the temperature of the $2V_0$ of gas when the pressure was $2P_0$, and what did it become if the pressure went down to P_0?) Write the values of the temperature (in terms of T_0) at the corresponding points on the plot.

Temperature decreased from $4T_0$ to $2T_0$.

e. Because processes 1 and 2 occur at constant volume, they are called...

Isovolumic or isochoric.

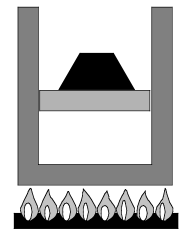
f. Notice that no work is done in this kind of process. The first law of thermodynamics simplifies. Write the simplified form.

$U = Q$

g. Write an expression for the heat (Q) in terms of the number of moles (n), molar specific heat of the gas at constant volume (C_V) and change in temperature (T).

$Q = nC_V\ T$

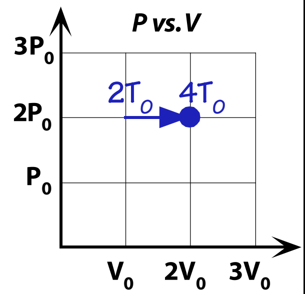
3. Consider a cylinder of gas with frictionless walls and a weighted piston. It encloses a certain volume of gas (V_0) at a certain pressure ($2P_0$) and a certain temperature ($2T_0$). The piston is free to move up or down.



a. What holds the piston up?

Gas particles colliding with the piston.

b. Plot that point on the graph shown to the right.



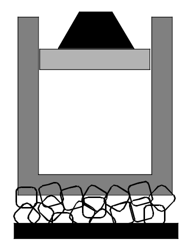
c. If the gas were heated, what would happen to its volume and pressure? Describe what would happen and show the result on the plot.

Pressure remains constant while volume increases.

d. What happened to the temperature of the gas? (Suppose the volume of the gas went to $2V_0$.) Label both temperatures at the corresponding points on the graph.

Temperature increases from $2T_0$ to $4T_0$.

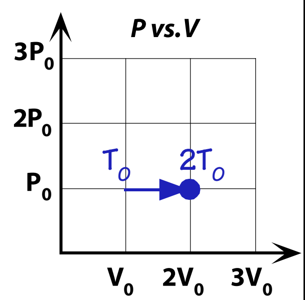
4. Consider another cylinder of gas with a frictionless piston. It encloses a certain volume of gas ($2V_0$) at a certain pressure (P_0).



a. Plot that point on the graph shown below to the right.

b. If the gas were cooled, what would happen to its volume and pressure? Describe what would happen and show the result on the plot.

Pressure remains constant while volume decreases.



c. What happened to the temperature of the gas? (What was the temperature of the $2V_0$ of gas when the pressure was P_0, and what did it become if the volume went down to V_0?) Write the values of the temperature (in terms of T_0) at the corresponding points on the plot.

Temperature decreases from $2T_0$ to T_0.

5. a. Because processes 3 and 4 occur at constant pressure, they are called...

Isobaric

b. Write an expression for the heat (Q) in terms of the number of moles (n), molar specific heat of the gas at constant pressure (C_p) and change in temperature (T).

$Q = nC_p\ T$

WORK

6. Work **is** done in this kind of process. Determine an expression of the work as follows.

a. Write an expression of pressure in terms force (F) and area (A).

$P = F/A$

b. Write an expression for the change in volume in terms of the distance the piston moved (*d*) and the cross-sectional area (*A*) of the piston.

$V = Ad$

c. Multiply the expression for the pressure by the expression for the change in volume. What do you get and how is it represented on the *PV* diagram?

$P\ \ V = (F/A)Ad = Fd$ = Work! Area under the plot.

d. Distinguish between when **positive** work is done **on** a gas, when **negative** work is done **on** a gas, and when **no** work is done **on** a gas.

Positive work when piston falls;
neg when piston rises;
zero when piston neither rises nor falls.

e. i. Calculate the work done **on** the gas in the process in question 1.

$W = -P\ \ V = P_0 \cdot (0) = 0$

ii. Calculate the work done **on** the gas in the process in question 2.

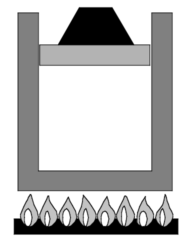
$W = -P\ \ V = P_0 \cdot (0) = 0$

iii. Calculate the work done **on** the gas in the process in question 3.

$W = -P\ \ V = -2P_0 \cdot (+V_0) = -2P_0V_0$

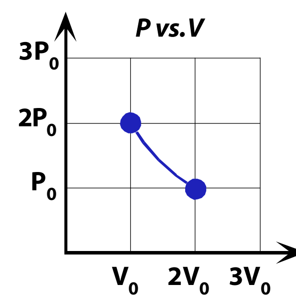
iv. Calculate the work done **on** the gas in the process in question 4.

$W = -P\ \ V = -P_0 \cdot (-V_0) = +P_0V_0$



ADVANCED PROCESSES

7. It is possible to heat the gas in our cylinder-piston arrangement in such a way as to let it expand and undergo a drop in pressure such that it doesn't undergo a change in temperature. Consider a sample of gas that starts with V_0 and $2P_0$. It is heated in such a way that it expands to $2V_0$ while the pressure drops to P_0.



a. What was the temperature at the beginning and end of this process? Label the temperature at both points on the plot.

$P_0V_0/T_0 \quad = \quad 2P_0V_0/2T_0 \quad = \quad P_02V_0/2T_0$

b. Does the internal energy of the gas __increase, __decrease, or __remain constant during this process? Explain.

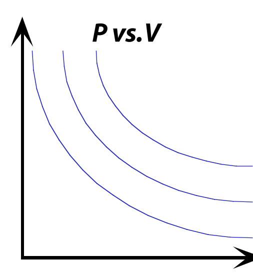
Internal energy varies with temperature: no T means no U.

c. How can the first law of thermodynamics be written (simplified if possible) for this process?

$U = Q + W$ becomes $Q = -W$ (since $U = 0$)

d. Because the temperature remains constant during this process, it's called...

Isothermal

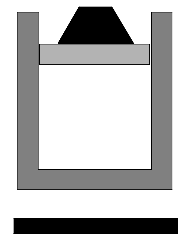


e. Lines of constant temperature on *PV* diagrams are called

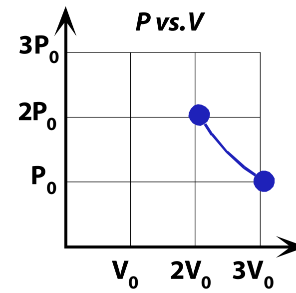
____isotherms____. Sketch a few on the diagram to the right.

f. The gas could have also undergone the reverse process: contracting under increasing pressure.

8. It is possible for the gas in our cylinder-piston arrangement to cool in such a way as to let it expand and undergo a drop in pressure while no heat is being added or removed. Consider a sample of gas that starts with $2V_0$ and $2P_0$. It cools in such a way that it expands to $3V_0$ while the pressure drops to P_0.



a. What was the temperature at the beginning and end of this process? Label the temperature at both points on the plot.



$$P_0V_0/T_0 \;=\; 2P_02V_0/4T_0 \;=\; P_03V_0/3T_0$$

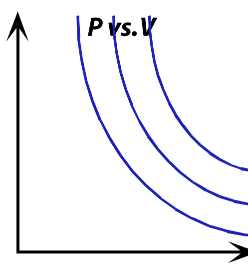
b. How can the first law of thermodynamics be written (simplified if possible) for this process?

U = Q + W becomes U = W (since Q = 0)

c. A process in which heat is neither added nor removed is called...

Adiabatic

d. Lines along which a gas can move on a *PV* diagram when no heat is added or removed are called ________adiabats________. Sketch a few on the diagram to the right. (It is often difficult to visually distinguish these lines from those described in the previous question.)



e. The gas could also contract under increasing pressure and temperature.

SO WHAT?

The processes described in this springboard are the "building blocks" of **thermodynamic cycles.** These cycles are the basis for heat engines such as those used for internal combustion engines (such as the kind still used in automobiles). Whenever heat is used to do mechanical work, thermodynamic cycles are involved.

We will examine thermodynamic cycles next time...