PV DIAGRAMS: A DIATOMIC IDEAL GAS UNDERGOES A RECTANGULAR CYCLE

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Reference: Daniel V. Schroeder, *An Introduction to Thermal Physics*, (Addison-Wesley, 2000) - Problem 1.34.

Here is a slightly more complex example of using a PV diagram to deduce some facts about heat and work flows into or out of an ideal gas. This time, the path is a rectangle starting at P_1 and V_1. On side A, the pressure is increased to P_2 while the volume is held constant. Then on side B, the volume is increased to V_2 while the pressure is constant at P_2. On side C, the pressure is decreased back to P_1 with the volume constant at V_2. Finally, on side D, the volume is decreased back to V_1 with the pressure constant at P_1.

The gas in this case is diatomic, but the temperature is low enough that only the translational and rotational degrees of freedom are excited; vibrational modes are frozen out. This means that the energy of the gas is

$$U = \frac{5}{2}NkT = \frac{5}{2}PV \tag{1}$$

The work done on any path is

$$W = -\int_{V_i}^{V_f} P(V)\,dV \tag{2}$$

and the heat is obtained from conservation of energy

$$Q = \Delta U - W \tag{3}$$

We can do similar calculations to our earlier example of the triangular path to get

Side	W	ΔU	Q
A	0	$\frac{5}{2}V_1(P_2-P_1)$	$\frac{5}{2}V_1(P_2-P_1)$
B	$-P_2(V_2-V_1)$	$\frac{5}{2}P_2(V_2-V_1)$	$\frac{7}{2}P_2(V_2-V_1)$
C	0	$-\frac{5}{2}V_2(P_2-P_1)$	$-\frac{5}{2}V_2(P_2-P_1)$
D	$P_1(V_2-V_1)$	$-\frac{5}{2}P_1(V_2-V_1)$	$-\frac{7}{2}P_1(V_2-V_1)$
Total	$-(P_2-P_1)(V_2-V_1)$	0	$(P_2-P_1)(V_2-V_1)$

Along side A, no work is done, but heat is added to the gas to increase the pressure. Along side B, the gas expands doing work on the piston, but heat must be added to achieve this. Along side C, again no work is done and the gas gives off heat. Along side D, work must be done on the gas to compress it, and in the process the gas gives off heat.

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