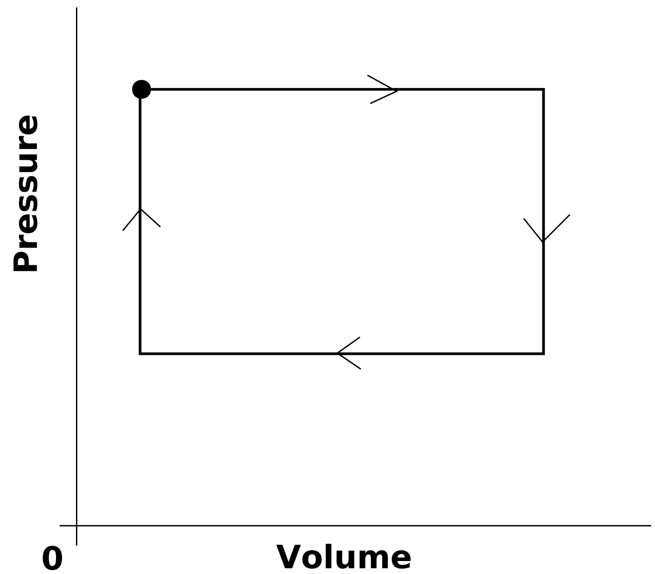
Instructor's guide Before starting this activity, students do need to be taught about heat and work as $đQ = TdS$ and $đW = -pdV$. If this did not happen recently, it might be worth reminding students of these relationships. Otherwise, the handout basically tells them what to do.

1 pV rectangle

This worksheet considers processes that happen at constant pressure, volume, temperature or entropy.

Earlier in PH423, we spent time discussing partial derivatives and how they relate to measurements. Today we will analyze a different type of measurement. The analysis will involve integrals. To visualize this analysis, it's common to use what are called pV diagrams such as the square shown in the Figure.



Note When you consider a pV diagram, you cannot assume that the substance which has pressure p and volume V is an ideal gas. It could equally well be water, or a strange gooey substance that you found on a distant planet. *You can* ***never*** *assume that we are talking about an ideal gas unless it is stated in the problem, or you have explained why the ideal gas as a suitable approximation!*

In your groups, work out the following questions:

1. What does this figure describe? Is p a function of V?
2. What is the net work done after one cycle of this process? How much work was done at each step?
3. What is the net energy transfered by heating over one cycle of this process? Try to find the energy transfered by heating at each step.

Instructor's guide **Student Conversations**

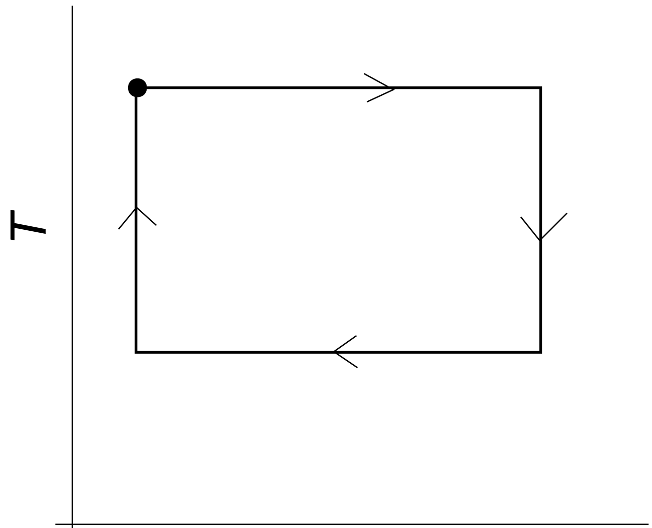
- Some students will claim that because we return to the original state, the net work (or possibly net heat) must be zero.
- Many students will not recognize that on a pV graph, the work is just (the negative of) the area under the curve. While I wouldn't want them to think of this as a definition of work, it is a necessary and useful tool to have in their toolbox.
- It is helpful to ask students to describe what is happening in each stage (e.g. "it is being compressed at fixed pressure... so probably its temperature is dropping, unless it is something weird like ice").

- Some students assume that temperature is fixed when working on the pV plot, because it isn't listed.
- Many students will try to invoke or use the ideal gas law.

2 TS rectangle

Now let's look at another cycle. Let's consider the following figure, which looks similar, but is now a plot of T vs. S, and answer the following questions:

1. What is this cycle? How would you go about running a cycle like this?
2. What is the net heat transfer over one cycle of this process? How much was transfered on each step?
3. What is the net work done after one cycle of this process? How much work was done at each step?



Instructor's guide **Student Conversations**

1. Although the math using TS diagram is effectively identical to that with the pV diagram (with heat and work swapped, and a few minus signs), students will still find the TS diagram challenging.

Instructor's guide

3 Wrap-up

Bring the class back together and have a group argue
if the work is positive or negative on each leg of either the pV or TS curve (instructor's preference of which to analyze first). Help groups resolve any inconsistencies in answers for the work and heat of each leg.

Many students become confused as to if work is being done on or by the system in these plots because of the minus sign associated with the thermodynamic identity term containing pdV. Be sure to point out that if the volume of the system increases, then work is being done by the system; show this by analyzing a leg of the pV curve where the pressure remains constant and the volume increases and display that the total work of the system would be negative.

The analysis of the TS curve should be nearly identical to the pV curve. Be sure to note that the minus sign that appears in the work term is no longer present in the heat expression.