# AP Physics - Heat Engines



***PV Diagrams:*** Pressure/volume graphs are of tremendous value in analyzing the performance of heat engines.

Let’s look at part of a thermodynamic cycle. We will look at the work for each step in the process.

Here is the first step - the process ***a*** → ***b*** represents an isobaric compression of a gas. From ***a*** to ***b***, the pressure remains constant – its value is ***P1*** . The volume decrease from ***V1*** to ***V2***. This represents work done ***on*** the system. It takes work to compress the gas. The work is the area under the curve, which is conveniently shaded in so you can see it. The work is: ***P1 ΔV***.

 

Now let’s look at the next step in the cycle. You can see the PV diagram to the right.

Process ***b*** → ***c*** is an isochoric compression. Isochoric because the volume does not change but the pressure increases. The work for this step is zero. This is because **Δ*V*** is zero.

 

The next step is process ***c*** → ***d***. This is an isobaric expansion. The gas expands from ***V1*** to ***V2***, doing work as it expands. The amount of work is equal to the area under the curve.

 



The final step to complete the cycle is process ***d*** → ***a***. This is an isochoric expansion. The volume stays constant, so no work. The pressure decreases.

 



The whole cycle looks like the graph to the right.

The net work done by the machine in one cycle is the area ***enclosed*** by the curve. It is the sum of the work, positive or negative, for each step in the cycle.

The work is just the difference in the two areas under the curve that we had.



The work done in a cycle depends on the path. Let’s look at the previous cycle and compare it with one that has a different path.



***Cycle 1*** is the one we just looked at. The gas is compressed from ***V2*** to ***V1***, compressed from ***P1*** to ***P2***. Then it is expanded from ***V1*** to ***V2*** and expanded from ***P2*** to ***P1***. Pretty much the same thing happens in ***cycle 2***, except that the two expansions take place in only one step instead of two. This difference is significant however as the net work for ***cycle 1*** is greater (twice the magnitude) than the net work for ***cycle 2***.

* A heat engine’s cycle is shown in the PV diagram to the right. ***P1*** = 345 kPa, ***P2*** = 245 kPa, ***P3*** = 125 k Pa, and ***P4*** = 225 kPa. ***V1*** = 35.0 L and ***V2*** = 85.0 L. What is the net work done during one cycle of the engine?

We can solve this by finding the area under the curve for the ***a*** → ***b*** step. Then we find the area under the curve for the ***c*** → ***d*** step. The net work is the difference in the two areas.

Find volume in m3:



 

Area for ***a*** → ***b***: 









Area for ***c*** → ***d***: 











* A substance undergoes a cyclic process shown in the graph. A work output occurs along path ***a*** → ***b***, a work input is required along path ***b*** → ***c***, and no work is involved in constant volume process ***c*** → ***a***. Heat transfer occurs during each process in the cycle. (a) what is the work output during process ***a*** → ***b***? (b) how much work input is required during process ***b*** → ***c***? (c) What is the net work done during the cycle?

***(a)*** 



  Expansion process, so negative work.

1. This is positive work. *W* = area of rectangle



 (c) 



***The Carnot Cycle:*** Sadi Carnot envisioned a perfect machine that would have the greatest possible efficiency that it could possibly have. We’ve already seen how the equation for this efficiency was developed. But what kind of machine could do that? Well, the machine that Carnot came up with is a simple piston/cylinder device. The operating sequence of the thing is called ***the Carnot cycle***.



Here is the device (the drawing above). The sides and top of the cylinder are insulated so heat cannot flow in or out of the system. The bottom is made of an ideal conductor so that heat can flow in or out of the system through the bottom of the cylinder. Three stands are available for cylinder placement; a hot stand, a cold stand, and a perfect insulator stand. Let’s see how the cycle works.

***Step1:*** ***Isothermal expansion***. The cylinder is placed on a high temperature heat sink that is at ***TH***. The heat is conducted through the bottom of the cylinder and the gas absorbs heat. We call this heat ***Qin*** . As a result of the added heat, the gas expands, pushing the piston upward. This step does some work. We call this step isothermal expansion because the temperature stays constant (isothermal means constant temperature) and the volume increases. The work done is equal to ***PΔV***. This step is represented as the curve ***AB*** on the PV diagram below.

***Step 2: Adiabatic expansion:*** The cylinder is immediately moved from the hot stand to the insulated stand. Once it is placed on the insulated stand, heat can no longer flow into the system (or out of it). The gas continues to expand, but since heat is no longer entering or leaving, this is an adiabatic expansion. The pressure in the cylinder drops to its lowest value. This is represented by the curve ***BC*** on the PV diagram. Work continues to be done by the system during this step.

***Step 3: Isothermal compression***: The cylinder is immediately place on the low temperature heat sink. Heat, which we call ***Qout***, flows from the cylinder into the heat sink. The system loses heat, the volume decreases, and the gas is compressed isothermally. This is represented by the curve ***CD*** on the PV diagram.

***Step 4: Adiabatic compression***: The cylinder is place on the insulated stand. Heat no longer can enter or leave, so the system undergoes adiabatic compression back to its original state along the curve ***AD***. The heat engine is now ready to undergo another cycle.

Here is the PV diagram for the Carnot cycle.

***A*** to ***B*** -- isothermal expansion.

## V increases and P decreases

***B*** to ***C*** -- adiabatic expansion.

***C*** to ***D --*** isothermal compression

***D*** to ***A --*** adiabatic compression



 Work is done along the curves ***AB*** and ***BC***.

The efficiency of the Carnot cycle, how well it operates, depends on the absorption of heat and the loss of heat in the respective steps of the cycle. One of the key factors that controls the flow of heat is the temperature difference. This would be the temperature of the hot stand and the cold stand. When placed on the hot stand, heat flows into the cylinder and it reaches (if left long enough) the same temperature as the hot stand. When placed on the cold stand, the temperature difference is equal to the hot temperature minus the cold temperature (of the cold stand).

If ***ΔT*** is increased, heat will flow faster and the machine will operate more efficiently.

So the higher the hot temperature reservoir (the hot stand), the greater the amount of heat absorbed by the system. Also, if we decrease the cold temperature reservoir, this too will increase the amount of heat that flows.

Increase the heat flow and you increase the efficiency of the system.

Dear Doctor Science,

You know those little birds filled with red stuff that bob up and down drinking from a glass of water? I can't make mine stop, even when I take away his water. He won't stop. Please help!

-- Joey Terry from Springfield, MO.

Dr. Science responds:

Those little birds are actually perpetual motion machines. Once you get them started, they'll never stop -- ever -- not until the sun winds down and our galaxy goes nova. Even then, somewhere in the imploded black holes that was once our solar system, little birds will be bob-bob-bobbing -- even in the noiseless vacuum of space. The "red stuff" inside these birds is actually a neutrino solution kept in place by a mysterious new force in the universe called hypercharge, which is a cross between a nuclear bond and superglue. Fortunately, most of these birds are what science calls "broken" and will not bob at all. This is true, at least for most of us, who bought these little birds at airport gift shops and we can only thank the powers-that-be. Otherwise, they'd just give us the creeps. Bobbing, bobbing, bobbing through eternity, through entropy, bobbing, bobbing, bobbing, bobbing...