THERMO NOTES_Processes

9.2.2 State that the first law of thermodynamics is a statement of the principle of energy conservation

The first law of Thermodynamics is simply a restatement of energy conservation. Energy can not be created or destroyed, but only changes from one form to another.

In terms of heat and energy we can state the first law of thermodynamics mathematically as:

(1)
$\Delta Q = \Delta U + \Delta W$

Where positive is thermal energy transferred to the system. Positive is an increase in internal energy of the system. Positive is work done by the system (i.e. work done on something outside of the system). In words this equation can be stated as:

In any thermodynamic process, the net heat absorbed by a system is equal to the sum of the thermal equivalent of the work done by the system and the change in the internal energy of the system.

9.2.3 Describe the isochoric (isovolumetric), isobaric, isothermal and adiabatic processes

An *isochoric* or *isovolumetric process* is one in which the volume of the system does not change unless there is work done on or by the system. If there is no work done on or by the system then the first law of thermodynamics becomes:

(2)
$\Delta Q = \Delta U$

In an isochoric process all the thermal energy absorbed by a system goes to increase its internal energy, this usually results in a increase in temperature.

An example of an isochoric process is the heating of water in a fixed volume container. As heat is added to the water the water will begin to boil, at which point the energy supplied to the system will go into vaporizing the water.

An *isobaric process* is one in which the pressure of the system is constant. The heat energy added to the system does work and increases the internal energy of the system. An example could be forcing the air out of a piston slowly so that the pressure is constant throughout the piston.

An *isothermal process* is one in which the temperature of the system is constant. It is possible to compress gas with a piston slowly so that the temperature of the gas itself does not change. The process is done slowly to allow the heat to transfer to the surroundings. If there is no phase change the lack of temperature change implies that there is no change in the internal energy of the gas or system. Thus we can write the first law of thermodynamics as:

(3)

$$\Delta Q = \Delta W$$

So all energy added to the system results in work being done by the system, or if work is done on the system heat energy leaves the system. D*uring an isothermal process the value of pV is constant.*

An adiabatic process is one in which there is no exchange of thermal energy between a system and it surroundings. An adiabatic process is often done very quickly, in a problem you may not be told that it is adiabatic, but it may be said to be done “quickly,” the assumption is that if a process is done quickly then there is not enough time for the heat energy to be transferred between the system and the surroundings. For an adiabatic process the first law of thermodynamics becomes:

(4)

$$\Delta W = -\Delta U$$

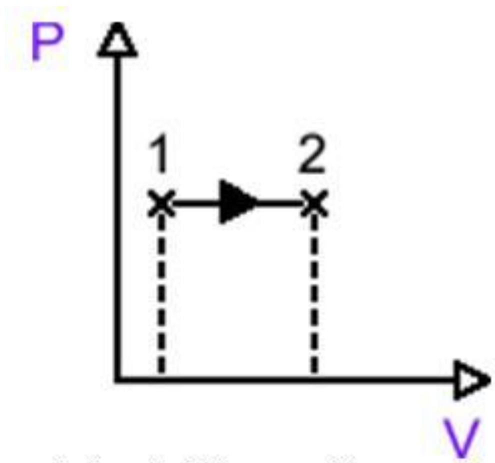
In other words all the work done is at the expense of the system’s internal energy.

An example of an adiabatic process is gas in an insulated piston, where the gas quickly expands and does work on the piston. This results in a decrease in internal energy and is most often accompanied by a drop in temperature.

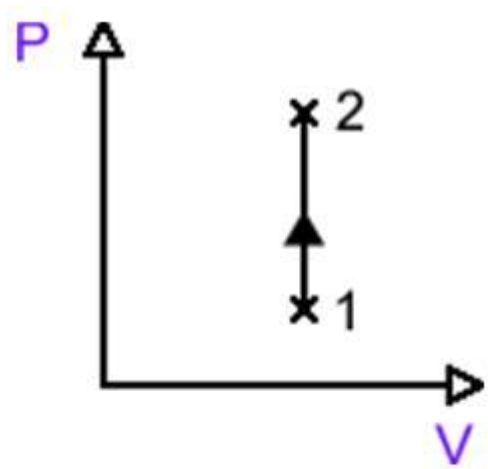
9.2.4 Draw and annotate thermodynamic processes and cycles on p-V diagrams

Any real thermodynamic process will not fit perfectly into one any of the categories described above. To visually represent the thermodynamic processes we frequently use a pressure-volume diagram or a p-V diagram. In a p-V diagram the vertical axis is the pressure and the horizontal axis is the volume.

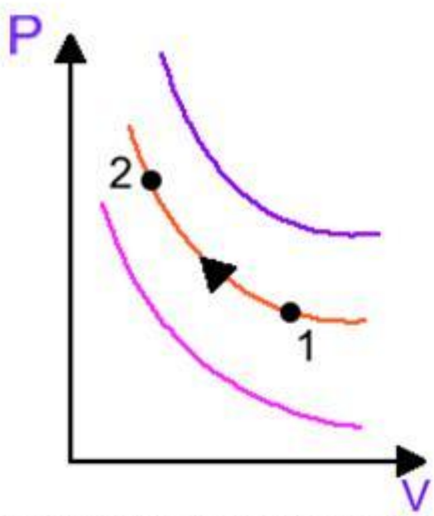
Below I have stolen p-V diagrams for several of the thermodynamic processes described above. I have stolen them from S-Cool! : http://www.s-cool.co.uk



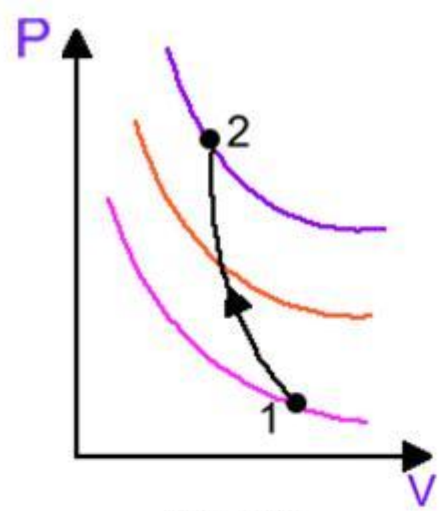
Isobaric (Constant Pressure)



Isochoric (constant volume)



Isothermal (constant temperature)



Adiabatic

In all the p-V diagrams above the thermodynamic system moves from the thermodynamic state or thermodynamic coordinates (p,V,T) at 1 to the thermodynamic state 2.

9.2.5 Calculate the work done in a thermodynamic cycle from a p-V diagram

9.2.6 Solve problems involving state changes of a gas

Before we calculated the work done by an expanding gas on a piston when at a constant pressure:

(5)
$W = P\Delta V$

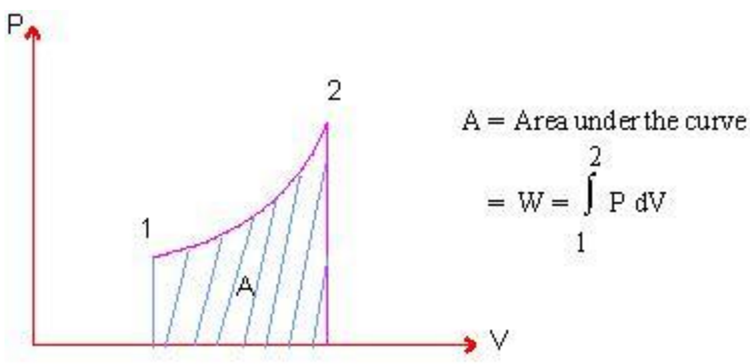


Figure 1

To calculate the work done by a gas at a non-constant pressure we must employ a little bit of calculus… Integration to be exact. In simple terms integration finds the area between a curve and the x-axis. What we find is that the work done by a gas can be found from a p-V diagram, by finding the area under the curve.

From this we can see the work done by an isobaric process is:

(6)
$W = P\Delta V$

Which is what we deduced earlier. For an isochoric process the work done is:

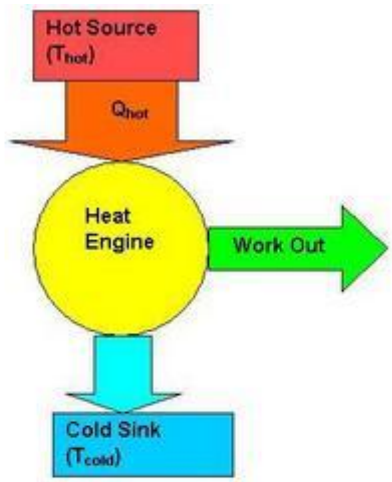
(7)
$W = 0$

There volume does not change, no work is done, all energy transfer is involved in internal energy or heat exchange.

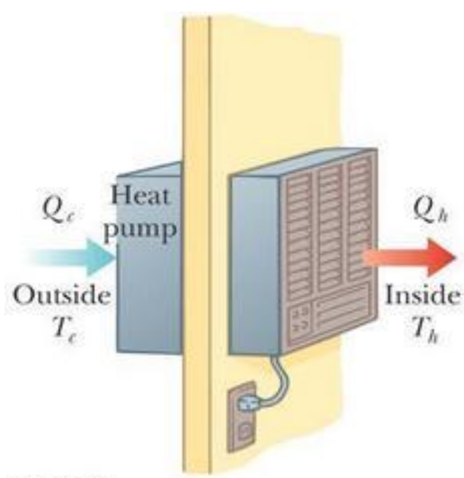
For an isothermal and adiabatic processes the work done is more complicated, but is still represented by the area under the curve.

9.2.7 Outline the concept of the heat engine and the heat pump

9.2.8 Draw and annotate schematic diagrams of a heat engine and a heat pump



A heat engine is a device used to convert thermal energy to mechanical energy. This is done through thermodynamic cycles. Simple examples are car engine and steam turbines. No heat engine is 100% percent efficient. It is possible to convert 100% of mechanical energy into heat energy, i.e. friction. When this is done the mechanical energy is distributed to the surrounding molecules which disperse the energy as they move. It is impossible to gather the energy back together in one organized location.



The heat engine takes in heat energy from a hot source or reservoir, extracts energy to do work and then expels waste (exhaust gas) to a cold reservoir. The temperature difference between the hot and cold reservoir dictates how much energy can be extracted to do work.

A heat pump does the exact opposite of a heat engine. Work is done on the heat pump, it then extracts energy from the cold reservoir and dumps it into the hot reservoir. This is essentially an air conditioner.

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9.2.9 Define the term thermal efficiency of a heat engine

In a perfect heat engine the internal energy of the heat engine would not change, therefore the first law of thermodynamic for a perfect heat engine is written as:

(8)
$$w = \Delta Q = QH - QC$$

So the work done is equal to the difference change in heat from the hot reservoir to the cold reservoir. Efficiency is defined as:

(9)
$$efficiency = EnergyOut/Energyin = WorkOut/HeatIn$$

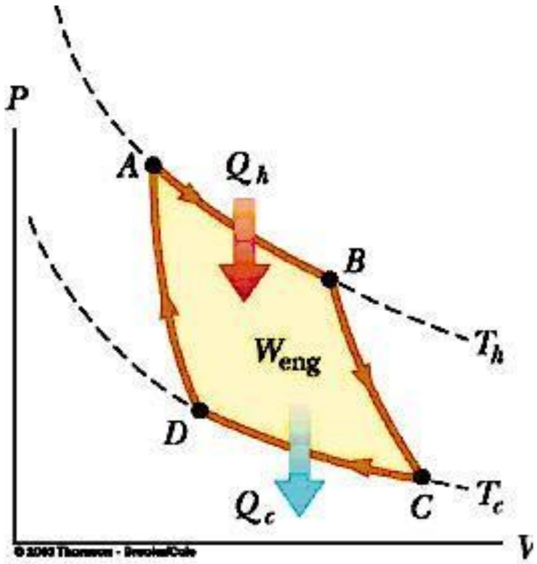
(10)
$$efficiency = QH - QC \ / \ QH$$

This is defined as the thermal efficiency, the equation is in your handbook.

For example if 100J of heat energy goes into a heat engine and 25 J of work is done then the efficiency of the heat engine would be:

(11)
$$e = 25J/100J = 25\%$$

9.2.10 Draw annotate the Carnot cycle on a p-V diagram



All heat engines lose energy to friction and lose heat by conduction or radiation. A Carnot engine is an engine that has the maximum possible efficiency for an engine extracting energy from a hot reservoir and deposits heat to a cold reservoir. A Carnot engine gives a benchmark for engine performance.

p-V diagram for a Carnot cycle:
A-B: The gas expands isothermally, while heat energy is added to the gas.
B-C: The gas expands adiabatically. Volume reaches a maximum and the pressure reaches a minimum.
C-D: The gas is compressed isothermally, while heat energy is dumped into a cold reservoir.
D-A: The gas is compressed adiabatically, Volume reaches a minimum and the pressure is maximum.

9.2.11 State Carnot's theorem

9.2.12 State an expression for the efficiency of a Carnot engine in terms of the temperatures of the two reservoirs

9.2.13 Solve problems involving heat engines and heat pumps

Carnot's theorem states that No engine operating between two heat reservoirs can be more efficient than a Carnot engine operating between the same reservoirs.

Above we define the efficiency as:

(12)
$efficiency = EnergyOut/Energyin = WorkOut/HeatIn$

(13)
$efficiency = QH - QC/QH$

Heat energy is directly related to temperature by heat capacity, in a Carnot engine there is no loss of energy. Therefore we can write an expression for efficiency in terms of temperature:

(14)
$efficiency = TH - TC/TH$

Sometimes we talk about an ideal engine, an ideal engine is an engine that has the highest possible efficiency for the temperature difference between the hot and cold reservoir.

Source: http://ibphysicsstuff.wikidot.com/processes