January 2017 - Bernabei

Physics AP – 2: Summary Notes – Chapter 15 - Thermodynamics

15.1: Thermodynamic systems

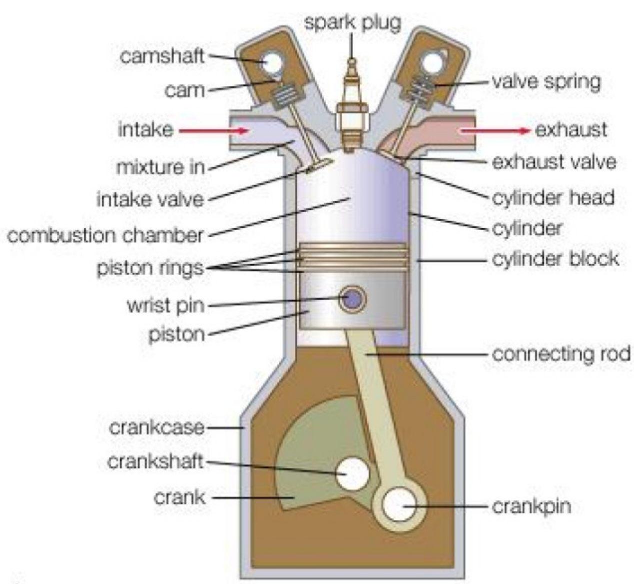
Thermodynamics = refers to work and energy that is associated with heat
Thermo = refers to heat
Dynamics = refers to mechanical work done by forces

At this level, we typically study ideal systems (i.e. not realistic – rather, we assume idealized limits and conditions – for example, no turbulence in the gases, and we assume that insulators perfectly prevent 100% of heat flow, etc).

Terms:

Adiabatic = no heat flow
i.e. *Adiabatic walls* are perfect insulators that prevent heat flow. So, if a gas is contained within a cylindrical piston with adiabatic walls, no heat from the gas can flow out through the walls to the surroundings, and no heat from the surroundings can flow into the gas (idealized system). In reality, the piston system shown in the diagram below does not have perfectly adiabatic walls. Some heat from the combustion of the gas within the cylinder is likely to flow through the walls of the container housing the piston. That waste heat would then flow into the air surrounding the engine. But, in the study of thermodynamics we often simplify the analysis of systems by assuming ideal conditions, even though we know that reality is never "ideal".

Diathermal wall = allows heat flow through the wall



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http://www.britannica.com/EBchecked/topic/461886/piston-and-cylinder

15.2: Zeroth Law of Thermodynamics

The Zeroth Law of Thermodynamics refers to thermal equilibrium and the conditions necessary such that no net heat will flow between systems (there is heat flow, but no "***net***" flow – i.e. the same amount of heat flows from system 1 to 2, as flows from 2 to 1 – thus, the systems are in equilibrium). If the systems are at the same temperature, the net heat flow will be zero, thus, the condition for equilibrium is satisfied.

15.3 First Law of Thermodynamics

The First Law refers to conservation of energy. The total change in internal energy of the gas (ΔU) equals the net flow of heat (Q) and the mechanical work (W) done on or by the gas.

**** **IMPORTANT NOTE** regarding the equation for this law!! The textbook uses a **different sign convention** for **WORK** than is used on the AP equation sheet. So, focus on making sense of the concept so that you can make sense of how and why the sign conventions differ. The textbook and the AP equation sheet are both correct and are equivalent to each other.*

Relevant Symbols:
U = internal energy of the gas (kinetic energy + potential energy of the atoms and molecules in the gas)
Q = heat added to or removed from the system
W = work done by or on the system

Textbook equation	***AP Equation Sheet***
$\mathbf{\Delta U = U_f - U_i = Q - W}$	$\mathbf{\Delta U = Q + W}$
$\Delta U = U_f - U_i$ = change in internal energy of the gas	$\Delta U = U_f - U_i$ = change in internal energy of the gas
Q = energy transferred *to* the system by heating (so, if heat is removed or lost from the system, Q is negative)	Q = energy transferred *to* the system by heating (so, if heat is removed or lost from the system, Q is negative)
W = work done ***on* or *by*** the system • *if work is done **on** the system, W is **negative*** • *if work is done **by** the system, W is **positive***	**W =** work done ***on or by*** the system • *if work is done **on** the system, W is **positive*** • *if work is done **by** the system, W is **negative***

An example of work done *by* a gas system: Work done by the moving piston in a car engine, as depicted in the animation at this link: http://auto.howstuffworks.com/engine1.htm

The moving piston does mechanical work that ultimately is delivered to the car wheels to make them spin.
The equation: *Work done by the system = Force exerted by the piston × distance travelled by the piston*
Work = Pressure ×Area (of the piston)×distance
Work = Pressure × change in Volume
$W = P\Delta V = \Delta(PV)$

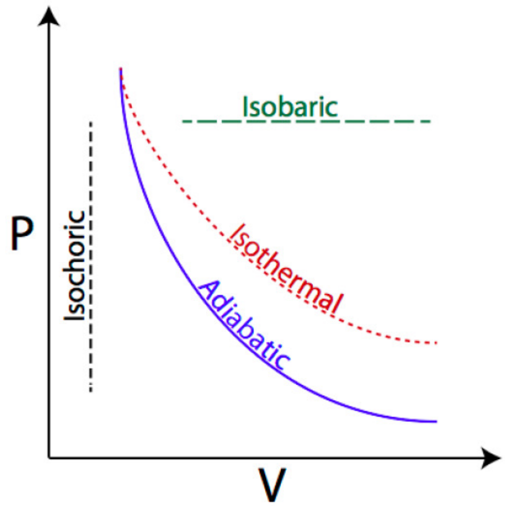
15.4: Thermal Processes

In this course we assume that the systems we are studying are "quasi-static" i.e. although they involve movement, we assume that the movement is so slow that changes that would happen within the gas if speed were significant, do not occur (e.g. changes in temperature and pressure due to changes in the state of motion of the gas particles).

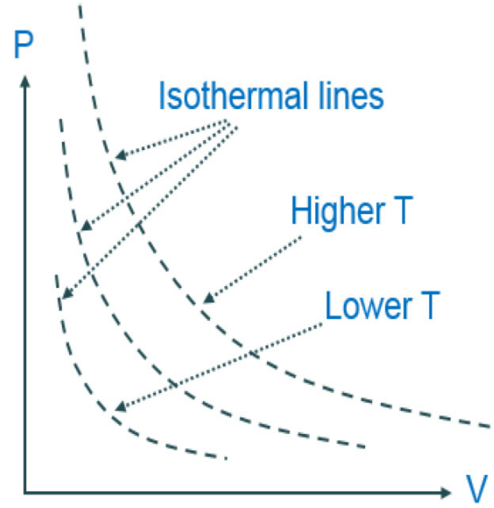
Terms:
iso = same/constant
bar = refers to pressure (e.g. a barometer measures atmospheric pressure)
chor = refers to volume
therm = refers to temperature

Thus,
- An ***isobaric*** process occurs at constant Pressure (P)
- An ***isochoric*** process occurs at constant Volume (V)
- An ***isothermal*** process occurs at constant Temperature (T)
- An ***adiabatic*** process occurs with no net transfer of heat (therefore Q = 0J, so $\Delta U = W$)

PV Processes



Isotherms on a PV graph



Determining Work from a Pressure (P) vs Volume (V) graph:

**** Refer to section 15.4 of the textbook for diagrams, examples, and "check your understanding" questions.* ***THIS IS A VITAL CONCEPT!!!! ******

This is yet another case when Calculus makes more sense of the situation than algebra, but we shall use algebra nonetheless. As is implied by the equation $W = \Delta(PV)$, Work is equal to the area under the Pressure (P) vs Volume (V) graph.

- If V increases, Work is done *on* the surroundings *by* the gas system (thus, if using the sign convention in the textbook, work is positive, or if using the AP equation sheet convention, work is negative)
- If V decreases, Work is done *on* gas system *by* the surroundings (thus, if using the sign convention in the textbook, work is negative, or if using the AP equation sheet convention, work is positive)
- If V doesn't change, W = 0J (no work done)

15.5: Thermal Processes using an Ideal Gas

- Read/review this section of the chapter for conceptual understanding

15.7: Second Law of Thermodynamics

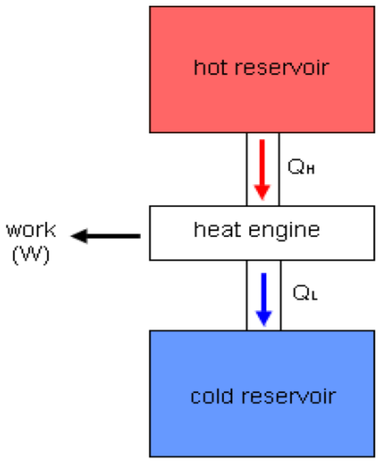
Heat spontaneously flows *from* regions of high temperature *to* regions of low temperature (i.e. heat does not naturally flow from low temperature regions to high).

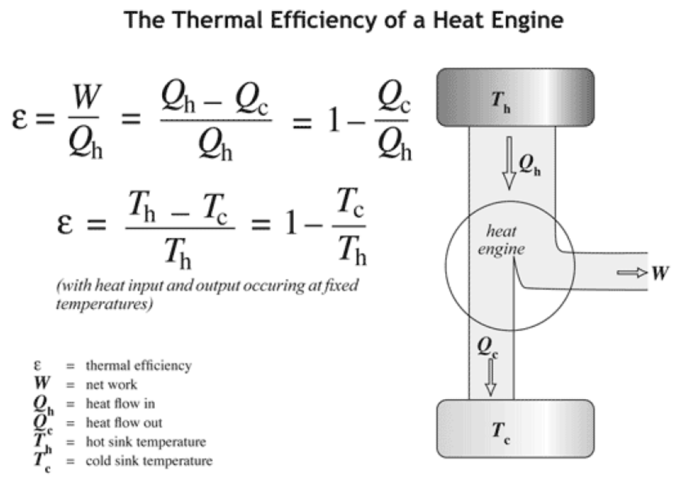
Devices such as heat engines (e.g. car engines) utilize the natural tendency of heat to flow from high temperature areas to low. In order to do mechanical work, a temperature difference is established in a system that has a mechanism for converting heat to mechanical work placed between the regions of high and low temperature. Thus, as it flows to the lower temperature region, some of the heat energy is used to do mechanical work.

Alternatively, devices such as refrigerators do work against the natural tendency of heat to flow from high to low temperature areas. The job of a refrigerator is to draw heat out the cold interior of the fridge/freezer, and dump that heat as waste into the surrounding air outside the refrigerator, which is much warmer than the air within the fridge.

15.8: Heat Engines

A heat engine is a device that uses heat to do mechanical work (for example, the engine in an automobile). The natural tendency of heat to flow from a region of high temperature to a region of low temperature is utilized. Heat (Q_H) is drawn from a high temperature region referred to as the "*hot reservoir*", and delivered to the engine, which is physically located between the hot and cold reservoirs. At the location of the engine some (but not all) of the energy Q_H is transformed to mechanical energy that is used to do work. The remaining heat ($Q_C = Q_H - W$) is delivered to a cold reservoir as waste. For example, Q_H can be generated through combustion of fuel, and the cold reservoir could be the air surrounding the engine.



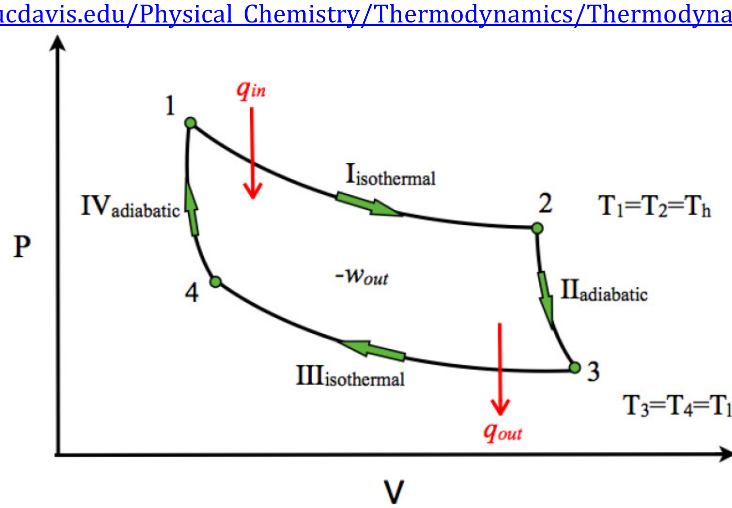


15.9: Carnot Engine

The Carnot Engine was theorized by Sadi Carnot in 1824. He proposed an idealized engine that has the maximum efficiency that is theoretically possible (i.e. it cannot actually be built in reality, but engine designers continue to use Carnot's principles to develop strategies to improve engine efficiency). Carnot theorized an idealized engine in which all processes are *reversible*. This reversibility is the key to establishing the maximum theoretical efficiency. By "reversible", he meant that the engine and surroundings could be returned to their original state (i.e. there are no energy losses or transformations beyond those that do the intended mechanical work – so, there is no unintended sound, heat, turbulence, etc). Carnot understood that this idealized engine could never actually be built, but it establishes the theoretical limits of efficiency, and it proves that 100% efficiency of an engine is neither theoretically nor physically possible.

The P-V diagram shown represents the Carnot Cycle

(http://chemwiki.ucdavis.edu/Physical_Chemistry/Thermodynamics/Thermodynamic_Cycles/Carnot_Cycle)



The relationship **PV = nRT** is relevant to this situation.

The steps of the Carnot cycle:

Step I: The gas *expands* from **1 to 2** along an *isotherm* (constant temperature). As the gas expands, pressure decreases. If gas were expanded in this way with no heat added, the temperature of the gas would decrease. So, in order to maintain a constant temperature, heat ($Q_H = Q_{in}$) is drawn from the high temperature reservoir (T_H). Thus, $\boldsymbol{T_1 = T_2 = T_H}$.

Step II: The gas *expands* further from **2 to 3**, *adiabatically* (no exchange of heat Q = 0J). Therefore pressure decreases more quickly than in Step 1. The system drops to a lower temperature, which is the temperature of the cold reservoir (T_C).

W = Δ(PV) = area under the graph

[according to the sign convention of the textbook, positive work is done in the expansion from position 1 to 3]

Step III: The gas is *compressed* from **3 to 4** (volume reduced) *isothermally* (constant temperature = T_C). Normally temperature would increase with compression, so in order to maintain a constant temperature some heat (Q_C) is released from the system into the cold reservoir.

Step IV: The gas is *compressed adiabatically* (no gain or loss of heat) from **4 to 1**. This step returns the system to its original starting point, and the cycle can then repeat.

W = Δ(PV) = area under the graph

[according to the sign convention of the textbook, negative work is done in the compression from 3 to 1]

Net Work = (Area under the graph from position 1 to 2 to 3) - (Area under the graph from 3 to 4 to 1)
= Area contained within the graphed lines depicting the cycle

$Q_H = W + Q_C$ $\qquad\qquad$ $Q_C/Q_H = T_C/T_H$

Carnot efficiency: $\mathbf{e_{Carnot} = 1 - T_C/T_H}$

Useful links:

http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/carnot.html

http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/carnot.htm