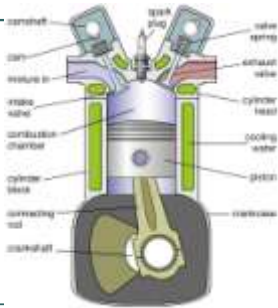


Engines—examples and efficiency

Internal combustion
Carnot Cycle
Efficiency of Heat Engines

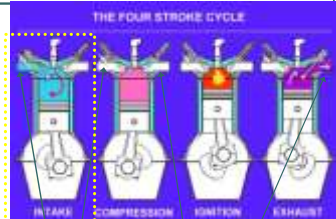
4-stroke Internal Combustion Engine

- Potentially informative link: <http://www.siu.edu/~autoclub/frange.html>
- This is the type of engine found in most cars
- Pistons that do the mechanical work are driven by “explosions” within a cylinder...



Steps in the Internal Combustion Engine Cycle:

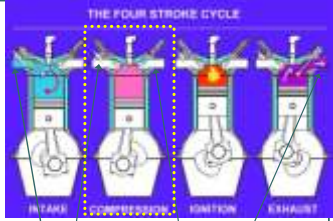
- **Intake Stroke:** a mix of air and gasoline vapor is pulled into the combustion chamber through the intake valve
 - Piston is moving down during this stroke



- Intake Valve
- Exhaust Valve

Steps in the Internal Combustion Engine Cycle:

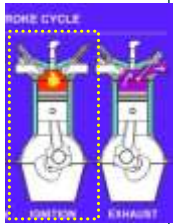
- Next, in the **compression stroke**, both valves are closed
- Piston moves upward and compresses the gasoline and air mixture into a volume ~ 1/8 its original volume



- Intake Valve
- Exhaust Valve

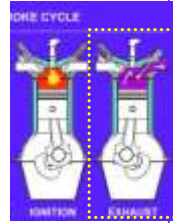
Steps in the Internal Combustion Engine Cycle:

- In the **Ignition stroke**, both valves remain closed
- Volume remains at the compressed volume
- **Spark Plugs** generate a spark within the chamber, causing the gas/air mixture to ignite within the cylinder
- Rapid burning occurs; hot gases in the cylinder expand, pushing against the piston = **Power Stroke**



Steps in the Internal Combustion Engine Cycle:

- **Exhaust Stroke:** the exhaust valve is now opened as the piston moves upward once more
- The intake valve is closed during this step
- The hot, spent fuel vapors are exhausted from the cylinder
- As the piston moves back down, the cycle begins again with the intake stroke...



Other notes about the I.C.E.

- The pistons in the cylinders are typically attached to flywheels that keep the engine going throughout all the strokes (especially the power stroke)
- Most automobile engines are only 25% efficient

Diesel Engines

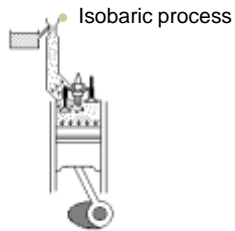
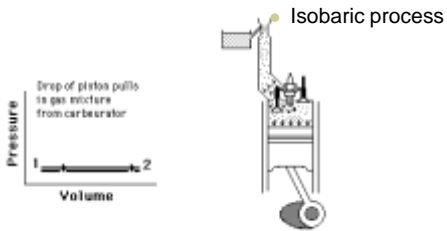
- Diesel engines use a different fuel, which is introduced to the cylinder and mixed with the air in a slightly different way than cars' gas/air mixtures.
- No spark plug is used in the process...the air is simply compressed about twice as much as a gasoline engine, which increases the temperature so much that there is no need for a spark to ignite the mixture!
- Diesel engines are approximately 40% efficient, which makes them among the most efficient engines available!

Otto Cycle

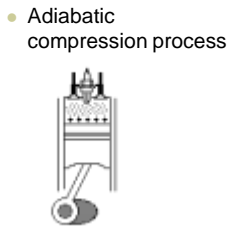
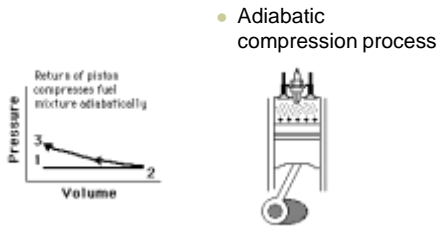
- The common name for the thermodynamic cycle that an internal combustion engine goes through.
- The following 6 slides are showing the cycle process and the associated p-V diagram. All images were taken from:

<http://hyperphysics.phy-astr.gsu.edu/Hbase/thermo/otto.html#c6>

Stroke 1-2: Intake

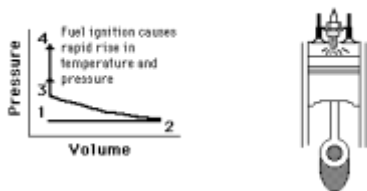


Step 2-3: Compression stroke



Step 3-4: Ignition

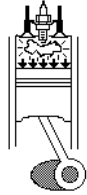
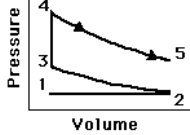
- Isochoric process



Step 4-5: Power Stroke

The power stroke: the adiabatically expanding gases do work on the piston

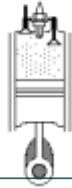
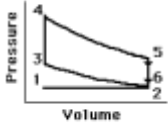
- Adiabatic expansion process



Step 5-6: Exhaust

The exhaust valve opens as the piston reaches the bottom of its travel, dropping the pressure to atmospheric pressure.

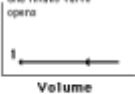
- Isochoric process



Step 6-1: Exhaust

Rise of piston drives out burnt gases. Exhaust valve closes at 1 and intake valve opens

- This step returns the cylinder to its initial conditions, and the cycle is ready to begin again



Efficiency of Thermodynamic Engines

- Symbol for Thermal Efficiency: η
- Definition: The ratio of the work the engine does to the heat energy that has been added (the heat input).

$$\eta = \frac{W}{Q_H}$$

- Thermal efficiency will always be < 1 , and should be reported as a percentage (by multiplying your calculated efficiency by 100)
- We can use this definition to derive a more usable expression... (see next slide ☺)

Efficiency—mathematical relationship

- Since work that the engine does is related to the difference in heat energy in vs. heat energy out of the engine, we can state efficiency as follows:

$$\eta = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} = \frac{Q_H}{Q_H} - \frac{Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

- Therefore, The efficiency increases as the heat output gets smaller. Perfect efficiency implies that $Q_L = 0$.

Efficiency example:

- An engine absorbs 230 J of thermal energy from a high temperature reservoir. It then does mechanical work and exhausts 140 J of thermal energy to a cold reservoir. What is this engine's efficiency?

Efficiency example answer:

$$\eta = 1 - \frac{Q_L}{Q_H} = 1 - \frac{140J}{230J} = 0.391$$

$$\eta = 39.1\%$$

Coefficient of performance (K)

- Used to define the efficiency of heat pumps (and refrigerators) rather than heat engines
- Slightly different expressions depending on if the heat pump is being used to **heat** a space or **cool** a space...
- CAN have a value greater than 1
- Larger the **K** value, the greater the devices' economy

Space cooling--refrigerator

- Ratio of heat absorbed from inside of the refrigerator to the work supplied to the refrigerator during one complete cycle.

$$K_{ref} = \frac{Q_L}{|W|}$$

Space Heater—Heat Pump

- The ratio of the total positive heat exhausted to the inside of the space, to the work supplied to the heat pump in one complete thermodynamic cycle.

$$K_{HP} = \frac{|Q_H|}{|W|}$$

The Carnot Engine

- Named for the engineer (early 1800's) who first determined the theoretical maximum efficiency possible for an engine working between two heat reservoirs
- His findings:
 “No engine working between two heat reservoirs can be more efficient than a reversible engine between those reservoirs.”

Carnot's Explanation/Arguments:

- If thermal energy DOES flow from the colder reservoir to the warmer reservoir, then work MUST be done
- Therefore: “no engine can be more efficient than **ideal reversible one**”
- And: “all such engines have the same efficiency”

So what IS a Carnot engine?

- This is a **Theoretical Engine!**
- It is an engine that is reversible (meaning that it will do work when energy flows from hot to cold and from cold to hot)
- The efficiency of a Carnot engine is dependent on the absolute **temperature** of each of the reservoirs, not the amount of thermal energy:

$$\eta = \frac{\Delta T}{T_H} = \frac{T_H - T_L}{T_H} = \frac{T_H}{T_H} - \frac{T_L}{T_H} = 1 - \frac{T_L}{T_H}$$

Carnot Cycle:

Efficiency: Carnot vs. "normal"

- No engine can have an efficiency greater than Carnot efficiency (if it did, it is breaking the 2nd law of thermodynamics)
- Carnot = ideal efficiency
- Comparing the ideal efficiency to an actual efficiency, we get the following:

$$\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$$

Efficiency: Carnot vs. "normal"

- Factors that reduce efficiency:
 - Friction, other mechanical losses
 - i.e. ~2/3 of heat generated by power stations is exhausted into the environment
- Because of the efficiency relationship set up by Carnot, scientists have stated an unofficial "3rd law" of thermodynamics:
It is impossible to reach the absolute zero of temperature, 0 K

Good links regarding Thermodynamics:

- [Types of Processes](#)
- [Second Law Qualitative Statements](#)
- [Internal Combustion Engine](#)
- [Internal Combustion Engine \(#2\)—includes animations](#)
- [Otto Cycle](#)
- [Otto Cycle #2](#)
- [Carnot Cycle—animation](#)
- [Carnot Cycle #2](#)
- Engine Efficiency
