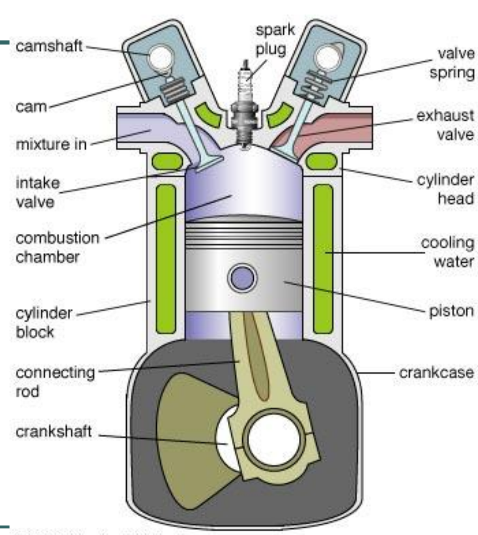
Engines—examples and efficiency

Internal combustion
Carnot Cycle
Efficiency of Heat Engines

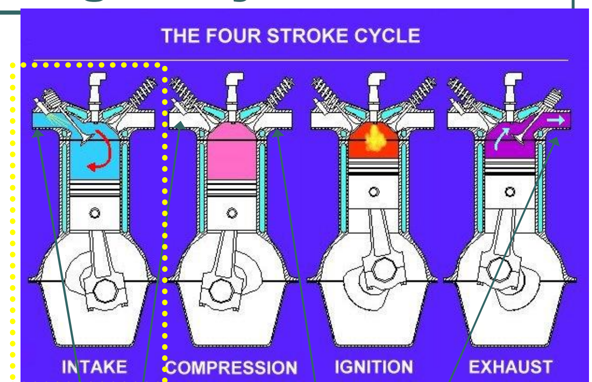
4-stroke Internal Combustion Engine

- *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:

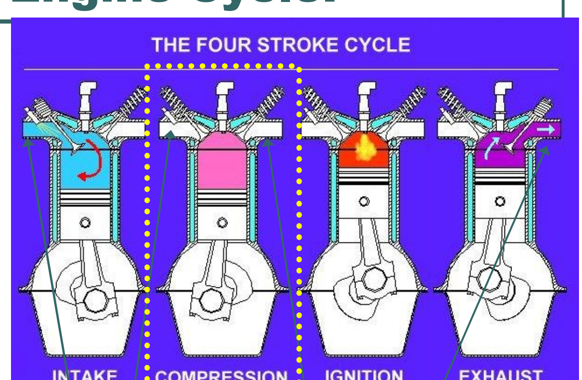
- Intake Stroke: a mix of air and gasoline vapor is pulled into the combustion chamber through the intake valve
  - Piston is moving down during this stroke



- Exhaust Valve
- Intake Valve

Steps in the Internal Combustion Engine Cycle:

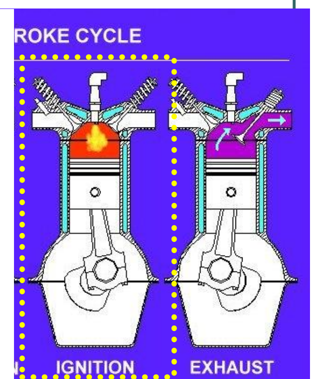
- Next, in the **compression stroke,** both valves are closed
- Piston moves upward and compresses the gasoline and air mixture into a volume ~ 1/8 its original volume



- Exhaust Valve
- Intake Valve

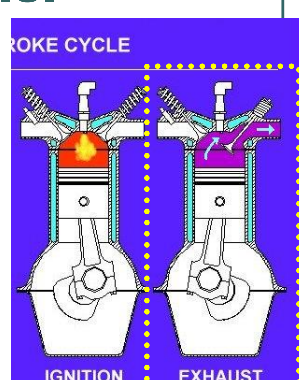
Steps in the Internal Combustion Engine Cycle:

- 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!

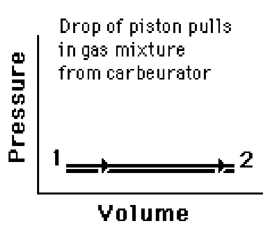
Otto Cycle

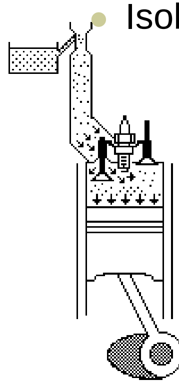
- The common name for the thermodynamic cycle that an internal combustion engine goes through.
- The following 6 slides are showing the cycle process and the associated p-V diagram. All images were taken from:

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

Stroke 1-2: Intake

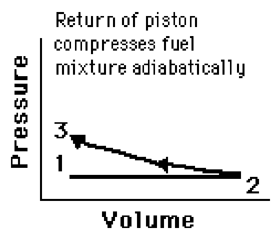
- Isobaric process

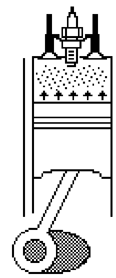




Step 2-3: Compression stroke

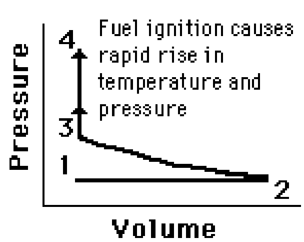
- Adiabatic compression process

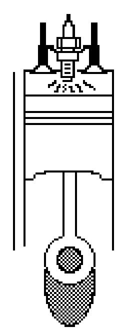




Step 3-4: Ignition

- Isochoric process

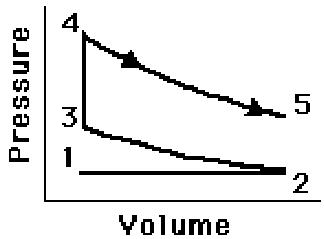


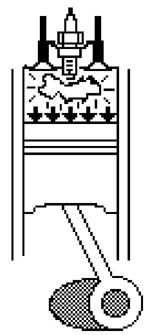


Step 4-5: Power Stroke

- Adiabatic expansion process

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

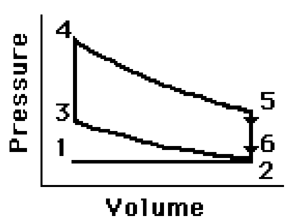


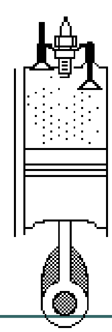


Step 5-6: Exhaust

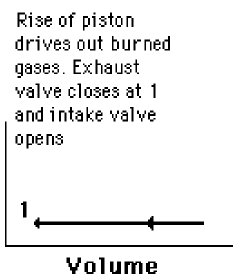
- Isochoric process

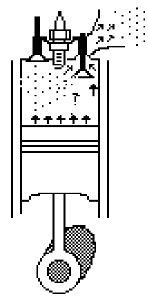
The exhaust valve opens as the piston reaches the bottom of its travel, dropping the pressure to atmospheric pressure.





Step 6-1: Exhaust





- 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:

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

$$\eta = 39.1\%$$

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?

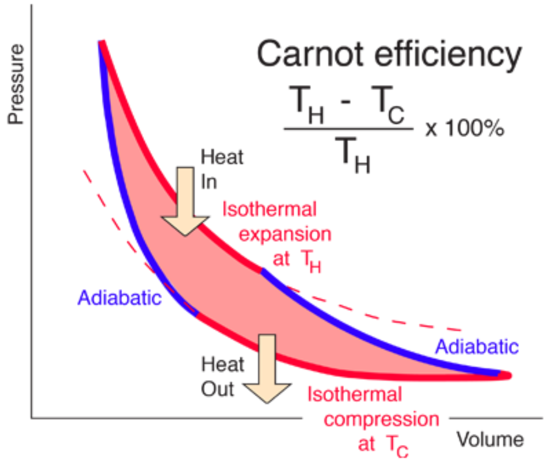
- This is a **Theoretical Engine!**
- It is an engine that is reversible (meaning that it will do work when energy flows from hot to cold and from cold to hot)
- The efficiency of a Carnot engine is dependent on the absolute **temperature** of each of the reservoirs, not the amount of thermal energy:

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

Carnot Cycle in action:

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

Carnot Cycle:



Efficiency: Carnot vs. "normal"

- No engine can have an efficiency greater than Carnot efficiency (if it did, it is breaking the 2^{nd} law of thermodynamics)
- Carnot = ideal efficiency = maximum possible efficiency based on temperatures of the reservoirs
- Actual efficiency is often less than Carnot efficiency

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 "3^{rd} law" of thermodynamics:

It is impossible to reach the absolute zero of temperature, 0 K

Good Review links regarding Thermodynamics of heat engines:

- Types of Processes
- Internal Combustion Engine—includes animations/illustrations
- Otto Cycle
- Carnot Cycle—animation
- Carnot Cycle #2