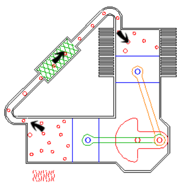
Heat engines



What does REALLY temperature mean?

- Molecules of a gas bounce off the walls of a container
- Recoil pushes outward on the walls
- Pressure depends on the kinetic energy of molecules
- The average kinetic energy per "simple" molecules is $\frac{3}{2}k_B T.$
- So temperature is a measure of the average kinetic energy of a molecule in the gas!!

Engines

- Thermodynamics: converting thermal energy to other forms of energy and vice versa
- What is the best way to get mechanical energy from thermal energy? Can 100 percent of thermal energy be converted into work?
- Let's begin with determining the work done by an expanding gas: Put a mass on top of a piston, raise T, and the mass moves up such that the GPE of the mass is increased---raising T of the gas causes it to do work

Work from an expanding gas

- Work, W, is force times displacement
- Force is equal to the pressure of the gas times the area of the piston "top"
- The change in volume of the gas is equal to the area of the piston "top" times the displacement
- So, $W = p\Delta V.$

World's simplest engine

- Starting position: gas is cool, piston is down
- Add mass (from lower shelf) to piston
- Warm up the gas; piston rises
- Remove mass onto higher shelf
- Cool down gas; piston sinks
- Repeat indefinitely

Engines must be cyclic; otherwise we consume the engine itself; we only want to consume thermal energy!

Stirling engine

- Four steps to the cycle:
- Expansion while held at high temperature T_h
- Move gas at constant volume from hot reservoir to cold reservoir, lowering temperature to T_l
- Compression while held at the lower temperature
- Move gas at constant volume from cool reservoir to hot reservoir thereby raising temp back to initial value

Parts of a Stirling engine

- Hot reservoir (hot plate)
- Cold reservoir (bin of ice)
- Displacer piston shuttles air between hot and cold reservoirs
- Power piston to turn crank
- Crank with clever bends to sequence motion of displacer piston and power piston
- Flywheel/pinwheel for rotational motion

What makes a Stirling engine go?

- Engine goes because warm air's pressure pushes power piston. Warm air does work. What is that work in terms of pressure and volume?
- But, to make a cycle, you have to compress air again.
- Why don't you need to do as much work to compress the gas as you got out it during expansion?
- Compress the gas when it is cool so lower pressure so work to compress is less.

Analysis of Stirling engine

- Determine the heat absorbed/dumped at each step in the cycle
- Determine the work done at each step of the cycle
- Determine the change in energy of the gas at each step in the cycle.
- What is the total work done during entire cycle? What about the change in energy during entire cycle?

Net work and efficiency

- Power stroke of Stirling engine supplies more work than is consumed by compression stroke so the engine "goes" and supplies net power to the outside world
- If we examine the relation between the net work and the heat input and heat output, we will expose a fundamental inefficiency, or waste of energy, in a heat engine cycle:

$$W_{net} = Q_{power} - Q_{compress}$$

Net work and efficiency

- Efficiency is the ratio of net work to the total thermal energy supplied, or

$$\varepsilon = \frac{W_{net}}{Q_{power}}.$$

- The maximum possible efficiency of a heat engine is

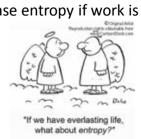
$$\varepsilon_{max} = 1 - \frac{T_l}{T_h}.$$

Why is there a maximum efficiency?

- Thermal energy is hidden mechanical energy.
- It is hidden because it is disordered, distributed among all the molecules of the system.
- Things can get more disordered, but don't spontaneously get ordered---It's hard to unscramble an egg.
- Work is ordered; thermal energy is less ordered at high temp.
- Heat never spontaneously flows from a cold substance to a hot substance.---one has to do work to do this---*2nd law of thermodynamics*!

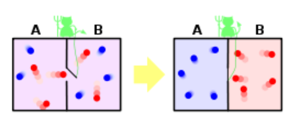
Entropy

- Entropy is a measure of the amount of disorder in a system
- If disorder increases, then entropy increases
- Can decrease entropy if work is put into system



Entropy and Maxwell's Demon

- In 1867 physicist Maxwell came up with a thought experiment meant to raise questions about the possibility of violating the 2nd law of thermodynamics



Otto engine: Car engine

- Intake stroke: The air-fuel mixture is sucked in the cylinder by the piston sliding downward
- Compression stroke: The piston sliding now upward compresses the mixture using work of a crankshaft
- Power stroke: Mixture is ignited and pressure of burning mixture pushes the piston back into cylinder performing work
- Ejection stroke: Burned exhaust is ejected by the rising piston through another valve.

Third law of thermodynamics

- A system can never reach absolute zero, 0 K.
- Postulated by Nernst around 1910
- Entropy of a perfect crystal is zero at 0 K.

Thermal expansion

- Due to a rise in temp. of a substance, molecules jiggle faster and move further apart
- *Most* substances expand when heated and contract when cooled
- Examples: railroad tracks laid on winter days expand and buckle in hot summer, warming metal lids on glass jars under hot water loosens the lid by more expansion of the lid than the jar
- When water becomes ice, it expands!!!! Water is most dense at 4 degrees Celsius!!!! Important for life!