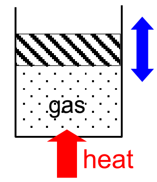
L 20 Thermodynamics [5]

- heat, work, and internal energy
- the 1st law of thermodynamics
- the 2nd law of thermodynamics
- Heat engines
- order to disorder → entropy
- Hybrid cars

Heat, work, and internal energy

- The gas has internal energy, as measured by its temperature
- if heat is added its internal energy increases
- if the gas expands and does work on the atmosphere, its internal energy decreases
- Heat and work are forms of energy which can change the internal energy
- the 1st law of thermodynamics keeps track of the balance between the heat, work and internal energy of the gas

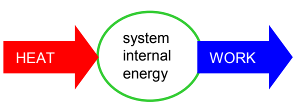


The First Law of Thermodynamics

- the change in internal energy of the gas

  = the heat **absorbed** by the gas

  minus the work done **by** the gas



- *this is a simple energy accounting principle (law of conservation of energy)*

work done by or on a gas

- if a *gas does work* (expansion) its internal energy goes down and so does its temp.
- if *work is done on a gas* (compression) its internal energy goes up and so does its temperature
- the internal energy of a gas can be changed by adding or taking away heat or by having the gas do work or doing work on the gas

EXAMPLE

- What is the change in the internal energy of a gas if 3000 J of heat are added while the gas does 1000 J of work?
- change in internal energy
  $\Delta IE = Q_{in} - W_{out}$
  $= 3000\ J - 1000\ J = 2000\ J$

the internal energy *increases* by 2000 J

Meteorology and the 1st Law

- Air temperature rises as heat is added
- Air temperature rises (or falls) as pressure increases (decreases)
- In processes called *adiabatic* the amount of heat added or lost is very small
- As a parcel of air rises it expands *adiabatically* and its temperature decreases by about 10° C for each kilometer of elevation

Heat engines

- A heat engine is a device that uses heat (*input, which you must pay for)* to do work (*output*, which is useful).
- The central issue is how much of the heat taken in can be converted into work
- This is quantified by the engine efficiency
- The amount of heat that can be converted to work is limited by the 1st law ➔ *you can't get more out than goes in*

The 2nd Law of Thermodynamics

- Not all of the heat can be converted into work.
- try to understand the difference between work energy and heat energy
- give the block a push– it will stop due to friction
- the kinetic energy is converted to **HEAT**
- but, I cannot make the block move by heating it!

Heat – *disordered* energy

- When an object is heated, the energy of all of its molecules is increased.
- however, the molecules do not all move in the same direction → they move about in all directions → this is what we mean by *disordered* (or thermal) energy
- on the other hand, if we want to get the system to do some useful work, we want it to move in some particular direction

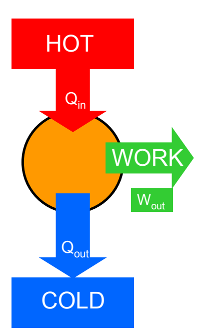
order to disorder

- All naturally occurring processes go in the direction from order to disorder
- for example: ice always melts
- ice, the solid state of H_2O is more ordered than water, the liquid state
- in a solid all the molecules are lined up in a regular (ordered) array; there is less order in the liquid state
- When salt is put in water it dissociates; crystals of salt never spontaneously form in a salt water solution

Work is *ordered* energy, heat is *disordered* energy

- It is possible to convert some of the random energy to do useful work
- when a gas is allowed to expand, some of its random thermal energy is converted into work
- **the 2nd law explicitly prohibits all of the heat from being converted into work**
- this is a fact of nature➔ the way things are!

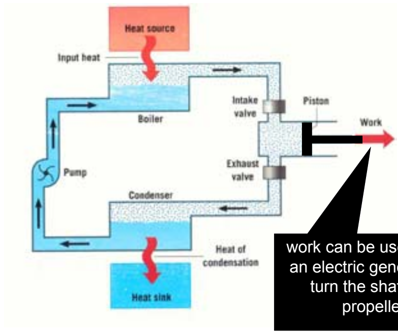
Heat Engines



- an engine operates in a ***cycle***
- fuel is burned to make heat
- some of the heat is converted into work
- the heat that is not converted to work is removed to bring the system back to the beginning state (cycle)
- since the system is always returned to the original state the change in internal energy is ZERO
- energy accounting: $Q_{in} = W_{out} + Q_{out}$

$$efficiency = \frac{W_{out}}{Q_{in}}$$

steam engines



work can be used to run an electric generator or turn the shaft of a propeller

1st and 2nd Laws of Thermodynamics

- the 1st law requires that
  work out = heat in – heat out
- the 2nd law says that it is impossible to make the heat out (Q_{out}) = 0, not all the heat energy can be converted into work, some must be discarded – *thermal waste*
- engine efficiency = work out / heat in
- no engine can be 100% efficient ➔ this is a law of nature!

Heat engine example

A heat engine, operating in a cycle, absorbs 10,000 J of energy from a heat source, performs work, and discards 6,000 J of heat to a cold reservoir.
(a) how much work is performed?
(b) what is this engine's efficiency?
(c) what is the change in internal energy of this engine?

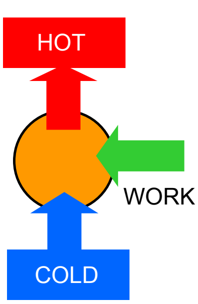
(a) $W_{out} = Q_{in} - Q_{out}$ = 10,000 J – 6,000 J = 4,000 J
(b) efficiency= W_{out}/Q_{in} = 4,000/10,000 = 0.4 or 40 %
(c) $\Delta IE = 0$, the change in internal energy for an engine operating in a cycle is ZERO

Second law of thermodynamics

I. (*Kelvin*) It is impossible to have a heat engine that is 100 % efficient
➔ Not all of the heat taken in by the engine can be converted to work

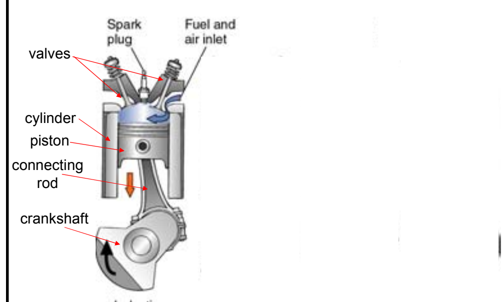
II. (*Clausius*) In a spontaneous process, heat flows from a hot to a cold substance
➔ Work must by done to move heat from a cold to a hot substance.

refrigerators and air conditioners



- Heat pump (heat engine in reverse)
- You can make heat flow backward (cold to hot) only if there is an input of work
- in an air conditioner or refrigerator, this work must be supplied by electricity.

internal combustion engine



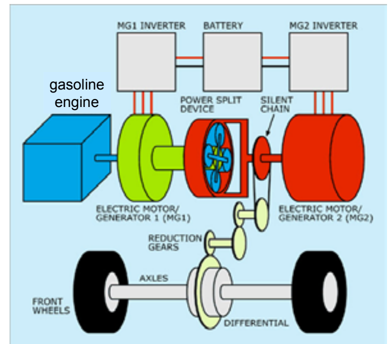
at cruising speeds this cycle happens at 3000 times/min (50 /s)

Hybrid Automobiles

Combination of 2 different systems

- A hybrid car propels itself on fuel or batteries
- It combines electrical and mechanical power
- It switches easily between fuel, batteries, or both
- It can recharge its batteries during braking. *In a conventional auto, much of the kinetic energy is dissipated as heat during braking.*
- It can turn its engine off when not needed
- It can restart its engine quickly and easily

Hybrid: gas engine + electric motor



Combining Mechanical Power

- A hybrid automobile uses a machine that blends
  - rotary mechanical power from its fuel-burning engine
  - rotary mechanical power from its electric motors
  - rotary mechanical power from its wheels
- That “transaxle” can transfer mechanical power between any of those devices in either direction!

Disadvantages of hybrid cars

- Expensive
- Limited top speed
- ➔ Poor acceleration (0 – 60 mph in 10 s)
- Mechanically complicated
- ➔ Batteries must be replaced; discarded batteries pose an environmental issue