L 19 - Thermodynamics [4]

- Change of phase
  ice → water → steam
- The Laws of Thermodynamics
  - The 1st Law
  - The 2nd Law
  - Applications
    - Heat engines
    - Refrigerators
    - Order to disorder

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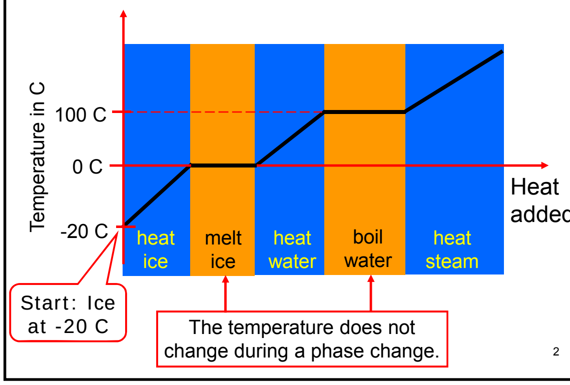
Change of Phase



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Both temperature and pressure affect the phase changes

- some recipes have high altitude instructions
- The temperature at which water boils is 212 F at **sea level**
- At higher altitudes, where the pressure is lower, water boils at a lower temperature
  - at 5000 ft it boils at 203 F (95 C)
  - at 7200 ft it boils at 199 F (93 C)
- if we increase the pressure above atmospheric pressure, water is harder to boil

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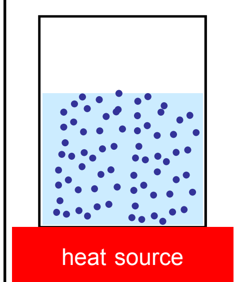
Boiling water



Liquid to gas phase change.
Energy is required to remove Molecules from a liquid

The buildup of pressure inhibits molecules from leaving the liquid.

A pressure cooker has a seal that allows the pressure to build up, so the liquid can reach a temperature above its usual boiling point.

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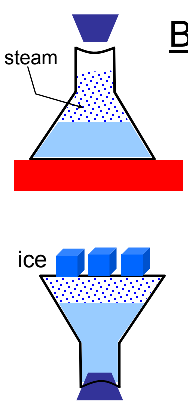
Boiling water with ice!



- as the water boils, the pressure (steam) builds up
- when removed from the heat source the boiling stops due to the pressure of the water vapor
- by cooling the water vapor, the pressure is lowered and the water will start boiling again

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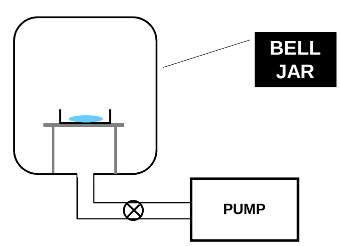
Making ice in a vacuum
Freeze drying



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REVIEW
internal energy, temperature, and heat

- The Internal Energy (U) of a system is the sum of the *kinetic energies* of all of its constituents
- Temperature (T) of a system is a measure of the *average kinetic energy* of its constituents
- Heat (Q) is the energy that is transferred from one system to another because they are initially at *different temperatures*; when the systems reach a common temperature, the flow of heat stops

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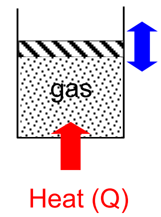
Heat, work, and internal energy

- a gas has internal energy (U) due to the kinetic energy of its molecules
- if heat (Q) is added, its internal energy *increases*
- if the gas *expands*, it does work on the atmosphere, and its internal energy *decreases*
- the 1st law of thermodynamics is a statement of how the internal energy of the gas changes if heat is added or removed, and/or is work is done by the gas (expansion) or on the gas (compression)



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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
- The *change* in internal energy is
  $\Delta U = U_{final} - U_{initial}$
- Then, the 1st Law requires: $\Delta U = Q - W$, where Q is the heat absorbed *by* the gas, and W is the work done *by* the gas.
- The 1st Law of Thermodynamics is a statement of *conservation of energy*

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EXAMPLE

- What is the change in the internal energy of a gas if it takes in 3000 J of heat while it does 1000 J of work?
- change in internal energy

$= \Delta U = Q - W$

$= 3000\ J - 1000\ J$

$= 2000\ J$ (increase if ΔU is +)

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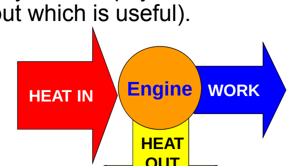
Heat engines

- A heat engine is a device that uses heat (input, which you must pay for in some form) to do work (output which is useful).



- *The central issue is how much of the heat taken in can be converted into work*
- The outcome is first of all limited by the 1st law (you can't get more out than goes in)

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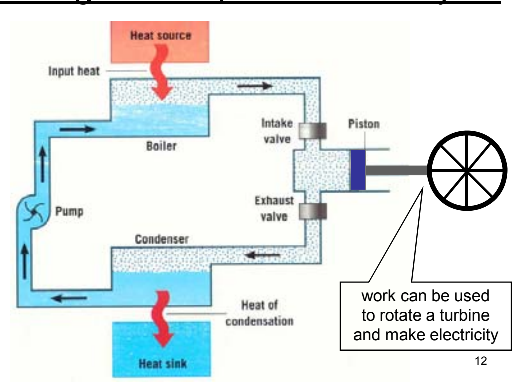
heat engine → operated in a cycle



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A cyclic heat engine

- Heat engines are operated in a *cycle*, which means that the working substance is returned to its original state at the end of the cycle.
- Therefore, the change in internal energy of the engine is ZERO, i.e., **$\Delta U = 0$** for the cycle
- The net heat into the engine is $Q_{NET} = Q_{IN} - Q_{OUT}$
- Then, the energy balance given by the 1st law is:

$$\Delta U = 0 = Q_{NET} - W = (Q_{IN} - Q_{OUT}) - W$$

- So that:

$$\boxed{W = Q_{IN} - Q_{OUT}}$$

Engine efficiency

- The engine efficiency is defined as the ratio of the work done by the engine to the heat that goes into the engine

$$\text{Engine efficiency} = \frac{\text{Work done}}{\text{Heat in}} = \frac{W}{Q_{IN}}$$

- Since, $W = Q_{IN} - Q_{OUT}$

$$\Rightarrow \text{Engine efficiency} = \frac{Q_{IN} - Q_{OUT}}{Q_{IN}}$$

- If $Q_{OUT} = 0$, the efficiency would be 100%, but this is *prohibited* by the second law

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?

solution

(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) $\Delta U = 0$, the change in internal energy for an engine operating in a cycle is zero

Second law of thermodynamics

There are 2 statements of the 2nd law which can be shown to be equivalent:

- (*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
- (*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.

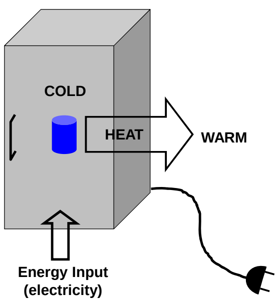
heat energy and work

- heat cannot be completely converted into work.
- the following example illustrates 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, the block will not 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 the system to do work, we want it to move in some particular direction (*work is directed energy*)

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 energy
- in an air conditioner or refrigerator, this energy must be supplied by electricity
- The electrical energy is used to run a motor (work) in the compressor

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order to disorder

- All naturally occurring processes go in the direction from order to disorder
- ice melts when placed in water; it never gets colder and the water gets warmer
- 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, and even less in the gaseous state
- when salt is put in water it dissociates; crystals of salt never spontaneously form in a salt water solution

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Ice always melts in water

- When ice is placed in a cup of water, it always melts → the water gets colder
- The first law of thermodynamics does not prohibit the ice from getting colder and the water getting warmer
- The first law only requires that energy is conserved → heat lost by ice = heat gained by water
- The second law specifies the *direction* in which spontaneous processes proceed (hot → cold)

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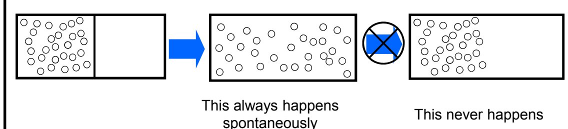
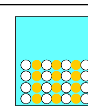
Order to disorder
Gas molecules expand to fill a volume



Under normal conditions there are several times 10^{23} molecules in a box. The chance that all of these are moving to the left at the same time is zero.

- Orange and white ping-pong ball demo
- What are the chances that after shaking the balls will all be lined up again?



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Just because it can happen doesn't mean it will happen

- Some processes are *possible*, but not *probable*
- The second law of thermodynamics is a statement of the overwhelming likelihood of what occurs in systems that contain very large numbers of particles

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