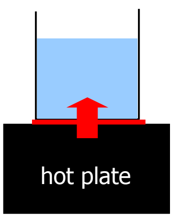
L 19 - Thermodynamics [4]

- Heat capacity
- Change of phase (ice → water → steam)
- heat, work, and internal energy
- the 1st Law of Thermodynamics
- THE 2ND Law of Thermodynamics

How do I boil water?

- How much heat does it take to boil water, i.e., how much heat must be transferred to a specific mass of water to raise its temperature to the boiling point?
- Related question: How much heat is required to raise the temperature of water by a specified number of degrees?
- The answer depends on how much water you have and how hot you want to get it → m and ΔT, where m is the mass and ΔT is the temperature *change*
- The answer would be different for a different material, say aluminum→ there must be a parameter for each substance – heat capacity, c.

Heat Capacity or specific heat



- The heat capacity is the amount of heat that is required to raise the temperature of 1 g of a substance by 1 degree C.
- it is measured in **Calories**
- for water it is 1 cal/g °C
- heat $Q = m \cdot c \cdot \Delta T$

mass of sample

specific heat

temperature *change* in C

Examples- heat capacity

(1) How much heat must be *added* to 1 kg of water to increase its temp from 20C to 60C?

$Q = mc\Delta T = 1000g \times 1cal/gC \times 40C$

$= 40{,}000C$

(2) How much heat must be *removed* from 2 kg of water to cool it from 90C to 10C?

$Q = mc\Delta T = 2000g \times 1cal/g \times C \times 80C$

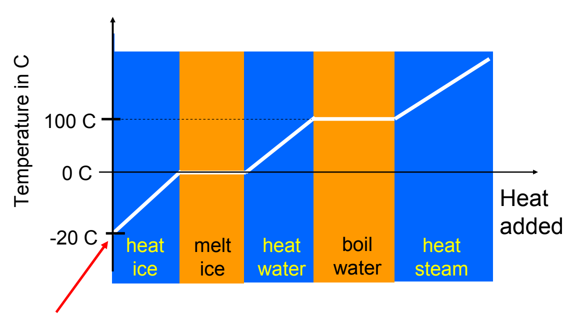
$=160{,}000C$

Temperature *change* is always positive

Some heat capacities

Substance	Specific heat in cal/g °C
water	1
Ethyl alcohol	0.58
Steel	0.11
Aluminum	0.215
lead	0.03

Change of Phase



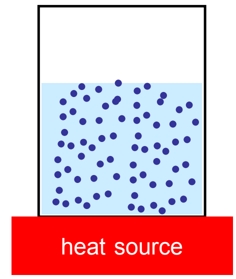
Start: ice at - 20 C

The temperature does not change during a phase change.

Temperature is not the whole story!

- 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
  - at 7200 ft it boils at 199 F
- if we increase the pressure above atmospheric pressure, water is harder to boil

Boiling water

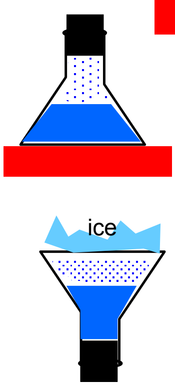


Energy is required to remove molecules from a liquid.

The buildup of pressure inhibits molecules from leaving the liquid.

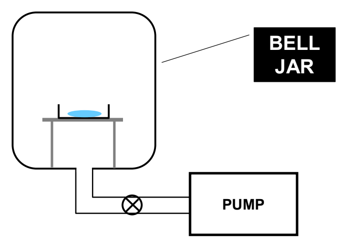
A pressure cooker cooks food at a temp above the boiling point

You can boil with ice!



- as the water boils, the pressure builds up
- by cooling the water vapor, the water can be made to boil

Making ice in a vacuum
Freeze drying



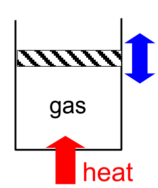
energy from natural gas

- 1 BTU = the heat needed to raise the temperature of 1 pound of water by 1 °F
- 1 cubic foot of natural gas gives off about 1000 BTU when burned
- so to boil (go from 72 °F to 212 °F) one *gallon* of water (about 8 lbs) requires about 1 BTU/1°F x 140 °F = 140 BTU/lb

  x 8 lbs → 1120 BTU's or more than 1 ft^3
- 1 cubic foot of natural gas costs about 1.5¢; it would cost about 3¢ using electricity

Heat, work, and internal energy

- The gas has internal energy, as indicated 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
- 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

Analogy to your bank account

- the **change** in your bank account balance

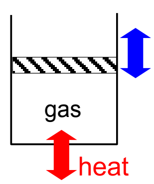
  = deposits ($ in) – withdrawals ($ out)

- the same conservation principle applies to energy transfers

  ➔ 1st Law of Thermodynamics

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



Change in internal energy	HEAT	WORK
increase	in	0
increase	0	on gas
decrease	out	0
decrease	0	by gas
increase	in	on gas
decrease	out	by gas

all quantities measured in Joules or Calories

EXAMPLE

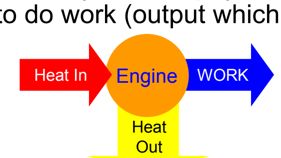
- What is the change in the internal energy of a gas if 3000 J of heat are added while the gas does 1000 J of work?
- change in internal energy

  = heat in - work done

  = 3000 J - 1000 J = 2000 J

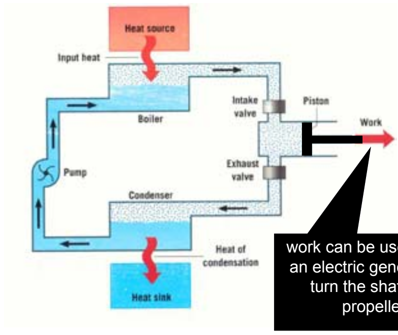
Heat engines

- 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).



- A 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)

heat engine→ operate in a cycle



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

Second law of thermodynamics

- 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
- HEAT is random energy and work is ordered energy