How do I boil water?

- How much heat does it take to boil water?
- Simpler question: how much heat is required to raise the temperature of water by so many degrees?
- The answer depends on how much water you have and how hot you want to get it.
- The answer would be different for a different material, say aluminum.

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.
- \[ Q = m \cdot c \cdot \Delta T \]

Some heat capacities

<table>
<thead>
<tr>
<th>Substance</th>
<th>Specific heat in cal/g °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>1</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>0.58</td>
</tr>
<tr>
<td>Steel</td>
<td>0.11</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.215</td>
</tr>
<tr>
<td>Lead</td>
<td>0.03</td>
</tr>
</tbody>
</table>

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.

boiling water with ice!

- as the water boils, the pressure builds up
- by cooling the water vapor, the water can be made to boil
- you can freeze water by lowering the pressure above it ➔ 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 ft³

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

<table>
<thead>
<tr>
<th>Change in internal energy</th>
<th>HEAT</th>
<th>WORK</th>
</tr>
</thead>
<tbody>
<tr>
<td>increase</td>
<td>in</td>
<td>0</td>
</tr>
<tr>
<td>increase</td>
<td>0</td>
<td>on gas</td>
</tr>
<tr>
<td>decrease</td>
<td>out</td>
<td>0</td>
</tr>
<tr>
<td>decrease</td>
<td>0</td>
<td>by gas</td>
</tr>
<tr>
<td>increase</td>
<td>in</td>
<td>by gas</td>
</tr>
<tr>
<td>decrease</td>
<td>out</td>
<td>by gas</td>
</tr>
</tbody>
</table>

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

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
The difference between heat flow and temperature

- You are at a campsite and you wake up one cold morning before dawn, stumble out of your tent in search of the outhouse.
- You enter the outhouse in which there are two facilities, one with a wooden seat and one with a metal seat.
- Both seats are at the same temperature.
- By not choosing wisely, you learn quickly of the difference between temperature and heat flow.