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. 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 capacity can be expressed as:
  \[ Q = m \cdot c \cdot \Delta T \]
  where m is the mass and \( \Delta T \) is the temperature change.

Examples- heat capacity

1. How much heat must be added to 1 kg of water to increase its temp from 20C to 60C?
   \[ Q = mc\Delta T = 1000g \times 1\text{cal/g}\text{C} \times 40\text{C} = 40,000\text{C} \]

2. How much heat must be removed from 2 kg of water to cool it from 90C to 10C?
   \[ Q = mc\Delta T = 2000g \times 1\text{cal/g}\text{C} \times 80\text{C} = 160,000\text{C} \]

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>

Change of Phase

- 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/°F x 140 °F = 140 BTU/lb x 8 lbs → 1120 BTU’s or more than 1 ft³
- 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
  \[ \text{change in internal energy} = \text{heat absorbed by the gas} - \text{work done by the gas} \]
  
- this is a simple energy accounting principle

Analogy to your bank account

- the change in your bank account balance
  \[ \text{change in balance} = \text{deposits} - \text{withdrawals} \]
  
- 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>
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<td>increase</td>
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</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
  \[ \text{change in internal energy} = \text{heat in} - \text{work done} = 3000 \text{ J} - 1000 \text{ J} = 2000 \text{ J} \]

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

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