Lecture 5 - Energy and Matter

Both physical and chemical changes are accompanied by changes in energy.

- We have already looked at two forms of energy
  - Kinetic energy (K.E.)
  - Potential energy (P.E.)

- We have seen how these two forms of energy can transform from one to the other.

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In lab we saw how chemical changes can be accompanied by a change in energy that is manifested by either an absorption or a release of heat:

\[
\text{H}_2\text{C}_6\text{H}_5\text{O}_7 + \text{NaHCO}_3 \rightarrow \text{NaH}_2\text{C}_6\text{H}_5\text{O}_7 + \text{CO}_2 + \text{H}_2\text{O}
\]

- Citric acid
- Sodium bicarbonate
- Sodium citrate
- Carbon dioxide
- Water

\[
\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2
\]

- Magnesium
- Hydrochloric acid
- Magnesium chloride
- Hydrogen

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Heat is one of the ways that energy can be transferred from one place to another.

- Temperature is used to measure how hot or cold an object is
- Heat flows spontaneously from hot regions to cold ones.
- When an object absorbs heat, it gains energy
- When an object release heat, it loses energy.
Heat is also transferred along with physical changes:
- For example, the melting of ice.
- In this case the heat does not go to change the temperature by rather to change the physical state.

Another way that energy can be transferred from one region to another is through work.
- One definition used for energy is the ability to do work.
- Example, when a heavy weight falls to the ground it does work by rearranging things on the ground.

To study these transfers in energy in more detail, we divide the universe up into two regions:
- The system
- The surroundings

The system can be almost anything that defines a region of the universe:
- a beaker
- a test tube
- the earth
- a human being
- ...

It represents what we are interested in studying.

There are are different forms of energy that can be evaluated:
- One of these, is the internal energy ($E$) - $E$ is the sum of all the kinetic and potential energies of all of the particles in a system.
- When a chemical or physical change occurs, the change in the internal energy, $\Delta E$, is equal to the energy after the change, $E_{\text{final}}$, minus the energy before the change, $E_{\text{initial}}$.

$$\Delta E = E_{\text{final}} - E_{\text{initial}}$$

- For a chemical reaction, this would be $\Delta E = E_{\text{products}} - E_{\text{reactants}}$.

- If the energy of the system decreases, $\Delta E < 0$.
- If the energy of the system increases, $\Delta E > 0$.
Lecture 5 - Energy and Change
When the energy of a system changes, heat and/or work flows into or from the system to the surroundings.

The change in the internal energy for the system can be determined by adding together
• the heat absorbed by the system ($q$) and
• the work done on the system ($w$).

Since the heat absorbed by the system is equal to the heat lost by the surrounding, and the work done on the system is equal to the work done by the surroundings,

\[ \Delta E_{\text{system}} = q + w \]
\[ \Delta E_{\text{system}} = -\Delta E_{\text{surroundings}} \]
\[ \Delta E_{\text{universe}} = \Delta E_{\text{system}} + \Delta E_{\text{surroundings}} = 0 \]

This is a statement of the First Law of Thermodynamics.
• The total energy of the universe is a constant; it can be neither created or destroyed.

The laws of thermodynamics were worked out in the 1800’s by studying the efficiency of steam engines.
Lecture 5 - Energy and Change

Efficiency comes with
• maximizing the work done while
• minimizing the amount of heat released

Example, the combustion of gasoline (octane):

\[ 2 \text{C}_8\text{H}_{18} + 25 \text{O}_2 \rightarrow 16 \text{CO}_2 + 18 \text{H}_2\text{O} \]

The work done can include:
• The mechanical work in moving the car down the highway and counteracting friction.
• The electrical work of running the headlights and the stereo system.
• The chemical work of charging the battery.

Where did the chemical energy in the gasoline come from?
• Ultimately, it came from the sun - in a process called photosynthesis:

\[ 6 \text{CO}_2 + 6 \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \]

The units of energy that are commonly used are based on either mechanical work (Joule) or heat (calorie)
• The Joule comes from Newton’s laws of mechanics
  • Work = Force x Distance \( (w = F \times d) \)
  • Force = mass x acceleration \( (F = m \times a) \)

\[ \text{Work} = \text{mass} \times \text{acceleration} \times \text{distance} \]

\[ \text{1 Joule} = 1 \text{ kg} \times \text{m}^2 \text{ / s}^2 \]
The units of energy that are commonly used are based on either mechanical work (Joule) or heat (calorie).

- The calorie is defined as the quantity of heat required to raise the temperature of 1 g of water from 14.5°C to 15.5°C.

James Joule (1818-1889) showed the equivalence of heat and mechanical work with a system of paddle wheels and weights:

\[ w = mgh \]

1 cal = 4.184 kg m\(^2\)/s\(^2\)

1 cal = 4.184 Joule

Quantities like \( \Delta E \) are independent of how you get from the initial to the final state.

\[ \Delta H = \Delta E + PV \]

Even when gases are produced, \( \Delta H = \Delta E \)

- For chemical reactions,
  - \( \Delta H \) is called the heat of reaction
- For freezing a liquid
  - \( \Delta H \) is called the heat of fusion, \( \Delta H_{\text{fus}} \)
- For boiling a liquid
  - \( \Delta H \) is called the heat of vaporization, \( \Delta H_{\text{vap}} \)

A system receives 425 J of heat and delivers 425 J of work to its surrounds. What is the change in internal energy of the system (in J)
Lecture 4 - Problem

What is the change in internal energy (ΔE) energy (in J) of a system that absorbs 0.615 kJ of heat from its surroundings and has 0.247 kcal of work done on it?

Lecture 4 - Problem

“Hot packs” used by skiers, snowmobilers, and others for warmth are based on the oxidation of iron filings in the presence of charcoal.

A) What is the sign of ΔH for this reaction?
B) Is the reaction **exothermic** or **endothermic**?

Unit I - Up Next

- The nature of light and other forms of electromagnetic energy
- What happens when light interacts with matter
- Some behaviors that light and matter share

The End