Chapter 3. Quantum Theory and the Electronic Structure of Atoms

Outline:
• Energy
• Light (electromagnetic radiation)
• Quantum description of atoms/electrons

3.1 Energy and energy changes

Definition: Energy is the capacity to do work or transfer heat.

Energy is classified as either kinetic or potential energy.

Kinetic energy: energy of motion
\[ E_k = \frac{1}{2}mv^2 \]

Potential energy: everything else.
Examples: gravitational potential energy, electrostatic energy, chemical energy, energy stored in a mechanical spring.

Chemical energy: the energy stored in chemicals.
Example: gasoline to power your car.

Electrostatic energy:
the energy stored in the arrangement of charged particles
\[ E_{el} = k_e \frac{q_1 q_2}{d} \]
this is called Coulomb’s Law
\[ (k_e = 9.0 \times 10^9 \text{ J m} / \text{C}^2) \]
**Law of conservation of energy:**
Energy can change form but cannot be created or destroyed.

Example: **burning wood:**
wood turns to ashes but also heat and gases are released.

Units of energy: The SI unit of energy is the **joule**, symbol $J$

The way I like to think about it:

one Newton is the force required (think $F=ma$) to accelerate a 1 kg mass at $1 \text{ ms}^{-2} = 1 \text{ m/s}^2$

one joule is the energy you have to spend to apply this force over a distance of 1 m

Therefore the joule has units of $\text{kg m}^2 \text{s}^{-2} = \text{kg m}^2/\text{s}^2$

**Example:** what is the kinetic energy of a helium atom moving at the speed of sound (340 m/s) ?

**Answer:**

$$E_k = \frac{1}{2} (4.003 \text{ amu})(340 \text{ m/s})^2 \frac{1.661 \times 10^{-24} \text{ g}}{1 \text{ amu}} \frac{1 \text{ kg}}{1000 \text{ g}} = 3.84 \times 10^{-22} \text{ J}$$
Example problem:
Arrange the following pairs of charged particles in order of increasing magnitude of electrostatic attraction ($E_{el}$).

- **a)** (+1) and (-3)
- **b)** (+2) and (-2)
- **c)** (+2) and (-3)
- **d)** (+4) and (-4)
3.2 The nature of light

*Motivation:* chemists use the interaction between light and matter (atoms and molecules) to study the properties of atoms and molecules.

Light, also called electromagnetic radiation, consists of two waves (electric and magnetic) with the same wavelength and frequency and speed, travelling at right angles to each other. (Maxwell’s theory).

(Often we just consider the electric field component)
• Properties of Waves:

- amplitude varies with both time and distance
- length of cycle = 1 wavelength (λ)
- # cycles per second = frequency (ν) (s⁻¹ = hertz = Hz)
- wave speed = λν
- speed of light is a constant
- in vacuum it is c = λν = 3x10⁸ m/s

\[
c = \lambda \nu, \quad \lambda = \frac{c}{\nu}, \quad \nu = \frac{c}{\lambda}
\]

Example problem:
green laser pointers emit light of wavelength 532 nm. What is the frequency of this light?

Answer:
\[
\nu = \frac{c}{\lambda} = \frac{3.00x10^8 \text{ ms}^{-1}}{532 \text{ nm}} = \frac{(3.00x10^8 \text{ ms}^{-1} / 532 \text{ nm}) (1 \text{ nm} / 10^{-9} \text{ m})}{5.64x10^{14} \text{ Hz}}
\]
Light can be of very different wavelengths and frequencies.