Mechanics

Energy and Force

In the description of the state and behavior of a body, physics uses two basic parameters: energy and force. The experimental fact that all bodies are constantly in motion can be explained with the interaction of one body with respect to another. These interactions can be described using the concepts of force and energy. Force is related to motion, while energy is related to the change in the state of a body. Newton, in his studies, showed that the gravitational force is acting at a distance, and thus, he introduced the concept of the force field. This concept correctly describes the behavior of the observed body, since we can observe and describe only the physical effect and neglect source of the force. A force field is the space in which a force acts. The force field is a vector, meaning at any point in the field, the direction and amount of force must be known. Field lines are a visual representation of the vector field forces. Field lines are the path by which the body moves freely in the field of forces. Direction of the field, at some point in the force field, is tangent to the field lines into that point. Homogeneous fields are the fields where value of the field strength is equal in all points of the field, i.e. the inhomogeneous field if this is not true. Homogeneous field is visually represented with equidistant lines of force.

The force, therefore, is defined as a measure of the interaction of the bodies. The force acting on the body changes its energy. For each position of the body in the vector field, the energy of the body is determined. With energy, which is scalar, the vector force field can be described as a scalar field of potential energy. The scalar field is visually described as an equipotential surface. This equipotential surface is the set of all points in the field in which the body has the same potential energy. On equipotential surface body is moving without energy consumption.

Energy is a concept in physics that is used to describe the events and changes in a system. The best definition of energy was proposed by H. Helmholtz: Energy is the body's ability to do work. On the other hand, work is measured by the change in energy and has the same unit. Although the definition of the term may be ambiguous, different types of energy can be calculated very accurately. For example, the potential energy of a body in a gravitational field is mgh, or the kinetic energy of the body that moves is $mv^2/2$, or the electric potential energy of the charge in an electric field is QE ... There are many other forms of energy: potential energy of a spring, stretched or compressed gas, or the energy of molecular bonds or heat. When energy changes its form from one to another, the total amount of energy is conserved. The law of conservation of energy is a fundamental law of physics.

There are four fundamental forces in nature that can explain all of these events. These are the gravitational, electromagnetic, and weak and strong nuclear interactions.

The first force observed and studied by man was the gravitational force. The gravitational force acts between all bodies, because of their mass, and it is always attractive. However, it is the weakest of the fundamental forces. At the level of elementary particles, the attractive gravitational force effects are negligible. Due to the attractive nature of this force, contributions of interactions between individual particles are added and thus, the effect of

these forces on the level of macroscopic objects, planets and galaxies, is prevalent. Our behavior on Earth is determined by the action of gravitational forces. Newton's general law of gravitation was defined in the 18th century. In the 20th century, Einstein expanded this law with the general theory of relativity. Newton's general law of gravitation states that gravitational force between two bodies with mass (m_1 and m_2), separated by a distance (r), can be calculated using the equation $F = G\frac{m_1 m_2}{r^2}$ where the gravitational constant (G) is approximately equal to 6,67 x 10^{-11} $m^3/(kgs^2)$. Thus, the amount of gravitational force on a body is decreasing with an increasing r^2, meaning that this is long range force. It can be observed at distances as large as 10^{-15} m.

The electrostatic force and the magnetic force are acting between charged bodies. These forces are either attractive or repulsive. For example, between two macroscopic bodies that have an equal number of positive and negative elementary charges, the action of these two forces is not observed. On the other hand, between two free charges, this is prevailing force. Between two still electrons, the electrostatic force is 10^{38} times greater than the gravitational force. The amount of electrostatic force between two point charges with charges q_1 and q_2, that are standing still at a distance, r, is expressed using Coulomb's law $F = k\frac{q_1 q_2}{r^2}$, where constant k is equal to 9 x 10^9 $NC^{-2}m^2$. If the charged particles are in motion, they will also interact with the magnetic force. Electrostatic and magnetic forces are long range forces.

Electrical forces are responsible for the most important interactions in our body. At the cellular level, all processes are controlled by electrical forces. Our senses, metabolism, and muscle work are guided by electrical signals. On the membrane of every cell of the body, there is a voltage (the membrane potential) that regulates the diffusion of ions and important molecules across the membrane. By measuring the electrical fields generated by organs and tissues in the body, one can monitor different processes in the body.

The action of electromagnetic forces is reflected through electromagnetic waves. Energy of varying electric and magnetic fields linked with electromagnetic induction is transmitted through space. In electromagnetism, we will further discuss the properties of these fields.

Strong nuclear interaction is the strongest interaction in the nature. It acts between nucleons, protons, and neutrons, and it is responsible for the stability of the nucleons and nuclei. Weak nuclear interactions are responsible for the radioactive beta decay of protons or neutrons. These interactions are detectable only at the levels of the nuclear core, 10^{-15} m, and thus, these forces have a very short range.

Table 1.1.
Basic forces in Nature

interaction	strength	Origin and law
electromagnetic	~ 1	charged particles; Coulomb Law
gravitational	~ 10^{-38}	mass; Newton's law
Week nuclear	~ 10^{-3}	Inside nucleon; unified electroweak interaction
Strong nuclear	~ 10^{2}	Inside nuclei; quantum chromodynamics

Friction

The friction force occurs whenever there is contact between two objects. In the descriptions of some events, its contribution can be neglected in comparison to the effect of other, more powerful forces. Friction is not a fundamental force, but its action is very important. Because of friction, the efficiency of each physical process is reduced. Part of the mechanical energy due to friction is irreversibly converted into heat. We will specifically discuss this in the thermodynamics section.

Friction force plays a significant role in our body. Without the existence of the friction force, we would not be able to walk. That force restricts the motion of joints, controls chewing, breathing, and our heartbeat, and influences many other processes in the body. The amount of friction depends on the properties of the surfaces in contact, which is described with the coefficient of friction, and force components, N, perpendicular to the contact surface:

$$F_{friction} = \mu N$$

Studies have shown that for safe walking on the horizontal plane, the frictional force must be at least 0.15 G, where G is the weight of the person. On the other hand, the motion of joints is facilitated by viscous fluid (synovial fluid), which reduces the friction between the surfaces of the bones. If the quality or quantity of the synovial fluid changes (due to changes in biological processes, such as a disease), there will be increased friction in the joint and the person will feel pain in those areas.

Table 1.2.

Friction coefficient for some types of friction

Materials in contact	?
steel / steel	0,15
tyre / dry asphalt	1,00
tyre / wet asphalt	0,70
steel / ice	0,03
bone/bone in joint	0,003

Atom structure

The atom is the fundamental particle of matter. Molecules are built from atoms. Molecules and their associations form biological organisms and determine their structure and function. Today, we are studying and explaining processes in living matter with models that primarily rely on interatomic and intermolecular interactions of complex structures. Therefore, it is necessary to know the basic principles of atomic and molecular structure and properties. The structure and properties of atoms and molecules are described by quantum mechanics. For easier understanding and description, we can still use the quasi-classical Bohr-Rutherford model. We will use this model when we need to explain phenomena at the level of molecules.

Based on the experiments of J.J. Thomson, E. Rutherfor,d and N. Bohr, the classical model of the atom was built. An atom consists of a nucleus and an electron cloud. Almost all of the mass of an atom is concentrated in the nucleus. The radius of an atom's nucleus is between 10^{-10} m and 10^{-15} m. We can determine the structure of an atom by answering this question: how much energy do the electrons have in the electric field of the atom core? Postulates of the quantization of energy and the radius of the electron paths enabled Bohr to define the structure of the hydrogen atom that satisfactorily match with the measurements of the radiation spectra. Bohr's postulates are, as follows:

1. The electrons in an electric field of the nucleus cannot move on an arbitrary path, and can thus, only move on equipotential surfaces. On an equipotential surface, an electron is in a stationary state and it does not emit or absorb energy.
2. An atom emits energy in the form of photons when an electron moves from higher to lower equipotential surface. The emitted quantum of energy is equal to the difference between the energy of these surfaces:

$$E=E_n-E_m.$$

3. Equipotential surfaces are discreetly distributed in space, so that the radius of the circles, at which the electron moves, and the energy of the electron on an observed equipotential surface is defined by an integer which is called Bohr quantum number

$$r_n \; n^2 \;\; \text{i} \;\; E_n = -13{,}6 \text{ (eV) } 1/\text{n}^2$$

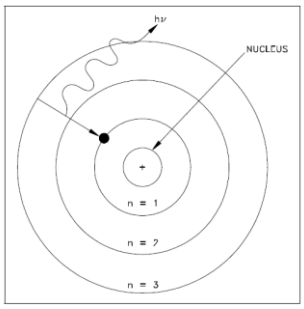
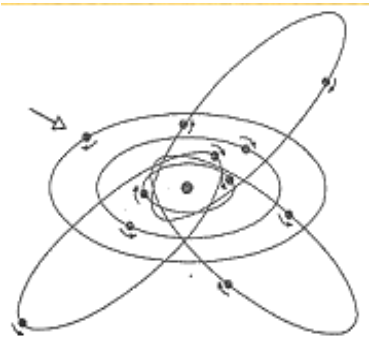


Figure 1 Bohr's Model of the Hydrogen Atom

a)



b)

Figure 1 Model of the atom

a**) Rutherford-Bohr model:** Electrons are moving around nucleus in circles. The distance from the nucleus determines the electron energy in the electric field of the nucleus. Energy is described with a whole number – the principal quantum number. The atomic ionization energy is smaller when the maximum radius of an electron orbit is larger.

b) **Sommerfeld model**: The elliptical shape of the electron path and its orientation in space determines the momentum and the magnetic properties of electrons (described by its orbital and magnetic quantum number). Electron spin in this pictorial image is shown as electron spin around its own axis.

Each electron is described by a discrete energy and a discrete amount and direction of momentum. Later, it was discovered that the electron has another feature, called spin. Changes in these parameters are described by the quantum numbers, which emphasize the discreteness of the quantum state.

It is now known, on the basis of theoretical considerations of quantum mechanics, that an electron in an atom behaves like a wave. Thus, we cannot define the trajectory of individual electrons, but we discuss the quantum states that are described with wave functions $\Psi(x,t)$. The square of the wave function, $|\Psi(x,t)|^2$, is the probability density that the electron is at position *x*, rather than some other location. Wave function can be calculated exactly for simpler systems, like the hydrogen atom, while for atoms with more electrons, numerical methods must be used. The electron state of an atom is described using four quantum numbers:

n - **principal quantum number** - determines the electron energy in the electric field of the nucleus. It has an integer value of 1, 2, 3, to n and corresponds with the energy shells: K, L, M, N, O and P. K is closest and P is furthest shell from the nucleus. Electrons in the K shell are most strongly bonded to the nucleus. The energy required to liberate an electron from the atom (ionization energy) is decreases with an increasing n. The number of electrons in a shell is $2n^2$.

ℓ - **orbital quantum number** - is associated with the amount of the angular momentum of an electron, L. It has a value from 0 to n-1 and corresponds with orbitals: s, p, d, f,..

$m_ℓ$ - the magnetic quantum number - it is linked to the orientation of the angular momentum vector of electrons with respect to the direction of the external magnetic field. The values of the quantum number changes from - ℓ to + ℓ. One orbital has 2 ℓ +1 electrons. It is important when observing the interaction of atoms with an external magnetic field.

m_s-magnetic spin quantum number - there are only two values: +1/2 and -1/2. It determines the electron spin vector projection with respect to the external magnetic field.

The particles that make up an atom – the proton, neutron, and electron - are described using three properties: mass, charge, and spin. By now, you probably have not come into contact with spin. It is a property of a particle that measures the particle's magnetic properties and its interaction with the magnetic field. All of the particles listed above have a spin of 1/2.

The arrangements of elementary particles in complex structures are determined by Pauli's exclusion principle: two electrons in an atom cannot be in the same quantum state, i.e. they cannot have the same four quantum numbers. Therefore, the electrons in atoms are arranged in different orbitals, so the n-th shell can hold maximum $2n^2$ electrons. Because of Pauli's exclusion principle, nucleons in nuclei are also arranged in energy levels.

The electron with the smallest amount of energy is in an electron in the K shell, the shell closest to the nucleus, since the discrete energy states have a negative sign. On the other hand, this electron is also the most strongly bounded electron, and thus, ionization energy of the atom for the electron from the K-shell is the greatest. An atom is in a ground energy state when all lower energy states are filled, and while an atom is in an excited state if some of the higher energy states are populated, while some of the lower energy states are empty. An atom can go from a ground to an excited state with the absorption of energy and conversely, it relaxes to the ground state with the emission of energy. These processes change the principal quantum number of electrons. By measuring the energies that are absorbed or emitted when energy transitions occur, the absorption or emission spectra are recorded. Those spectra are always line spectra and they are characteristic for an individual atom.

An atom is neutral – the amount of positive charges in the nucleus is equal to amount of negative charges in the electronic cloud. The atom becomes ionic with the emission (cation) or the absorption (anion) of electrons. The ionization energies of an atom for its electrons, in different shells, are different. As stated above, the electrons in the K – shell have the largest ionization energy. In different atoms, the ionization energies of electrons in equal shells are different. Hence, atoms with higher ordinal number have a larger ionization energy for K-electrons.

Molecular structure

An infinite number of forms of matter, found in nature, are built by the mutual coupling of atoms of only eighty-one elements. Different forms of matter are built from different combinations of these atoms and their interconnections. Those combinations of atoms are called molecules and they are the basic building blocks of matter. Molecules are, more or less, stable associations of atoms and they determine the macroscopic properties of matter. Substances can be in solid, liquid, or gaseous states. Identical molecules can form substances in all three states, but their macroscopic characteristics are different. Therefore, for the understanding of processes, on a macroscopic level, it is necessary to introduce and explain the

basic principles of molecular structure. One atom, within a molecule, acts on other atoms in the same molecule and simultaneously, feels the effects of all other atoms. The molecule will be stable if the spatial distributions of the atoms have a certain, minimum total energy. The atoms in a molecule are connected by chemical bonds. The molecule may also have increased energy - then we may discuss the excited energy state of the molecule. The energy states of molecules can be quantized. In this complex system, the number of possible different energy transitions is larger than in the atom.

In molecules, there are electrons that are involved in chemical bonding and those that are not. Bonding electrons are particularly important in determining the energy of a molecule, because their energy changes with the creation of the molecule, while the energy of electrons that do not participate in the molecular connection remain unchanged. The two basic types of chemical bonds, between atoms in a molecule, are covalent and ionic bonds.

Covalent bond

If we want to exactly describe the bond between two atoms, we must calculate the wave functions and energies of the electrons involved in molecular bonding. Thus, we must define the molecular orbital of the electrons. Covalent bonding is achieved by the overlapping of atomic orbitals, of at least two electrons, from the atoms that are involved in forming a bond. Since the atomic orbitals are oriented (except the *s* orbital), formed molecular orbitals will also be oriented. That's the reason why molecules have different spatial structure.

A covalent bond is made from sharing a common electron between two bonded atoms. This type of bond is a very strong bond, with a high binding energy. Binding energy is the energy that must be introduced into a molecule to break it into constituent atoms. With a higher binding energy, the bond is stronger and the molecule is more stable.

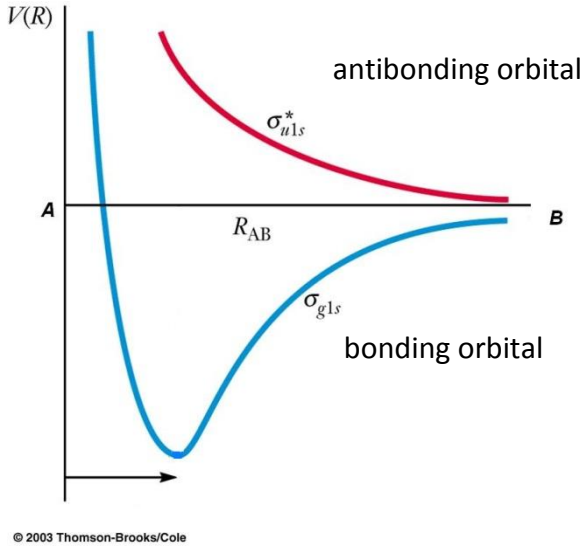


Figure 2. Bonding energy dependence on distance between two atoms in a molecule

The energy of two independent atoms is represented by a horizontal line. Approaching atoms,

due to the attractive forces between the atoms, decrease their potential energy and at some distance, $R'_{AB,}$ achieves a minimum value. This distance (R'AB) is the equilibrium distance of atoms in a molecule and at this distance, two electrons can be found in the bonding orbital. If the spins of the the outer orbital electrons are equal, the two atoms will not form a molecule - the Pauli exclusion principle. For these two atoms, the potential energy will grow as they are approaching. The minimum potential energy in the bonding orbital means that the energy of the atoms in a molecule is lower than the free energy of these atoms.

Ionic bond

An ionic bond occurs between atoms that have different binding affinities for their electrons or electronegativity. In the interaction of these atoms, the electron cloud density is higher around the atom with a greater electronegativity. If the asymmetry is large, there is a transition of electrons from the atom with a smaller electronegativity to the atom with a larger electronegativity. As a result, two ions are created. It is important to note that this process requires energy. An ionic bond is a stable bond since the energy of the molecule is decreased with the attractive Coulomb interaction. Ionic bond energy is lower than the energy covalent bond.

Polar molecules are formed when a bond is partially covalent and partially ionic. The electronic cloud has an asymmetric distribution around the molecule, but there is no transfer of electrons between atoms. The atoms in the molecule are connected by sharing an electron pair, like in covalent bond. An example of a polar molecule is a water molecule. In this molecule, the electron density distribution in the joint electron cloud is moved towards the oxygen atom and thus, the water molecule has a separated center of mass for positive and negative charges. In physics, the polar molecule is described with an electric dipole model.

Bindings between molecules or small groups of atoms within a large biological molecule

The binding energies between molecular groups, which form larger molecules, are much lower than the binding energies between atoms within a single group. This describes a weak Van der Waals bonds. These interactions are, in nature, electrostatic interactions and are generated by dipole - ion, dipole - dipole, and induced dipole - ion interactions.

The hydrogen bond should be specifically emphasized since it is important for many molecular properties, e.g.: spatial structure of macromolecules. It is the strongest of the weak bonds. It occurs when a hydrogen atom is covalently bonded to an oxygen, nitrogen or halogen atom. This covalent bond is asymmetric, because the electron cloud moves away from the hydrogen atoms. The positive electric field of the hydrogen in the bond, in that way, attracts outer electrons of other electronegative atoms (usually oxygen or nitrogen), and creates an

additional electrostatic link between parts of the molecules. Hydrogen bonds, for example, are responsible for the spatial structure of globular proteins and water's high boiling point – an important property of water. Additionally, the double helix form of DNA molecule is built by transverse hydrogen bonds between corresponding base pairs. Hydrogen bond are also important for the activity of biological molecules. Interruption of only one hydrogen bond can cause changes in the structure, resulting in changes in the biological activity of macromolecules.

Molecular energy

In biology and medicine, spectroscopic methods are used to determine the structures of biological macromolecules. Spectra measured in the ultraviolet, visible, and infrared regions reveal information about molecular structure. The spectrum of the atom represents the transition of electron energy between different electron states. They are linear since each transition is recorded as a line in the spectrum. The spectra of molecules are more complex, because additional interactions are responsible for molecular energy states. In addition to energy necessary for transitions of electrons between molecular orbitals, molecules can change their energy due to transitions in rotational and vibrational states. The amounts of different types of molecular energies, and what can be learned from them, will be presented with the simple example of a diatomic molecule.

Electron transitions in the molecule

Electrons involved in molecular bonding can cross between molecular orbitals. The energy required for these transitions have values of several eV, and are much lower than the energy of the electron transitions between atomic orbitals, which can be up to 90 keV. These transitions are characteristic of the individual bonds between atoms. The spectra of electronic transitions in molecules is not linear because in addition, there are also vibrational and rotational transitions. They use energies lower than 0.1 eV.

Vibrational molecular states

The diatomic molecule can be studied using the simple model of an elastic oscillator - two balls connected with an elastic spring, with an elastic constant k. Such an oscillator can vibrate in all directions. We observe oscillations in one dimension. The x-axis will be set to coincide with the coupling balls. Atoms oscillate synchronously. The amplitude of oscillation depends on the mass of the atom. Energy of the vibrations for a given system can be calculated by solving the equations of motion for a harmonic oscillator if the system with two bodies is replaced with one body with a reduced mass. Then second Newton's Law can be applied:

$$F = Ma = - kx$$

where M is reduced mass of the system $M = \frac{m_1 \cdot m_2}{m_1 + m_2}$

Figure 3. Model of diatomic molecule as an elastic oscillator
Atoms represented as solid balls with mass *m* can vibrate around their equilibrium position. Since they are connected with elastic forces, represented with elastic coil, they vibrate at the same frequencies.

By the solving equation for classical harmonic oscillator energy dependence on amplitude A and frequency $\omega = \sqrt{\frac{k}{M}}$ is obtained, $E = \frac{M\,\omega^2\,A^2}{2}$. In quantum mechanics, vibrational energies are discreet, so the energy of vibrational state of the molecule is given with the equation

$$E_\nu = \frac{\omega h}{2\pi}\left(\nu + \frac{1}{2}\right)$$

where ν is vibrational quantum number with integer values (ν = 0,1,2,3,..). The ground vibrational state for ν = 0 has an energy equal to $E = \frac{\omega h}{4\pi}$. Transition between any two adjacent vibrational states requires an energy equal to the energy difference between these states. Calculations show that this energy will be the same for any two adjacent states - we say that the vibrational energy levels are equidistant. Energy differences between vibrational energy levels in molecules are in range from 0.04 to 0.1 eV. The transition from one to another molecular vibrational state will occur with the absorption or emission of energy quant equal to

$$\Delta E = E_\nu - E_{\nu-1} = \frac{\omega\, h}{2\,\pi}$$

Rotation energy levels in the molecule

In addition to the vibrational motion of atoms in molecules, the molecule as a whole rotates with an angular velocity around an axis that is perpendicular to the coupling of the

atoms. We will consider only one type of rotation. In classical physics, the expression for the energy of rotation is $E_{rot} = \frac{1}{2} I \omega^2 = \frac{L^2}{2I}$. Quantity I is moment of inertia of the molecule and it depends on the distribution of a mass in it. For the case of two rotating bodies, the moment of inertia is calculated from expression above, while angular momentum is equal to $L=I\omega$. In quantum mechanics, *j* is the angular momentum quantum number, so the energy of j rotational energy level is equal to

$$E_j = \left(\frac{h}{2\pi}\right)^2 \frac{j(j+1)}{2I}$$

The rotation of the rotational energy of the ground state, j = 0, is zero. The rotational levels are not equidistant. The distance between them depends on the rotational quantum number. For a higher rotational energy level, the energy of the transition to the next rotational level will be also higher.

For small values of quantum number j transition energies are around 10^{-3}eV.

All molecular energy states are quantized and the molecule can be only in one of them. Within an electronic state, there are varieties of rotational and vibrational states. Transitions between any of these states will be caused by the emission or absorption of energy quanta. There are three possible cases of energy transfer in a molecule:

a) the transition between the electronic states. This can be achieved simultaneously with transitions between different rotational and vibrational states of the molecule. Because of many vibrational and rotational transitions with small energy differences, the molecular spectrum is a band spectrum. Electronic transitions in molecules are measurable in the visible region of the spectrum of electromagnetic radiation.

b) there is no transition between the electronic states, but there are transitions between vibrational and rotational states of the molecule. Energies of the transitions are around 0.1 eV, and they are observable in the infrared range of electromagnetic waves.

c) there are only rotational transitions. The energies of these transitions are in the range of microwave energy.

Waves

For centuries scientists have built their knowledge about nature by collecting information through two senses, hearing and sight. These processes pass on important data to the observer, without physical contact with the subject, and "bring" them by sound and light. Although different in nature, sound and light have one common feature - the energy is a transmitted wave.

A wave is a periodic disturbance in space that transmits energy without mass transfer. A sound wave is a mechanical wave. This means that the energy of the source of vibration spreads throughout a medium from one particle to another. The spreading of the wave of particle motion is not equal to the particle motion of the medium in which the wave spreads. Particles are vibrating around the equilibrium position, and the wave transfers energy throughout the medium in some direction.

Light is an electromagnetic wave. The energy is transmitted through space with varying electric and magnetic fields. An electromagnetic wave can spread through the vacuum. For energy transfer with electromagnetic waves, a medium or any kind of particles are not necessary.

While the sources of mechanical waves are a body that oscillates in the elastic medium, the source of electromagnetic waves is an accelerated charge. Sources of low frequency electromagnetic waves are accelerated charges in electric circuits (radio waves) and sources of high-frequency waves are charges in atoms (X-rays, light) and the nucleus (-radiation).

The nature of electromagnetic waves

An electromagnetic wave is a transfer of electric and magnetic field energies through space. Fields are variable and mutually induced. Electric and magnetic fields have the same frequency and oscillate in phase. The direction of electric and magnetic fields in electromagnetic waves are perpendicular to each other and perpendicular to the direction of the wave propagation. According to the direction in which electromagnetic waves spread and in relation to the electric and magnetic fields, it is a transverse wave. The Nature and the emergence of electromagnetic waves was explained by J.C. Maxwell (1831st-1879th) in his theory of electromagnetism. In the mid-nineteenth century, he linked the known facts about electricity, magnetism and optics, all of which, at that time, were separate fields of physics. Maxwell's theory predicted that the occurrence of an electromagnetic wave explained the properties and spreading of light. Classical laws of electromagnetism predict that each variable of a magnetic field is induced around a variable electric field, whose field lines are perpendicular to the

direction of the magnetic field. On the other hand, each motion of the charge induces a magnetic field in the plane perpendicular to the direction of the electric field of that charge. Maxwell assumed that the charge is not necessary for the induction of the magnetic field. It is sufficient that there is a varying electric field. This mutual induction of electric and magnetic fields in space is spreading at a speed that depends on the properties of space.

At some point in space, the dependence of the field strength on time is shown with a sinusoidal function. The spatial distribution of the magnetic and electric fields strength, in some moment of time, is also described with sinusoidal function. Expressions that describe the space and time of electric and magnetic fields, respectively, are:

$$E = E_0 \sin\omega\left(t - \frac{x}{c}\right) \qquad B = B_0 \sin\omega\left(t - \frac{x}{c}\right)$$

where x is the distance from the wave source to the point where we measure the field strength, and c is the speed of the wave propagation in air or in a vacuum. x/c is the phase shift and it indicates the time that is necessary for the information about the current value of the field when it gets to measuring point. Taking into account the above relations, we can write above equations like this:

$$E = E_0 \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right) \qquad B = B_0 \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$

Wave speed depends on the electrical and magnetic properties of matter. The speed of the electromagnetic wave, c, in a vacuum and air, according to Maxwell's theory of electromagnetic radiation, is defined by the expression:

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}; \qquad \varepsilon_0 = \frac{1}{36\pi} \times 10^{-9} Fm^{-1}; \qquad \mu_0 = 4\pi \times 10^{-7} Hm^{-1}$$

where ε_0 is dielectric permittivity of a vacuum and μ_0 is magnetic permeability of a vacuum. From the above equation, the speed of the electromagnetic waves, in a vacuum, was calculated: $c=3x10^8$ m/s. The propagation velocity, v, of the electromagnetic waves in any other medium is lower than c. That speed is determined with a dielectric permittivity, ε, and a magnetic permeability, μ, of the medium:

$$v = \frac{1}{\sqrt{\epsilon\mu}}$$

In the same medium, waves with different wavelengths are spreading with different speeds.

Electromagnetic waves transfer the energy of electric and magnetic fields. The density of the electromagnetic energy, U / V, at some point in space, depends on the current value of the electric and magnetic fields:

$$\frac{U}{V} = \frac{1}{2}\left(\varepsilon_0 E^2 + \frac{B^2}{\mu_0}\right) \qquad \frac{U}{V} = \frac{1}{2}\left(\varepsilon E^2 + \frac{B^2}{\mu}\right)$$

The first term is in relation to the energy density of an electromagnetic wave in the air and the other is the energy density of an electromagnetic wave if the wave spreads through the medium.

Table 1.3

Electromagnetic wave

Wave type	***λ / m***	***source***
radiowaves	$3x10^{7}$ - 10^{-2}	oscillator circuit and antena; in communication
microwaves	10^{-2} - 10^{-4}	molecular rotation; klystron, magnetron in therapy
Infrared radiation	10^{-4} - $8x10^{-7}$	vibrations and rotations of molecules used in diagnosis and therapy
Visible light	$7,5x10^{-7}$ - $3,9x10^{-7}$	transitions of electrons between the outer orbitals
Ultraviolet radiation	$3,9x10^{-7}$ - $2x10^{-8}$	transitions of electrons between the shells of atoms and molecular orbitals
X-rays	10^{-8} - 10^{-10}	transitions of electrons from the inner atomic orbitals, X-ray. tube, diagnostics
t**herapeutic X-rays**	10^{-10} - 10^{-13}	impact high energy electrons in the metal plate, therapy
γ-rays	10^{-11} - 10^{-15}	nucleus radiation, radionuclides, diagnosis and therapy