Life Science and Future Perspectives

No prerequisite required, for students of all majors

The introduction of recent developments in life science and its impact on the society will be analyzed with special emphasis on the aftermath of DNA recombination and associated advances in biotechnology and animal or human cloning on the future of humanity among responsible citizens. The course is intended to give an overview in the emerging field of genome-based biotechnological breakthroughs and to evaluate the changing concepts on the heredity of life on the basis of recent advances in modern biology to improve the students' awareness of fast-changing knowledge in life science and its great impact on the future of human beings. The object of this course is also to acquaint the students of science and liberal arts with the basic facts and principles of modern concepts of biotechnology and gene cloning in relation to their effects on the traditional moral values and conscience of each individual citizen in the society in general.

Now that the map of a complete set of human genetic material has been completed, scientists are turning their attention to how that information will be mined for a greater understanding of the role genes play in health and disease and how those insights will yield better treatments of various diseases.

References Books for the Course:

INTRODUCTION

§ What is Life Science?  The Study of the Function and Mechanism of Various Phenomena of Living Cells

§ The Molecular Logic of Life

I. The chemical unity of diverse living organisms:
Three characteristics to distinguish living organisms from inanimate objects:
(1) Highly organized molecular and cellular structures
(2) Ability of extracting and transforming energy from environment
(3) Capacity of performing precise self-replication and self-assembly
Living organisms are composed primarily of macromolecules, polymers of simple building units of just a few different types. Each type of organism constructs a unique set of macromolecules from these monomeric units, resulting in the structural and functional diversity among species. The properties of these polymers are determined by their sequences of monomers. Diversity is achieved through the nearly limitless varieties of sequences that can exist when amino acids are linked to form proteins, nucleotides are linked to form nucleic acids and monosaccharides to form polysaccharides.

II. Energy production and consumption in metabolism:
The macromolecules in a cell are continuously being synthesized (Anabolism) and degraded (Catabolism). The cell thus maintains a dynamic steady state in which the amount of each macromolecule remains fairly constant at the level required under given physiological conditions. Living organisms are open systems and exchange both matter and energy with their surroundings. They are not at equilibrium with their surroundings: i.e., the concentrations of some molecules inside the cells of the organism are not the same as their concentrations in the surroundings. To maintain this situation, the organism must acquire energy from its surroundings, either in the form of chemical energy or directly from sunlight. Energy transduction occurs in living cells primarily by oxido-reduction reactions. One of the most important carriers of chemical energy in all cells is ATP (adenosine triphosphate).

III. Biological information transfer:
The genetic information is encoded in the sequence (order) of the four different deoxyribonucleotides in the DNA. Hereditary transmission of genetic information occurs via replication of DNA, the information-containing molecule (except some viruses). This process is very accurate and thus results in relatively few changes in genetic information. This stability is important to maintain individual and species characteristics over long periods of time. On the other hand, regular changes in genetic information (mutation) do occur,
primarily as a result of infrequent errors in replication. These mutations are essential for generating genetic diversity, which allows for adaptation of species. The three-dimensional structures of informational macromolecules are formed and maintained primarily through noncovalent interactions, which include hydrogen bonds, ionic interactions between charged groups, van der Waals interactions, and hydrophobic interactions (will be discussed later). They are weak, and can form, break and re-form more rapidly and with less energy input than can covalent bonds. This is important to maintain the flexibility needed in macromolecules.

§ Biochemical Unity from Bacteria to Humans
Understanding the biochemical evolution of life is the "Holy Grail" of all biological studies.

Origin of Life vs Search of Fundamental Particles in the Physical World

§ Chemical composition of an E. coli cell
H₂O- 70 %; Protein- 15 %; DNA- 1 %; RNA- 6 %; Carbohydrate- 3 %; Lipid- 2 %;
Inorganic salts- 1 %; free amino acids, nucleotides, etc.

* Relative abundance of various elements (% atom number)

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Protein: Enzymes, oxygen-transport hemoglobin, collagen, myosin etc.

DNA: Genetic information of cells. Ex. Each human cell has 23 pairs of chromosomes, i.e. 46 DNA molecules encoding about 50,000 distinct kinds of protein molecules.

RNA: New concept of acting as enzyme in some self-splicing reactions.

Origin of all biomolecules?

Carbohydrate: Energy source of cells. Ex. glucose, starch, glycogen.

Lipid: Membrane constituents and energy source.

* Lipoprotein, Glycoprotein, Glycolipid, Metalloprotein, Nucleoprotein etc.

* Polymers:
  heteropolymer (informational), for example proteins and DNA/RNA.
  homopolymer (noninformational), for example starch and glycogen of carbohydrate.

What is Biochemistry? The Chemical Reactions of Living Cells

Background: General Chemistry, Organic Chemistry and simple Mathematics
§ "All life is chemistry, the more we know of these chemical reactions, the more we know of life." - Severo Ochoa, 1959 Nobel prizewinner for Medicine (Died in Nov. 1993 at 88).

§ Origin of Life and Evolution of Species

* Life or living matter contains C, H, O, N, P, and S.

Of about more than 100 chemical elements, only about 28 (about 25%) occur naturally in plants and animals. Elements found in the earth and atmosphere may have been tested by trial and error in living organisms during millions of years. Those elements that most effectively performed the necessary tasks and most importantly, allowed the plant or animal to thrive were retained.

* Combining elements into compounds and further to biological macromolecules

Well-known examples illustrate the diverse array of organic molecules or compounds that perform a variety of cellular roles including carbohydrates, lipids, proteins and DNA. Although their structures and functions are quite different, all macromolecules have one common characteristic: they are polymers constructed by combining hundreds, thousands and even millions of smaller, prefabricated molecules called monomers or building blocks of these biological molecules. For instances, proteins are polymers composed of 20 different amino acid building blocks whereas nucleic acids (DNA or RNA) are polymers of the combination of 4 different nucleotides. Carbohydrates or called polysaccharides consist of different types of monomeric sugars such as glucose, galactose etc.

The synthesis of proteins, DNA and polysaccharides requires complex cellular machinery, exacting control to assure reproducibility and an enormous amount of chemical energy.

* Construction of organelles, cells and organisms from biological macromolecules

Viruses are perfect examples of simple combination of biological macromolecules. Most viruses consist of a single DNA or RNA molecule wrapped in a protein coat or package. They cannot exist independently and reside usually inside living cells like parasites. They are the major causes of many plant and animal maladies and diseases and their presence in the world attests to the serious outcome of human suffering.
§ Protein (from Greek proteios meaning primary):

They are complex, biologically important molecules composed of building blocks of 20 amino acids joined by peptide bonds. Proteins can be molded (folded) into characteristic three-dimensional structure, which may be fibrous, globular or pleated shape. Proteins are essential to all living organisms. As enzymes they regulate all aspects of metabolism. Structural proteins such as keratin and collagen make up the hair, skin, nail, bones and tendons. Muscle proteins can contract to produce movement. Hemoglobins in red blood cells transport oxygen to tissues.

§ Enzyme (from Greek enzymos meaning leavened):

Enzymes are biological catalysts produced in cells, and are capable of speeding up the chemical reactions necessary for life by converting one molecule (substrate) into another (product). Enzymes are not themselves destroyed by this process. They are large, complex proteins, and are highly specific, each chemical reaction requiring its own particular enzyme. The enzyme must fit into a “slot” of the substrate molecule, thus the substrate may therefore be compared to a lock and the enzyme to the key required to open it.

* Protein or enzyme engineering:

It is the process of the creation of synthetic proteins designed to carry out specific tasks. For example, an enzyme may be designed to remove grease from soiled clothes and remain stable at the high temperature in a washing machine.

§ DNA (deoxyribonucleic acid):

It is a complex giant molecule that contains, in chemically coded form, all the information needed to build, control and maintain a living organism. DNA is a ladderlike double-stranded nucleic acid that form the basis of genetic inheritance in all organisms, except for a few viruses that have only RNA. In organisms other than bacteria it is organized into chromosomes and contained in the cell nucleus.

Hereditary information is stored as a specific sequence of bases. A set of three bases, known as a triplet “codon”, acts as a blueprint for the manufacture of a particular amino acid, the subunit of a protein molecule. For example the sequence of the codon GAG codes for the amino acid, glutamic acid. There are four different bases, that means there must be $4 \times 4 \times 4 = 64$ different codons which have all been worked out by biochemists. Proteins are usually made up of only 20 amino acids, so many amino acids have more than one codon. The
information encoded by the codons is transcribed to messenger RNA (mRNA) and is then translated into amino acids in the ribosomes of cytoplasm.

“We have discovered the secret of life!”
Francis Crick on the discovery of DNA double helix in 1953.

§ The roots and development of conventional and modern life science

People early civilization in Egypt, Greece, China, India and Rome plus elsewhere did not understand the biochemical principles underlying the baking of leavened bread, the fermentation of fruit juices, or the treatment of maladies with plant and animal materials. Early studies in biology, which concentrated on the treatment of illness and the attainment of good health, were firmly rooted in philosophy and religion.

The Chinese in the fourth century B.C. (399-301 B.C.) believed that humans contained five elements: water, fire, wood, metal and earth. An imbalance in these elements caused illness. Similar thought also prevailed in early Greek history, although it was more involved in the realm of unexplained natural force or region. They had so called “sacred disease”, which was an illness caused by the will of God and could not be cured by the human means. The concept was abandoned by the teaching of Hippocrates until about the fifth century (about 460-360 B.C.). Ancient people started to think and trace the causes of human illness. The early Greeks, including Plato (427-347 B.C.) and Aristotle (384-322 B.C. tutor of Alexander the Great), all attempted to explain the human body in terms of cosmological theories and stressed diet for treatment of disease and good health. The digestive enzyme “pepsin” originated from the Greek term for digestion “pepsis”, a word indicating inner heat.

Arabic biology, which flourished after the founding of Baghdad in 762 A.D., was greatly influenced by early Greek scientific literature. They advanced the use of Greek pharmaceutical recipes by determining and classifying the strength and chemical nature of natural drugs. Thereafter the Greek and Arabic scientific literature and influence slowly arrived in western Europe around the 11th century A.D. A key figure in European science, Paracelsus (1493-1541 A.D., Swiss physician and alchemist), began a move away from the ancient medical doctrines of Aristotle, Galen (Greek physician 129-199 A.D.), and the Arab scientist, Avicenna (980-1037 A.D.), which were mainly based on “vitalism” in nature. Paracelsus asserted that man is made out of the same material as the rest of creation, feeds on the substances which make up the universe, and is subjected to the laws which govern their growth and decay.

Influenced by Paracelsus, in the 17th and 18th centuries, biologists began in earnest a more molecular approach to the study of biological materials and processes. However even until the 19th century, any biological process that could not be understood in chemical terms was explained by the doctrine of vitalism. These so called “vitalists” argued that it was the presence of a vital force (life force or supernatural spirit) that distinguished the living organic
world from the inanimate inorganic world. Only in 1828, using only the inorganic or lifeless chemicals ammonia and cyanic acid, the German chemist Friedrich Wöhler synthesized urea and started the modern biochemistry.

§ The road to new life science based on biochemistry and molecular biology.

The origin of biochemistry from two perspectives, the physical sciences and the biological sciences. The dates of important events in the development of biochemistry are noted on the scale on the left.
§ Development of protein research

* The structure of proteins: All proteins contain four essential elements: carbon, hydrogen, oxygen and nitrogen plus sulphur (in two of the amino acids, *i.e.* cysteine and methionine). These elements are bonded together to form compounds called amino acids. Being organic acids these compounds contain the COOH or carboxyl group and each has also the NH₂ or an amino group. Twenty different amino acids are commonly found in most proteins, the structural formulas of some of them are shown below.

* Formation of a polypeptide chain or protein from the condensation of the COOH and the NH₂ groups of various amino acids