Alles Introductory Biology: Illustrated Lecture Presentations

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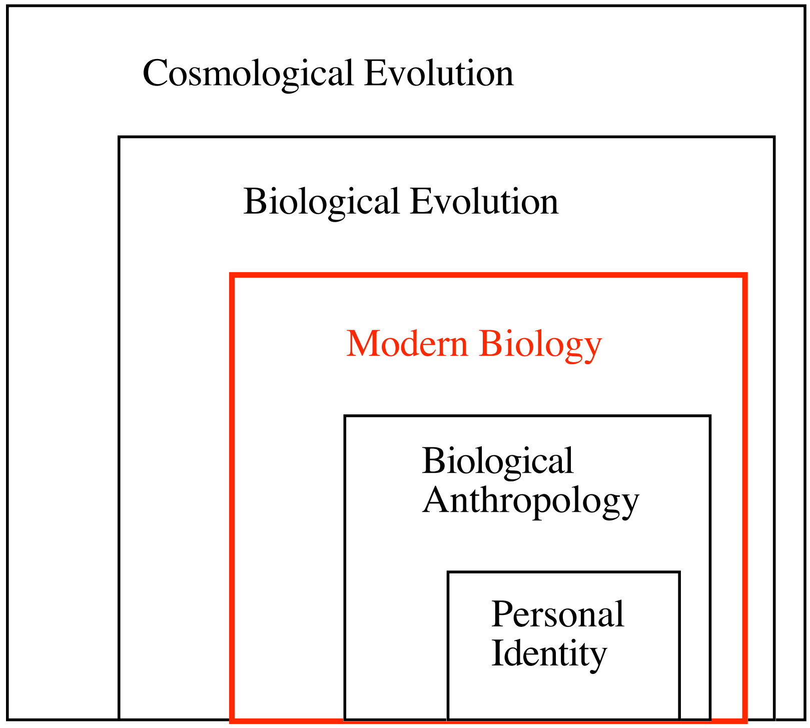
Western Washington University

Part Two: The Conceptual Framework of Biology

Life as a Chemical Function—Biochemistry & Genetics

Increasingly Inclusive Concepts in Science



Conceptually modern biology today is characterized by the study of life at the molecular level. This powerful tool has opened up new vistas in our understanding of life on Earth by showing us the biochemical basis of life.

Life as a Chemical Function

Introduction: We gained a fundamentally new understanding of nature when scientific research was able to shift scale in size from the macroscopic, or human scale, to the nanometer scale of molecules. This is one of the strengths of the reductionist method in science. Biology today is characterized by this reductionist program; we live in the age of molecular biology.

The Chemical Dimension of Life—Biochemistry

- **atoms —> to molecules —> to macromolecules**

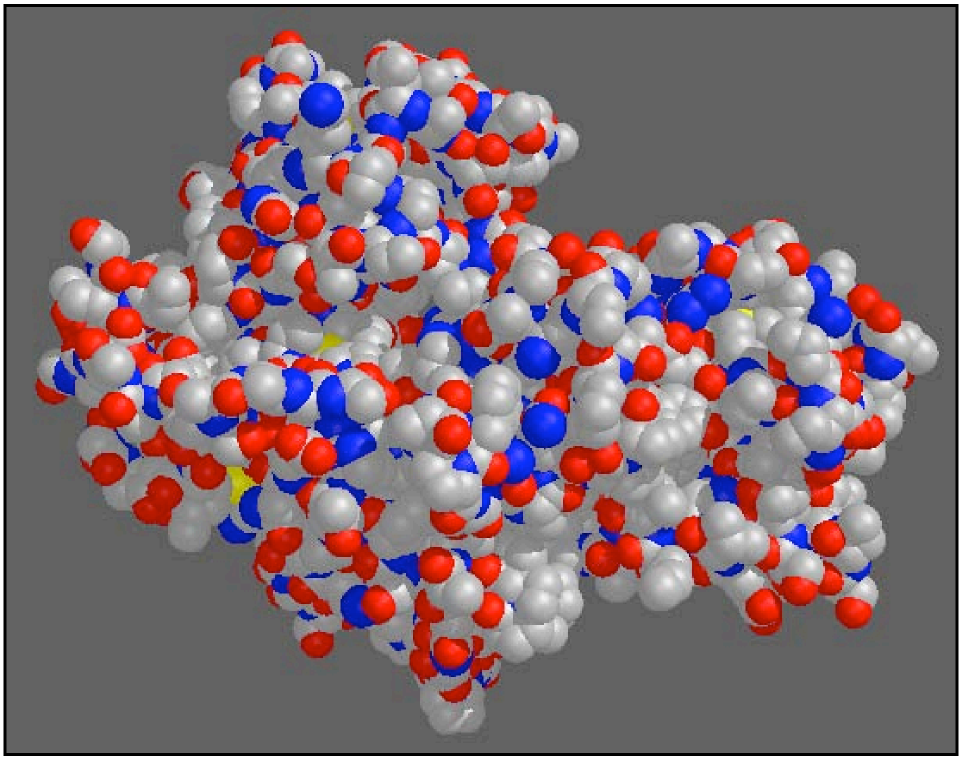
There are four main groups of biologically important macromolecules:

(1) Proteins both structural such as keratin, and regulatory such as enzymes

(2) Nucleic Acids such as DNA and RNA

(3) Carbohydrates such as glucose, a simple sugar

(4) Lipids such as fatty acids that form membranes



Proteins

This is a molecule of Hexokinase, a protein enzyme found in almost all living organisms. Hexokinase is a central enzyme in the production of energy in the cell. The protein is composed of approximately 6000 atoms.

Four Levels of Protein Structure

• The first or **Primary Level** is simply the order of amino acids in a polypeptide chain.

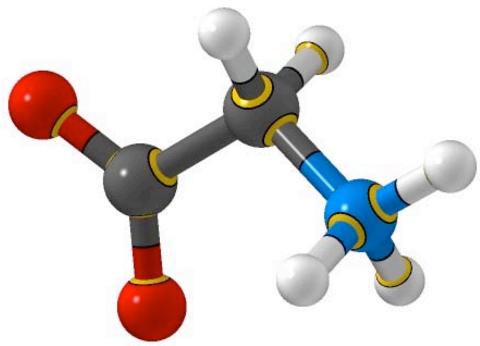
• The **Secondary Level** is the first folding of the polypeptide chain into either an Alpha Helix or Beta Pleated Sheet.

• The third or **Tertiary Level** is the second folding of the polypeptide chain into a Globular Protein which may contain both helix and pleated sheet structures.

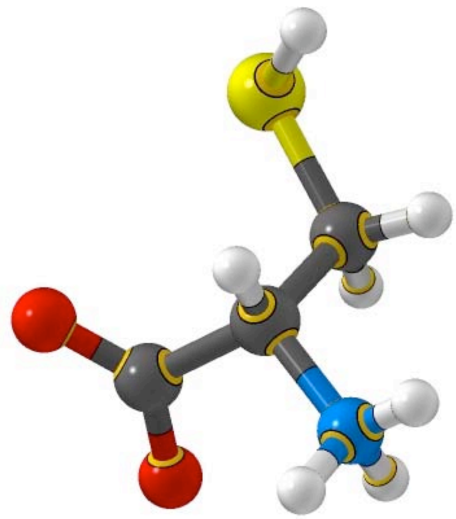
• The fourth or **Quaternary Level** consists of more than one globular protein that combine together to form the finished protein.

• Hemoglobin is an example of Quaternary structure.

• In all cases, it is the **final shape** of the protein that determines its chemical activity.

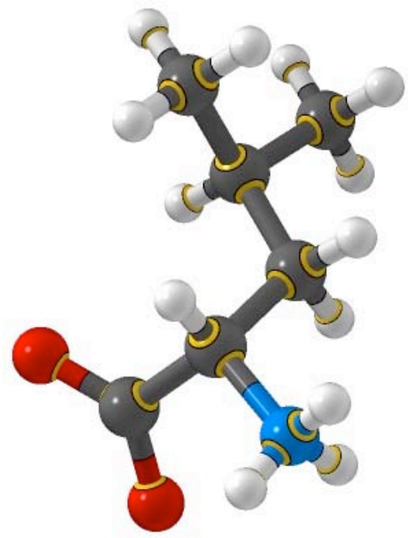


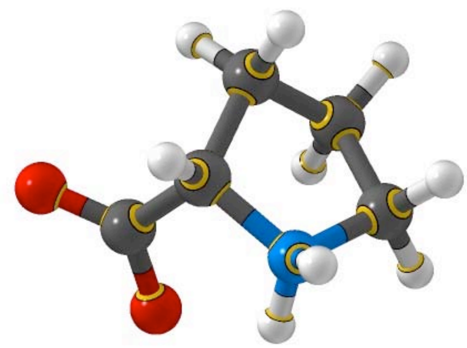
Glycine



Cysteine

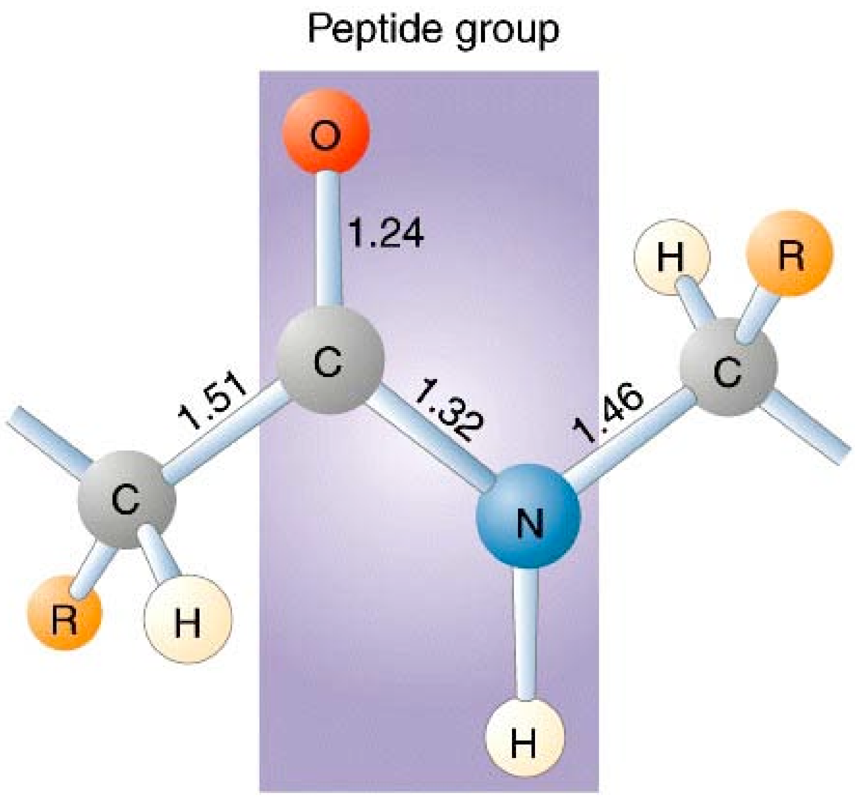
Examples of Amino Acids



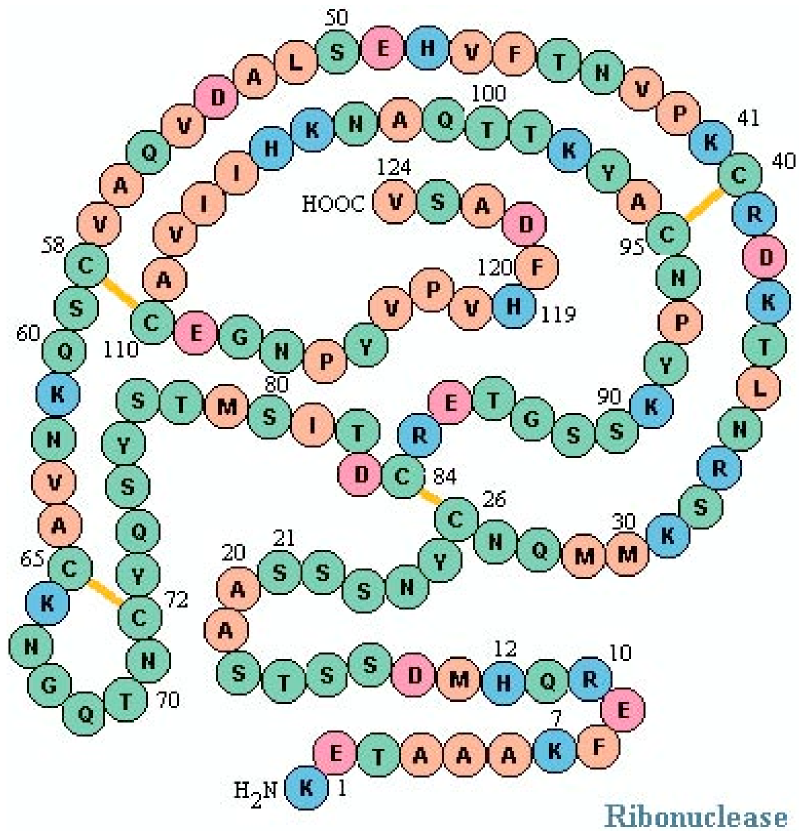


Leucine **Proline**

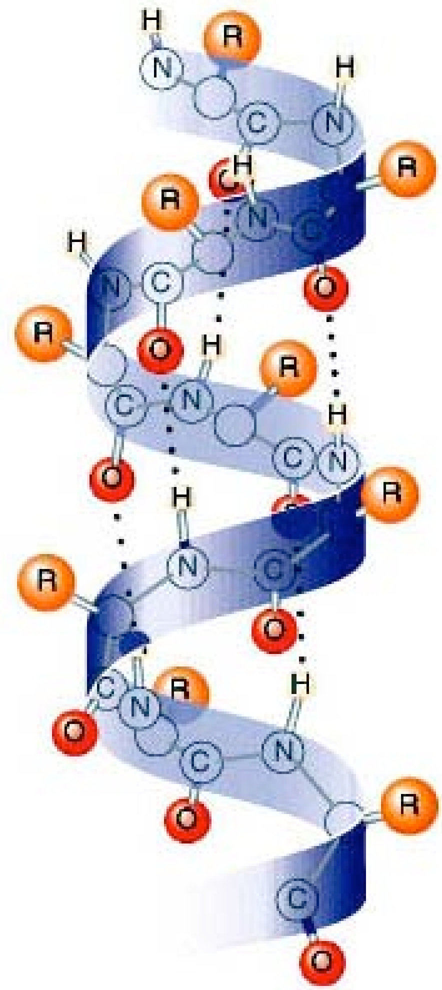
Examples of Amino Acids



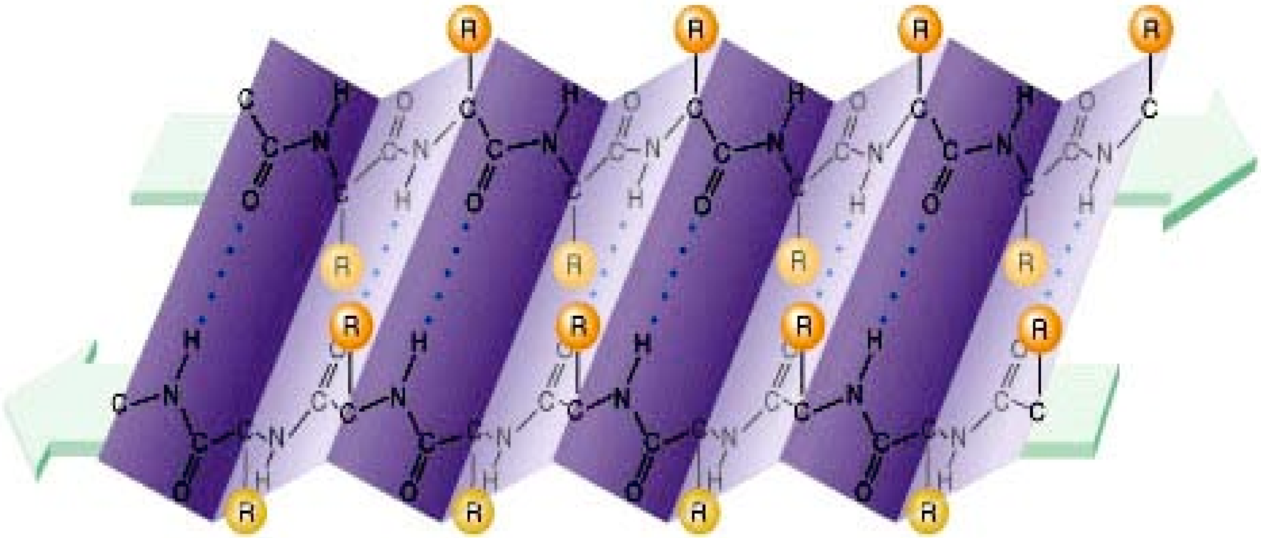
Amino acids are chemical linked together to form a polypeptide chain.



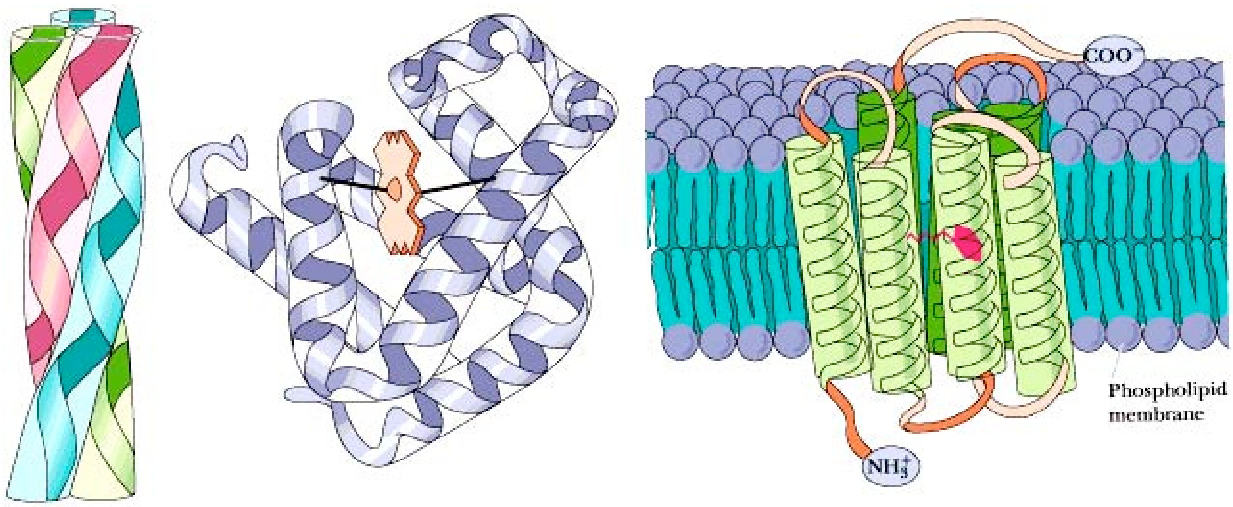
The Primary Structure of a protein is the order of amino acids in the polypeptide chain.



The Secondary Structure Alpha Helix



The Secondary Structure Beta Pleated Sheet

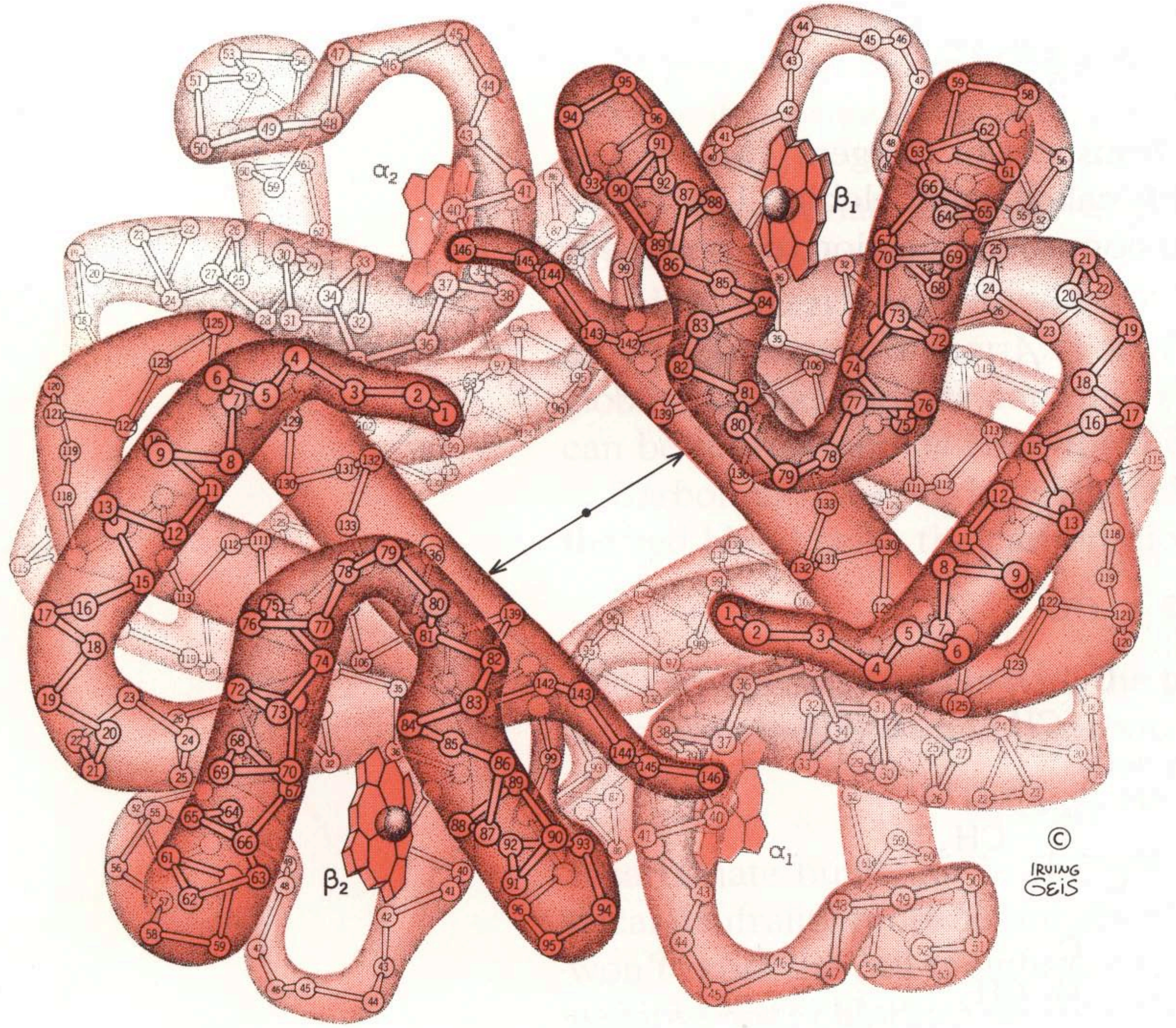


Collagen, a fibrous protein

Myoglobin, a globular protein

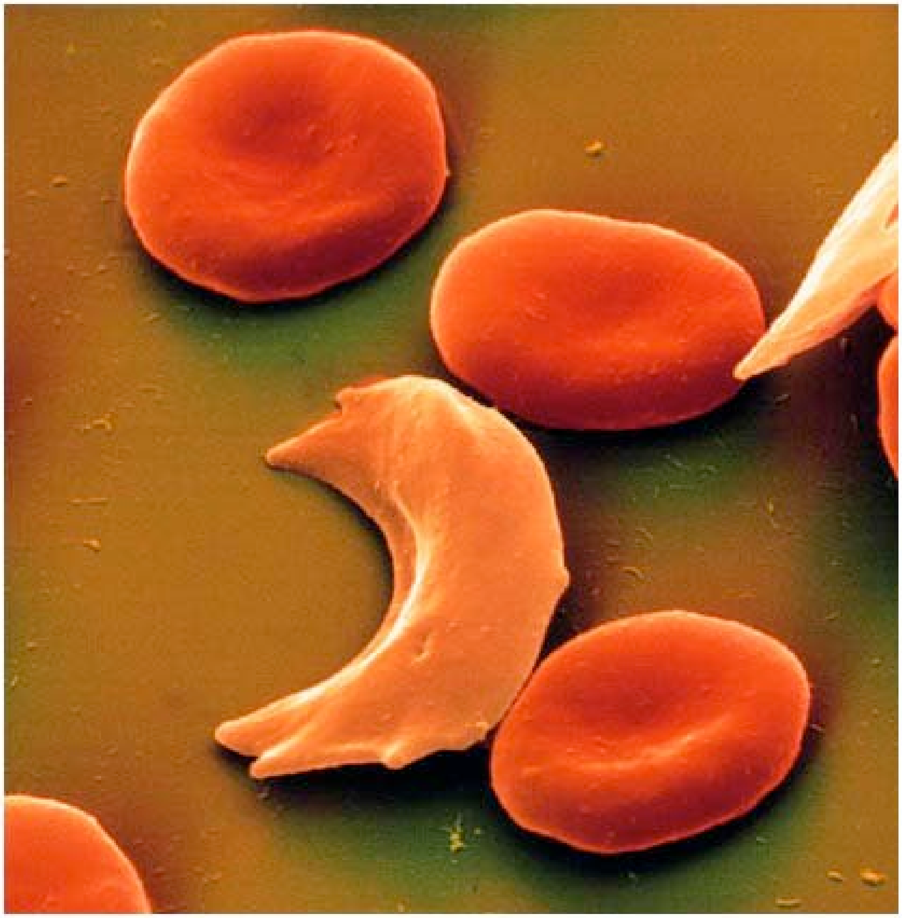
Bacteriorhodopsin

Some examples of Tertiary Structure in Proteins

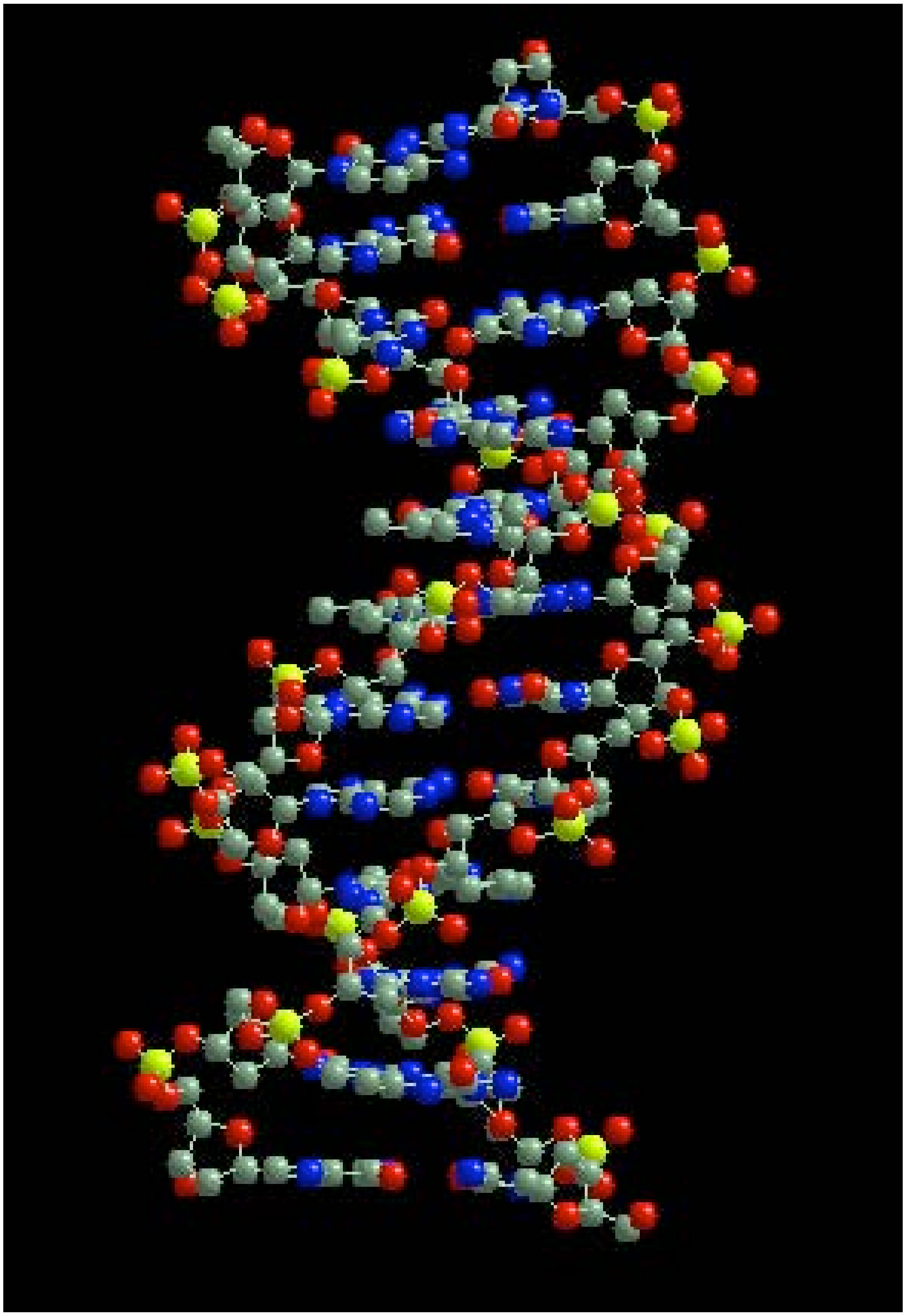


Deoxyhemoglobin

Hemoglobin is an example of Quaternary structure in proteins.

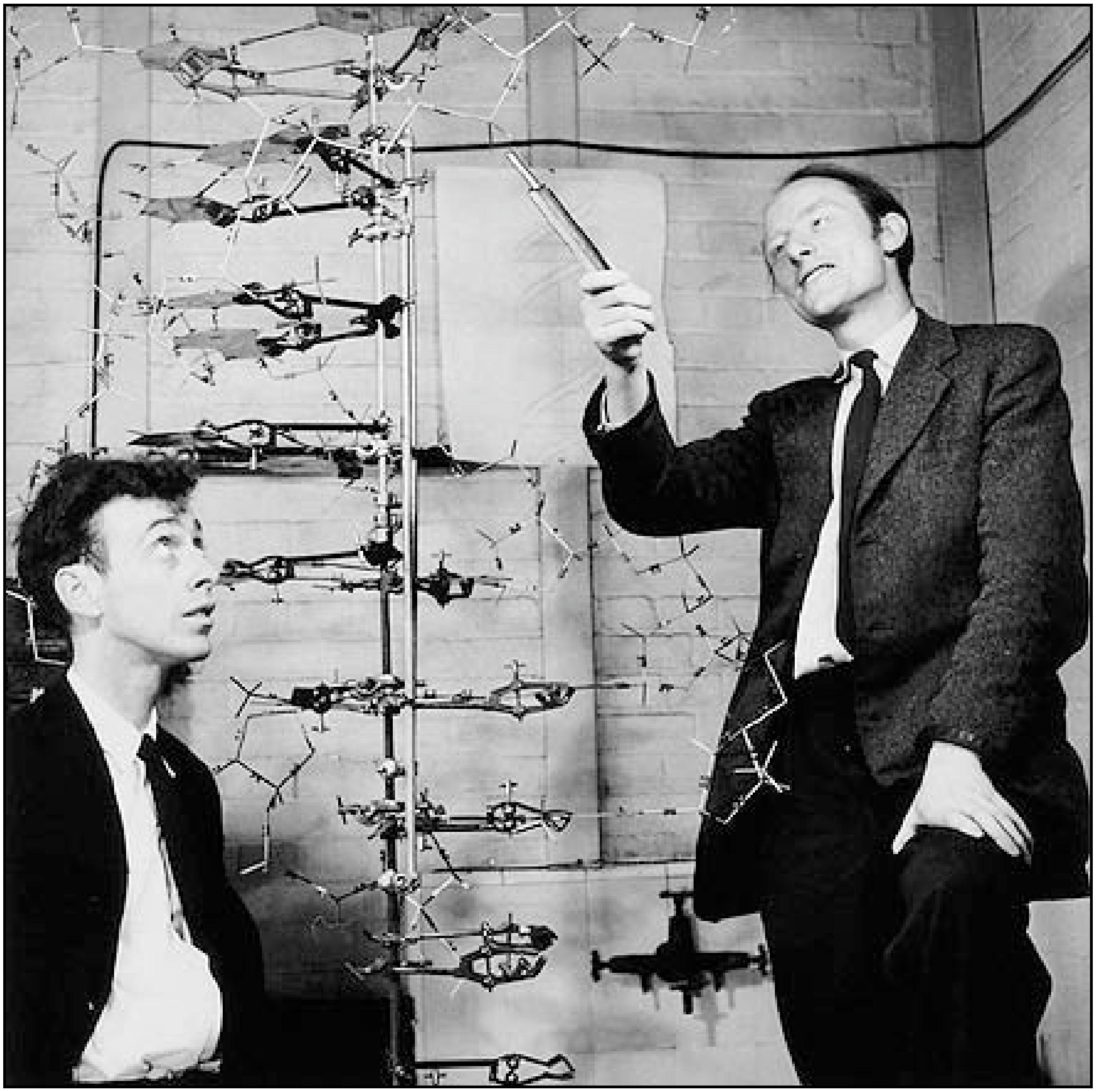


Sickle Cell Mutation in Red Blood Cells

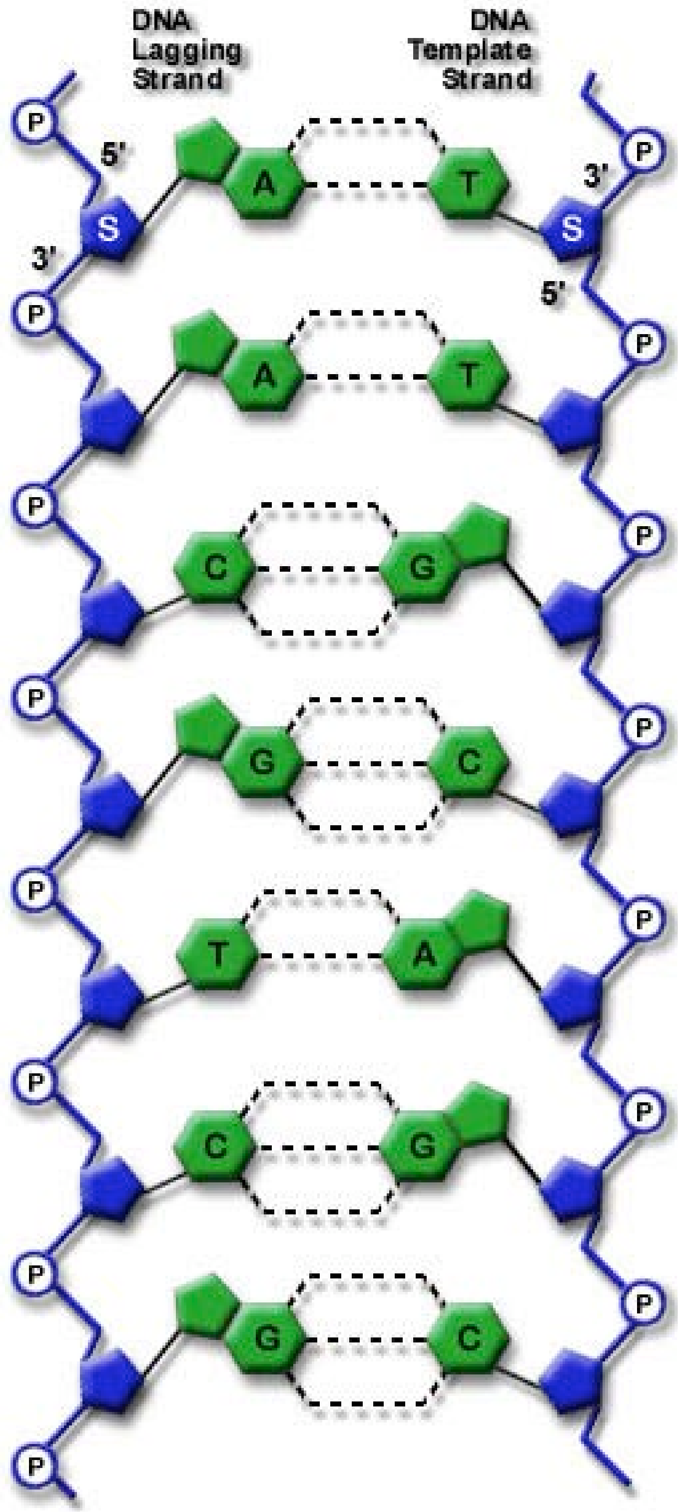


Nucleic Acids—DNA and RNA

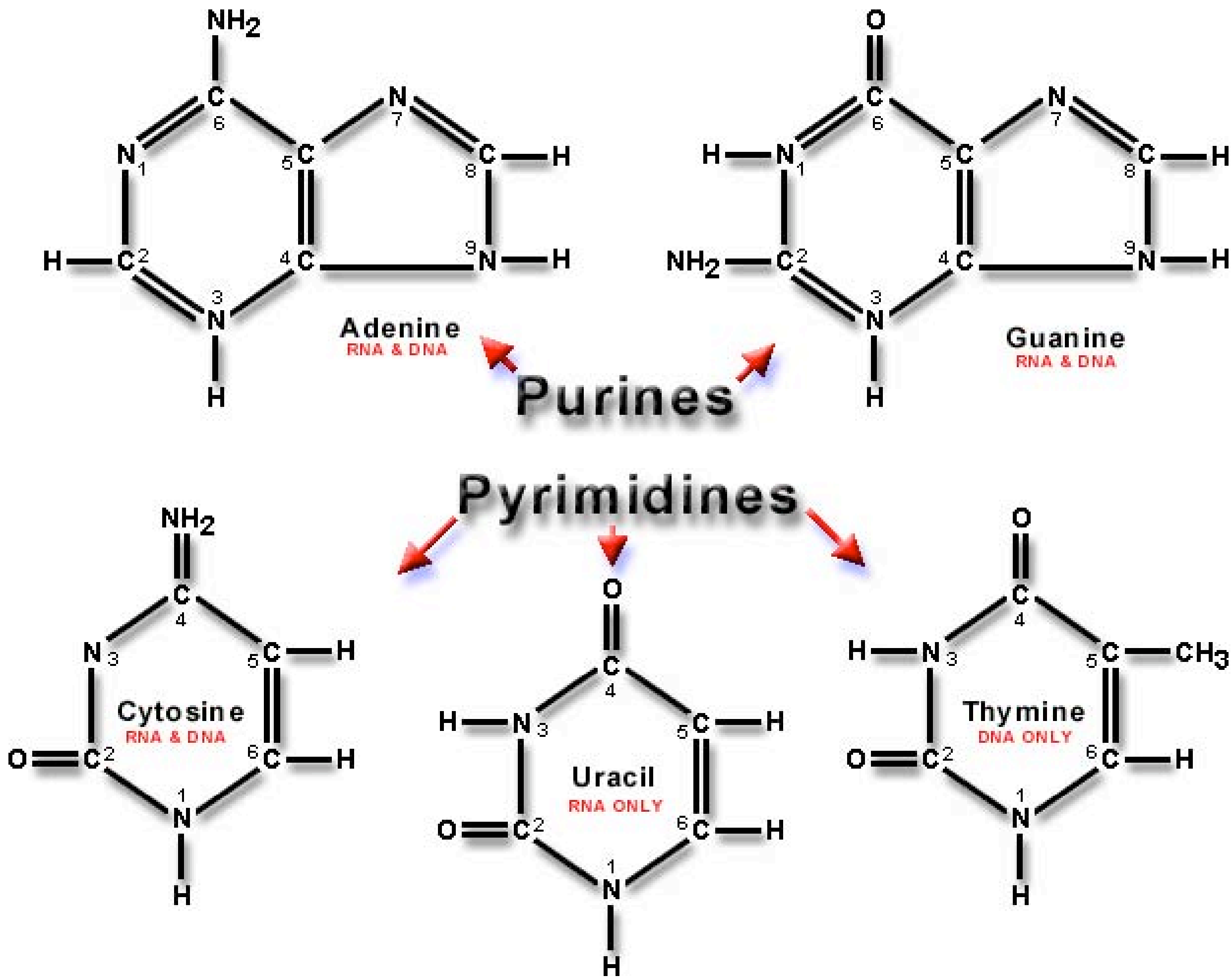
For more on DNA and RNA go to:
http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/D/DoubleHelix.html



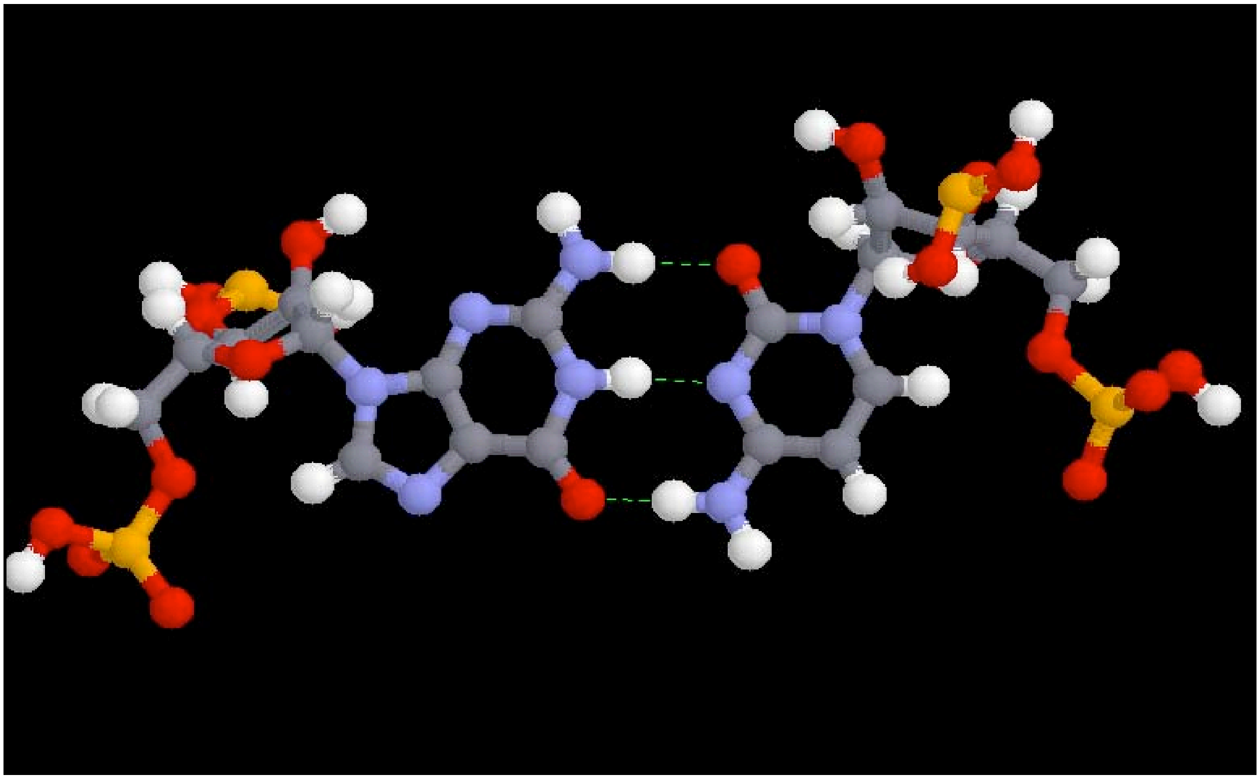
James Watson (left) and Francis Crick in 1953, were the first to discovered the structure of DNA .



The structure of DNA, blue is the sugar/phosphate backbone, the sides of the ladder, green are the nitrogen bases, the rungs of the ladder.



There are five different nitrogen bases that make DNA and RNA. Uracil is found only in RNA and Thymine only in DNA.

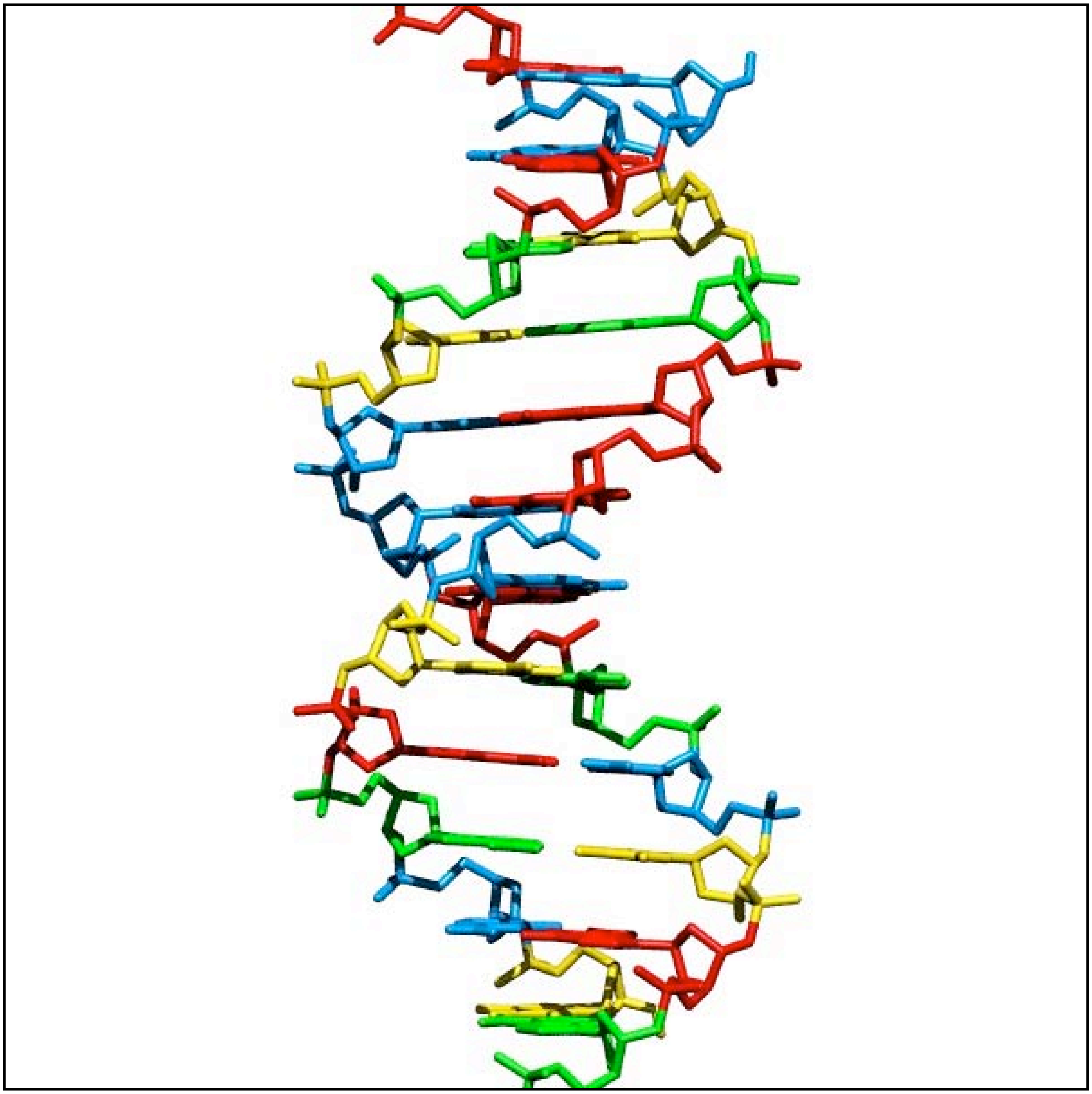


Structure of a single DNA base pair (Guanine to Cytosine)

• In DNA base pairs are composed of four different nitrogen bases, called nucleotides, that weakly bond in pairs to link the sides of the DNA double helix.

• The DNA nucleotides are adenine, thymine, cytosine and guanine. They are abbreviated A, T, C and G in the scientific description of the genome.

• The bases form specific nucleotide pairings, with "A" linking only with "T", and "C" only with "G".



The base pairs resemble rungs in a coiled ladder.

Nucleic Acids and Protein Synthesis

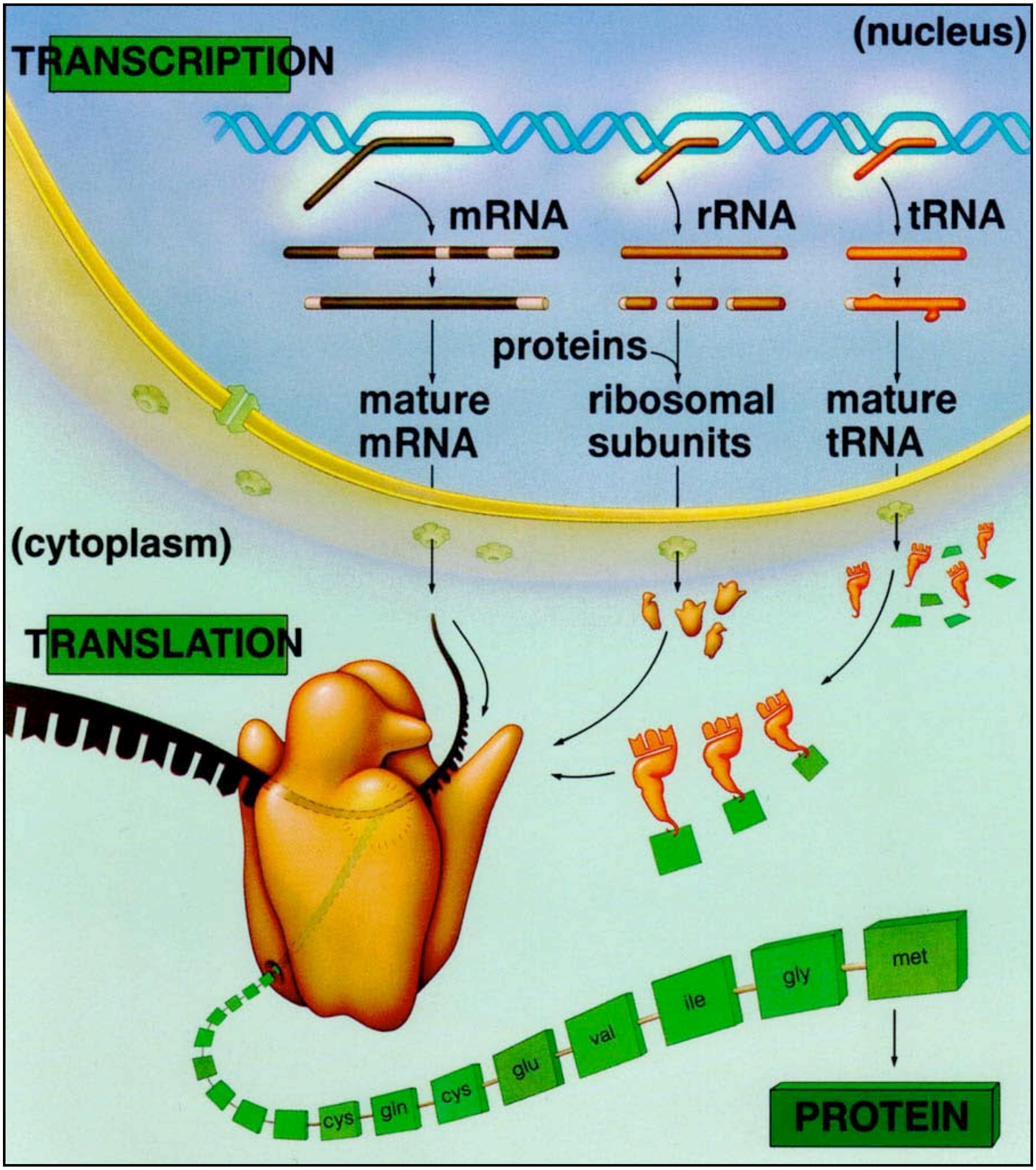
- **Transcription**

DNA (genes) —> to mRNA —> to ribosomes

- **Translation**

amino acids —> to tRNA —> to ribosomes —> makes proteins

- **Genes code only for proteins and RNAs.**



TRANSCRIPTION
(nucleus)
mRNA
rRNA
tRNA
proteins
mature mRNA
ribosomal subunits
mature tRNA
(cytoplasm)
TRANSLATION
met
gly
ile
val
glu
cys
gln
cys
PROTEIN

The Information Dimension of Life—Genetics

Terms and Definitions to Know

- **genes —> genetic information**
- **genome —> genetic makeup of the individual**
- **gene pool —> genetic makeup of a population**
- **biodiversity —> genetic sum of all of life on earth**
- **genotype —> • phenotype**

Gene Pool to Genotype to Phenotype

"The gene pool of a population is a record of reproductive success and failure in that population, and at conception an organism gets a sample of this record. The sample [genotype] is its instructions for producing the machinery by which it adapts to its environment. All other useful information, such as that learned and stored in the brain [phenotype], depends on the initial genetic information. New information can be exploited [only] because organs for the gathering, storage, and use of information are specified in the genes. Such organs are no less biological than those for the gathering, storage, and use of food. Both kinds of organs are there because they have been useful in previous generations for transmitting genes to later generations."

George C. Williams from his essay *A Sociobiological Expansion of Evolution and Ethics* in Paradis & Williams (1989)

Essay—Nature, Nurture, or Neither

The Failure of both Cultural and Genetic Determinism

There has been a long running battle between the social sciences and the natural sciences over the causal source of human behavior (Degler, 1991). The struggle is between the view that our behavior is culturally determined versus the view that our behavior is genetically determined. The debate has traditionally been known as nature versus nurture. It establishes a dichotomy between the influences of "nature" which today we recognize as our genetic makeup, our genome, and "nurture" which is shorthand for the environmental, cultural determinants of behavior.

Simple logic should have resolved this debate long ago, if only the parties to the debate had recognized that there is no evidence that precludes the obvious combination of genetic and environmental influences in determining our behavior. The western mind-set of thinking in opposites, however, has a long tradition beginning with the early Greek philosopher Anaximander. It was Anaximander who first proposed that nature was composed of opposites: hot and cold, wet and dry, light and heavy, life and death (Burke, 1985, 16). We continue this tradition by thinking that behavior must be determined by one of two opposites, nature or nurture.

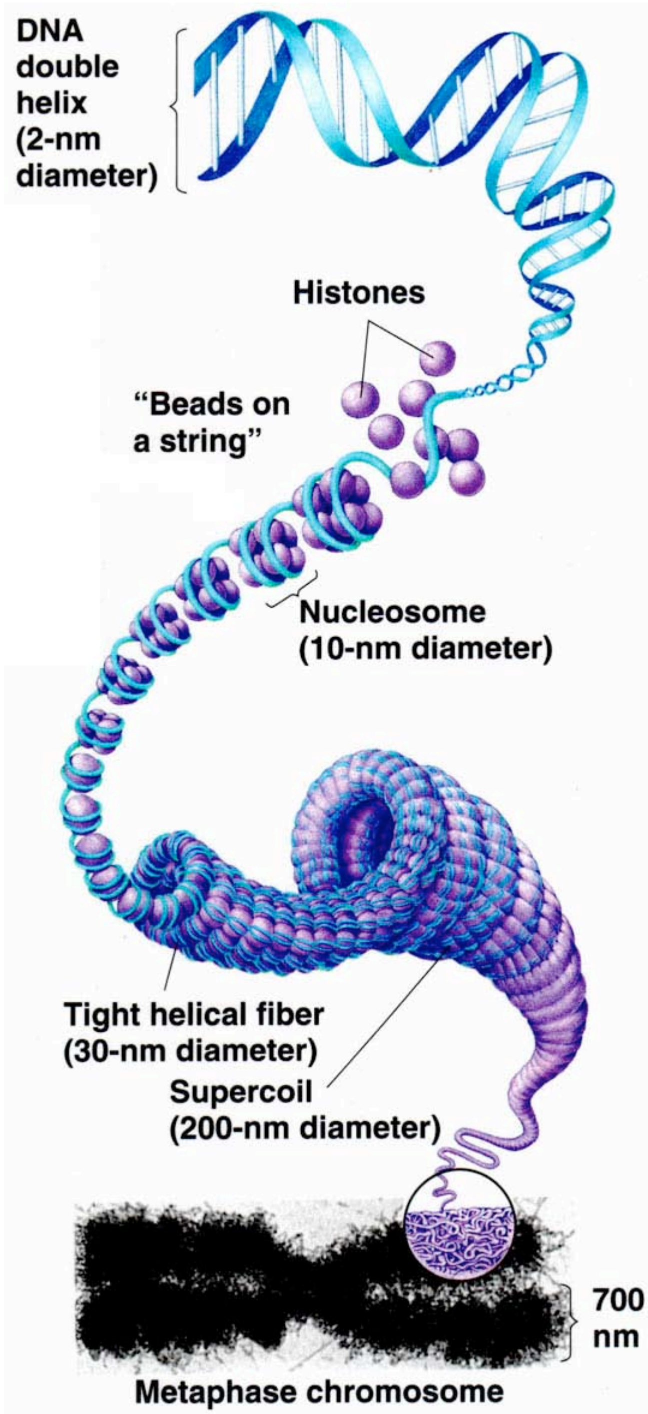
This debate, however, sets up a false dichotomy. In a true dichotomy a position is set against its only possible alternative. In a false dichotomy these two alternatives do not exhaust all the possible explanations of the phenomenon. The key to understanding the false dichotomy of nature versus nurture is that neither nature nor nurture *alone* determines our behavior. There is an obvious third alternative.

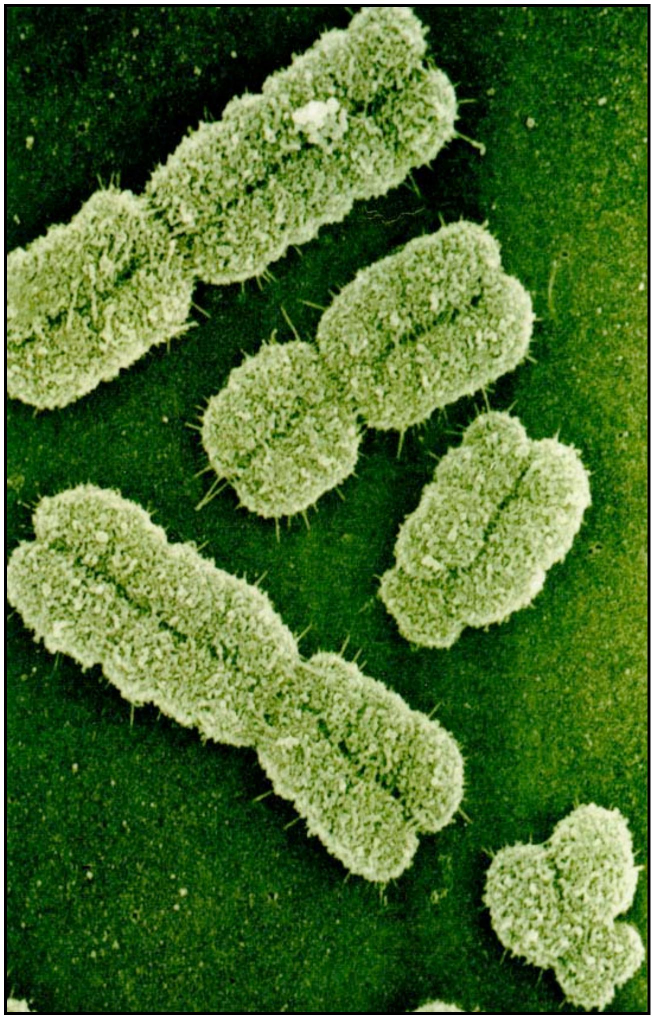
Today, although the debate still goes on, there is a growing consensus that our behavior is determined by a dynamic interaction between our genes and the environment. In biology this product of the interaction between a genome and its environment is called the phenotype. Our behavior should be seen as a purely phenotypic response of our genome to the external world.

Genetics and Reproduction

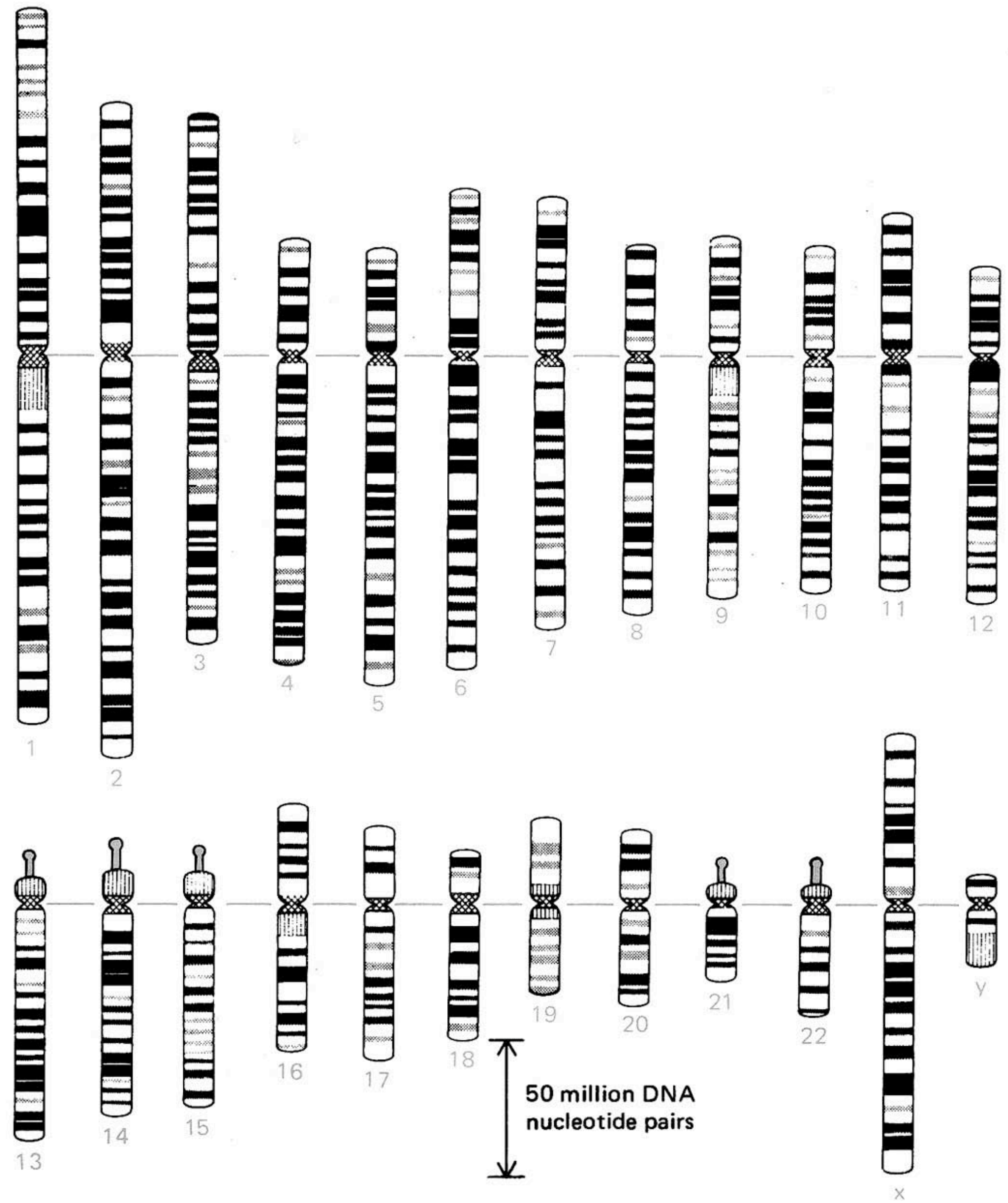
Terms and Definitions to Know

- **genetic mutation**
- **allele**
- **variation in genes**
- **variation in alleles**
- **dominant alleles**
- **recessive alleles**
- **heterozygote**
- **homozygote**
- **gene expression**
- **single gene traits**
- **polygenic traits**
- **pleiotropy**
- **somatic cells**
- **germ cells**
- **mitosis**
- **meiosis**


DNA
double
helix
(2-nm
diameter)
Histones
"Beads on
a string"
Nucleosome
(10-nm diameter)
Tight helical fiber
(30-nm diameter)
Supercoil
(200-nm diameter)
700
nm
Metaphase chromosome



Electron Micrograph of Human Chromosomes



There are 24 different chromosomes in the human genome.

A Primer on Human Genetics

• The human genome is the biological instruction for how an individual is formed and how the cells in the body function.

• There are between 20,000 to 25,000 genes in the human genome (Stein 2004).

• Except for identical twins, the gene structure is unique in each individual.

• Half the DNA in the nucleus of each cell comes from each parent.

• Genes direct the formation, or expression, of proteins that a cell uses to function, repair or defend itself, and to divide.

• Genes are contained in the chromosomes in the nucleus of each cell.

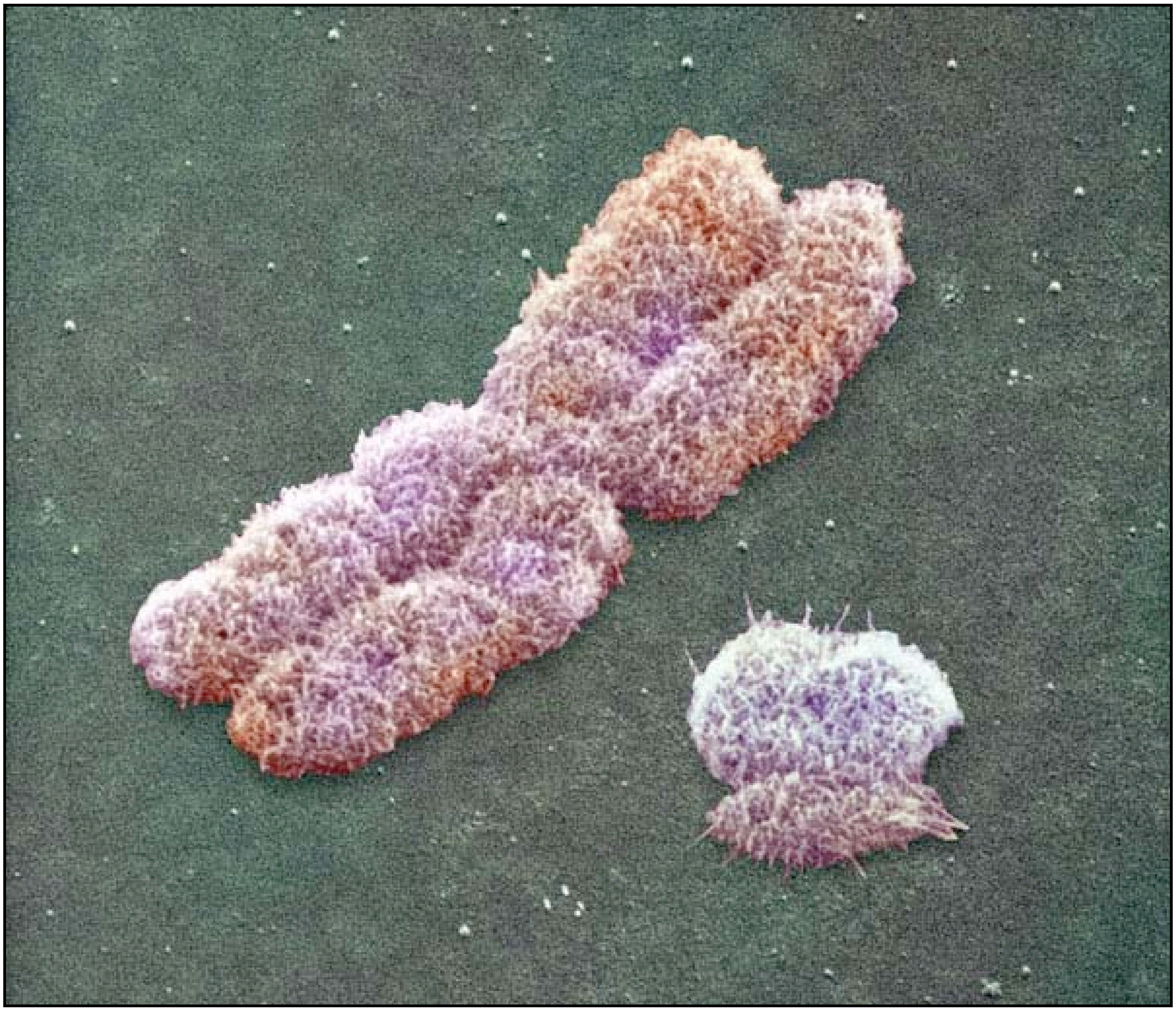
• There are 22 numbered chromosomes, plus two that determine gender, X and Y. A female has two X chromosomes, while a male has an X and a Y.

• A human normally has 23 pairs of chromosomes (46 total) in each cell.

• About 3 billion DNA subunits, called base pairs, make up the human genome.

• Genes can have thousands of base pairs. The sequence and arrangement of these base pairs create a genetic code.

• Genes give coded instructions to the cell on how to assemble proteins. Making of a protein from this code is called “gene expression.”



X (left) and Y chromosomes, magnified about 10,000 times

Because of its distinctive role in sex determination, the Y chromosome has long attracted special attention from geneticists, and evolutionary biologists. It is known to consist of regions of DNA that show quite distinctive genetic behavior and genomic characteristics (Willard, 2003).

Cell Division—Mitosis and Meiosis

For more on chromosomes and cell division go to:
http://www.biology.arizona.edu/cell_bio/cell_bio.html

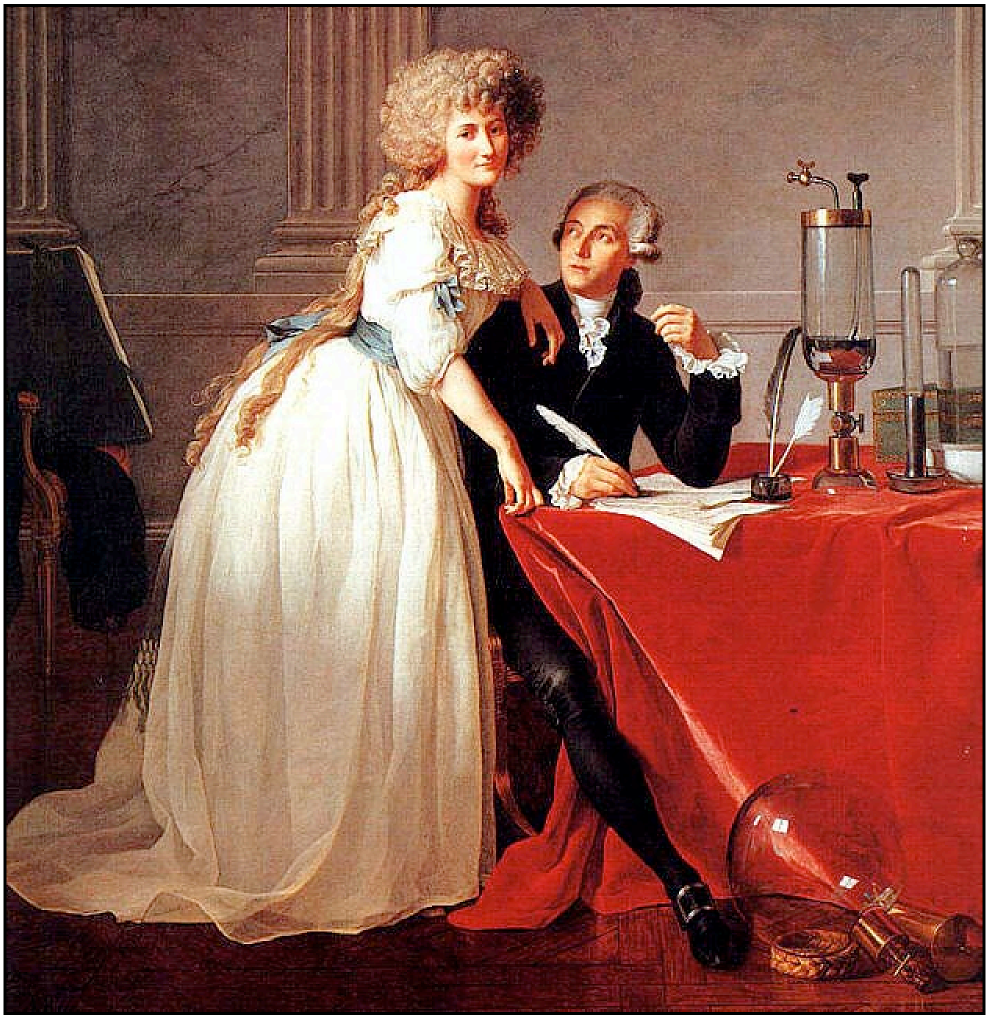
Biochemical Evidence for the Unity of Life

- **DNA is the universal genetic material.**

- **The process of protein synthesis is universal.**

- **The genetic code for specifying amino acids is universal for all life-forms.**

- **Metabolic pathways for producing energy such as glycolysis and the cycling of ATP and ADP are universal for all life-forms.**



Antoine-Laurent Lavoisier and his wife,
Marie-Anne Pierrette Paulze

It was the great 18th century French chemist, Antoine Lavoisier (1743-1794), who first asserted that life is a chemical function. Modern molecular biology has reinforced that all the phenomena we associate with life are the product of the chemistry of life. It is not, therefore, misleading to say that life is a single, ongoing, genetically controlled chemical chain reaction. That this incredibly complex chemistry is common to all life-forms is compelling evidence for the unity of life based on common descent (Moore, 1993).

Web Reference (page 28)
http://fire.biol.wwu.edu/trent/alles/Gallery.pdf

The "Modern Synthesis" of Evolution by Natural Selection and Genetics

The Same but not the Same

Who was the first geneticist?

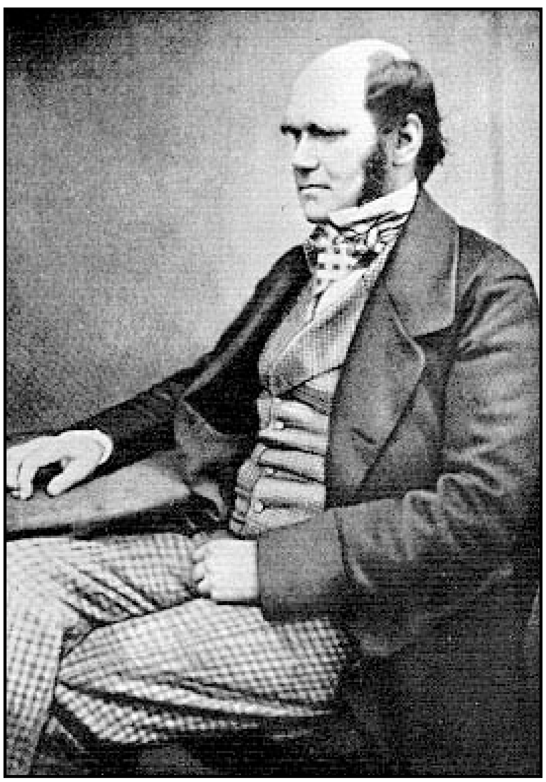
Darwin or Mendel

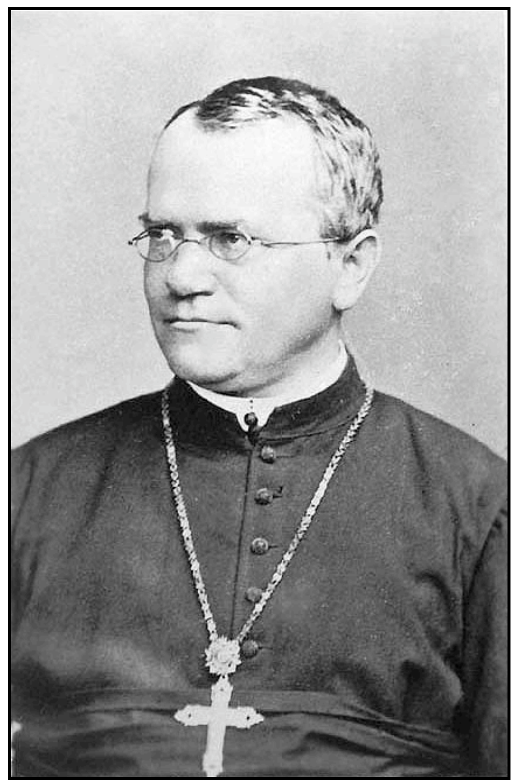
Why was Darwin unable to figure out the mechanism of inheritance?

Why was Mendel able to?

Reduction or Holism / Numerate or Innumerate

Darwin and Mendel





Essay—Darwin and Mendel: Who was the first geneticist?

Gregor Mendel is acknowledged as the first geneticist, and no one would argue that he wasn't. But there is a growing awareness that Darwin's influence should be recognized in the history of genetics. Darwin's theory of evolution by natural selection creates the theoretical need for understanding the mechanism of inheritance. But Darwin was ultimately a synthetic rather than a reductionist thinker. His view was of the whole.

As Colin Tudge offers, "Darwin, I believe, was simply the wrong kind of thinker to arrive at the correct mechanism of heredity. He conceived his grand over-view of evolution by looking at thousands of different instances, in thousands of different species: beetles, finches, barnacles, orchids, human beings; in other words, through the eyes of a tremendously accomplished naturalist. Nothing short of such a grand sweep could suggest a convincing mechanism that could be seen to apply to all of them."—Tudge, 1993, 6

"Darwin produced the theory that has transformed biology, and indeed has changed the course of modern philosophy more profoundly than that of any other thinker of the past three centuries. Yet the mechanism he proposed [natural selection] cannot work unless the process of heredity operates in a particular way, a way that can produce variation from generation to generation even while respecting the general condition that 'like begets like' [i.e. the same but not the same]. But what that mechanism might be Darwin failed absolutely to perceive.

Here we come to yet another irony, in fact to several more. First, the mechanism of inheritance that Darwin sought and needed was worked out and published during his own lifetime [in 1866]—indeed, just a few years after *On the Origin* appeared—by a scientist-monk [Mendel] in what was then called Moravia [now the Czech Republic]. Second, however, this crucial insight was overlooked by the scientific community at large, and was in fact forgotten until rediscovered at the beginning of the twentieth century. Third, when the vital mechanism of inheritance was finally rediscovered, it was not at first recognized as the key to evolution by natural selection."—Tudge, 1993, 10

Darwin's holistic viewpoint, as well as his being innumerate, prevented him from being able to determine the mechanisms of inheritance. Mendel on the other hand was trained as a physics teacher in a time when the reductionist methodology was being rigorously promoted, and Mendel was numerate (Orel, 1996). The question then "Who was the first geneticist?" reveals the tension between the reductionist and the holistic methods in science. But the central point must not be lost—both methods are necessary for science to progress toward its goal of understanding nature. Mendel completed what Darwin had begun, a true understanding of inheritance.

The story is not complete, however, until the modern synthesis of evolution by natural selection and genetics is achieved in the twentieth century. It was not until the 1940's that Julian Huxley (T.H. Huxley's grandson) would coin the term "the Modern Synthesis" to describe the grand unification of evolutionary theory with classical genetics that had finally taken place. In America, Ernst Mayr, Theodosius Dobzhansky, George G. Simpson, and G. Ledyard Stebbins were the major figures in creating this synthesis. With the achievement of the modern synthesis Darwin's theory of evolution by natural selection once again demonstrated its consilient power in bringing all of biology under one theoretical framework.

• **Point:** It should now be clear that only when both methods, reductionism and holism, are combined, as in the modern synthesis, do we come to fully understand the natural world.

For more on Mendel and the history of the modern synthesis see:

http://fire.biol.wwu.edu/trent/alles/Mendel_Physics_Teacher.pdf

http://fire.biol.wwu.edu/trent/alles/Stenseth_Crafoord_Prize.pdf

Biochemistry & Genetics

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The Modern Synthesis

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