Modelling Biochemical Reaction Networks

Lecture 2: Overview of biochemistry

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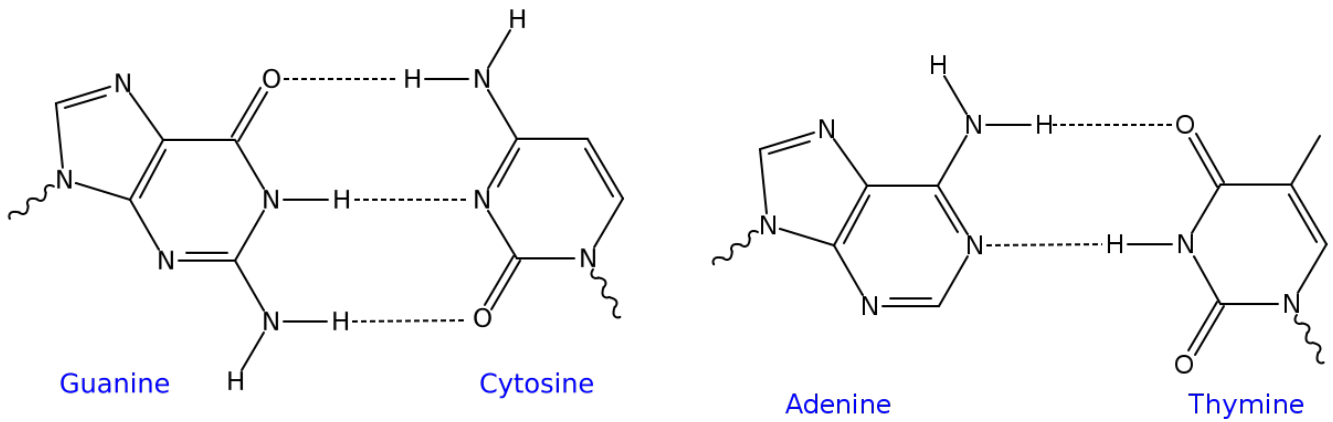
Structure, function, and thermochemistry

- Molecular masses: $1\,\mathrm{g/mol} \equiv 1\,\mathrm{amu} \equiv 1\,\mathrm{Da}$
- Living organisms contain molecules of all sizes, ranging from the very small (e.g. water, molecular mass 18 Da) to truly massive molecules (e.g. DNA, molecular masses in the GDa range).
- The functions and functioning of larger biomolecules are largely determined by their structures:
  - Positioning of certain chemical groups
  - Shape complementarity
- Mixture of molecular conformations ("structures") is determined by thermochemistry:
  balance of energetic and entropic effects/decrease in free energy.

DNA

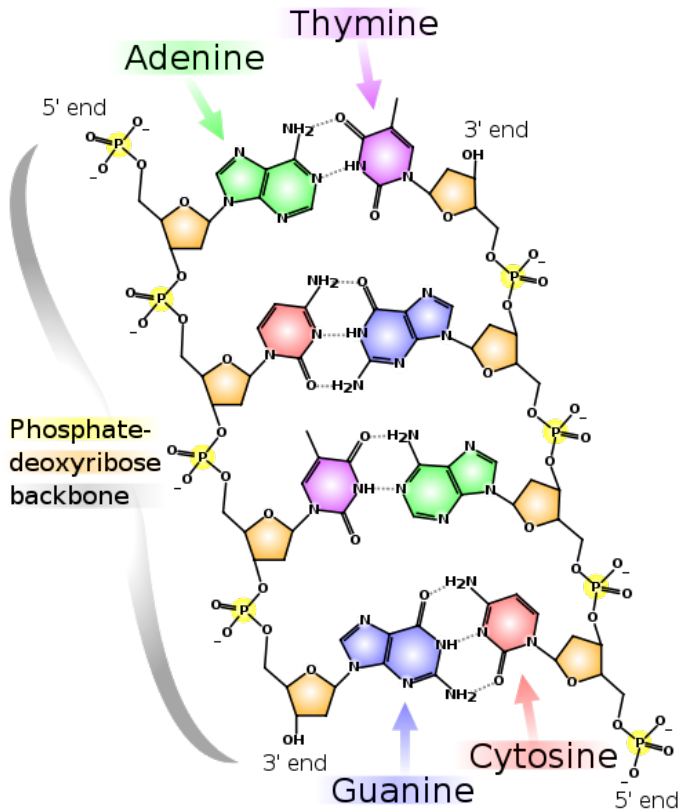
- Deoxyribonucleic acid (DNA) carries the genetic code of all cells and some viruses.
- A polymer of the four nucleotides adenine (A), thymine (T), guanine (G) and cytosine (C)
- Because of their shapes and of the complementarity of their chemical groups, the nucleotides can base pair through hydrogen bonds.



Graphics: Isilanes, public domain images (`http://en.wikipedia.org/wiki/File:GC_DNA_base_pair.svg` and `http://en.wikipedia.org/wiki/File:AT_DNA_base_pair.svg`)

DNA

- Most DNA found as a duplex (the famous double helix) in which each nucleotide is base-paired to the appropriate nucleotide in a complementary strand:



Source: Madeleine Price Ball, Creative Commons license
(`http://en.wikipedia.org/wiki/File:DNA_chemical_structure.svg`)

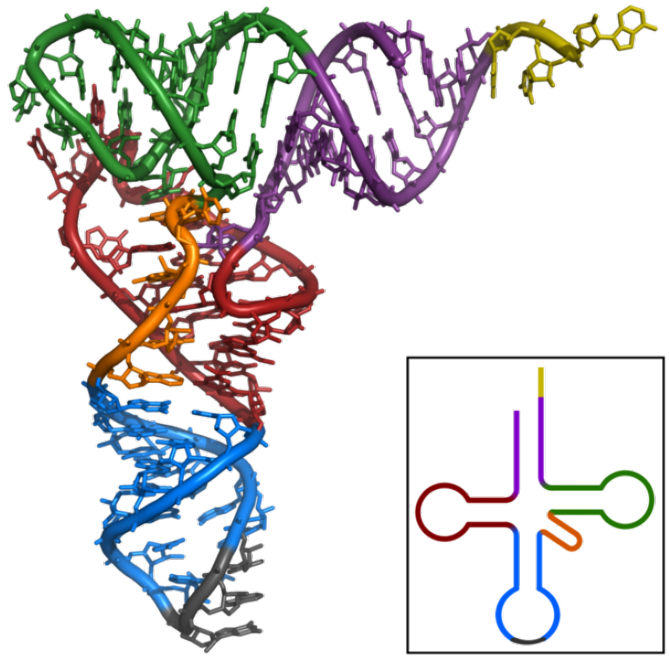
RNA

- Ribonucleic acid (RNA) is a close cousin of DNA.
- A polymer of the four nucleotides guanine (G), cytosine (C), adenine (A) and uridine (U)
- RNA is transcribed from DNA using base pairing to direct the synthesis of a mirror image of the template:

DNA G—RNA C
DNA C—RNA G
DNA A—RNA U
DNA T—RNA A

RNA structure

- RNA is typically *not* found in double-stranded form.
- Base-pair complementation in different parts of an RNA molecule can lead to specific three-dimensional structures.



Source: Yikrazuul, Creative Commons license
(`http://en.wikipedia.org/wiki/File:TRNA-Phe_yeast_1ehz.png`)

RNA functions

Messenger RNA (mRNA): Carries genetic information from the nucleus to the ribosomes

Ribosomal RNA (rRNA): Key parts (including all the catalytic functions) of ribosomes

Transfer RNA (tRNA): Recognize complementary sequences on mRNA and carry amino acids for the synthesis of proteins in the ribosome

Regulation: Some RNAs, including some very small ones, have regulatory roles, often by binding to complementary RNA or DNA sequences.

RNA processing: Most of the machinery that processes RNAs after their transcription uses RNA parts.

- Splicing
- Modification of some nucleotides, e.g. of uridine to pseudouridine

Proteins

- Polymers of amino acids
- Function requires folding into specific structures, sometimes spontaneously, and sometimes with help
- Sometimes function in complexes either with other proteins of the same type or with different proteins, and sometimes with RNA
- Synthesized by ribosomes based on the instructions carried by mRNA in a process called translation
- May be modified post-translationally

Genetic code

- Ribosomes synthesize proteins from 20 amino acids.
- mRNA is read as a series of triplets known as codons.
  - Need to encode 20 amino acids + *start* and *stop*
  - The start codon is also used to encode one of the amino acids (methionine).
  - There are three stop codons.
  - $4^3 = 64$ possible triplets, so the genetic code has some redundancy
- tRNAs have a particular region called an anticodon that is designed to base-pair with a complementary mRNA sequence in the ribosome.
- tRNAs are covalently bound to an amino acid, which is then available for protein synthesis.

Genetic code

- Base pairing of the third nucleotide in a codon-anticodon pair is somewhat sloppy, a feature exploited by the genetic code, so that fewer than 61 anticodons are required.
- Some examples:
  - GUX encodes valine, regardless of the identity of X.
  - GCX encodes alanine.
  - UU$\left\{\begin{array}{c} \mathrm{U} \\ \mathrm{C} \end{array}\right\}$ encode phenylalanine;

    UU$\left\{\begin{array}{c} \mathrm{A} \\ \mathrm{G} \end{array}\right\}$ and CUX encode leucine.

Protein functions

Enzymes: Biological catalysts (speed up reactions)

Structural functions: e.g. actin and microtubules

Molecular motors

Signal detection and transduction: e.g. detection of hormones, modulation of transcription in response to signals

Channels and pores

Antibodies