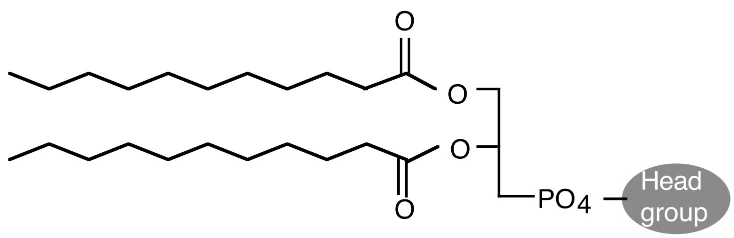
PHYS 4xx Intro 2 - Molecular building blocks

We now describe in more detail the nomenclature and composition of several classes of compounds of relevance to the cell, including:

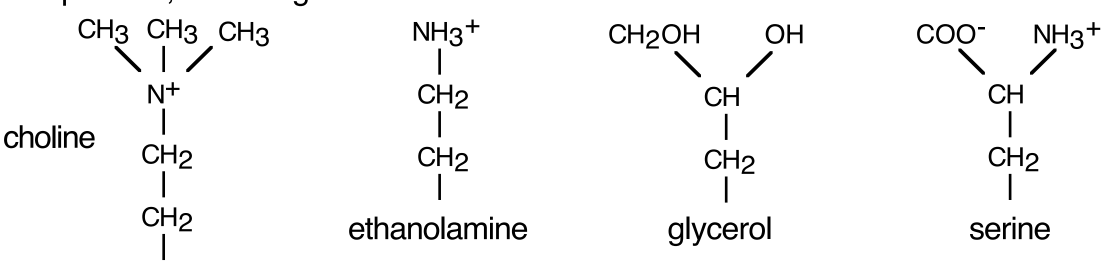
membrane components: fatty acids and phospholipids
biopolymers: sugars, amino acids and proteins
the genetic blueprint: DNA and RNA.

Fatty acids and phospholipids

Phospholipids contain two fatty acids linked to a glycerol backbone. The remaining OH group in the glycerol is replaced by a phosphate group PO_4 that is linked a the polar head group:



The polar head groups of phospholipids may be chosen from a variety of organic compounds, including



Because PO_4 has a negative charge, serine and glycerol phospholipids are negative while choline and ethanolamine phospholipids are neutral.

The naming convention for a phospholipid mirrors, in part, its fatty acid composition. Common abbreviations (italics provided for ease of pronounciation) include:

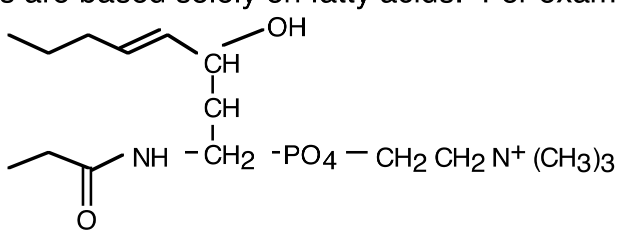
phosphatidyl*choline*	PC	phosphatidyl*ethanolamine*	PE
phosphatidyl*glycerol*	PG	phosphatidyl*serine*	PS.

Some fatty acids commonly found in membrane lipids

Acid name	Total number of carbon atoms	Number of double bonds	Position of double bond
lauric	12	0	
myristic	14	0	
palmitic	16	0	
palmitoleic	16	1	9-*cis*
stearic	18	0	
oleic	18	1	9-*cis*
linoleic	18	2	9-*cis*, 12-*cis*
arachidonic	20	4	9-*cis*, 8-*cis*, 11-*cis*, 14-*cis*

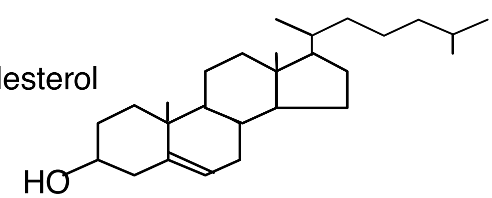
Column 4 displays the C-C bond numbers on which any double bonds occur.

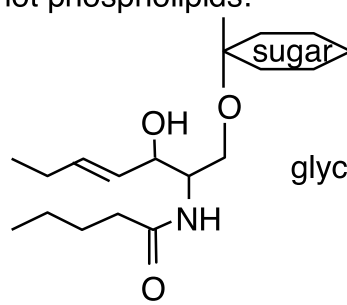
Not all phospholipids are based solely on fatty acids. For example, sphingomyelin



Some lipids present in cellular membranes are not phospholipids:

cholesterol

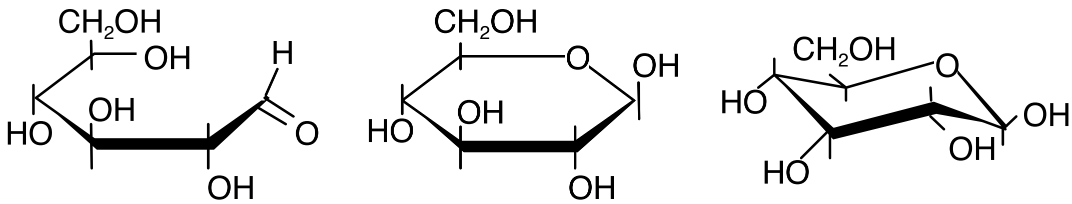




glycolipid

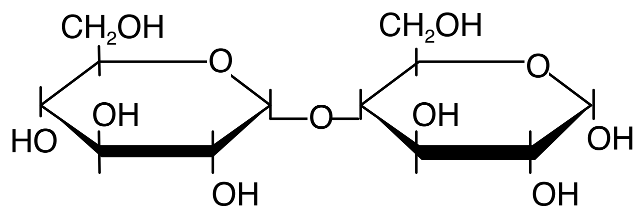
Sugars

Sugar molecules are one component of DNA and of the peptidoglycan network of the bacterial cell wall. A single sugar molecule has the chemical formula $(CH_2O)_n$, the most biologically important sugars having n = 5 or 6. Examples of the conformations available for the glucose molecule (n = 6) are:



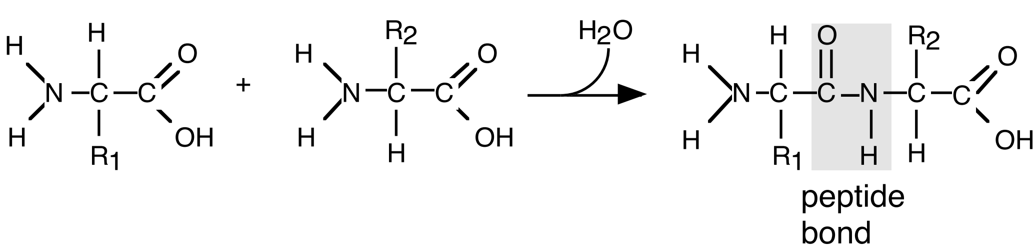
(a) (b) (c)

Panel (a) shows the molecule as a linear chain. Five of the oxygens are part of -OH groups while the sixth is double-bonded as an aldehyde. The double-bonded oxygen can be placed at one of several different positions on the chain, each corresponding to an inequivalent, yet related, molecule. The chain can be closed into a ring using one of the oxygens in a hydroxyl group (not the oxygen in the aldehyde group (RCOH)) as illustrated in Panel (b). As drawn, the ring in part (b) appears planar, in spite of the lack of in-plane double bonds such as are present in planar compounds like benzene. In fact, the actual configuration of a glucose ring is the bent form in part (c), just as it is in the single-bonded ring of cyclohexane. A single sugar molecule in isolation is referred to as a *monosaccharide*. But sugar molecules can polymerize through reactions in which two alcohol groups (one on each ring) combine to give a single bond between rings, liberating H_2O as a product. Two glucose molecules may combine to form the disaccharide maltose (as shown) or longer polysaccharides.

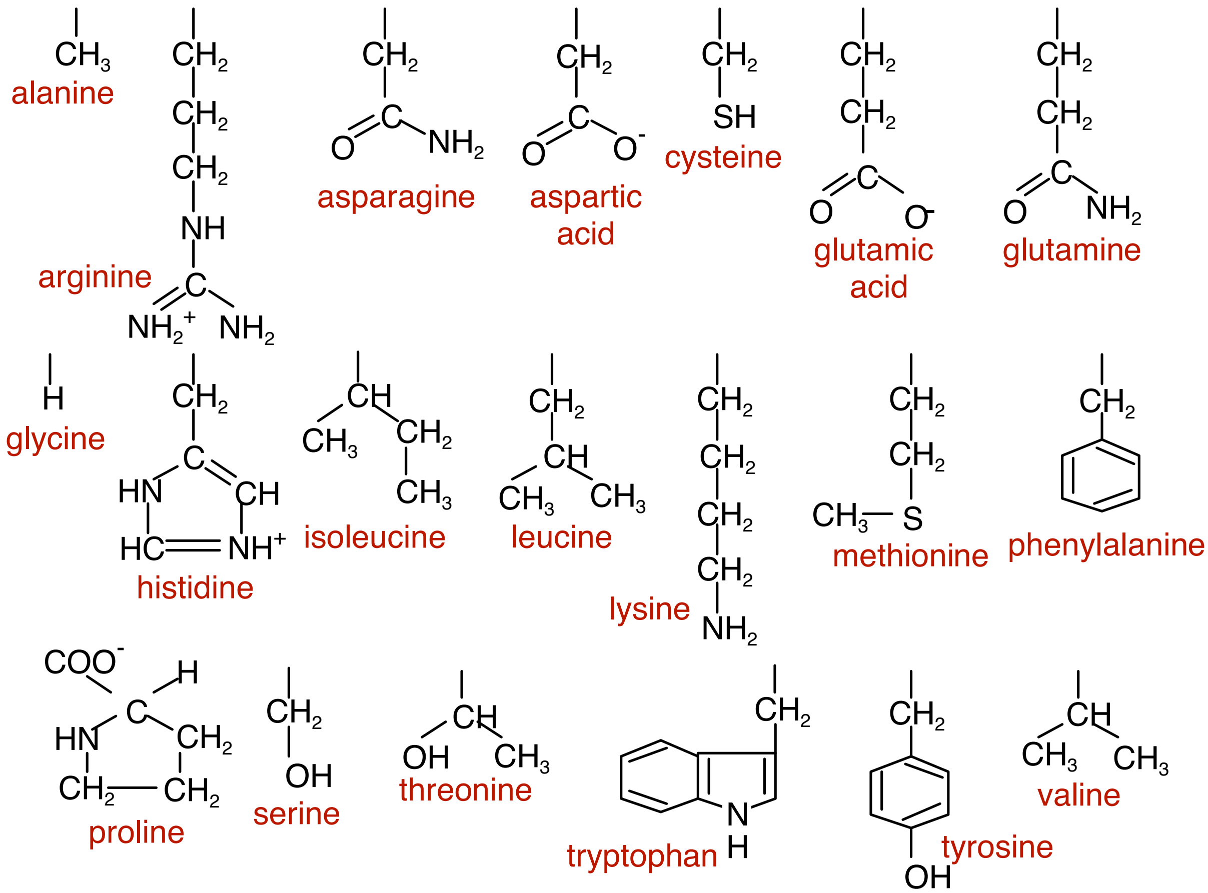


Amino acids and proteins

Proteins are linear chains of amino acids, a family of organic compounds containing an amino group ($-NH_3^+$) and a carboxyl group ($-COO^-$). Amino acids can join together to form chains through an amide linkage (-OC-N-) referred to as a peptide bond. The reaction liberates H_2O, and has the general form:



The side groups R_1 and R_2 are chosen from only 20 different residues in protein construction, none of which has a high molecular mass:

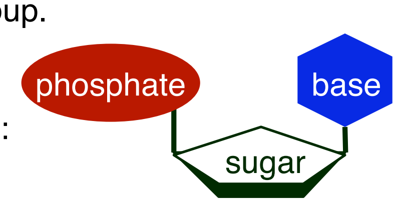


A protein chain of high molecular mass will be built up as this reaction occurs repeatedly; for example, the two inequivalent spectrin proteins in the human erythrocyte have molecular masses of ~220 000 and ~230 000 Da.
Amino acids appear in a protein with varying relative abundance, and some, such as tryptophan, are uncommon.
In a large protein, the average molecular mass of the amino acids is 115 Da.

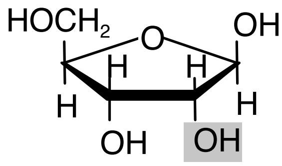
Nucleotides and DNA

Ribonucleic acid, or RNA, directs protein synthesis in the cell, whereas **deoxy**ribonuclei acid, or DNA, is the carrier of genetic information. The elementary chemical units of DNA and RNA are nucleotides, which are composed of subunits, namely a sugar, an organic base and a phosphate group.

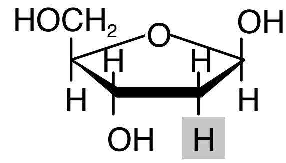
nucleotide:



The two different sugars found in nucleotides, ribose in RNA and deoxyribose in DNA, are five-membered rings differing from each other by only one oxygen atom.



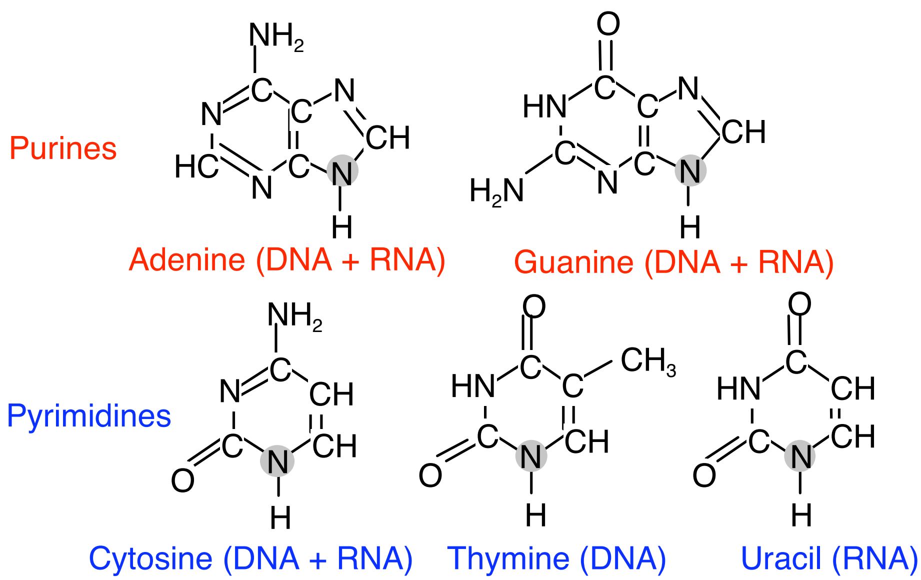
ribose



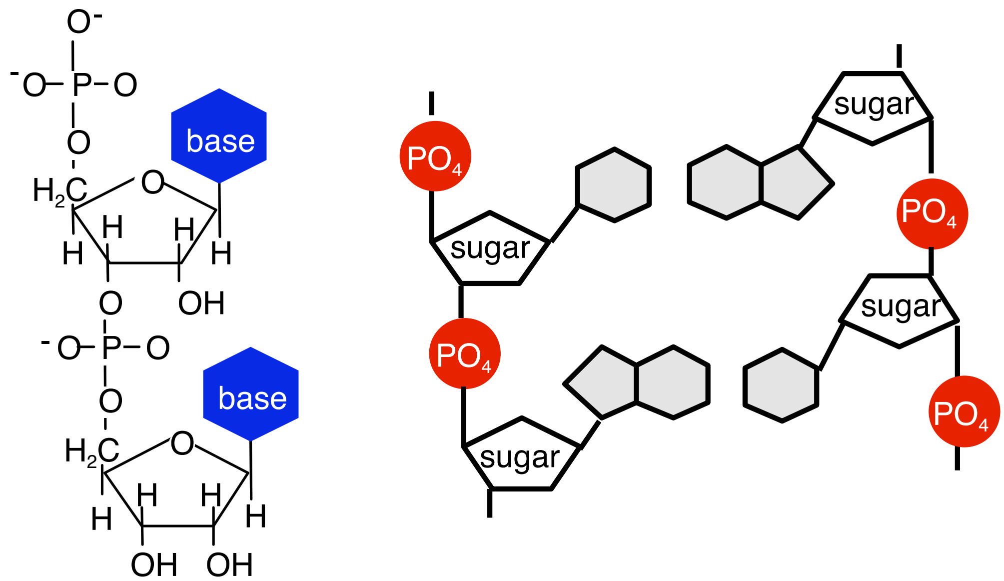
deoxyribose

In either molecule, the OH groups are potential reaction sites for addition of a base. Five organic bases are found in nucleotides, and they fall into two chemically similar groups - purines and pyrimidines. Only four of the five bases are present in a given DNA or RNA molecule, and the one "missing" base is different for each:

RNA: adenine, guanine, cytosine, uracil
DNA: adenine, guanine, cytosine, thymine.



The reaction of a sugar with a base releases water (an -OH from the sugar plus an H from the base) and produces a sugar-base combination called a *nucleoside*. Addition of a phosphate to a nucleoside releases water and produces a *nucleotide*, two of which are shown in the chain of Panel (a). The nucleotides themselves can polymerize to form DNA and RNA, through a linkage between a sugar from one nucleotide and a phosphate from another, as schematically illustrated in Panel (a).

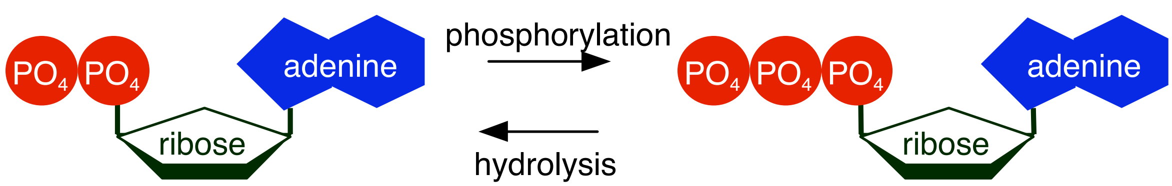


(a) (b)

In the double-stranded helix of DNA, the bases lie in the interior of the helix, and hold the helix together through hydrogen bonding between base-pairs. Each matching base pair on the opposing strands consists of one purine and one pyrimidine: adanine/thymine and guanine/cytosine.

ADP and ATP

The energy currency of the cell is based upon a sugar-base-phosphate nucleotide whose elementary components are the same as RNA. The sugar of the currency is ribose of RNA, and the most common base is adenine (or, much less frequently, guanine). The currency differs from RNA by the presence of more than one phosphate group: the lower energy state of the pair has two phosphate groups (adenosine diphosphate, or ADP), while the higher energy state has three (adenosine triphosphate, or ATP).



The energy-consuming process of adding a phosphate is called phosphorylation, while the release of a phosphate is hydrolysis. Depending on conditions, the energy change for a single phosphate group is 11-13 kcal/mol, corresponding to 8×10^{-20} J = $20k_BT$ per reaction.