JEE MAIN · PAPER 1 · CHEMISTRY

19 Biomolecules

Formula & concept sheet

The chemistry of life: carbohydrates (glucose structure and the evidence for it, anomers, mutarotation, disaccharides and polysaccharides), amino acids, peptides and proteins (structure levels, denaturation, tests), enzymes, nucleic acids (DNA, RNA, base pairing), vitamins and hormones. Each idea is explained first, then the structures drawn and the facts tabulated.

INSIDE THIS SHEET

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READ ALONGSIDE NCERT XII · Biomolecules

HOW TO USE THIS SHEET

1. **Skim** — Read the Key ideas, then the formula cards.
2. **Memorise** — Learn the formulas and check every Trap box.
3. **Test** — Do the worked examples, then this chapter's PYQs.
4. **Revise** — Use the last-minute checklist before the exam.

Formula memorise · **Key idea** why it works · **Trap** marks lost here · **PYQ** how it is asked

Practise this chapter with real past-paper questions on Prep Vault. Written for revision, not as a first read.

CHAPTER 19

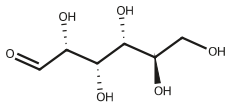
Biomolecules

NCERT XII · Biomolecules

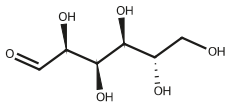
Covers: classification of carbohydrates, glucose and fructose, anomers, mutarotation · sucrose, maltose, lactose, starch, cellulose, glycogen · amino acids, zwitterion, peptide bond, protein structure, denaturation · enzymes · nucleic acids · vitamins and their deficiency diseases · hormones.

1 Carbohydrates: glucose, fructose and the cyclic structures

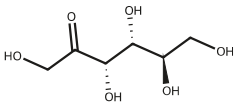
- **Carbohydrates** are polyhydroxy aldehydes or ketones (or compounds that give them on hydrolysis), $\mathrm{C}_x(\mathrm{H_2O})_y$ in general. **Monosaccharides** cannot be hydrolysed (glucose, fructose, galactose, ribose); **oligosaccharides** give 2 to 10 units on hydrolysis (disaccharides: sucrose, maltose, lactose); **polysaccharides** give many (starch, cellulose, glycogen). **Aldoses** have $-\mathrm{CHO}$ (glucose, an aldohexose); **ketoses** have $\mathrm{C{=}O}$ (fructose, a ketohexose).
- **Reducing sugars** have a free hemiacetal or hemiketal (anomeric) carbon and reduce Tollens' and Fehling's reagents: all monosaccharides, maltose, lactose. **Non-reducing**: sucrose (both anomeric carbons are tied in the glycosidic bond), starch, cellulose.



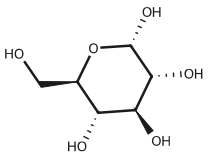
D-(+)-glucose
open chain, 4 stereocentres



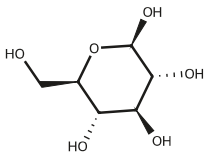
L-(–)-glucose
mirror image



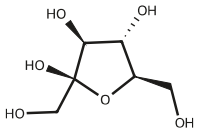
D-(–)-fructose
ketohexose



α-D-glucopyranose
m.p. 419 K, [α] +112°



β-D-glucopyranose
m.p. 423 K, [α] +18.7°



β-D-fructofuranose
5-membered ring

D- and L-glucose are mirror images (every stereocentre inverted; D/L refers to C-5, not to the sign of rotation); D-fructose is the ketohexose; glucose cyclises to the pyranose α and β anomers (they differ at C-1) and fructose to the furanose ring

EVIDENCE FOR THE OPEN-CHAIN STRUCTURE OF GLUCOSE

REACTION	RESULT	SHOWS
HI, prolonged heating	n-hexane	six carbons in a straight chain
$\mathrm{NH_2OH}$; HCN	oxime; cyanohydrin	a carbonyl group $\mathrm{C{=}O}$
$\mathrm{Br_2}$ water	gluconic acid $\mathrm{C_6H_{12}O_7}$: $\mathrm{C_6H_{12}O_6 + Br_2 + H_2O \longrightarrow C_6H_{12}O_7 + 2\,HBr}$	the carbonyl is an aldehyde
acetic anhydride	pentaacetate ($M = 180 + 5 \times 42 = 390$)	five OH groups on different carbons
$\mathrm{HNO_3}$	saccharic (glucaric) acid, a dicarboxylic acid	a primary alcohol $-\mathrm{CH_2OH}$ at the other end

EVIDENCE FOR THE CYCLIC (HEMIACETAL) STRUCTURE

OBSERVATION	EXPLANATION
no Schiff's test, no $NaHSO_3$ adduct; the pentaacetate does not react with NH_2OH	no free $-CHO$ (it is tied up in the ring)
two crystalline forms: α (m.p. 419 K) and β (423 K)	**anomers**: differ only at C-1; the ring is formed by C-5 OH adding to $C\text{-}1=O$ (hemiacetal, six-membered **pyranose**)
mutarotation	the specific rotation of either anomer ($+112^\circ$ for α, $+18.7^\circ$ for β) changes with time to the equilibrium value $+52.7^\circ$ (through the open chain)
D and L	configuration of the carbon farthest from the carbonyl (C-5 of glucose) compared with D-glyceraldehyde (OH on the right in the Fischer projection); unrelated to the sign (+) or (–) of rotation
fructose	ketohexose, $[\alpha] = -92.4^\circ$; cyclises to the five-membered **furanose** ring through the C-5 OH

KEY IDEA

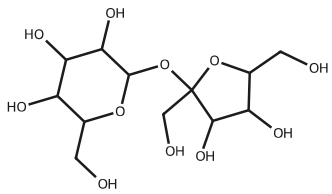
D- and L-glucose differ at every stereocentre; α and β differ only at C-1 (anomers). Glucose gives no Schiff's test although it is an aldose: in solution it is mostly the ring form, and only a little open chain.

QUICK CHECK

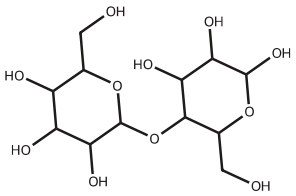
Preparation of glucose, and the oxidation product of glucose with bromine water and with nitric acid.

Answer: Hydrolysis of sucrose (dilute HCl/H_2SO_4, boil) or starch (dilute H_2SO_4, 393 K, 2 to 3 atm). Br_2 water: gluconic acid; HNO_3: saccharic acid.

2 Disaccharides and polysaccharides



sucrose
α(1→2)β, non-reducing



maltose
α(1→4), reducing

glycosidic links shown as connectivity only (ring and link configurations are in the table): sucrose joins C-1 of glucose to C-2 of fructose (both anomeric carbons used: non-reducing); maltose joins C-1 of one glucose to C-4 of another (free anomeric OH: reducing); lactose (galactose C-1 to glucose C-4, β) is reducing like maltose

DISACCHARIDES AND POLYSACCHARIDES

SUGAR	UNITS AND LINK	REDUCING?
sucrose (cane sugar)	α-D-glucose C-1 to β-D-fructose C-2 (α,β-1,2 link)	no
maltose	two α-D-glucose, C-1 to C-4 (α-1,4)	yes
lactose (milk sugar)	β-D-galactose C-1 to C-4 of β-D-glucose (β-1,4)	yes
starch: amylose (15 to 20%)	α-D-glucose, C-1 to C-4, unbranched, water soluble; blue with iodine	no
starch: amylopectin (80 to 85%)	α-D-glucose, C-1 to C-4 chains with C-1 to C-6 branches, insoluble	no
cellulose	β-D-glucose, C-1 to C-4, linear (humans cannot digest it)	no
glycogen (animal starch)	like amylopectin but more highly branched; stored in liver and muscle	no

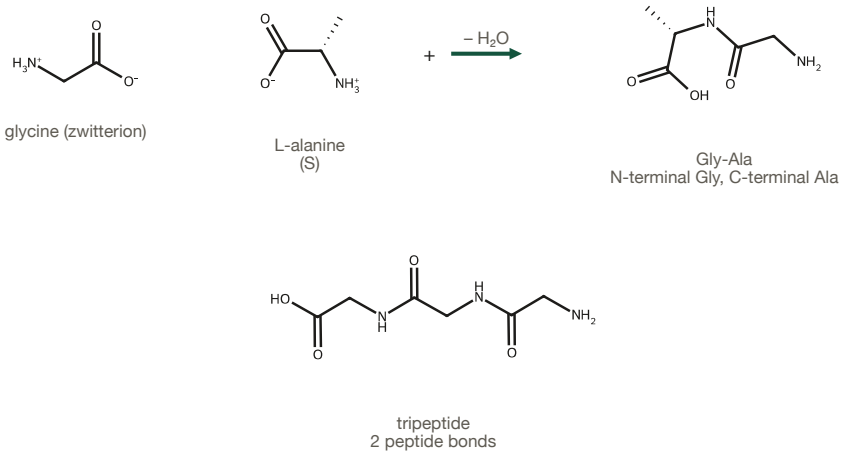
HYDROLYSIS AND INVERT SUGAR

- ✓ $C_{12}H_{22}O_{11} + H_2O \longrightarrow C_6H_{12}O_6\ (\text{glucose}) + C_6H_{12}O_6\ (\text{fructose})$ with dilute acid or invertase.
- ✓ Sucrose is dextrorotatory ($+66.5^\circ$); the hydrolysate is laevorotatory because fructose (-92.4°) outweighs glucose ($+52.7^\circ$): the mixture is called **invert sugar**.
- ✓ Maltose gives 2 glucose; lactose gives glucose + galactose.

TRAP

Sucrose is a non-reducing sugar (negative Fehling's test); maltose and lactose are reducing. Amylose is water soluble, amylopectin is not. Cellulose has β links, starch α links. The linkage between sugars is **glycosidic**, between amino acids **peptide**, between nucleotides **phosphodiester**.

3 Amino acids, peptides and proteins



amino acids exist as zwitterions; the peptide bond –CO–NH– joins the COOH of one to the NH_2 of the next with loss of water; a peptide is written from the N-terminal (left) to the C-terminal (right)

- **α-Amino acids** $H_2N-CHR-COOH$: all natural ones except glycine are chiral (L-configuration). They exist as **zwitterions** ($H_3N^+-CHR-COO^-$): crystalline, high melting, water soluble, amphoteric; the **isoelectric point** is the pH of zero net charge. Neutral amino acids have equal numbers of NH_2 and $COOH$; acidic ones (aspartic, glutamic) have more $COOH$; basic ones (lysine, arginine, histidine) more NH_2. Proline is a secondary (imino) acid; cysteine and methionine contain sulphur.
- **Essential amino acids** (10, must come from the diet): valine, leucine, isoleucine, phenylalanine, tryptophan, threonine, methionine, lysine, arginine, histidine. Non-essential: glycine, alanine, serine, cysteine, tyrosine, proline, aspartic and glutamic acids, asparagine, glutamine.

PROTEIN STRUCTURE AND FACTS

LEVEL OR FACT	DETAIL
primary	the amino-acid sequence, held by covalent **peptide bonds** ($n-1$ bonds in an n-residue chain)
secondary	α-helix (right-handed) or β-pleated sheet, by H bonds between backbone C=O and N−H
tertiary	overall folding (fibrous or globular): H bonds, disulphide bridges, van der Waals and electrostatic forces
quaternary	arrangement of two or more polypeptide subunits (haemoglobin: 4)
fibrous vs globular	fibrous: parallel chains, insoluble (keratin, myosin); globular: spherical, soluble (insulin, albumins)
denaturation	heat, pH change or reagents destroy the secondary and tertiary structure, the **primary structure stays**, activity is lost (boiled egg-white albumin coagulates; curdling of milk)
ninhydrin test	purple (Ruhemann's purple) with α-amino acids and proteins; proline gives yellow
biuret test	violet in alkaline $CuSO_4$ with peptide bonds (two or more)
enzymes	biological catalysts, mostly proteins, highly specific and efficient at body temperature; names end in -ase (maltase, invertase, urease); inhibited by poisons
counting	3 different amino acids, each once: $3! = 6$ tripeptides; with repetition allowed k^n

KEY IDEA

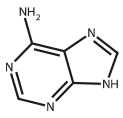
Hydrolysis of proteins gives only α-amino acids. Peptide = amide link formed with loss of water; the sequence is read from the N-terminal (free NH_2) to the C-terminal (free $COOH$). Glycine is the only achiral standard amino acid.

QUICK CHECK

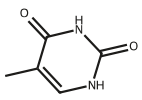
Number of peptide bonds in a pentapeptide, and number of tripeptides from three different amino acids used once each.

Answer: $5-1=4$; $3!=6$.

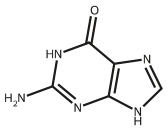
4 Nucleic acids



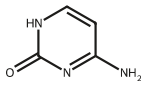
adenine (A)



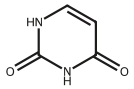
thymine (T)
A = T (2 H bonds)



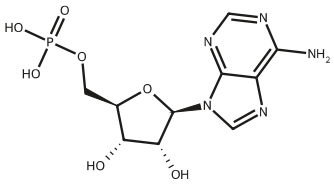
guanine (G)



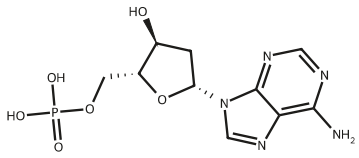
cytosine (C)
G ≡ C (3 H bonds)



uracil (U)
RNA only



adenosine monophosphate (a ribonucleotide)
base – sugar (C-1′) – phosphate (C-5′)



deoxyadenosine monophosphate
2-deoxyribose: no OH at C-2′

nucleic acids: purines A and G, pyrimidines C, T (DNA) and U (RNA); A pairs with T (two H bonds) and G with C (three H bonds); a nucleotide is base + sugar (2-deoxy-D-ribose in DNA, D-ribose in RNA, furanose, β-linked) + phosphate

DNA AND RNA

FEATURE	DNA	RNA
sugar	2-deoxy-D-ribose	D-ribose
bases	A, G (purines); C, T (pyrimidines)	A, G; C, U (uracil replaces T)
structure	double helix, two antiparallel strands, complementary	usually single strand
pairing	A=T (2 H bonds), G≡C (3); Chargaff: %A = %T, %G = %C	A=U, G≡C within folded regions
function	stores heredity, replicates	protein synthesis: messenger (mRNA), ribosomal (rRNA), transfer (tRNA)

BUILDING BLOCKS

- **Nucleoside** = base + pentose sugar (the base on C-1′). **Nucleotide** = nucleoside + phosphate (on C-5′).
- Nucleotides are linked by **phosphodiester** bonds (C-5′ of one to C-3′ of the next): the sugar-phosphate backbone.
- The sugar is D-ribose or 2-deoxy-D-ribose in the **furanose** form, β-linked to the base; a viral genome may be RNA.

TRAP

DNA has deoxyribose and thymine; RNA has ribose and uracil. The sugar in nucleic acids is in the **five-membered** (furanose) form, not pyranose. Base pairing A—T has two H bonds and G—C three, so G-C rich DNA melts at a higher temperature.

5 Vitamins and hormonesr

Vitamins are organic compounds needed in small amounts that the body cannot make. **Fat-soluble**: A, D, E, K (stored in the liver and adipose tissue). **Water-soluble**: B group and C (excreted in urine, must be supplied regularly), **except vitamin** B_{12}, which is stored in the liver. So the stored ones are A, D, E, K and B_{12}.

VITAMINS: SOURCE AND DEFICIENCY DISEASE

VITAMIN	SOURCE (EXAMPLES)	DEFICIENCY
A (retinol)	fish liver oil, carrots, butter, milk	xerophthalmia, night blindness
B1 (thiamine)	yeast, milk, green vegetables, cereals	beriberi
B2 (riboflavin)	milk, egg white, liver, kidney	cheilosis, fissures at the mouth corners, digestive disorders
B6 (pyridoxine)	yeast, milk, egg yolk, cereals, grams	convulsions
B_{12} (cyanocobalamin, contains Co)	meat, fish, egg, curd	pernicious anaemia
C (ascorbic acid)	citrus fruits, amla, green leafy vegetables	scurvy (bleeding gums)
D	sunlight, fish, egg yolk	rickets (children), osteomalacia (adults)
E	vegetable oils (wheat germ, sunflower)	fragile red blood cells, muscular weakness
K	green leafy vegetables	increased blood-clotting time

HORMONES (CHEMICAL MESSENGERS FROM ENDOCRINE GLANDS)

TYPE	EXAMPLES AND DEFICIENCY
proteins and peptides	insulin (lowers blood glucose; deficiency: diabetes mellitus) and glucagon
amino-acid derivatives	thyroxine (iodinated tyrosine; deficiency: goitre, hypothyroidism), adrenaline
steroids	oestrogens, androgens (testosterone), progesterone, glucocorticoids

6 Worked examples

REDUCING SUGAR

Which of glucose, fructose, sucrose, maltose, lactose, starch, cellulose give a positive Fehling's test?

glucose, fructose (it isomerises to an aldose in base), maltose, lactose; not sucrose, starch, cellulose

STORED VITAMINS

How many of A, B1, B6, B12, C, D, E, K are stored in the body?

A, D, E, K and B_{12}: 5

PEPTIDES

Tripeptides from glycine, alanine and valine, each used once, and from two amino acids (Gly, Ala) with repetition allowed, length 3.

$3! = 6$; $2^3 = 8$

MOLAR MASS

Molar mass of glucose pentaacetate; and the mass of glucose from 342 g of sucrose on complete hydrolysis.

$180 + 5 \times 42 = 390$; 342 g sucrose is 1 mol $\rightarrow 1$ mol glucose $= 180$ g (and 180 g fructose)

STRUCTURE EVIDENCE

Which reaction proves glucose has a straight six-carbon chain, and which an aldehyde group?

prolonged heating with HI gives n-hexane; Br_2 water oxidises $-CHO$ to $-COOH$ (gluconic acid)

NUCLEIC ACIDS

A DNA sample has 30% adenine. Percent of cytosine and the number of H bonds per A-T and G-C pair?

$\%T = 30$, so $\%G + \%C = 40$, $\%C = 20$; A=T 2 H bonds, G≡C 3

7 Last-minute checklist

BEFORE YOU ANSWER

Free anomeric carbon (reducing)? α or β link? Which linkage name: glycosidic, peptide, phosphodiester? Which structure level does denaturation destroy?

- Glucose: aldohexose, $[\alpha]$ $+52.7°$ at equilibrium (α $+112°$, β $+18.7°$); fructose $-92.4°$; D/L from C-5; anomers differ at C-1; pyranose vs furanose; open-chain evidence: HI, NH_2OH, Br_2 water, acetylation, HNO_3.
- Reducing: monosaccharides, maltose, lactose; non-reducing: sucrose, starch, cellulose; invert sugar; amylose (soluble, blue with I_2), amylopectin, glycogen.
- Amino acids: zwitterion, 10 essential, glycine achiral; $n - 1$ peptide bonds; $k!$ tripeptides; ninhydrin purple; biuret violet; structures: primary (sequence), secondary (H bonds, helix, sheet), tertiary, quaternary; denaturation keeps the primary.
- DNA: deoxyribose, A, T, G, C, double helix; RNA: ribose, U, single strand (mRNA, rRNA, tRNA); nucleotide = base + sugar + phosphate; phosphodiester link.
- Vitamins: A, D, E, K fat soluble (stored); B and C water soluble except B_{12} (stored); deficiency diseases: A night blindness, B1 beriberi, B12 pernicious anaemia, C scurvy, D rickets, K clotting; hormones: insulin, thyroxine, steroids.

Now test it. Practise this chapter with past-paper and bank questions on Prep Vault. **Practice this chapter →**