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GATE BT

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General Biology Formula Sheet

INSIDE

- 46 formulas in 7 topics
- When to use each one
- Taken from the free topic notes on iaeacademy.in

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Biomolecules and biological membranes

HENDERSON-HASSELBALCH EQUATION

$$\mathrm{pH} = \mathrm{p}K_a + \log_{10}\frac{[\mathrm{A}^-]}{[\mathrm{HA}]}$$

Ratio of deprotonated (A-) to protonated (HA) form of one ionisable group, with pKa = -log10 Ka. At pH = pKa the two forms are equal, and a group buffers best within about 1 pH unit of its pKa.

ISOELECTRIC POINT, AMINO ACID WITH A NON-IONISABLE SIDE CHAIN

$$\mathrm{p}I = \frac{\mathrm{p}K_1 + \mathrm{p}K_2}{2}$$

pK1 is the alpha-COOH and pK2 the alpha-NH3+. For any amino acid, pI is the average of the two pKa values that lie on either side of the neutral (net charge zero) form.

ALPHA HELIX GEOMETRY

$$\text{pitch} = 3.6 \times 0.15\ \text{nm} = 0.54\ \text{nm}$$

Right-handed alpha helix: 3.6 residues per turn, 0.15 nm rise per residue, i to i+4 hydrogen bonds.

STEREOISOMERS OF A SUGAR

$$N_{\text{stereoisomers}} = 2^n$$

n is the number of chiral carbons in the open-chain form (valid when there are no meso forms). Aldohexoses have n = 4, giving 16 (8 D and 8 L); ketohexoses have n = 3, giving 8. Cyclisation adds one more chiral centre, the anomeric carbon.

B-DNA LENGTH AND TURNS

$$L = N_{bp} \times 0.34\ \text{nm}, \qquad N_{\text{turns}} = \frac{N_{bp}}{10}$$

Idealised B-form: 0.34 nm rise per base pair, 10 bp per turn, so pitch 3.4 nm; diameter about 2 nm; right-handed. B-DNA in solution has about 10.5 bp per turn; use 10 unless a question states otherwise.

CARRIER-MEDIATED (FACILITATED) TRANSPORT

$$J = \frac{J_{\max}[S]}{K_t + [S]}$$

Same form as Michaelis-Menten kinetics: flux saturates at Jmax, and Kt is the solute concentration giving half-maximal flux. Simple diffusion has no such limit; its flux rises linearly with the concentration difference.

FREE ENERGY OF MOVING A SOLUTE FROM SIDE 1 TO SIDE 2

$$\Delta G = RT\ln\frac{C_2}{C_1} + zF\,\Delta\psi$$

R = 8.314 J mol^{-1} K^{-1}, T in kelvin, F = 96,485 C mol^{-1}, z the signed charge of the solute, and $\Delta\psi = \psi_2 - \psi_1$ in volts; ΔG is in J mol^{-1}. For an uncharged solute z = 0 and only the concentration term remains. A negative value means the movement is spontaneous (passive); a positive value means it needs an energy input.

OSMOTIC PRESSURE (DILUTE SOLUTIONS)

$$\pi = iCRT$$

i is the number of particles each formula unit gives in solution (1 for glucose, about 2 for NaCl), C the molar concentration, R the gas constant (0.0821 L atm mol^{-1} K^{-1} gives π in atm) and T in kelvin; iC is the osmolarity. Valid for ideal dilute solutions. Water moves by osmosis from lower to higher osmolarity, often through aquaporins; a cell swells in a hypotonic medium and shrinks in a hypertonic one (tonicity also depends on whether the solute can cross the membrane).

NERNST EQUATION

$$E_{\text{ion}} = \frac{RT}{zF}\ln\frac{[\text{ion}]_{\text{out}}}{[\text{ion}]_{\text{in}}} \approx \frac{61.5\ \text{mV}}{z}\log_{10}\frac{[\text{ion}]_{\text{out}}}{[\text{ion}]_{\text{in}}}$$

One permeant ion at equilibrium; z is its signed charge (+1 for K+ and Na+, -1 for Cl-, +2 for Ca2+). 2.303RT/F = 61.5 mV at 37 degrees C (about 59 mV at 25 degrees C).

GOLDMAN (GOLDMAN-HODGKIN-KATZ) EQUATION

$$V_m = \frac{RT}{F}\ln\frac{P_K[\text{K}^+]_o + P_{Na}[\text{Na}^+]_o + P_{Cl}[\text{Cl}^-]_i}{P_K[\text{K}^+]_i + P_{Na}[\text{Na}^+]_i + P_{Cl}[\text{Cl}^-]_o}$$

Steady-state potential (no net current) with several monovalent permeant ions, assuming a constant electric field across the membrane. P is each ion's permeability; only ratios matter. The Cl- terms are inverted because it is an anion. The result lies between the ions' Nernst potentials, closest to that of the most permeable ion; with only one permeant ion it reduces to the Nernst equation.

Metabolism: pathways, photosynthesis and respiration

FREE ENERGY UNDER CELLULAR CONDITIONS

$$\Delta G = \Delta G^{\circ\prime} + RT\ln Q$$

R = 8.315 J/(mol·K); RT ≈ 2.48 kJ/mol at 25 °C. Q is the mass-action ratio [products]/[reactants]; at equilibrium Q = K'eq and ΔG = 0.

STANDARD FREE ENERGY AND EQUILIBRIUM CONSTANT

$$\Delta G^{\circ\prime} = -RT\ln K'_{eq}$$

K'eq is the equilibrium constant at pH 7. Each tenfold change in K'eq changes ΔG°' by about 5.7 kJ/mol at 25 °C (this is RT ln 10).

FREE ENERGY OF A REDOX REACTION

$$\Delta G^{\circ\prime} = -nF\,\Delta E^{\circ\prime}$$

n = electrons transferred per mole of the reaction as written, F = 96.5 kJ/(V·mol), ΔE°' = E°'(electron acceptor) minus E°'(electron donor), both at pH 7.

ADENYLATE ENERGY CHARGE

$$\text{Energy charge} = \frac{[\text{ATP}] + \frac{1}{2}[\text{ADP}]}{[\text{ATP}] + [\text{ADP}] + [\text{AMP}]}$$

Ranges from 0 (all AMP) to 1 (all ATP); cells usually hold it at about 0.8–0.95. ATP-generating pathways are inhibited and ATP-using pathways stimulated as it rises. Adenylate kinase (2 ADP ⇌ ATP + AMP) makes [AMP] change far more, in proportion, than [ATP], which is why AMP is a sensitive low-energy signal.

COMPLETE OXIDATION OF GLUCOSE (2.5 / 1.5 CONVENTION)

$$\text{ATP per glucose} = 2 + 2(2.5 \text{ or } 1.5) + 2(2.5) + 2 + 6(2.5) + 2(1.5)$$

Terms: glycolysis ATP, cytosolic NADH (2.5 each via the malate-aspartate shuttle, 1.5 each via the glycerol-3-phosphate shuttle), PDH NADH, TCA GTP (counted as ATP), TCA NADH, TCA FADH2. Gives 32 with the malate-aspartate shuttle and 30 with the glycerol-3-phosphate shuttle.

RESPIRATORY QUOTIENT

$$\text{RQ} = \frac{\text{moles of } \text{CO}_2 \text{ released}}{\text{moles of } \text{O}_2 \text{ consumed}}$$

Carbohydrate 1.0 (C6H12O6 + 6 O2 → 6 CO2 + 6 H2O). Fat about 0.7 (palmitic acid: C16H32O2 + 23 O2 → 16 CO2 + 16 H2O, RQ = 16/23 ≈ 0.70). Protein about 0.8. Above 1 for oxygen-rich substrates such as organic acids (malate 4/3), when fat is being made from carbohydrate, or with fermentation.

COMPLETE OXIDATION OF AN EVEN-CHAIN SATURATED FATTY ACID WITH C CARBONS (C ≥ 4)

$$\text{Net ATP} = 4\left(\tfrac{C}{2} - 1\right) + 10 \cdot \tfrac{C}{2} - 2 = 7C - 6$$

Uses 2.5 per NADH and 1.5 per FADH2, so 4 per β-oxidation round and 10 per acetyl-CoA, and 2 spent on activation. For palmitate (C = 16): 7 rounds give 28, 8 acetyl-CoA give 80, gross 108, net 106. Stearate (C = 18) gives 120. With the older ratios (3 and 2) palmitate gives 129.

CALVIN CYCLE STOICHIOMETRY

$$6\,\mathrm{CO_2} + 18\,\mathrm{ATP} + 12\,\mathrm{NADPH} \rightarrow \text{one hexose}$$

Per CO2 fixed: 3 ATP and 2 NADPH. Three CO2 give one net G3P using 9 ATP and 6 NADPH.

Enzymes: classification, catalysis, kinetics and inhibition

MICHAELIS-MENTEN EQUATION

$$v = \frac{V_{max}[S]}{K_m + [S]}$$

Initial velocity of a single-substrate enzyme under steady state with $[S] \gg [E]_T$. K_m is in concentration units (mM or μM), V_{max} in concentration per time (for example μM/min).

MICHAELIS CONSTANT

$$K_m = \frac{k_{-1} + k_2}{k_1}$$

For $E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \xrightarrow{k_2} E + P$. K_m equals the substrate concentration at which $v = V_{max}/2$. It equals the dissociation constant $K_d = k_{-1}/k_1$ of ES only if $k_2 \ll k_{-1}$.

MAXIMUM VELOCITY AND TURNOVER NUMBER

$$V_{max} = k_{cat}[E]_T$$

k_{cat} (units s^{-1}) is the number of substrate molecules converted per active site per second at saturation. For the simple mechanism above $k_{cat} = k_2$.

CATALYTIC EFFICIENCY

$$\text{catalytic efficiency} = \frac{k_{cat}}{K_m}$$

Units $M^{-1}s^{-1}$. It is the apparent second-order rate constant at $[S] \ll K_m$, where $v \approx (k_{cat}/K_m)[E]_T[S]$. Its upper limit is set by diffusion, about 10^8 to 10^9 $M^{-1}s^{-1}$.

FRACTION OF VMAX REACHED AT A GIVEN [S]

$$\frac{v}{V_{max}} = \frac{[S]}{K_m + [S]} \;\Rightarrow\; [S] = \frac{f}{1-f}K_m \text{ for } v = fV_{max}$$

For example $f = 0.5$ gives $[S] = K_m$, and $f = 0.9$ gives $[S] = 9K_m$.

LINEWEAVER-BURK (DOUBLE RECIPROCAL)

$$\frac{1}{v} = \frac{K_m}{V_{max}} \cdot \frac{1}{[S]} + \frac{1}{V_{max}}$$

Plot $1/v$ against $1/[S]$: slope $= K_m/V_{max}$, y-intercept $= 1/V_{max}$, x-intercept $= -1/K_m$.

EADIE-HOFSTEE

$$v = V_{max} - K_m \frac{v}{[S]}$$

Plot v against $v/[S]$: slope $= -K_m$, y-intercept $= V_{max}$, x-intercept $= V_{max}/K_m$.

HANES-WOOLF

$$\frac{[S]}{v} = \frac{1}{V_{max}}[S] + \frac{K_m}{V_{max}}$$

Plot $[S]/v$ against $[S]$: slope $= 1/V_{max}$, y-intercept $= K_m/V_{max}$, x-intercept $= -K_m$.

APPARENT CONSTANTS WITH A REVERSIBLE INHIBITOR

$$V_{max}^{app} = \frac{V_{max}}{\alpha'}, \qquad K_m^{app} = \frac{\alpha}{\alpha'}K_m$$

General mixed case. Competitive: $\alpha' = 1$. Uncompetitive: $\alpha = 1$. Pure non-competitive: $\alpha = \alpha'$ ($K_i = K_i'$), so K_m is unchanged.

HILL EQUATION FOR COOPERATIVE ENZYMES

$$\log \frac{v}{V_{max} - v} = n_H \log[S] - \log K'$$

Here $K' = (K_{0.5})^{n_H}$. A plot of the left side against $\log[S]$ has slope n_H, the Hill coefficient. $n_H > 1$ means positive cooperativity, $n_H = 1$ no cooperativity, $n_H < 1$ negative cooperativity. n_H cannot exceed the number of substrate-binding sites.

Bacterial classification, cell walls, growth and nutrition

THERMAL DEATH (D-VALUE)

$$\log_{10} \frac{N_0}{N_t} = \frac{t}{D}$$

N_0 is the initial count and N_t the survivors after time t at one fixed temperature; D is in the same unit as t. Valid while the death curve is a straight line on a log scale.

Z-VALUE

$$\log_{10} \frac{D_{T_1}}{D_{T_2}} = \frac{T_2 - T_1}{z}$$

D_{T_1} and D_{T_2} are the D-values at temperatures T_1 and T_2 ($T_2 > T_1$); z is in the same temperature unit.

RESOLVING POWER OF A LIGHT MICROSCOPE

$$d = \frac{0.61\,\lambda}{\mathrm{NA}}, \qquad \mathrm{NA} = n \sin\theta$$

d is the smallest resolvable distance, λ the wavelength, n the refractive index between specimen and objective and θ half the angle of the cone of light entering the objective. This is the Rayleigh form; some texts use $d = 0.5\,\lambda/\mathrm{NA}$. A smaller d means better resolution.

VIABLE COUNT FROM SERIAL DILUTION

$$\mathrm{CFU/mL} = \frac{\text{colonies counted}}{\text{volume plated (mL)} \times \text{dilution factor}}$$

Here the dilution factor is the fraction left after all dilutions, for example 10^{-6} after six tenfold steps. Equivalently, CFU/mL = colonies × reciprocal of the dilution ÷ volume plated.

NUMBER OF GENERATIONS

$$n = \frac{\log_{10} N - \log_{10} N_0}{\log_{10} 2} \approx 3.32\,\log_{10} \frac{N}{N_0}$$

Use only for the exponential phase. N_0 and N are the cell counts at the start and end of the interval.

GENERATION TIME AND DIVISION RATE CONSTANT

$$g = \frac{t}{n}, \qquad k = \frac{n}{t} = \frac{1}{g}$$

t is the elapsed exponential time; k is generations per unit time.

SPECIFIC GROWTH RATE

$$\mu = \frac{\ln N - \ln N_0}{t} = \frac{\ln 2}{g} \approx \frac{0.693}{g}$$

Per unit time (for example per hour). It uses the natural log, so $\mu = 0.693\,k$.

MONOD GROWTH EQUATION

$$\mu = \mu_{\max}\frac{S}{K_s + S}$$

S is the limiting nutrient concentration; K_s is the value of S at which $\mu = \mu_{\max}/2$ (units of concentration). It applies when one nutrient is limiting.

CHEMOSTAT STEADY STATE

$$\bar{S} = \frac{K_s\,D_{\text{dil}}}{\mu_{\max} - D_{\text{dil}}}, \qquad \bar{X} = Y_{X/S}\left(S_R - \bar{S}\right)$$

$\bar{S}$ and $\bar{X}$ are the steady-state substrate and biomass concentrations, and $Y_{X/S}$ is the biomass yield (mass of cells formed per mass of substrate used). This assumes Monod kinetics with no cell death and no maintenance consumption.

Operons, nitrogen fixation, pathogens, antibiotics and viruses

NITROGENASE REACTION (CONVENTIONAL STOICHIOMETRY)

$$\mathrm{N_2} + 8\mathrm{H^+} + 8e^- + 16\,\mathrm{ATP} + 16\,\mathrm{H_2O} \rightarrow 2\mathrm{NH_3} + \mathrm{H_2} + 16\,\mathrm{ADP} + 16\,\mathrm{P}_i$$

Convention: 2 ATP hydrolysed per electron transferred; 8 electrons per N_2 (6 to make 2 NH_3 and 2 for the obligatory H_2), so 16 ATP per N_2. In cells the cost is often higher because extra H_2 is made.

PLAQUE ASSAY TITER

$$\text{Titer (PFU/mL)} = \frac{\text{number of plaques}}{\text{dilution} \times \text{volume plated (mL)}}$$

Use a plate with a countable number of plaques (conventionally 30 to 300). The dilution is the fraction of the original stock in the plated sample (such as 10^{-6}).

MULTIPLICITY OF INFECTION (POISSON DISTRIBUTION)

$$P(k) = \frac{m^k e^{-m}}{k!}, \qquad P(0) = e^{-m}, \qquad \text{fraction infected} = 1 - e^{-m}$$

m is the multiplicity of infection (phage added per bacterium), assuming random adsorption. P(k) is the fraction of cells infected by exactly k phages.

Immune system: lymphoid organs, innate immunity, complement and antibodies

C3 CONVERTASES

$$\text{C3 convertase: C4b2a (classical, lectin)}, \quad \text{C3bBb (alternative)}$$

Each cleaves C3 into C3a (anaphylatoxin) and C3b (opsonin); C3b joining the convertase makes the C5 convertase.

TERMINAL PATHWAY AND MEMBRANE ATTACK COMPLEX

$$\mathrm{C5} \xrightarrow{\text{C5 convertase}} \mathrm{C5a} + \mathrm{C5b}; \quad \mathrm{C5b} + \mathrm{C6} + \mathrm{C7} + \mathrm{C8} + n\,\mathrm{C9} \rightarrow \mathrm{MAC}$$

Common to all pathways. The MAC is a pore that lyses Gram-negative bacteria and other susceptible cells.

VALENCY OF AN ANTIBODY

$$\text{binding sites} = 2 \times (\text{number of monomer units})$$

Applies when each monomer has two sites: IgG, IgE, IgD = 2; secretory IgA dimer = 4; IgM pentamer = 10.

COMBINATORIAL DIVERSITY

$$N_H = V_H \times D_H \times J_H, \qquad N_L = V_\kappa J_\kappa + V_\lambda J_\lambda$$

Counts of functional segments. Total combinations are N_H x N_L (assuming any heavy chain pairs with any light chain), before junctional diversity and somatic hypermutation are added.

T and B cells, MHC, antigen presentation and immune regulation

HLA MATCH BETWEEN TWO FULL SIBLINGS

$$P(\text{HLA-identical}) = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}, \qquad P(\text{exactly one shared}) = \frac{1}{2}, \qquad P(\text{none shared}) = \frac{1}{4}$$

Applies when the two parents carry four different haplotypes between them and there is no recombination within the MHC. Each child receives one of two maternal and one of two paternal haplotypes, each with probability 1/2.

VACCINATION COVERAGE NEEDED FOR HERD IMMUNITY

$$p_c = \frac{1 - \dfrac{1}{R_0}}{E}$$

R_0 is the basic reproduction number and E is vaccine efficacy (fraction, 0 to 1). $1 - 1/R_0$ is the herd immunity threshold, the coverage needed when $E = 1$. Assumes homogeneous mixing, and applies when E is high enough that p_c does not exceed 1.

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