Acid-base catalysis: the mechanisms and examples sheet

Acid catalysis: the acid protonates the substrate, so a C=O, C=C or C-OR carbon becomes a far better electrophile and -OH becomes a good leaving group (-OH2+). Base catalysis: the base deprotonates the nucleophile or an alpha carbon, so an alcohol becomes an alkoxide and a ketone an enolate, both far stronger nucleophiles. In both cases the proton is returned in the last step: the catalyst is regenerated, lowers the activation energy of the slow step, and does not appear in the overall equation.

Specific or general: the distinction the rate equation tests

	Specific acid (or base) catalysis	General acid (or base) catalysis
Who moves the proton	Only H3O+ (or only OH-)	Every acid present: H3O+ and undissociated HA (or every base B)
When	Fast pre-equilibrium before the slow step	In the slow, rate-determining step itself
Rate depends on	[H3O+] only, i.e. on pH	[H3O+] and [HA] for each acid in the solution
Rate equation	rate = k [S] [H3O+]	rate = [S] (k0 + kH [H3O+] + kHA [HA])
The experiment	Buffer at fixed pH, raise the buffer concentration: rate unchanged	Same experiment: rate rises with buffer concentration
Typical case	Sucrose inversion, ester hydrolysis in dilute acid	Enzyme active sites; mutarotation of glucose with weak acids

Five reactions where it appears

Reaction	Catalyst	What the proton does	Kinetics / notes
Ester hydrolysis and Fischer esterification: CH3COOC2H5 + H2O <=> CH3COOH + C2H5OH	H2SO4 (acid)	Protonates C=O (carbon attacked by water); then protonates OC2H5 so ethanol leaves	Reversible; saponification with OH- is NOT catalysis, the OH- is consumed
Iodination of propanone: CH3COCH3 + I2 -> CH3COCH2I + HI	H+ (acid)	Converts the ketone to its enol in the slow step; the enol then reacts with I2 fast	rate = k [CH3COCH3] [H+]; zero order in I2; HI product makes it autocatalytic
Hydration of ethene: CH2=CH2 + H2O -> CH3CH2OH	H3PO4, 300 C, 60 atm	H+ adds to the C=C to give a carbocation; water attacks; H+ is lost	Markovnikov's rule decides the carbon for an unsymmetrical alkene
Aldol condensation of ethanal	dilute NaOH (base)	OH- removes an alpha-H to give the enolate, which attacks a second C=O	3-hydroxybutanal; warm to dehydrate to but-2-enal
Inversion of sucrose: sucrose + H2O -> glucose + fructose	dilute HCl (acid)	Protonates the glycosidic oxygen so it becomes a leaving group	First order in sucrose and in H+; followed by polarimeter, rotation changes sign

Is it catalysis, and which kind? Tick, then check against the key

Case	Catalysis?	Specific or general	Why
Ester + NaOH(aq), heated (saponification)			
Ester + water with a drop of H2SO4			
Chymotrypsin cutting a peptide bond at pH 7			
Rate at fixed pH rises when the buffer is made stronger			
Propanone + I2 with H+: zero order in I2			

Key: no (OH- is consumed as the carboxylate forms) / yes, acid, specific (fast protonation pre-equilibrium, rate on pH) / yes, general acid-base (His57 moves the proton in the slow step) / general (the buffer's own acid and base are catalysing) / yes, acid; the slow step is the acid-catalysed enolisation, so I2 does not appear in the rate equation.

From sciencewithshobha.com/blog/acid-base-catalysis-explained-with-examples-and-mechanisms/

The mechanism, the enzyme version, and the six-mark answer

What the proton does at each stage

Stage	Acid catalysis	Base catalysis
Activation	Protonate a C=O, C=C or C-OR: the carbon becomes more electrophilic	Deprotonate an O-H, N-H or alpha C-H: a stronger nucleophile forms
Attack	A weak neutral nucleophile (H2O, ROH) can now attack	The anion (RO-, enolate) attacks a neutral electrophile
Leaving	Protonate the leaving group so it leaves as H2O or ROH	The anionic intermediate expels a leaving group or is protonated by solvent
Regeneration	The proton returns to the solvent in the last step	The base takes a proton back from the solvent in the last step

Enzymes: general acid-base catalysis at pH 7

Side chain	pKa in the active site	Role
Histidine (imidazole)	about 6 to 7	Accepts a proton, then donates it a step later; the commonest catalytic residue (His57 in chymotrypsin)
Aspartate, glutamate	about 4; higher in a hydrophobic pocket	General base; general acid when protonated (lysozyme Glu35 donates, Asp52 stabilises)
Lysine	about 10	General acid; also forms imines (aldolase)
Cysteine	about 8	Nucleophile once deprotonated by a nearby base (papain)
Serine, tyrosine	about 13 and 10	Nucleophile once deprotonated (Ser195 in the serine proteases)

Chymotrypsin's catalytic triad: His57 (general base) takes the proton from Ser195, the serine oxygen attacks the peptide C=O, then His57 (general acid) gives the proton to the nitrogen so the amine leaves; Asp102 holds the histidine in place. The proton moves in the slow step, so enzyme rates depend on the residues' pKa and give the bell-shaped rate-against-pH curve.

Draw it: acid-catalysed attack on a carbonyl

1. Lone pair on O to H+ ; draw C=OH+	2. Resonance form with + on carbon	3. Nucleophile lone pair to C; pi bond onto O	4. Protonate the leaving group; it leaves; H+ returns

The six-mark answer: how an acid catalyst speeds up ester hydrolysis

[ ] The acid protonates the carbonyl oxygen
[ ] This increases the partial positive charge on the carbonyl carbon
[ ] So water, a weak nucleophile, can attack that carbon
[ ] Protonation of the alkoxy oxygen makes the alcohol a good leaving group
[ ] The proton is regenerated in the final step, so the catalyst is not consumed
[ ] The activation energy of the rate-determining step is lowered