Engineering Chemistry

Short notes for 1st year B.Tech (all branches) · BCA · GATE

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1. Water: Hardness

- **Hard water**: does not give lather easily with soap, due to Ca^2+ and Mg^2+ salts.
- **Temporary hardness** (carbonate): bicarbonates of Ca and Mg. Removed by boiling.
  - $Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2$
- **Permanent hardness** (non-carbonate): chlorides and sulphates of Ca and Mg. Not removed by boiling.
- Hardness is expressed as **CaCO3 equivalent** (CaCO3 is chosen because its molar mass is 100 and it is insoluble).

FORMULA CaCO3 equivalent = (mass of salt x 100) / (molar mass of salt), for salts with a 2+ ion. (General: mass x 50 / equivalent mass of salt.)

➤ Units of hardness

Unit	Meaning
ppm	parts of CaCO3 per 10^6 parts of water
mg/L	mg CaCO3 per litre (= ppm)
°Fr (French)	parts per 10^5
°Cl (Clarke)	parts per 70,000

REMEMBER 1 ppm = 1 mg/L = 0.1 °Fr = 0.07 °Cl.

➤ Solved example

- Water has 16.2 mg/L $Ca(HCO_3)_2$ (molar mass 162) and 9.5 mg/L $MgCl_2$ (molar mass 95).
- $Ca(HCO_3)_2$ as CaCO3 = 16.2 x 100 / 162 = 10 ppm (temporary).
- $MgCl_2$ as CaCO3 = 9.5 x 100 / 95 = 10 ppm (permanent).
- Total hardness = 20 ppm.

➤ EDTA method

- Water + buffer (pH 10) + Eriochrome Black T (EBT) indicator ⇒ wine red. Titrate with EDTA until blue.
- Hardness (ppm) = (V of EDTA x M of EDTA x 100 x 1000) / V of water sample (with molarity M).

2. Water Treatment

➤ Softening methods

Method	Principle	Note
Lime–soda	Lime Ca(OH)2 and soda Na2CO3 precipitate Ca and Mg salts	Hot process is faster
Zeolite (permutit)	Na2Ze + Ca^2+ → CaZe + 2Na^+	Regenerated with NaCl brine. Leaves Na salts
Ion exchange	Cation resin (H+) + anion resin (OH-)	Gives demineralised water (near zero hardness)

FORMULA Lime = (74/100)[temp Ca + 2 x temp Mg + perm (Mg + Fe + Al) + CO2 + H+ + HCO3- - NaAlO2] x volume. Soda = (106/100)[perm (Ca + Mg + Fe + Al) + H+ - HCO3-] x volume. (All as CaCO3 equivalents.)

- Exam questions give the impurity table; apply the factor 74/100 for lime and 106/100 for soda, then multiply by volume.

➤ Boiler troubles

Problem	Cause	Prevention
Scale and sludge	Hard salts deposit (scale = hard, sludge = soft)	Softening, phosphate conditioning
Priming and foaming	Water droplets carried with steam, oil/alkali	Antifoam, keep water level steady
Caustic embrittlement	High NaOH in boiler cracks steel	Add Na2SO4 or use phosphate instead of soda
Boiler corrosion	Dissolved O2, CO2, acids	De-aeration, Na2SO3 or hydrazine

Drinking water

- Steps: screening → sedimentation → coagulation (alum) → filtration → **disinfection**.
- Disinfection by chlorine, bleaching powder, UV or ozone. **Break-point chlorination**: add Cl2 until free residual chlorine appears.
- **Desalination**: reverse osmosis (RO) and electrodialysis.
- BIS limit for total hardness in drinking water: 200 mg/L (acceptable).

3. Fuels

- **Fuel** = a substance that gives heat on burning. **Calorific value (CV)** = heat from burning unit mass (or volume).
- **HCV (gross)** includes latent heat of water vapour. **LCV (net)** = HCV − latent heat of steam formed.

FORMULA LCV = HCV − 0.09 × H × 587 (cal/g), where H = % hydrogen. (9 g water forms from 1 g H; latent heat 587 cal/g.)

FORMULA Dulong formula: HCV = (1/100)[8080 C + 34500 (H − O/8) + 2240 S] kcal/kg.

Solved example

- Coal: C = 80%, H = 5%, O = 8%, S = 1%.
- HCV = (1/100)[8080 × 80 + 34500 × (5 − 1) + 2240 × 1] = (1/100)[646400 + 138000 + 2240] = 7866.4 kcal/kg.
- LCV = 7866.4 − 0.09 × 5 × 587 = 7866.4 − 264.15 = 7602.3 kcal/kg.

Coal analysis

- **Proximate**: moisture, volatile matter, ash, fixed carbon. **Ultimate**: C, H, N, S, O.
- Bomb calorimeter measures CV of solid / liquid fuels. Junkers gas calorimeter for gases.

Petroleum

- Refining by fractional distillation. **Cracking** = breaking big molecules into smaller (petrol).
- **Knocking**: early uncontrolled burning in a petrol engine.

- **Octane number**: iso-octane = 100, n-heptane = 0. Higher is better for petrol.
- **Cetane number**: for diesel; cetane = 100, α-methylnaphthalene = 0.

- Antiknock: TEL (old, banned due to lead), now MTBE, ethanol blends.
- Gaseous fuels: CNG (mainly methane), LPG (propane + butane), producer gas, water gas.

4. Corrosion

- **Corrosion** = slow destruction of a metal by chemical or electrochemical reaction with its surroundings. Example: rusting of iron ($Fe_2O_3 \cdot xH_2O$).

Type	How	Example
Dry (chemical)	Direct attack by gases like O_2	Oxide layer on metals at high temperature
Wet (electrochemical)	Anode and cathode in moisture or electrolyte	Rusting of iron
Galvanic	Two different metals in contact	Steel screw in copper plate
Differential aeration	Less oxygen part becomes anode	Pitting, waterline corrosion

- Wet corrosion of iron: anode $Fe \rightarrow Fe^{2+} + 2e^-$. Cathode (neutral, with O_2): $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$.
- **Pilling–Bedworth rule**: oxide protects the metal if volume of oxide >= volume of metal used (ratio >= 1). Example: Al is protected; Na, K are not.

➤ Prevention

- Proper design, pure metals, alloys (stainless steel).
- **Cathodic protection**: sacrificial anode (Mg, Zn) or impressed current.
- **Coatings**: galvanising (Zn on iron), tinning (Sn on iron), paints, electroplating.

EXAM POINT Galvanised iron is protected even if scratched (Zn is more active and corrodes first). Tinned iron corrodes faster at a scratch (iron becomes the anode).

5. Electrochemistry

- **Electrochemical cell**: converts chemical energy into electrical energy. Anode = oxidation, cathode = reduction.
- **Standard hydrogen electrode (SHE)**: $E^\circ = 0$ V.

- **EMF of cell**: E°cell = E°cathode - E°anode.
- ΔG = -nFE (F = 96500 C). Cell is spontaneous when E > 0.

FORMULA Nernst equation: E = E° - (0.0591 / n) log10 Q at 25 °C.

➤ Solved example

- Daniell cell: Zn | Zn^2+ (0.01 M) || Cu^2+ (1 M) | Cu. E°(Cu) = +0.34 V, E°(Zn) = -0.76 V.
- E°cell = 0.34 - (-0.76) = 1.10 V. Reaction Zn + Cu^2+ → Zn^2+ + Cu, n = 2.
- Q = [Zn^2+]/[Cu^2+] = 0.01. log Q = -2.
- E = 1.10 - (0.0591/2)(-2) = 1.10 + 0.0591 = 1.159 V.

➤ Batteries

Battery	Type	Note
Dry cell (Leclanché)	Primary	Zn anode, MnO2 cathode, 1.5 V
Lead–acid	Secondary	Pb / PbO2 in H2SO4, about 2 V per cell
Ni–Cd	Secondary	Rechargeable, 1.2 V
Lithium-ion	Secondary	Mobiles, EVs, about 3.7 V
Fuel cell (H2–O2)	Continuous fuel	Product is water, high efficiency

- **Conductometric** and **potentiometric** titrations use conductance / EMF change to find end points.
- pH = -log[H+]. Measured by a glass electrode.

6. Polymers

- **Polymer** = large molecule made of many repeating units (**monomers**). **Degree of polymerisation** = number of repeating units.
- **Addition polymerisation**: monomers with double bonds add without loss (polythene, PVC).
- **Condensation polymerisation**: a small molecule like H2O is lost (nylon 6,6, Bakelite, polyester).

Property	Thermoplastic	Thermosetting
On heating	Softens, can be reshaped	Does not soften, sets hard
Structure	Linear chains	Cross-linked 3D network
Recycling	Possible	Not possible
Example	Polythene, PVC, nylon	Bakelite, epoxy, urea-formaldehyde

➤ Important polymers

Polymer	Monomer(s)	Use
Polythene	Ethylene	Bags, pipes
PVC	Vinyl chloride	Pipes, cable insulation
Teflon	Tetrafluoroethylene	Non-stick pans
Nylon 6,6	Hexamethylenediamine + adipic acid	Fibres, ropes
Bakelite	Phenol + formaldehyde	Switches, handles
Natural rubber	Isoprene	Tyres (after vulcanisation)

- **Vulcanisation**: heating rubber with sulphur to make cross-links; rubber becomes stronger and less sticky.
- **Conducting polymers**: polyacetylene, polyaniline. **Biodegradable**: PHBV, PLA.

7. Most Asked Questions (practice)

1. What is hardness of water? Calculate hardness from a given salt table.
2. Explain the EDTA method for hardness with the reactions.
3. Explain the zeolite and ion exchange processes of softening.
4. What are boiler troubles? Explain caustic embrittlement.
5. Calculate HCV and LCV of a coal sample using Dulong's formula.
6. What is knocking? Define octane and cetane numbers.
7. Explain the electrochemical theory of corrosion. How is it prevented?
8. Derive the Nernst equation and find the EMF of a given cell.
9. Differentiate thermoplastics and thermosetting plastics with examples.
10. Write the preparation and uses of PVC, nylon 6,6 and Bakelite.

TIP Every paper has a hardness numerical and a calorific value numerical. Also learn the reactions of corrosion and cell EMF calculation step by step.