



Carbon, the Shape-Shifter

Why one tiny element builds diamonds, pencils, fuels, soaps and you

INSTITUTE Prodigy Educlasses	CLASS X (Class 10)	BOARD CBSE / ICSE / WB Board
TOPIC Carbon and its Compounds	CHAPTER / UNIT Carbon and its Compounds	FACULTY Surajit Sir (Chemistry)

Here is a riddle for you. What do a diamond ring and your pencil have in common?

Answer: **they are made of exactly the same element, carbon.** One is the hardest natural substance known and costs a fortune. The other is soft enough to write with and costs a couple of rupees. Same atoms, wildly different personalities. Carbon also makes up about 18% of your own body weight, and chemists have identified over ten million carbon compounds. No other element comes close. Today we find out why carbon is the most creative element in the periodic table.

The Mystery Box: 4 questions to keep in your head

- How can diamond, graphite and soot be the same element and yet so different?
- Why does carbon form millions of compounds while most other elements form only a handful?
- Why does an LPG flame burn blue, while a candle flame is yellow and leaves black soot?
- How does soap remove grease that plain water cannot budge?

1 Why carbon shares instead of giving or taking

Carbon has atomic number 6, so its electrons are arranged 2, 4. It has **four valence electrons**: exactly halfway to a full shell. To become stable it would have to lose 4 electrons (too much energy) or gain 4 electrons (the nucleus with only 6 protons cannot hold 10 electrons). So carbon takes the diplomatic route: it **shares** electrons. A pair of electrons shared between two atoms is a **covalent bond**.

Because covalent compounds are made of neutral molecules (not ions), they behave differently from salts:

- **Low melting and boiling points.** The forces *between* molecules are weak, so little energy is needed to separate them.
- **Poor conductors of electricity.** There are no free ions or free electrons to carry current.
- Usually **insoluble in water** but soluble in organic solvents (like petrol or ether).

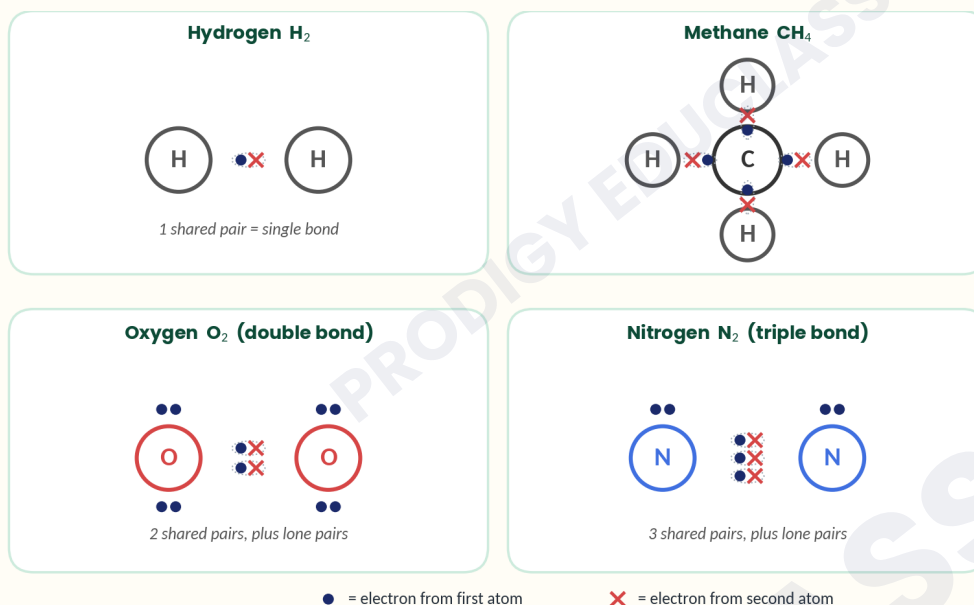


Fig 1. Electron dot structures. Each shared pair is one covalent bond, so O_2 has a double bond and N_2 a triple bond.

2 The secret of carbon's endless variety

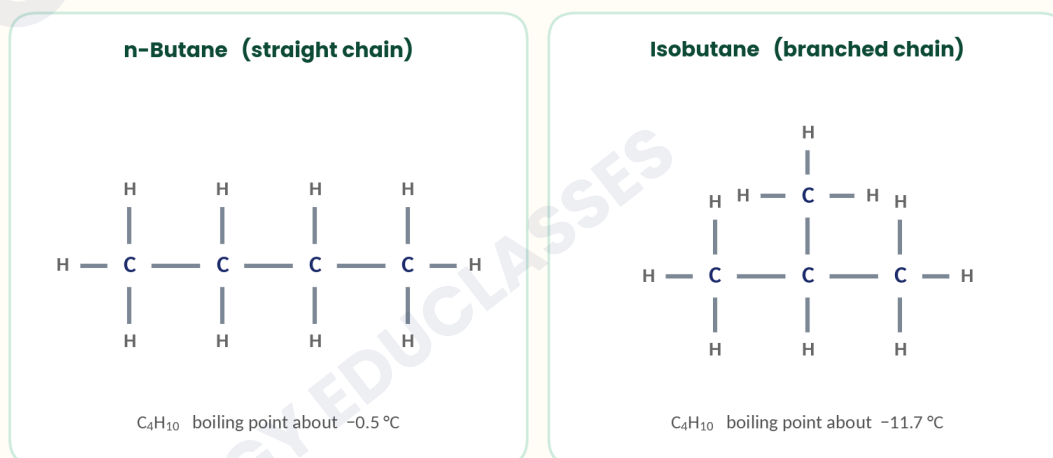
Two special abilities explain the ten million compounds:

- **Catenation:** carbon atoms link with each other to form long chains, branched chains and rings. Silicon can do it too, but its bonds break easily. The C-C bond is remarkably strong because carbon atoms are small.
- **Tetravalency:** each carbon forms 4 bonds, so it can bond with H, O, N, S, halogens and other carbon atoms all at once. The bonds can be single, double or triple.

Compounds with only single bonds are **saturated** (like ethane). Those with double or triple bonds are **unsaturated** (like ethene and ethyne). And here is the fun part: the same molecular formula can be arranged in different shapes. These are called **isomers**.

Did you know?

Pentane, C_5H_{12} , has 3 isomers. Hexane has 5. Decane, $C_{10}H_{22}$, has 75. By the time you reach C_{30} there are over 4 billion possibilities. That is how a few atoms create such a huge universe of compounds.



Same formula, different shape = ISOMERS

Fig 2. Butane, C_4H_{10} , has two isomers. Different arrangements give different properties (note the boiling points).

3 Allotropes: same atoms, different personalities

When the same element exists in different physical forms because its atoms are arranged differently, the forms are called **allotropes**. Carbon has several. Chemically they are all carbon (burn any of them and you get only CO_2), but physically they could not be more different.

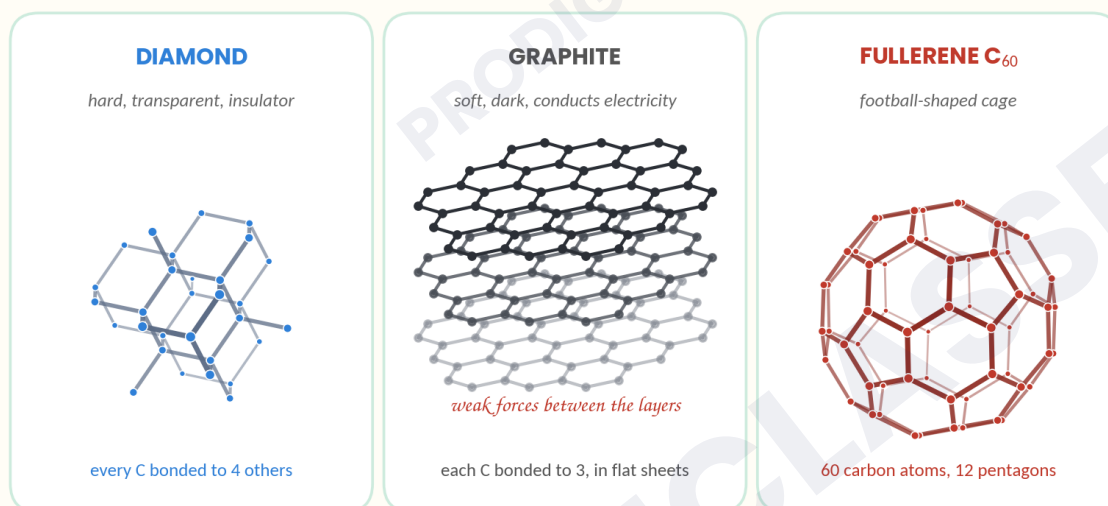


Fig 3. Diamond, graphite and fullerene C_{60} (structures are schematic).

	Diamond	Graphite	Fullerene (C_{60})
Bonding	Each C bonded to 4 others in a rigid 3-D network	Each C bonded to 3 others in flat hexagonal layers	60 atoms in a hollow football-shaped cage
Hardness	Hardest natural substance	Soft and slippery, layers slide over each other	Fairly soft solid
Conducts electricity?	No (no free electrons)	Yes (one free electron per atom)	Slightly
Uses	Jewellery, cutting and drilling tools	Pencil 'lead', lubricant, electrodes	Research, nanotechnology

Did you know?

The stories behind them. Diamond can burn! In the 1770s Lavoisier heated diamonds with a huge lens and showed they turned into carbon dioxide, proving diamond is pure carbon. The 'lead' in your pencil contains no lead at all: it is graphite mixed with clay. C_{60} was named *buckminsterfullerene* after the architect Buckminster Fuller, whose dome buildings look the same. Its discoverers won the 1996 Nobel Prize in Chemistry. And a single layer of graphite, called **graphene**, was first peeled off using ordinary sticky tape in 2004, which led to another Nobel Prize.

4 Homologous series and naming

Carbon compounds are so many that scientists sorted them into families. Members of a family form a **homologous series**: they share the same functional group, have similar chemical properties, and each member differs from the next by exactly one $-\text{CH}_2-$ unit (14 u). Here is the alkane family, general formula $\text{C}_n\text{H}_{2n+2}$:

Name	Formula	Condensed structure	Boiling point	State at room temp
Methane	CH ₄	CH ₄	-162 °C	Gas
Ethane	C ₂ H ₆	CH ₃ -CH ₃	-89 °C	Gas
Propane	C ₃ H ₈	CH ₃ -CH ₂ -CH ₃	-42 °C	Gas
Butane	C ₄ H ₁₀	CH ₃ -CH ₂ -CH ₂ -CH ₃	-0.5 °C	Gas
Pentane	C ₅ H ₁₂	CH ₃ -(CH ₂) ₃ -CH ₃	36 °C	Liquid
Hexane	C ₆ H ₁₄	CH ₃ -(CH ₂) ₄ -CH ₃	69 °C	Liquid

Notice the trend: as the chain grows, the boiling point rises, because bigger molecules attract each other more strongly. Similarly, **alkenes** (C=C, general formula C_nH_{2n}; ethene, propene, butene) and **alkynes** (C≡C, general formula C_nH_{2n-2}; ethyne, propyne, butyne) form their own series.

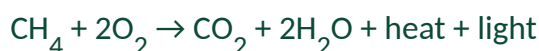
Functional group	Structure	Suffix / prefix	Example
Halo (chloro, bromo)	-Cl, -Br	prefix: chloro-, bromo-	CH ₃ CH ₂ Cl chloroethane
Alcohol	-OH	suffix: -ol	CH ₃ CH ₂ OH ethanol
Aldehyde	-CHO	suffix: -al	CH ₃ CHO ethanal
Ketone	C=O (inside chain)	suffix: -one	CH ₃ COCH ₃ propanone
Carboxylic acid	-COOH	suffix: -oic acid	CH ₃ COOH ethanoic acid

🔑 Teacher's Trick

Naming in 4 steps. (1) Count the carbon chain: 1 = meth, 2 = eth, 3 = prop, 4 = but, 5 = pent, 6 = hex. (2) Add **-ane** if all bonds are single, **-ene** for a double bond, **-yne** for a triple bond. (3) Add the functional group suffix. (4) If the suffix starts with a vowel (a, e, i, o, u), drop the final **e**. So propane + one = **propanone**, and butane + oic acid = **butanoic acid**.

5 How carbon compounds react

1. Combustion. Carbon compounds burn in oxygen to give carbon dioxide, water, heat and light:

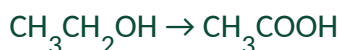


Saturated hydrocarbons burn with a clean **blue flame**. Unsaturated ones burn with a **yellow, sooty flame** because their carbon percentage is higher and it is not completely burnt; the unburnt carbon is the black soot.

🔥 Teacher's Trick

Why is the bottom of your cooking vessel black? The air holes of your gas stove are partly blocked. Less oxygen means incomplete combustion, so you get a yellow flame and soot instead of a clean blue one. Cleaning the burner fixes it. That is chemistry saving your gas cylinder!

2. Oxidation. Alcohols are converted into carboxylic acids using oxidising agents (alkaline KMnO₄ or acidified K₂Cr₂O₇):



3. Addition reaction. Unsaturated compounds add hydrogen in the presence of a nickel or palladium catalyst and become saturated:



This is how liquid vegetable oils (unsaturated) are turned into solid vanaspati ghee (saturated). Unsaturated fats are generally considered better for your heart than saturated ones, so choose your cooking oil wisely.

4. Substitution reaction. Saturated compounds (which do not add anything) let one atom be replaced by another, usually in sunlight:



! Did you know?

LPG has no smell of its own. It is mainly propane and butane, which are odourless. Suppliers add a small amount of ethanethiol, a chemical that smells like rotten eggs, so that you can detect a leak instantly. Your nose becomes the gas detector.

6 Two star compounds: ethanol and ethanoic acid

Ethanol ($\text{C}_2\text{H}_5\text{OH}$) is a colourless liquid, soluble in water in all proportions, and used as a solvent in medicines, cough syrups and tinctures. It is also mixed with petrol as a cleaner fuel. Drinking alcohol is harmful, and industrial 'denatured' alcohol has poisonous additives (like methanol) to make it undrinkable. Methanol can cause blindness and death, so never taste an unknown alcohol.

Ethanoic acid (CH_3COOH), commonly acetic acid, gives vinegar its sour taste (5 to 8% solution). Pure ethanoic acid freezes at 290 K (16.6 °C), so on a cold winter morning it turns into ice-like crystals and is called **glacial** acetic acid. It is a *weak* acid, much weaker than hydrochloric acid, but it still turns blue litmus red.

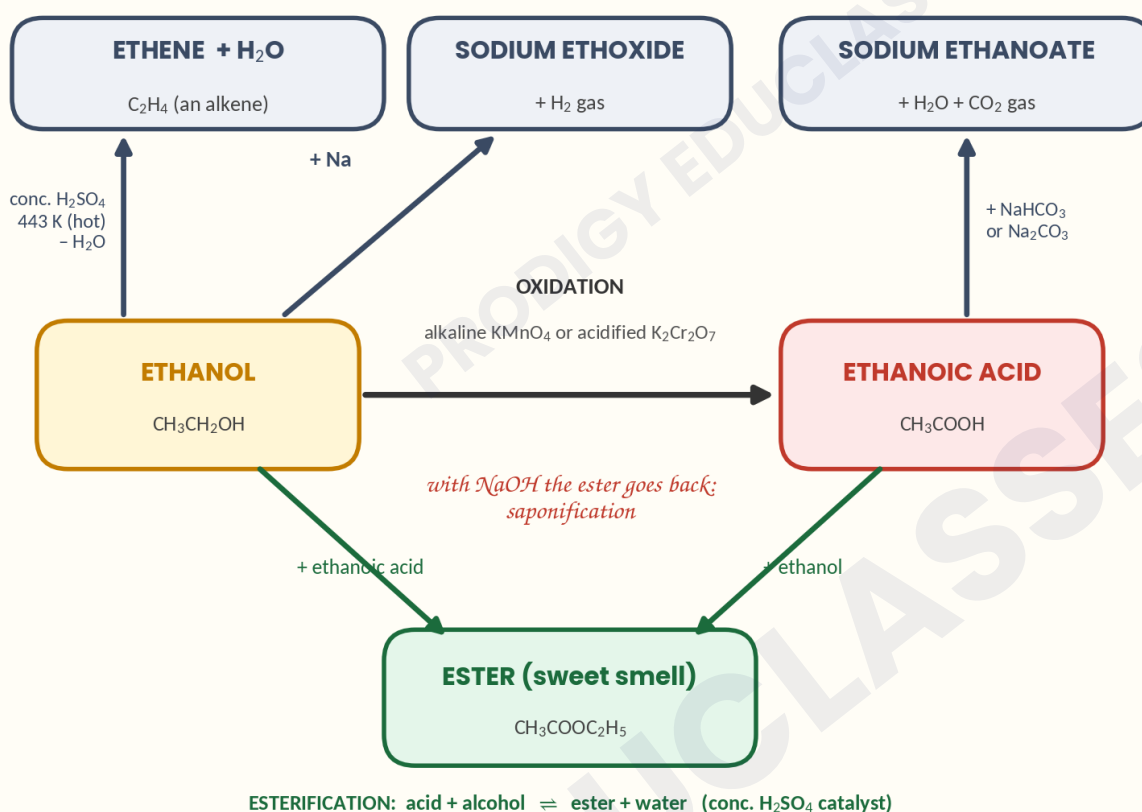


Fig 4. The reaction map of ethanol and ethanoic acid. Learn the arrows and you know 90% of this chapter.

Reaction	Equation	What you observe
Ethanol + sodium	$2\text{Na} + 2\text{CH}_3\text{CH}_2\text{OH} \rightarrow 2\text{CH}_3\text{CH}_2\text{ONa} + \text{H}_2$	Bubbles of hydrogen; a lit splinter gives a 'pop'
Dehydration of ethanol	$\text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_2=\text{CH}_2 + \text{H}_2\text{O}$ ($\text{conc. H}_2\text{SO}_4$, 443 K)	Ethene gas forms; $\text{conc. H}_2\text{SO}_4$ removes water
Ethanoic acid + NaOH	$\text{CH}_3\text{COOH} + \text{NaOH} \rightarrow \text{CH}_3\text{COONa} + \text{H}_2\text{O}$	Neutralisation, gives a salt and water
Ethanoic acid + sodium carbonate	$2\text{CH}_3\text{COOH} + \text{Na}_2\text{CO}_3 \rightarrow 2\text{CH}_3\text{COONa} + \text{H}_2\text{O} + \text{CO}_2$	Brisk fizzing; gas turns lime water milky
Esterification	$\text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \rightarrow \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O}$ ($\text{conc. H}_2\text{SO}_4$)	Sweet, fruity smell of an ester
Saponification	$\text{CH}_3\text{COOC}_2\text{H}_5 + \text{NaOH} \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{CH}_3\text{COONa}$	Ester is broken back into alcohol and sodium salt

🎯 Exam Alert

Test to tell them apart: add a pinch of sodium hydrogencarbonate. Ethanoic acid fizzes and releases CO_2 . Ethanol shows no reaction. This 'distinguishing test' comes up in board exams almost every year.

🍊 Did you know?

Esters make your world smell nice. Many fruit and flower smells are esters, such as the banana aroma of isoamyl acetate. Chemists use esters in perfumes and food flavours. The smell of an ester is your nose telling you that an alcohol and an acid met.

7 Soaps and detergents: how they clean

Grease and oil do not dissolve in water, which is why washing an oily plate with plain water fails. Soap solves the problem with a clever two-faced molecule. A **soap** is the sodium or potassium salt of a long-chain carboxylic acid. Its molecule has a **water-loving (hydrophilic) ionic head** and an **oil-loving (hydrophobic) hydrocarbon tail**.

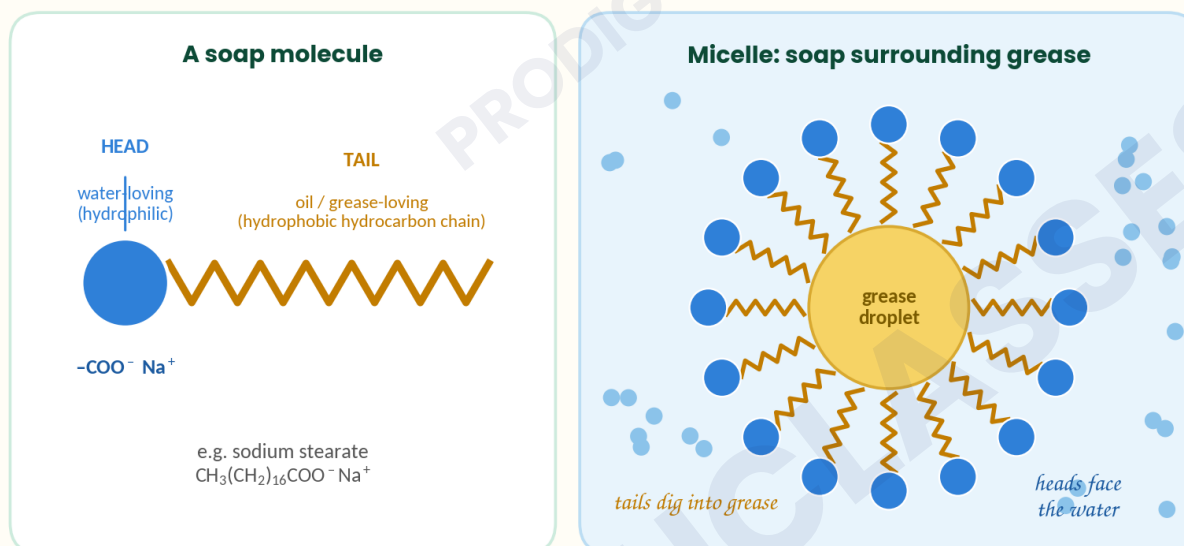


Fig 5. The tails bury themselves in the grease while the heads point to the water. This ball is a micelle.

Soap molecules gather around a grease droplet with their tails inside and their heads outside, forming a **micelle**. Because the outside of the micelle loves water, the whole ball is pulled away from the cloth and rinsed off. Soap is made by heating fat or oil with sodium hydroxide, a reaction called **saponification** (from the Latin *sapo*, meaning soap), which also gives glycerol.

⚠ Careful! Common Mistake

Hard water problem. Hard water contains calcium and magnesium salts. Soap reacts with them and forms a sticky, insoluble **scum** instead of a lather, wasting soap. **Detergents** (sodium salts of sulphonic acids or ammonium salts with long chains) do not form scum, so they work in both soft and hard water. Older detergents with branched chains did not biodegrade and produced foam in rivers, which is why modern ones use straight chains.

8 One-page cheat sheet

- ✓ Carbon shares electrons (covalent bonds) and is tetravalent. Covalent compounds have low melting points and do not conduct electricity.
- ✓ **Catenation + tetravalency** give chains, branches and rings, and therefore isomers.
- ✓ Allotropes: diamond (4 bonds, hardest), graphite (3 bonds, layers, conducts), fullerene C_{60} (cage).
- ✓ Homologous series differ by $-CH_2-$. Alkanes C_nH_{2n+2} , alkenes C_nH_{2n} , alkynes C_nH_{2n-2} .
- ✓ Reactions: combustion, oxidation, addition (unsaturated, Ni catalyst), substitution (saturated, sunlight).
- ✓ Ethanol + Na gives H_2 . Ethanoic acid + carbonate gives CO_2 . Acid + alcohol gives an ester (esterification).
- ✓ Soap = sodium/potassium salt of a fatty acid. Micelles trap grease. Hard water makes scum with soap, but not with detergents.

9 Test yourself

- Q1. How many covalent bonds are there in ethane (C_2H_6) and in propane (C_3H_8)?
- Q2. Name: (a) $CH_3CH_2CH_2OH$ (b) CH_3CH_2CHO (c) CH_3CH_2COOH (d) CH_3COCH_3 .
- Q3. Write the balanced equation for the complete combustion of ethane.
- Q4. Write the equation for ethanol reacting with sodium. What will you observe?
- Q5. How will you chemically distinguish ethanol from ethanoic acid?
- Q6. Why does an unsaturated hydrocarbon burn with a sooty yellow flame?
- Q7. How many isomers does pentane have? Draw or name any two.
- Q8. Why does soap not lather well in hard water, and how do detergents solve this?

Peek only after trying!

Answers. 1) Ethane: 7 (6 C-H, 1 C-C). Propane: 10 (8 C-H, 2 C-C). 2) (a) propan-1-ol (b) propanal (c) propanoic acid (d) propanone. 3) $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O + \text{heat}$. 4) $2Na + 2C_2H_5OH \rightarrow 2C_2H_5ONa + H_2$; bubbles of hydrogen gas. 5) Add $NaHCO_3$: only ethanoic acid gives brisk effervescence of CO_2 . 6) Its carbon content is high and is not burnt completely, so unburnt carbon appears as soot. 7) Three: n-pentane, isopentane (2-methylbutane) and neopentane (2,2-dimethylpropane). 8) Soap forms insoluble scum with calcium and magnesium salts. Detergents do not form scum.



A last word from your teacher

A humble atom with four hands has given us diamonds, fuels, medicines, plastics and life itself. Whenever the chapter feels long, remember that you are learning the language of living things. Practise the reaction map, draw the structures with your own hands, and you will enjoy this chapter. **Keep exploring!** - Surajit Sir