Atmospheric pollutants from fuels

4.9.3.1 · Chemistry of the atmosphere · revision notes

Which pollutants are released when fuels burn and how each one forms: carbon dioxide, water vapour, carbon monoxide, soot and other particulates, sulfur dioxide and oxides of nitrogen. Expect 'describe how X is produced' questions, combustion equations, and questions where you predict the products from information about a fuel and how it is burned.

Key facts

- Complete combustion: C → CO_2, H → H_2O
- Sulfur in the fuel + oxygen → sulfur dioxide: S + O_2 → SO_2
- Particulates = solid particles (e.g. soot) and unburned hydrocarbons
- Grade 7+ only $2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$
- Incomplete combustion (limited oxygen): CO and C (soot), as well as H_2O
- Oxides of nitrogen: nitrogen and oxygen from the air react at high temperatures (e.g. in engines)
- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Notes

What is in fuels

- Burning fuels is a **major source of the pollutants** in the atmosphere.
- Most fuels, coal included, are made mainly of **carbon** and/or **hydrogen**, and some also contain a little **sulfur**.
- Combustion is an oxidation reaction: the elements in the fuel react with oxygen from the air.

Complete and incomplete combustion

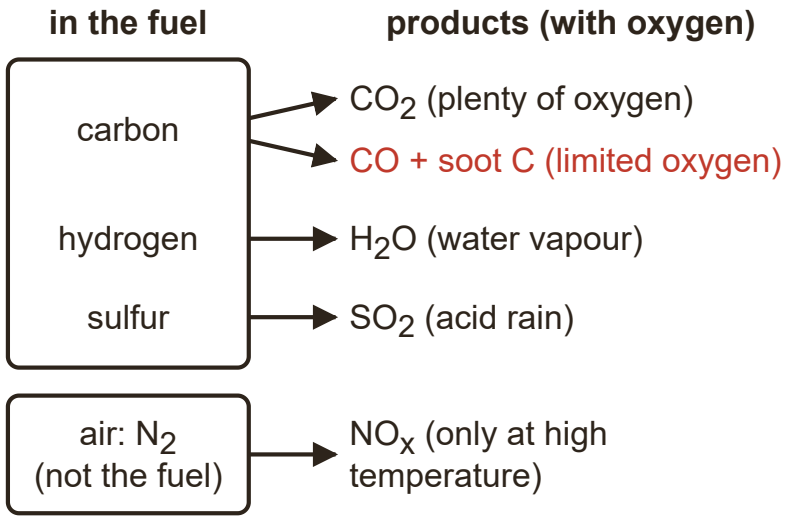
- **Complete combustion** (plenty of oxygen): carbon forms **carbon dioxide** and hydrogen forms **water vapour**, e.g. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$.
- **Incomplete combustion** (limited supply of oxygen): some of the carbon forms **carbon monoxide**, CO, and some forms solid **carbon particles (soot)**. Water is still formed.
- Examples: $2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$ and $CH_4 + O_2 \rightarrow C + 2H_2O$. Grade 7+ only
- Solid particles (such as soot) and **unburned hydrocarbons** can also be released. These form **particulates** in the atmosphere.

Sulfur dioxide and oxides of nitrogen

- **Sulfur dioxide**: sulfur in the fuel reacts with oxygen as the fuel burns: $S + O_2 \rightarrow SO_2$.
- **Oxides of nitrogen** (NO_x): at the **high temperatures** in engines, **nitrogen and oxygen from the air** react together. The nitrogen comes from the air, not from petrol or diesel.
- Examples: $N_2 + O_2 \rightarrow 2NO$, and then $2NO + O_2 \rightarrow 2NO_2$. Grade 7+ only

Predicting the products

- Go element by element through the fuel: C → CO_2 (or CO and soot if oxygen is limited); H → H_2O; S → SO_2.
- Then check the conditions: limited air means incomplete combustion; a high temperature means oxides of nitrogen.



Work element by element, then check the oxygen supply and the temperature.

- A fuel with no carbon, such as hydrogen, forms only water, although oxides of nitrogen can still form from the air at high temperatures.

How to answer each type of question

Describe how a pollutant is produced 2 to 4 marks **Grade 5**

1. Say where the element comes from: the fuel (carbon, sulfur) or the air (nitrogen).
2. Give the condition: limited oxygen for carbon monoxide and soot, high temperature for oxides of nitrogen.
3. Name the product.

Example. Describe how sulfur dioxide and oxides of nitrogen are produced when diesel fuel is burned in a lorry engine.

Model answer. The diesel contains sulfur (1), which reacts with oxygen to form sulfur dioxide (1). Nitrogen and oxygen from the air (1) react at the high temperature inside the engine to form oxides of nitrogen (1).

Explain why incomplete combustion happens

2 marks | Grade 5

1. Say the supply of oxygen (air) is limited.
2. Say that some carbon forms carbon monoxide (or soot) instead of carbon dioxide.

Example. A gas heater is used in a small room with poor ventilation. The heater produces carbon monoxide.
Explain why.

Model answer. There is a limited supply of oxygen in the room (1), so incomplete combustion occurs and some of the carbon in the fuel forms carbon monoxide instead of carbon dioxide (1).

Write a balanced combustion equation

2 marks | Grade 7

1. Write the correct formulae: the fuel and O_2 on the left; CO_2 or CO (or C) and H_2O on the right.
2. Balance C first, then H, then O last.
3. If you need half an O_2, double every number.

Example. Propane, C_3H_8, burns in a limited supply of oxygen to form carbon monoxide and water only.
Write a balanced equation for this reaction.

Model answer.

Correct formulae: $C_3H_8 + O_2 \rightarrow CO + H_2O$ (1)

Balanced: $2C_3H_8 + 7O_2 \rightarrow 6CO + 8H_2O$ (1)

($C_3H_8 + 3½O_2 \rightarrow 3CO + 4H_2O$ is also accepted.)

Predict the products of burning a fuel

3 to 6 marks | Grade 5

1. List the elements in the fuel and give the product of each.
2. Use the oxygen supply to decide between complete and incomplete combustion.
3. Use the temperature to decide whether oxides of nitrogen form.
4. Explain each product, not just name it.

Example. A fuel oil contains compounds of carbon and hydrogen, and a small amount of sulfur. It is burned in a power station furnace at a very high temperature with a plentiful supply of air.
Predict the gases released and explain why each one forms.

Model answer.

Carbon dioxide, because the carbon reacts completely with the plentiful oxygen (1)

Water vapour, because the hydrogen reacts with oxygen (1)

Sulfur dioxide, because the sulfur in the fuel reacts with oxygen (1)

Oxides of nitrogen, because nitrogen and oxygen from the air react at the very high temperature (1)

Don’t lose marks

- Saying oxides of nitrogen come from nitrogen in petrol or diesel. They form from nitrogen and oxygen in the air at high temperatures.
- Saying sulfur dioxide comes from sulfur in the air. The sulfur is in the fuel.
- Writing 'carbon' when you mean carbon monoxide, or CO_2 when you mean CO.
- Forgetting that incomplete combustion still produces water.
- Saying incomplete combustion is caused by 'not enough fuel'. It is caused by not enough oxygen.

More tips

Memory tricks

- Element → product: C → CO_2, H → H_2O, S → SO_2. Oxides of nitrogen come from the AIR, not the fuel.
- Less oxygen, less oxidised carbon: CO_2 (plenty of oxygen) → CO (less) → C, soot (even less).
- Hot engine → NO_x. Sulfur in the fuel → SO_2.
- Balancing combustion: C, then H, then O, and double everything if you get a half.

Exam technique

- For 'describe how X is produced', give the source (fuel or air) AND the condition (limited oxygen or high temperature).
- In prediction questions, go through the fuel element by element, then check the conditions.
- Write 'a limited supply of oxygen', not 'no oxygen': with no oxygen, nothing burns.
- Use correct formulae in equations: CO, CO_2, SO_2, NO_2, H_2O.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Name the products of complete combustion**
A fuel containing carbon and hydrogen forms carbon dioxide and water when it burns in plenty of oxygen.

Grade 4 — **Name the pollutants released by burning fuels**
Carbon dioxide, water vapour, carbon monoxide, sulfur dioxide, oxides of nitrogen and particulates.

Grade 5 — **Describe how carbon monoxide and soot form**
Incomplete combustion in a limited supply of oxygen produces carbon monoxide and carbon particles (soot).

Grade 5 — **Describe how sulfur dioxide forms**
Sulfur in the fuel reacts with oxygen when the fuel burns.

Grade 5 — **Describe how oxides of nitrogen form**
At the high temperatures in engines, nitrogen and oxygen from the air react together.

Grade 5 — **Predict combustion products from fuel information**
Use the elements in the fuel and the conditions (oxygen supply, temperature) to predict and explain every product.

Grade 7 — **Write balanced equations for combustion**
For example, $2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$ for incomplete combustion of methane.

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