Combustion stoichiometry

FizziQ activity · Middle and high school · 60 min

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Connected O2 and CO2 sensors stream data to FizziQ on a smartphone or tablet while a candle burns in a sealed chamber; students derive the stoichiometric ratio.

Learning objectives

- Measure gas concentrations before and after combustion
- Calculate the O_2 consumed and CO_2 produced
- Determine the experimental stoichiometric ratio
- Compare with the theoretical ratio from the balanced equation
- Understand atom conservation in chemical reactions

Instruments and sensors

O_2 concentration meter · CO_2 concentration meter · O_2 sensor · SCD40 sensor

Materials

- Smartphone or tablet with FizziQ Connect
- SCD40 and O_2 sensors
- M5 Stack module and multiport hub
- Sealed chamber
- Tea light candles
- Note: the protocol remains adaptable to any comparable gas concentration data acquisition tool.

Protocol

1. Set up the experiment: O_2 and SCD40 sensors mounted in the sealed chamber via the multiport hub, connected to the M5 Stack module.
2. Before any combustion, note the initial reference concentrations in ambient air: $C\_ini(O_2)$ in % and $C\_ini(CO_2)$ in ppm.
3. Fix a tea light candle to the bottom of the chamber. Set the measurement interval to 250 ms on the M5 Stack.
4. Start recording (REC), light the candle, and quickly close the chamber lid.
5. Let the combustion proceed until the candle goes out. Wait 1-2 more minutes for concentrations to stabilize.
6. Stop the recording (STOP). Note the final concentrations: $C\_fin(O_2)$ in % and $C\_fin(CO_2)$ in ppm.
7. Calculate the variations: $\Delta C(O_2) = C\_fin(O_2) - C\_ini(O_2)$ (negative, O_2 decreases) and $\Delta C(CO_2) = C\_fin(CO_2) - C\_ini(CO_2)$ (positive, CO_2 increases).
8. Calculate the experimental ratio: $n\_exp = -\Delta C(O_2) \times 10^4 / \Delta C(CO_2)$. The factor 10^4 converts % to ppm for consistent units.
9. Open the chamber, ventilate, replace with a fresh candle, and repeat. Perform 6 to 10 trials total for statistical reliability.
10. Calculate the mean n_exp after removing any outliers. Compare with the theoretical value $n\_att = 38/25 = 1.52$.

Expected results

Typical observed values: O_2 initial ≈ 20.9%, O_2 final ≈ 15-16%, giving $\Delta C(O_2) \approx -5\%$. CO_2 initial ≈ 400-800 ppm, CO_2 final ≈ 25,000 ppm, giving $\Delta C(CO_2) \approx$ 24,000-25,000 ppm. The experimental ratio n_exp is typically 1.6-2.2, somewhat higher than the theoretical 1.52 due to incomplete combustion.

Questions

- Why is the experimental ratio often higher than the theoretical value of 1.52?
- What products are formed during incomplete combustion?
- Why does the candle go out before all the O_2 is consumed?
- How does atom conservation determine the stoichiometric coefficients?
- What happens to the water produced by the combustion?
- Why do you need multiple trials to get a reliable result?

Going further

- Compare candles of different sizes and verify that the stoichiometric ratio is independent of candle size
- Use a longer or shorter burning time and check if the ratio changes
- Test with different fuels (ethanol lamp, butane lighter) and compare the ratios
- Investigate the effect of initial O_2 concentration by flushing the chamber with O_2-enriched air
- Calculate the mass of paraffin consumed from the O_2 data and compare with the actual mass loss