5 Ideal gases

Teaching plan

Sub-chapter	Approximate number of learning hours	Learning content	Resources
5.1 Real gases and ideal gases 5.2 Macroscopic properties of ideal gases	1–2	Recognise the assumptions in the ideal gas model and explain how real gases deviate from the ideal gas model. Explain the limitations of the ideal gas model. Know and apply the gas laws relating pressure, volume and temperature for ideal gases.	**Coursebook** Sections 5.1 and 5.2 Test your understanding Questions 1–6 Exam-style Question 7 **Workbook** Exercises 5.1–5.2 **Teacher's resource** PowerPoint 5, slides 2–6 Worksheet 5.1 Questions 1 and 3 End of Chapter 5 test Questions 1–3, 6–9
5.3 Calculations involving ideal gases	2–3	Apply the ideal gas equation to solve problems. Determine the molar volume of an ideal gas at a certain temperature and pressure.	**Coursebook** Section 5.3 Test your understanding Questions 10–12, 15–16, 19–21 **Workbook** Exercise 5.3 **Teacher's resource** PowerPoint 5, slides 6–7 Worksheet 5.1 Question 2 Worksheet 5.2 End of Chapter 5 test Questions 4–5, 10–11

BACKGROUND KNOWLEDGE

- Explain the physical properties of matter using kinetic molecular theory (Chapter 1).
- Know the SI units for temperature, pressure and volume.
- Know what a mole is (Chapter 4).
- Apply Avogadro's law to solve problems involving mole ratio and the volume of gases (Chapter 4).
- Sketch graphs showing qualitative trends.

Syllabus overview

- From Chapter 4, students should understand how the amount of a substance can be calculated when it is a pure solid or in an aqueous solution. This chapter focuses on the moles of gases. The large distances between gas particles at room temperature and pressure mean that most gas particles behave like point masses. Students are introduced to the ideal gas model and its assumptions. This helps to make sense of Avogadro's law mentioned in Chapter 4, in which the volume occupied by a gas at a certain temperature and pressure mostly depends on the number of particles present and not on the nature of the gas. The relationships between the ideal gas's volume, pressure and temperature are summarised in the gas laws. There are many opportunities to practice sketching graphs to show proportional/inverse proportional relationships between variables.
- At a specific temperature and pressure, the moles of gas can be calculated using volume/molar volume. The molar volume of an ideal gas at STP (273.15 K and 100 kPa) is given in the IB data booklet. This value should not be used for working out gas moles at other temperatures and pressures.
- The ideal gas equation relates the physical properties of a gas to its number of moles. Students need to be aware that the units for volume, pressure and temperature used in this equation must be SI only, unless R is given in a unit other than J K^{-1} mol^{-1}. To solve problems related to the combined gas law and ideal gas equation, students should convert units of pressure, volume and temperature and rearrange algebraic equations to work out an unknown.

5.1 Real gases and ideal gases and 5.2 Macroscopic properties of ideal gases

LEARNING PLAN

Learning objectives	Success criteria
Understand the assumptions of the ideal gas model	Students should be able to explain the key assumptions of the ideal gas model.
Understand under what conditions a real gas is most different to an ideal gas	Students should be able to explain the limitations of the ideal gas model.
Describe the relationships between pressure, volume and temperature for an ideal gas	Students can describe qualitatively the relationships between pressure, volume and temperature for an ideal gas.
Carry out calculations using $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$	Students can carry out calculations using combined gas law.

Common misconceptions

Misconceptions	How to identify	How to overcome
Learners are unsure how to correctly apply Avogadro's law	Ask students to work out the number of moles of a gas using its volume; see which equations the students use (incorrect: concentration × volume; correct: volume / molar volume).	Most gases at typical temperatures and pressures behave approximately like an ideal gas, so their volumes depend only on the number of gas particles rather than the nature of the gas. Students should not work out the number of moles of a solute in a solution using volume/molar volume.
Students are unsure of the difference between STP and RTP	Ask students to work out the number of moles of a gas at STP and see if they divide the volume by 24 or 22.7.	In some pre-IB syllabi, the molar volume of a gas is given as 24 dm^3/mol. This is the approximate volume per mole of gas at RTP (room temperature and pressure) and this is usually given as 298.15 K and 1 atm pressure (1.01×10^5 Pa). STP refers to standard temperature and pressure and is defined as 273.15 K and 100 kPa. The molar volume at STP is lower than 24 at 22.7 dm^3/mol due to the lower temperature and pressure than RTP. Both molar volumes can be confirmed using the ideal gas equations by inputing the respective temperature and pressure.

Starter ideas

1 Recap knowledge from Chapter 1 (10 minutes)

Resources: Pen and paper or space!

Description and purpose: Either by asking students to draw the particle models of solids/liquids/gases and describe the properties of gas particles, or, if possible and safe to do so outside a lab, by asking students to model the behaviour of gas particles. They should be running around at a good speed randomly with no interactions in between, unless they 'bump' into each other.

What to do next: Summarise the macroscopic properties of particles in an ideal gas. If there is time, ask students to move in a smaller space or with slower speed, and comment on how their properties would change.

Main teaching ideas

1 The model of ideal gas (15 minutes)

Resources: An IB textbook or internet for research.

Description and purpose: Introduce what ideal gases are and the key assumptions in the ideal gas model. Students then carry out their own research on the conditions when real gases deviate from the ideal gas model, with explanations.

Differentiation ideas

Support: Direct students to specific pages in the coursebook (Chapter 5.1) to find out when real gases behave non-ideally. Students should be aware of the meaning and the different types of intermolecular forces.

Stretch and challenge: Students can research into the Van der Waals equation on how to model the behaviour of real gases and the opposite effects of the molecular volume and intermolecular forces on the non-ideal behaviour of real gases. Chemguide has a resource page on this. You can use the internet to search for this content.

2 The properties of ideal gases (20 minutes)

Resources: Simulations on ideal gas properties, pen and graph paper.

Description and purpose: Demonstrate the properties of the ideal gases using online simulations. Students are divided into three stations to look at three pairs of variables, P and T while V is constant, P and V while T is constant and V and T while P is constant. Each group of students should collect at least five data points, plot a graph on graph paper or using computer software and use the graph to deduce the properties of the ideal gases.

Differentiation ideas

Support: Collaborative learning; students can be allocated to mixed-ability groups, so they can learn from their peers. Group work encourages more discussions and allows teachers to give verbal support accordingly.

Stretch and challenge: For the more able students, they can look into how changing the units of P, V and T can or cannot affect the relationship summarised above.

3 Combined gas law calculations (15 minutes)

Resources: Questions of different levels of difficulty

1 **Easy:** Test your understanding questions 1–4 from the Coursebook
2 **Intermediate:** Test your understanding questions 1–4 from the Coursebook; students to work on their own and self-assess
3 **Hard:** Test your understanding questions 5 and 6 from the Coursebook.

Description and purpose: Practice combined gas law calculations. Students should be able to analyse problems (clearly identify P, V and T for a gas before and after a change of properties) and rearrange equations to find solutions.

Differentiation ideas

Support: Remind students beforehand that there is no need to convert units for P and V, as long as they are the same on both sides of the equation $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$. The temperature must be converted into kelvin. Students should start with the easy level questions and the structures of calculations can be laid out for them: $P_1 =$ $V_1 =$ $T_1 =$ and $P_2 =$ $V_2 =$ $T_2 =$, etc.

Stretch and challenge: Start with the hard level questions. For something more challenging, try question 3 from the 2011 UK Chemistry Olympiad R1 and question 2 from the 2013 UK Chemistry Olympiad R1 (search the Royal Society of Chemistry website for Chemistry Olympiad past papers)

Plenary ideas

1 Filling the gaps on ideal gas law conditions (5 minutes)

Resources: In an ideal gas model, the gas particles are assumed to have ________ volume and no ________ forces. When the gas particles collide, no ________ energy is lost, so the collisions are considered to be ________. This means that equal ________ of all ideal gases contain equal ________ of particles, when measured under the same conditions of ________ and ________. Real gases deviate from the ideal gas model, in particular, at ________ temperature and ________ pressure.

Description and purpose: This activity is to consolidate the students' knowledge on the assumptions used in the ideal gas model.

Language focus: Application and correct use of terms.

2 Conversion of units (10 minutes)

Resources: Convert the following pressure units

1. 1 bar into Pa
2. 101 kPa into Pa
3. 9.75×10^4 Pa into kPa

Convert the following volumes units:

1. 365 cm^3 into m^3
2. 22.7 dm^3 into m^3
3. 5.8×10^{-5} m^3 into dm^3

Convert the following temperature units:

1. 23 °C into K
2. 385.15 K into °C

Description and purpose: Assess how confident students are at converting units of *P*, *V* and *T*, which is important for the next sub-chapter on the ideal gas equation.

3 Multiple-choice question (5 minutes)

Resources: Exam-style question 7 on the relationships between *P*, *V* and *T* of an ideal gas.

Description and purpose: Students attempt the question and self-assess their understanding of the gas laws. They need to think critically before deciding on the answer.

5.3 Calculations involving ideal gases

LEARNING PLAN

Learning objectives	Success criteria
Carry out calculations involving the ideal gas equation	Students can carry out calculations involving the ideal gas equation.
Understand what is meant by the molar volume of a gas	Students are confident with converting between volumes and amount of substance using the molar volume of a gas.

Common misconceptions

Misconceptions	How to identify	How to overcome
Students confuse the different units for pressure, volume and temperature	Ask students to work out the molar volume of gas at STP (273.15 K and 100 kPa) using the ideal gas equation and see if they can get to 2.27×10^{-2} m^3/mol.	The value and unit of the gas constant *R* given in the IB data booklet is 8.31 J K^{-1} mol^{-1}. To use this value, the units for volume, pressure and temperature must be m^3, Pa and K. It is possible to use other units for volume and pressure, but the value/unit of *R* would be different.

Starter ideas

1 Plotting graphs for gas laws (10 minutes)

Resources: Pen and paper.

Description and purpose: Students sketch graphs of P against V, P against $\frac{1}{V}$, PV against P at constant T; P against T in kelvin, P against T in °C at constant V; V against T in kelvin and V against T in °C at constant P. This activity helps to revise contents covered in the previous lesson and the relationships of P, V and T can be summarised in the ideal gas equation, which is introduced in this subchapter.

What to do next: This activity recaps students' knowledge from the previous lesson. If there are common misunderstandings, teachers should go back and re-teach part of the previous lesson.

2 Molar volume calculations (10 minutes)

Resources: Calculate the amount of gas in moles at STP in

1. 4.5 dm^3
2. 7 m^3
3. 250 cm^3.

Description and purpose: Students can work out the number of moles of gas using volume/molar volume.

What to do next: This activity recaps students' pre-IB knowledge. If some are struggling with the calculations, teachers can help with converting units of volumes and give the triangle for working out gas moles.

Main teaching ideas

1 The ideal gas equation calculations (30 minutes)

Resources: Test your understanding questions 10–12, 15 and 16 from the Coursebook.

Description and purpose: Introduce $PV = nRT$ with units; give students time to practice questions of different types.

› Differentiation ideas

Support: Teachers can show a model calculation on a board, listing out all the conditions given and convert them into the required units (P in Pa, V in m^3 and T in K).

Stretch and challenge: Students attempt the questions on their own and self-assess their answers. In addition, students can derive the expression of the gradient of a graph of P against T expressed in terms of n, R and V, and the gradients of a graph of V against T expressed in n, R and P.

2 Determining the identity of gases using their molar masses and the ideal gas equation (30 minutes)

Resources: Easy: Test your understanding questions 19–21 from the Coursebook

1. **Intermediate:** Test your understanding questions 19–21; students to attempt the questions on their own
2. **Hard:** Deriving M_r from the density of a gas, for example, the density of dry air is 1.2041 kg/m^3 at a temperature 293 K and a pressure of 101 kPa; calculate its average molar mass.

Description and purpose: The identity of an unknown gas can be found from its macroscopic properties of mass, pressure, volume and temperature. These calculations illustrate the usefulness of the ideal gas model.

Answer:
to the 'Hard question': 29.0 g/mol

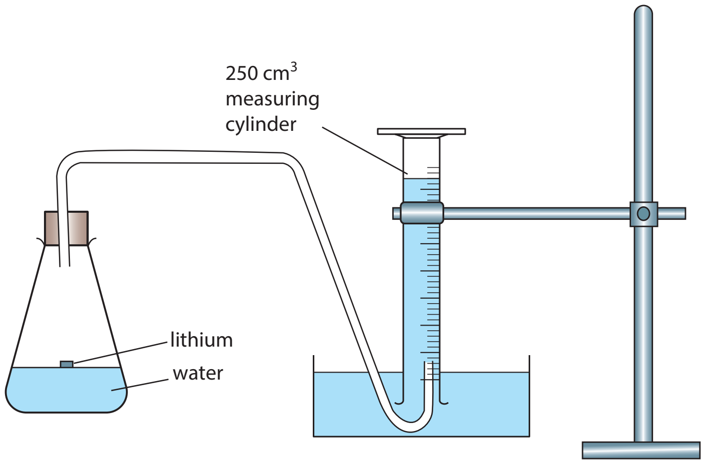
› Differentiation ideas

Support: Teachers can give support during calculations, laying out steps to work out the number of moles from the ideal gas equation and then calculating M_r from mass/number of moles.

Stretch and challenge: Students can attempt the hard level questions on their own and convert the units of density into SI units.

3 Practical on determining the A_r of Li (45 minutes)

Resources: The experiment can be done with about 0.15g of lithium in 100cm^3 of distilled water. Collect the hydrogen gas produced and measure its volume and temperature. The apparatus can be set up as shown in the diagram below. Worksheet 5.2.



Description and purpose: A practical for working out the molar mass of Li by reacting it with water and deducing the number of moles of H_2 (and hence, Li) from the pressure, temperature and volume of the gas. It is a good opportunity for students to propagate errors in their measurements and evaluate their effects on the results of A_r calculated. These skills are practised in the Analysis of results and Evaluation of experiment sections of Worksheet 5.2.

Differentiation ideas

Support: Give a step-by-step method and ask students to consider the observations made in the experiments. For example, some gas was lost before its collection. This leads to a smaller *n* value being calculated for the gas and Li, so a larger A_r than expected is recorded. Another example would be that Li is usually black when it is taken out of its storage oil, meaning the surface layer is oxidised. This decreases the number of moles of gas produced, and so, again, a larger A_r than expected will be obtained.

Stretch and challenge: Students can study how to propagate errors in calculations themselves and work out the absolute uncertainty in the final answer of A_r from their experiments.

Plenary ideas

1 Create exam-style questions on working out molar mass of a gas using the ideal gas equation, with answers, and swap with other students (15 minutes)

Resources: Pen, paper, a periodic table (if students want to model their question on a particular gas).

Description and purpose: This exercise gives students an opportunity to apply their knowledge. To write a good question, students must understand the SI units for *P*, *V* and *T* and check their values to make sure that the answers make sense.

Language focus: Students can interpret the success criteria of the sub-chapter and apply their understanding to write exam-style questions that address the topic successfully.

Assessment ideas

- Test your understanding questions from the Coursebook.
- Give students wrong solutions for calculations on molar volume or molar mass for gases and ask them to identify and correct the mistakes.
- Ask students to summarise the gas laws and present the conclusion using graphs.
- Calculation practice (short and longer calculations) on molar gas volume, combined gas laws and the ideal gas equation from Exercises 5.1–5.3 of the Workbook.
- Writing exam-style questions for peer assessment.

Homework ideas

- Exam-style questions from the Coursebook.
- Many past paper questions are available for practice by searching the internet for questions on moles. Some of these are questions from A-level examinations; however, the syllabus points on this topic are very similar to those of the IB.
- Write up the practical on determining the molar mass of lithium. Students should record and process data (with uncertainties), propagate the errors, draw conclusions and evaluate the methodology (suggesting systematic/random errors and specific improvements). Students should explain to a partner how to find the identity of an unknown gas using the ideal gas equation.
- Prepare a 5-minute presentation on explaining the properties of an ideal gas, including its definition, the key assumptions in the ideal gas model, the individual and combined gas laws (with sketched graphs) and the ideal gas equation.

Links to digital resources

- Properties of real gases vs ideal gases (search on chemguide for 'real gases')
- Simulations on ideal gas properties (search for 'ideal gas simulation' on the internet)
- Extension questions on gas calculations: question 3 from the 2011 UK Chemistry Olympiad R1 and question 2 from 2013 UK Chemistry Olympiad R1 (search the Royal Society of Chemistry website for 'chemistry olympiad past papers')
- Past paper questions for practice (search the internet for 'past paper questions on moles')

CROSS-CURRICULAR LINKS

- Maths: Basic arithmetic calculations, involving decimals, fractions, percentages, ratios, reciprocals, standard notations and using approximation. Manipulate and solve simple algebraic equations. Plot graphs (with suitable scales and axes) including two variables that show directly proportional and inversely proportional relationships. Use appropriate SI units in calculations. Understand the importance of uncertainties in raw data and how to propagate errors in processed data.
- Physics: Use SI units in the ideal gas equation calculations. Solve problems using ideal gas equations and gas laws. Draw and interpret gas law diagrams. Experiments to demonstrate gas laws. Assumptions used in the ideal gas model and the conditions under which real gases can be assumed to behave as ideal gases.
- TOK: Why are the laws in the natural sciences sometimes represented using mathematical languages? The roles of assumptions used in modelling the behaviour of real gases as ideal gases.