PASSchem

PASSchem

Platform Adapted Strategic Solutions: Comprehensive Solutions for General Chemistry Practice Questions

SHARON BREWER AND LINDSAY BLACKSTOCK

TRU OPEN PRESS
KAMLOOPS

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Introduction - Welcome Users

Welcome Students!

We are passionate believers in open educational resources (OER) and made the move to an OER textbook for our general chemistry courses a few years ago. One of the key things our students wanted, in addition to a free textbook, was access to practice problems with solutions beyond what we provided in our courses. Doing homework problems helps you practice your skills and reinforce your understanding of chemistry concepts — so this is important!

When we searched online, we found lots of OER repositories for practice questions, but while some questions had answers, not many had solutions. That discovery led us down the path to figuring out the best approach to create the PASS solutions in this book. We designed them so YOU can choose how much help you need to answer the question. You can **check your answer**, **see the steps** to get the answer or work through the **guided solution**, which provides the same kind of 'teacher-talk' we would use if you were sitting with us in our offices or explaining the approach to solving the problem in lecture.

We hope this helps you build your confidence in working through these practice chemistry problems!

You can find more information on how to use this book in the How to Use This Book section.

Happy studying!

Cheers, Sharon & Lindsay

Information for Educators

The PASS (Platform Adapted Strategic Solutions) Framework was developed in 2021 with the help of a grant (see Acknowledgements) to provide a literature-based approach for solving practice problems in general chemistry within the realm of open educational resources (OER). The PASS project focuses on finding, collecting, adapting/revising (where needed) and creating automated digital Chemistry solutions and feedback for OER practice problems for first-year Chemistry Courses using the PASS Framework.

Using the PASS Framework, we developed this PASSchem solutions collection, which features templated solutions tailored for general chemistry problems found in first-year courses at Thompson Rivers University (TRU) and modified for use on the Pressbooks platform. The goal is to provide students with questions and systematic solutions for open problems to support their individual formative assessment. Each solution follows a scaffolded template designed to allow students to choose the level of support they need as they work through practice questions, which provide formative feedback and guidance.

Meet the Creators

Content Creators

The content creators for this PASSchem solutions resource are from Thompson Rivers University (TRU). They are Associate Professor Dr. Sharon Brewer, Student Research Partners Ashlynn Jensen and C. Esther Ojukwu, and Assistant Teaching Professor Dr. Lindsay Blackstock.

PASSchem Pressbook content creators (from left to right): Dr. Sharon Brewer, Ashlynn Jensen and C. Esther Ojukwu, and Dr. Lindsay Blackstock.

Ashlynn Jensen: I live in a small town just outside of Kamloops and graduated from Chase Secondary School. In my spare time love to paint, draw and write poetry! I am a second year student studying at Thompson Rivers University in a bachelor of science, majoring in Chemical Biology. I plan to pursue a career in education and become a high school science teacher.

C. Esther Ojukwu: My name is Esther C. Ojukwu. I'm an international student from Nigeria and I'm in my second year of the

Bachelor of Science program. I hope to pursue a career in Nursing and also finish my BSc with a chemical biology major.

Dr. Sharon Brewer: I am an Associate Professor of Chemistry at TRU where I teach a variety of courses including general chemistry and upper-level analytical chemistry. I did my undergraduate and M.Sc. degrees at the University of New Brunswick and my Ph.D. at Carleton University where I developed and taught a 'Chemistry of Pollutants' course as a graduate student and first fell in love with teaching. I typically teach general chemistry, analytical chemistry and applied chemistry. My research interests include remote instrumentation as a teaching tool, OER use and assessment, many topics in chemistry education, analytical method development, environmental analysis and water treatment.

Dr. Lindsay Blackstock: I am an early career, tenure-track assistant teaching professor at TRU. I was born and raised in Kamloops, attended TRU for my Bachelor of Science degree (Environmental Chemistry Major) and I am so grateful to be able to give back to my amazing community. I completed my PhD at the University of Alberta and my specialty is analytical environmental toxicology. At TRU I teach general chemistry as well as both upper-level environmental courses offered here: atmospheric chemistry and aqueous chemistry. I love making memories with my husband Colten, my son Alec, and my frenchie-pug Donny; and in my spare time I participate in powerlifting: squat – bench – deadlift!!!

Dr. Verena Roberts [PASS Framework and website]; Dr Verena Roberts is a passionate online and blended K-12 and Higher Education educator, open learning designer and consultant who completed her EdD in Learning Sciences with a focus on K-12 Open Educational Practices with the Werklund School of Education, University of Calgary. She is currently an Instructional Designer with Thompson Rovers University (Open Learning) and an Adjunct Assistant Professor with the University of Calgary. She is a 2018-2019 OER Research fellow and 2018 Global Open Graduate Network (#GO-GN) member. She lives in Edmonton, Alberta and

her current research interest is figuring out Authentic Assessment using AI tools, Open Online Homework option and equity in children's soccer programs (football everywhere else in the world).

How to Use This Book

Introduction

This book follows the Platform Adaptable Strategic Solution (PASS) template designed by Drs. Lindsay Blackstock, Sharon Brewer, and Verena Roberts to support students at various levels of understanding and mimic the experience that a student may have during an office hour. You can find the first examples using this template on the PASS Chem website: https://chempass.opened.ca/.

For each question, students may attempt and check their answer with **Show/Hide Answer.** If you were correct, **AMAZING!** You can move on to the next question.

Strategy Map: If you need assistance in *what general steps to take* (i.e., spoiler-free!) then move on to the **strategy map** (see the yellow box below). The strategy map will provide you with a procedure (instructions) of what to do to reach the answer.

Solution: If you would like to see each step (i.e., spoiler alert!), move on to the **solution** (see the green box below). This section shows a simple step-by-step solution to reach the answer but without any commentary.

Guided Solution: If you need more help and want to know *why* you are performing each step in the solution, move on to the **guided solution** (see the blue box below).

The guided solution explains the chemistry theory or rationale behind the process. The guided solution's purpose is to replicate what a student may experience during an office hour or a lecture, working through a problem supported by the 'teacher talk.' Here, you will also find hints embedded throughout, including:

- Links to read more from the LibreTexts reference textbooks
- Additional context or an alternative perspective

- Reminders about various unit conversions or significant figures
- Common mistakes to avoid

Complete Solution: Below the guided solution is the **complete solution** that combines the step-by-step solution with the key context points from the guided solution.

Check Your Work: In chemistry, you can often avoid mistakes by thinking critically about the theory related to the problem and predicting what the answer *should or shouldn't be*. Be sure to **check your work** (see the purple box below). This section provides the rationale of why your answer 'makes sense' with respect to the chemistry theory. Use this strategy to avoid making mistakes in similar problems.

Question

The creators of this Pressbook currently use the free open LibreTexts platform CHEM1500: Chemical Bonding and Organic Chemistry to host their remixed General Chemistry textbook for Thompson Rivers University (TRU). Each topic will have a question that we will be working through together. Clicking on '**Show/Hide Answer**' below will only reveal the answer.

Our suggested approach:

1. Attempt it yourself. Check to see if you need additional assistance to get the correct answer.
2. After checking your answer, decide how much additional support you need to understand how to solve the problem yourself. Navigate to one of the three boxes below:
    1. **Strategy Map**
    2. **Solution**
    3. **Guided Solution.**

The boxes are listed in order of how much assistance is provided from least to most.

Below the answer is the link to the online resource to find supplementary information about this topic.

Show/Hide Answer

Under each question, you will find the **Show/Hide Answer**, which ONLY reveals the answer.

- For a quantitative (calculation) question, you will find the numerical value with correct significant figures and units (where appropriate).
- For a qualitative (theory) question, you will find the brief answer to what the question asked.

Topics

At TRU, General Chemistry is divided by topic as follows:
General Chemistry 1 (TRU Course Code CHEM1500):
CHEM1500: Chemical Bonding and Organic Chemistry

- Background Material
- Quantum Theory and Electronic Structure of Atoms
- Periodic Relationships Among the Elements
- Chemical Bonding I — Basic Concepts
- Chemical Bonding II — Molecular Geometry and Hybridization of Atomic Orbitals
- Intermolecular Forces and Liquids and Solids
- Organic Chemistry I — Bonding and Structure
- Organic Chemistry II — Stereochemistry
- Organic Chemistry III — Conformational Analysis

General Chemistry 2 (TRU Course Code CHEM1510 or CHEM1520): TRU: Fundamentals and Principles of Chemistry (CHEM1510 and CHEM1520)

- Background
- Gases
- Thermochemistry
- Kinetics
- Chemical Equilibrium
- Acid-Base Equilibrium
- Buffers, Titrations and Solubility Equilibria
- Entropy and Free Energy
- Electrochemistry

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

- **Spoiler Free!**
    - If you reveal the strategy map, you will still need to do the work to come up with the solution on your own. This section tells you what to do *in general*.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps (*p.s., many chemistry questions can be solved using a different order or combination of steps; below are our suggestions for you!*)
1. General procedure step 1
2. General procedure step 2
3. General procedure step 3 **Show/Hide Hint** Here is a hint to support step 3

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

- **Spoiler Alert!**
    - If you reveal the solution you will see each step required to reach the answer. No *commentary is provided as to WHY you are*

performing each step.

Show/Hide Solution

Step 1 details

Step 2 details

Step 3 details

Answer

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

- Different types of hints are labelled as follows:
  - **Resource** – *Review the relevant section in the*

textbook.

- **Think About This!** – *Read additional context or alternate perspectives.*
- **Don't Forget!** – *Review unit conversions, process steps, and significant figures.*
- **Watch Out!** – *Beware of common mistakes to avoid.*

Show/Hide Guided Solution

Table 2: Guided Solution – Generalized Example

Guided Solution Ideas
Here, we identify if this problem requires a calculation (quantitative) or a written answer (qualitative). **Show/Hide Resource** Refer to a specific section of the reference LibreTexts textbook.
What is the question asking you to do? **Show/Hide Think About This!** A hint! — Consider this additional context or an alternate way to think about the problem.
Consider what you know about the theory related to this question. **Show/Hide Watch Out!** A hint! — Avoid this common mistake!
Here is a formula to use: **Show/Hide Don't Forget!** Remember to convert your units and show the proper significant figures!

Table 3: Complete Solution

Complete Solution
The compete solution will show the steps taken to answer the question, including explanations. Step 1 context in words • Step 1 details
Step 2 context in words • Step 2 details
Step 3 context in words • Step 3 details

Check Your Work

Here is something to consider when reviewing your final answer. Based on our understanding of the chemistry theory, we can expect that our answer will not contradict this.

Does your answer make chemical sense?

Show/Hide Answer

We can predict that the answer should correspond with some key aspects or trends described in the chapter, and it does!

This section explains in more detail why the answer makes sense: consider how the molecules interact at the molecular level.

PASS Attribution (revised for generic page)

- LibreTexts PASS Chemistry Book CHEM 1510/1520 (2).
- Question 2.E.12 from LibreTexts PASS Chemistry Book CHEM 1510/1520 (3) is used under a CC BY-NC-SA 4.0 license.
    - Question 2.E.12 is question 9.2.10 from LibreTexts Chemistry 1e (OpenSTAX) (4), which is under a CC BY 4.0 license.
    - Question 9.2.10 is question 27 from OpenStax Chemistry (5), which is under a CC BY 4.0 license. Access for free at https://openstax.org/books/chemistry/pages/1-introduction.

References

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Acknowledgements

The Open Press

The Open Press combines TRU's open platforms and expertise in learning design and open resource development. TRU Open Press supports the creation and reuse of open educational resources, while encouraging open scholarship and research.

Land Acknowledgement

Thompson Rivers University (TRU) campuses are situated on the traditional lands of the Tk'emlúps te Secwépemc (Kamloops) and the T'exelc (Williams Lake) within Secwepemcúl'ecw, the traditional and unceded territory of the Secwépemc. The rich tapestry of this land also encompasses the territories of the St'át'imc, Nlaka'pamux, Tŝilhqot'in, Nuxalk, and Dakelh. Recognizing the deep histories and ongoing presence of these Indigenous peoples, we express gratitude for the wisdom held by this land. TRU is dedicated to fostering an inclusive and respectful environment, valuing education as a shared journey. The TRU Open Press, inspired by collaborative learning on this land, upholds open access principles, and freely accessible education for all.

Resource Development Team 2024

Resource Development Team

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Resources

PASSchem by Sharon Brewer and Lindsay Blackstock has been created from a combination of original content and materials compiled and adapted from the following open text publications:

General Chemistry 1 (TRU Course Code CHEM1500): CHEM1500: Chemical Bonding and Organic Chemistry

- Background material

- Quantum Theory and Electronic Structure of Atoms
- Periodic Relationships Among the Elements
- Chemical Bonding I – Basic Concepts
- Chemical Bonding II – Molecular Geometry and Hybridization of Atomic Orbitals
- Intermolecular Forces and Liquids and Solids
- Organic Chemistry I – Bonding and Structure
- Organic Chemistry II – Stereochemistry
- Organic Chemistry III – Conformational Analysis

General Chemistry 2 (TRU Course Code CHEM1510 or CHEM1520):
TRU: Fundamentals and Principles of Chemistry (CHEM1510 and CHEM1520)

- Background
- Gases
- Thermochemistry
- Kinetics
- Chemical Equilibrium
- Acid-Base Equilibrium
- Buffers, Titrations and Solubility Equilibria
- Entropy and Free Energy
- Electrochemistry

You can find both these resources on the Thompson Rivers University LibreText Bookshelf.

Funding and Support

The content development for this OER resource was made possible by funding and other support from:

2024

- TRU Open Press
    - "[To] offer wrap-around supports for the creation and development of open educational resources, open scholarship, and open pedagogy projects."

2023

- TRU Instructional Innovation Grant (TIIG), awarded to Dr. Blackstock & Dr. Brewer (excerpt included)
    - "[To] enhance and build the classroom experience by adopting or experimenting with instructional approaches that challenge, support, and encourage students."

2021

- TRU Open Educational Resources Grant, awarded to Dr. Blackstock, Dr. Brewer, and Dr. Verena Roberts
    - Development of the PASS framework
    - "To support faculty to integrate OER into their courses (through course release or other financial support/incentive) [and] to build capacity at TRU for creating and adapting open textbooks and other OER that are up to date and appropriate for TRU curricula."

Special Thanks to...

PASSchem has been an evolving project since 2021.

Dr. Verena Roberts: an instrumental team member of the original TRU OER Development grant.

- Thank you for your foundational work in investigating OER resources as part of the Zero Textbook Cost initiative. For accruing and curating the available general chemistry OER practice problems collection, for your collaboration on the PASS framework, and your invaluable insight into instructional design and literature based rationale behind pedagogical practices

TRU Grant Management/Coordinators:

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- Dr. Diane Janes (TRU, Centre for Excellence in Learning and Teaching) – Thank you for your coordination of the 2023/2024 TRU Instructional Innovation Grant project

Accessibility

The web version of PASSchem has been designed to meet Web Content Accessibility Guidelines 2.0, level AA. In addition, it follows all guidelines in Appendix A: Checklist for Accessibility of the Accessibility Toolkit – 2nd Edition.

Includes:

- **Easy navigation.** This resource has a linked table of contents and uses headings in each chapter to make navigation easy.
- **Accessible videos.** All videos in this resource have captions.
- **Accessible images.** All images in this resource that convey information have alternative text. Images that are decorative have empty alternative text.
- **Accessible links.** All links use descriptive link text.

Accessibility Checklist

Element	Requirements	Pass
Headings	Content is organized under headings and subheadings that are used sequentially.	Yes
Images	Images that convey information include alternative text descriptions. These descriptions are provided in the alt text field, in the surrounding text, or linked to as a long description.	Yes
Images	Images and text do not rely on colour to convey information.	Yes
Images	Images that are purely decorative or are already described in the surrounding text contain empty alternative text descriptions. (Descriptive text is unnecessary if the image doesn't convey contextual content information.)	Yes
Tables	Tables include row and/or column headers with the correct scope assigned.	Yes
Tables	Tables include a title or caption.	Yes
Tables	Tables do not have merged or split cells.	Yes
Tables	Tables have adequate cell padding.	Yes
Links	The link text describes the destination of the link.	Yes
Links	Links do not open new windows or tabs. If they do, a textual reference is included in the link text.	Yes
Links	Links to files include the file type in the link text.	Yes
Video	All videos include high-quality (i.e., not machine generated) captions of all speech content and relevant non-speech content.	Yes
Video	All videos with contextual visuals (graphs, charts, etc.) are described audibly in the video.	Yes
H5P	All H5P activities have been tested for accessibility by the H5P team and have passed their testing.	Yes
H5P	All H5P activities that include images, videos, and/or audio content meet the accessibility requirements for those media types.	Yes
Font	Font size is 12 point or higher for body text.	Yes
Font	Font size is 9 point for footnotes or endnotes.	Yes
Font	Font size can be zoomed to 200% in the webbook or eBook formats.	Yes

Known Accessibility Issues and Areas for Improvement

- None

Adapted from the Accessibility Toolkit – 2nd Edition by BCcampus, licensed under CC-BY.

Other Formats Available

- In addition to the web version, this book is available in a number of file formats, including PDF, EPUB (for eReaders), and various editable files. The Digital PDF has passed the Adobe Accessibility Check.

OER Adoption Form

Please consider filling out a survey about this textbook to help us better understand how it's used and fits with the needs of our readers.

QUANTUM THEORY AND ELECTRONIC STRUCTURE

Quantum Theory and Electronic Structure: Bohr Model, Determine Photon Energy in Joules

Question

Using the Bohr model:

1. Determine the change in energy (in joules) when the electron in a Li^{2+} ion moves from the n = 2 to the n = 1 orbit.
2. What is the energy (in joules) of the photon produced?

Show/Hide Answer

$$\Delta E = -1.47 \times 10^{-17} J$$
$$E_{photon} = 1.47 \times 10^{-17}\ J$$

Refer to Section 2.2: Atomic Spectroscopy and The Bohr Model (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify the information (data and/or variables) given the question. **Show/Hide Hint** $n_i = 2$, $n_f = 1$ (initial and final energy levels).
2. Identify what the question is asking for; what variable would represent it in a formula (E, λ, n, etc.). **Show/Hide Hint** You are looking for ΔE (total energy change).

3. Choose a formula that allows you to plug in your given information. Fill in any known constant values.

Show/Hide Hint

To check if you are using the correct formula, ask yourself:

- Does this formula help you?
- Are you closer to finding the desired variable?

$$\Delta E = -2.18 \times 10^{-18}\,J \left(\frac{Z^2}{{n_f}^2} - \frac{Z^2}{{n_i}^2} \right)$$

$$n_i = 2$$

$$n_f = 1$$

$$\Delta E = ?$$

Rydberg's Constant (R_H)=2.18×10^{-18} J

Z = Atomic Number = 3

Note that you can find the atomic number on the periodic table. Most questions consider 'hydrogen's electron' because hydrogen has an atomic number of Z=1. The formula is often simplified to:

$$\Delta E = -R_H \left(\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2} \right)$$

4. Calculate the final answer. Do not forget about sign, units and significant figures.

Show/Hide Watch Out!

Be sure to follow typical math rules such as order of operations. Recall the Order of Operations.

Refer to Section 1.3: The Order of Operations (2).

Show/Hide Hint

Students commonly make mistakes when filling in the formula. When using nonhydrogen atoms, students often forget to include the atomic number (Z) in the numerator of both fractions. In this example, the atomic number is for Li^{2+} is 3.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

1. Change in energy (in joules) when the electron in a Li^{2+} ion moves from the n = 2 to the n = 1 orbit:

$$\Delta E = -R_H \left(\frac{Z^2}{n_f^2} - \frac{Z^2}{n_i^2} \right)$$

$$\Delta E = -2.18 \times 10^{-18} J \left(\frac{Z^2}{n_f^2} - \frac{Z^2}{n_i^2} \right)$$

$$\Delta E = -2.18 \times 10^{-18} J \left(\frac{3^2}{1^2} - \frac{3^2}{2^2} \right)$$

$$\Delta E = -2.18 \times 10^{-18} J \left(\frac{9}{1} - \frac{9}{4} \right)$$

$$\Delta E = -2.18 \times 10^{-18} J \left(\frac{27}{4} \right)$$

$$\Delta E = -2.18 \times 10^{-18} J (6.25)$$

$$\Delta E = -1.4715 \times 10^{-17} J$$

$$\Delta E = -1.47 \times 10^{-17}\ J$$

2. Energy (in joules) of the photon produced:

Energy of the photon = Ephoton = |ΔEelectron|

$$\Delta E_{electron} = -1.47 \times 10^{-17} \text{ J}$$

$$E_{photon} = 1.47 \times 10^{-17} \text{ J}$$

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a calculation problem where you use the Rydberg Equation to calculate the energy of the transition of the electron. **Show/Hide Resource** Refer to Section 2.2: Atomic Spectroscopy and The Bohr Model (1).
Using the Bohr model, 1. Determine the change in energy (in joules) when the electron in a Li^{2+} ion moves from the n = 2 to the n = 1 orbit. **Show/Hide Don't Forget!** change in energy = ΔE "from the" = initial energy level = $n_i = 2$ "to the" = final energy level = $n_f = 1$ 2. What is the energy (in joules) of the photon produced? **Show/Hide Don't Forget!** $E_{photon} = \lvert\Delta E\rvert$
Summarize what the question is asking. **Show/Hide Think About This!** You are looking for the change in energy of the Li^{2+} electron when it transitions from n = 2 to n = 1. The energy change is exactly the same (quantized) amount as what is emitted (i.e., as a photon).
Based on your understanding of the related chemistry concepts, predict what you expect the answer to be. **Show/Hide Think About This!** Since the Li^{2+} ion is going from a higher energy orbital (n = 2) to a lower energy orbital (n = 1), you can expect the answer to be negative. When energy is emitted, it is released or lost from the system; ΔE is a negative value. When energy is absorbed, it is added to the system; ΔE is a positive value.

Table 3: Complete Solution

Complete Solution
Recall the Rydberg equation. **Show/Hide Don't Forget!** The Rydberg equation allows you to calculate the overall change in an atom's energy, given its initial(n_i) and final(n_f) energy values. $$\Delta E = -2.18 \times 10^{-18} J \left(\frac{Z^2}{n_f^2} - \frac{Z^2}{n_i^2} \right)$$
Input your data provided by the question. • ΔE = unknown • Z = atomic number of atom (Li^{2+}) = 3 • n_f = Final energy state = 1 • n_i = Initial energy state = 2 • R_H = Rydberg's Constant (2.18×10^{-18} J) **Show/Hide Watch Out!** Students commonly make mistakes here. When using nonhydrogen atoms, students often forget to include the atomic number. $$\Delta E = -2.18 \times 10^{-18} J \left(\frac{3^2}{1^2} - \frac{3^2}{2^2} \right)$$ Square the numerator and denominator of both fractions.

Start by solving inside the brackets.

$$\Delta E = -2.18 \times 10^{-18} J \left(\frac{9}{1} - \frac{9}{4} \right)$$

Combine the fractions by subtracting them.

$$\Delta E = -2.18 \times 10^{-18} J \left(\frac{27}{4} \right)$$

Optional: Convert your fraction before the multiplication step.

Multiply your constant R_H and the number inside the brackets.

$$\Delta E = -1.4715 \times 10^{-17} J$$

$$\Delta E = -1.47 \times 10^{-17} J$$

Notice that there is a negative sign in front of the constant value.

Recall the relationship between the energy change for the transition of an electron to the energy of the photon that is absorbed or emitted during that change.

Show/Hide Think About This!

The energy of a photon must exactly match the energy change resulting from the transition of the electron from one energy level (orbit) to another (orbit).

A photon is a quantized packet of energy.

When an electron transitions from a low to a high energy level, the electron must absorb energy ($\Delta E_{electron}$ = positive) from a photon with the same amount of energy required for that transition.

When an electron transitions from a high to a low energy level, the electron must release energy ($\Delta E_{electron}$ = negative). The energy lost from the electron is emitted as a photon with the same amount of energy released during that transition.

Energy of the photon = $E_{photon} = |\Delta E_{electron}|$

$$\Delta E_{electron} = -1.47 \times 10^{-17} \text{ J}$$

therefore,

$$E_{photon} = 1.47 \times 10^{-17} \text{ J}$$

Check Your Work

Comparing the bond energy values, we see that the product bond (2 H-Br) have a greater magnitude than the reactant bonds (H-H and Br-Br), so we would expect this reaction to have an exothermic ΔH.

Show/Hide Watch Out!

Make sure you add up all bonds and consider the reaction stoichiometry.

Does your answer make chemical sense?

Show/Hide Answer

When any reaction occurs, energy will be absorbed and released; however, the overall sum can be endothermic (requires more energy than it releases) or exothermic (releases more energy than it requires). You can numerically

observe this using the enthalpy change from the bond energies equation.

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PERIODIC RELATIONSHIPS BETWEEN THE ELEMENTS

Periodic Relationships Between the Elements: Ranking Atomic Radius Size

Question

Based on their positions in the periodic table, list the following atoms in order of increasing radius: Ca, Cs, Mg, Rb.

Show/Hide Answer

Mg, Ca, Rb, Cs

Refer to Section 3.2: Periodic Variations in Element Properties (1).

Strategy Map

Do you need a little help to get started?

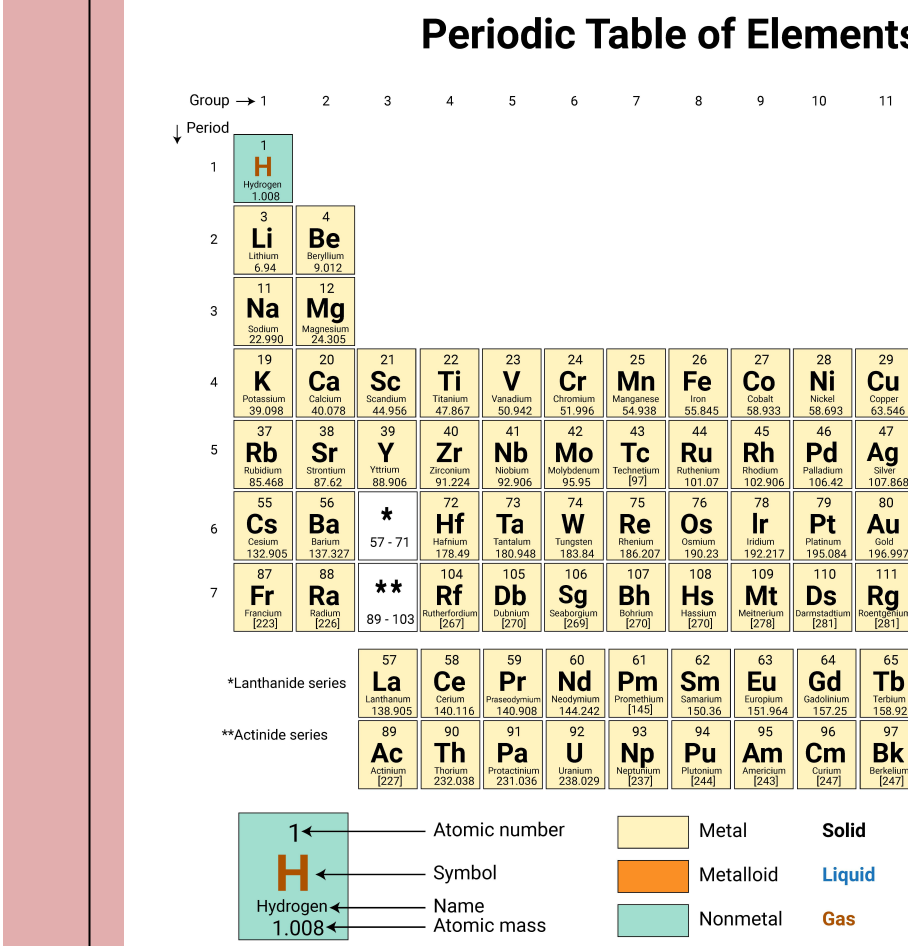
Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Recognize the context of the question and confirm the requested format of t **Show/Hide Hint** This question requires an understanding of atomic radii. You must list these el Refer to Section 3.2.2: Variation in Covalent Radius (1).

2. Find each element on the periodic table.
Show/Hide Periodic Table


Periodic Table of Elements
Group → 1 2 3 4 5 6 7 8 9 10 11
Period
1 H Hydrogen 1.008
2 Li Lithium 6.94 Be Beryllium 9.012
3 Na Sodium 22.990 Mg Magnesium 24.305
4 K Potassium 39.098 Ca Calcium 40.078 Sc Scandium 44.956 Ti Titanium 47.867 V Vanadium 50.942 Cr Chromium 51.996 Mn Manganese 54.938 Fe Iron 55.845 Co Cobalt 58.933 Ni Nickel 58.693 Cu Copper 63.546
5 Rb Rubidium 85.468 Sr Strontium 87.62 Y Yttrium 88.906 Zr Zirconium 91.224 Nb Niobium 92.906 Mo Molybdenum 95.95 Tc Technetium [97] Ru Ruthenium 101.07 Rh Rhodium 102.906 Pd Palladium 106.42 Ag Silver 107.868
6 Cs Cesium 132.905 Ba Barium 137.327 * 57 - 71 Hf Hafnium 178.49 Ta Tantalum 180.948 W Tungsten 183.84 Re Rhenium 186.207 Os Osmium 190.23 Ir Iridium 192.217 Pt Platinum 195.084 Au Gold 196.997
7 Fr Francium [223] Ra Radium [226] ** 89 - 103 Rf Rutherfordium [267] Db Dubnium [270] Sg Seaborgium [269] Bh Bohrium [270] Hs Hassium [270] Mt Meitnerium [278] Ds Darmstadtium [281] Rg Roentgenium [281]
*Lanthanide series La Lanthanum 138.905 Ce Cerium 140.116 Pr Praseodymium 140.908 Nd Neodymium 144.242 Pm Promethium [145] Sm Samarium 150.36 Eu Europium 151.964 Gd Gadolinium 157.25 Tb Terbium 158.92
**Actinide series Ac Actinium [227] Th Thorium 232.038 Pa Protactinium 231.036 U Uranium 238.029 Np Neptunium [237] Pu Plutonium [244] Am Americium [243] Cm Curium [247] Bk Berkelium [247]
1 H Hydrogen 1.008
Atomic number
Symbol
Name
Atomic mass
Metal
Metalloid
Nonmetal
Solid
Liquid
Gas

The Periodic Table of Elements (Thompson Rivers University Open Learning) CC BY-SA 4.0 li

3. Recall relevant concepts that impact atomic radii. Summarize the periodic tr

Show/Hide Hint

Consider effective nuclear charge (Zeff).

Refer to Section 3.2.1 Effective Nuclear Charge: Penetration and Shielding (1).

Atomic radii increase as you move down a period and decrease as you move rig

- The largest element is located at the bottom left of the periodic table.
- The smallest element is located at the top right of the periodic table.

Solution

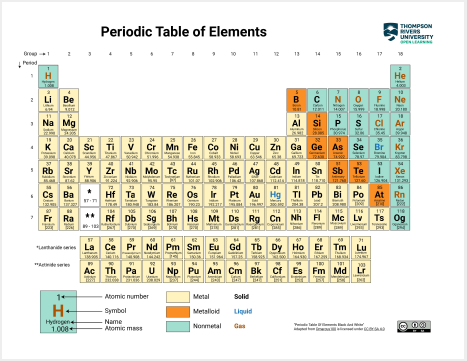
Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

The column (group) and period (row) locations of Ca, Cs, Mg, and Rb on the periodic table:

- Ca — atomic number 20, group 2, period 4
- Cs — atomic number 55, group 1, period 6
- Mg — atomic number 12, group 2, period 3
- Rb — atomic number 37, group 1, period 5



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Smallest to largest atomic radii: Mg < Ca < Rb < Cs

Answer (in order of increasing radius): Mg, Ca, Rb, Cs

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Soluti

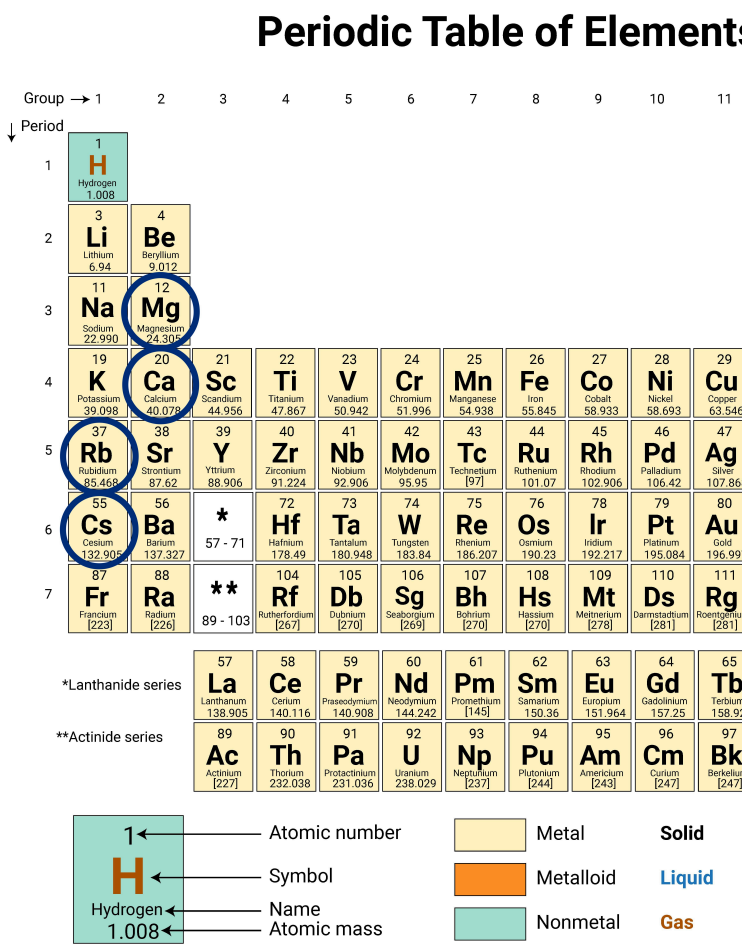
Guided Solution Idea
This question is a theory problem that requires the understanding and applica effective nuclear charge, and atomic radii. This question asks us to rank the given elements by their size. Refer to Atomic Radii (2). **Show/Hide Don't Forget!** Recognize that as principal quantum number (n) increases (i.e., as you move do Refer to Section 2.5: The Shape of Atomic Orbitals (3). **Show/Hide Don't Forget!** Recognize that as Zeff increases (i.e., as you move left to right across the perio Refer to: • Section 3.2.1 Effective Nuclear Charge: Penetration and Shielding (1). • Section 3.2.2: Variation in Covalent Radius (1).
Consider what characteristics may influence the distance between the nucleus **Show/Hide Think About This!** Principal quantum number (n): • Shielding — consider how many complete shells of electrons are betwee Effective Nuclear Charge (Zeff): • Shielding — electrons in the same shell (i.e., across the same row) are no nucleus. • As you move left to right across a row, the number of protons and effecti electron) increases. ◦ The electrons are held more tightly (i.e., closer) to the nucleus, and **Show/Hide Don't Forget!** (n) influences size more than (Zeff).

Summarize the trend of atomic radii across the periodic table.
Show/Hide Don't Forget!
The atomic radius decreases from left to right and increases from top to botto

- The largest element is located at the bottom left of the periodic table.
- The smallest element is located at the top right of the periodic table.

Locate the elements on the periodic table
Show/Hide Element Locations

- Ca (calcium) — atomic number 20, group 2, period 4
- Cs (cesium) — atomic number 55, group 1, period 6
- Mg (magnesium) — atomic number 12, group 2, period 3
- Rb (rubidium) — atomic number 37, group 1, period 5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6 Cs Cesium 132.905 | Ba Barium 137.327 | * 57 - 71 | Hf Hafnium 178.49 | Ta Tantalum 180.948 | W Tungsten 183.84 | Re Rhenium 186.207 | Os Osmium 190.23 | Ir Iridium 192.217 | Pt Platinum 195.084 | Au Gold 196.99
7 Fr Francium [223] | Ra Radium [226] | ** 89 - 103 | Rf Rutherfordium [267] | Db Dubnium [270] | Sg Seaborgium [269] | Bh Bohrium [270] | Hs Hassium [270] | Mt Meitnerium [278] | Ds Darmstadtium [281] | Rg Roentgenium [281]
*Lanthanide series
57 La Lanthanum 138.905 | 58 Ce Cerium 140.116 | 59 Pr Praseodymium 140.908 | 60 Nd Neodymium 144.242 | 61 Pm Promethium [145] | 62 Sm Samarium 150.36 | 63 Eu Europium 151.964 | 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.9
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89 Ac Actinium [227] | 90 Th Thorium 232.038 | 91 Pa Protactinium 231.036 | 92 U Uranium 238.029 | 93 Np Neptunium [237] | 94 Pu Plutonium [244] | 95 Am Americium [243] | 96 Cm Curium [247] | 97 Bk Berkelium [247]
1
H
Hydrogen
1.008
Atomic number
Symbol
Name
Atomic mass
Metal
Metalloid
Nonmetal
Solid
Liquid
Gas

The Periodic Table of Elements, with Mg, Ca, Rb, and Cs Circled (Modified from Thompson Riv

List the elements in order of increasing principal quantum number (n).

- Mg — period 3
- Ca — period 4
- Rb — period 5
- Cs — period 6

Show/Hide Don't Forget!
As (n) increases, the size of the orbital increases.

Recall: The valence electrons for all of the listed elements are in s-orbitals:

- Mg — 3s
- Ca — 4s
- Rb — 5s
- Cs — 6s

Note that because all the elements are in different periods, we do not need to c
left to right).

Refer to Section 3.2.2: Variation in Covalent Radius (1).

Table 3: Complete Solution

Complete Solution
Atomic radius increases as you move down rows from the top to the bottom of the periodic table. This increase is because the principal quantum number (n) increases, meaning the element requires more shells to house additional electrons around the nucleus. Elements at the bottom of the periodic table have a larger 'period' number.
Atomic radius decreases as you move from left to right across the columns of the periodic table. This decrease is because the effective nuclear charge (Zeff) increases, meaning that outer shell valence electrons feel a stronger attractive force from the protons that pull them closer to the nucleus. Elements towards the right of the periodic table have a larger 'group' number.
Because of the left-to-right trend, the atomic number (i.e., the number of electrons) is not the only factor to consider when ranking atomic size. • First, consider the period — row: top to bottom (bottom is largest). • If more than one element is in the same period, consider the group — column: left to right (left is smallest).

Locate each element on the periodic table to find their relative period and group numbers.

- Ca (calcium) — atomic number 20, group 2, period 4
- Cs (cesium) — atomic number 55, group 1, period 6
- Mg (magnesium) — atomic number 12, group 2, period 3
- Rb (rubidium) — atomic number 37, group 1, period 5

Because each listed element is in a different row (i.e., period), they can be ranked for size using this information alone.

- Mg — period 3
- Ca — period 4
- Rb — period 5
- Cs — period 6

Smallest to largest atomic radii: Mg, Ca, Rb, Cs

Check Your Work

The element at the bottom left (Fr: Francium) in the periodic table is the largest, and the element at the top right (He: Helium) is the smallest.

From the provided list, Mg is closest to the top and should be listed first; Cs is nearest to the bottom and should be listed last. No two elements are in the same period (row), so you do not need to consider the group (column) number in this question.

Does your answer make chemical sense?

Show/Hide Answer

In general, atomic radii increase as you move from top to bottom on the periodic table. It makes sense that size increases as the principal quantum number (n) increases. The periodic table is arranged logically, with each row representing an increased (n). As the 'n' value increases, the size of the orbital increases. This is because there are complete shells (i.e., core electrons) between the nucleus and the valence electrons. The core electrons effectively shield the valence electrons from the positive force. Therefore, the more core electrons there are, the weaker the attractive force; the valence electrons are held more weakly (i.e., at a

further distance) from the nucleus, resulting in increased atomic radii.

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CHEMICAL BONDING – BASIC CONCEPTS

Chemical Bonding — Basic Concepts: Calculate Enthalpy Change from Bond Energy

Question

Using the bond energies in Table 4.6.1: Bond Energies (kJ/mol) from Section 4.6: Strengths of Ionic and Covalent Bonds (1), determine the approximate enthalpy change for each of the following reactions:

1. $H_2(g) + Br_2(g) \rightarrow 2HBr(g)$
2. $CH_4(g) + I_2(g) \rightarrow CH_3I(g) + HI(g)$
3. $C_2H_4(g) + 3O_2 \rightarrow 2CO_2(g) + 2H_2O(g)$

Show/Hide Answer

1. −114 kJ
2. 30. kJ
3. −1055 kJ

Refer to Section 4.6: Strengths of Ionic and Covalent Bonds (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify which molecules have bonds broken and which have bonds formed. **Show/Hide Hint** Reactant bonds break, and product bonds form in a chemical reaction.
2. Create Lewis structures for each of the molecules to know what bonds there are. **Show/Hide Hint** If you are unsure which elements are bonded to which, try making a Lewis Structure of the molecule. Refer to Section 4.4 Lewis Symbols and Structures (2).
3. Use the provided table to look up the corresponding bond energies. **Show/Hide Hint** Table 4.6.1: Bond Energies (kJ/mol) from Section 4.6: Strengths of Ionic and Covalent Bonds (1).
4. Plug the values into the enthalpy change equation and solve for each reaction. **Show/Hide Hint** Breaking bonds requires an energy input. When bonds form, energy is released. When energy is released, it is negative. Recall the equation that demonstrates this relationship.

Solution

Do you want to see the steps to reach the answer?
Check out this solution.

Show/Hide Solution

1. H_2 (g) + Br_2 (g) → 2HBr (g)

$$\Delta H = \left(\sum \text{Bonds broken}\right) - \left(\sum \text{Bonds formed}\right)$$

$$\Delta H = (1(H - H) + 1(Br - Br)) - (2(H - Br))$$

$$\Delta H = (1\ \text{mol}(436\ \text{kJ/mol}) + 1\ \text{mol}(190.\ \text{kJ/mol})) - (2\ \text{mol}(370.\ \text{kJ/mol}))$$

$$\Delta H = (626\ \text{kJ}) - (740.\ \text{kJ})$$

$$\Delta H = -114\ \text{kJ}$$

2. CH_4 (g) + I_2 (g) → CH_3I (g) + HI (g)

$$\Delta H = \left(\sum \text{ Bonds broken }\right) - \left(\sum \text{ Bonds formed }\right)$$

$$\Delta H = (4(C-H) + (I-I)) - (3(C-H) + (C-I) + (H-I))$$

$$\Delta H = (4\ \text{mol}(415\ \text{kJ/mol}) + 1\ \text{mol}(150.\ \text{kJ/mol})) - (3\ \text{mol}(415\ \text{kJ/mol}) + 1\ \text{mol}(240.\ \text{kJ/mol}) + 1\ \text{mol}(295\ \text{kJ/mol}))$$

$$\Delta H = (1660\ \text{kJ} + 150.\ \text{kJ}) - (1245\ \text{kJ} + 240.\ \text{kJ} + 295\ \text{kJ})$$

$$\Delta H = (1810\ \text{kJ}) - (1780\ \text{kJ})$$

$$\Delta H = 30.\ \text{kJ}$$

3. C_2H_4 (g) + $3O_2$ (g)→ $2CO_2$ (g) + $2H_2O$ (g)

$$\Delta H = \left(\sum \text{ Bonds broken }\right) - \left(\sum \text{ Bonds formed }\right)$$

$$\Delta H = (4(C-H) + (C=C) + 3(O=O)) - (2(2(C=O)) + 2(2(H-O)))$$

$$\Delta H = (4\ \text{mol}(415\ \text{kJ/mol}) + 1\ \text{mol}(611\ \text{kJ/mol}) + 3\ \text{mol}(498\ \text{kJ/mol})) - (4\text{mol}(741\ \text{kJ/mol}) + 4\ \text{mol}(464\ \text{kJ/mol}))$$

$$\Delta H = ((1660\ \text{kJ} + 611\ \text{kJ}) + (1494\ \text{kJ} - 2964\ \text{kJ} + (1856\ \text{kJ})$$

$$\Delta H = (3765\ \text{kJ}) - (4820\ \text{kJ})$$

$$\Delta H = -1055\ \text{kJ} = 1.05_5\text{x}10^3\ \text{kJ}$$

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a calculation problem in which you must identify what bonds are broken and formed during a chemical reaction. This type of problem requires you to use a table of values to calculate the overall energy change in the reaction using bond energies. **Show/Hide Resource** Refer to Section 4.6: Strengths of Ionic and Covalent Bonds (1).

It can be difficult to know how many bonds are in a molecule. The easiest way to find what bonds there are is to create a Lewis Structure of the molecule.

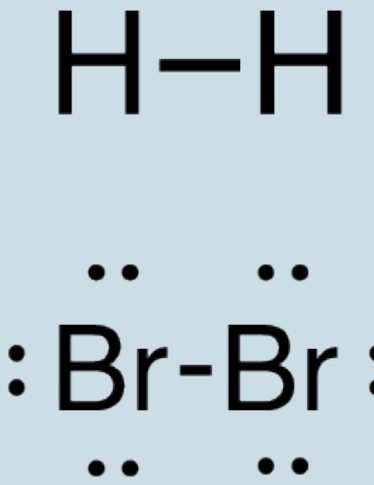
Show/Hide Resource

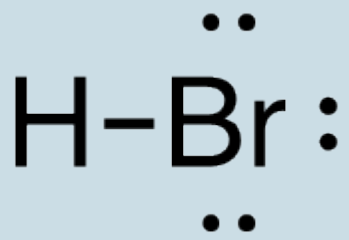
Refer to Section 4.4 Lewis Symbols and Structures (2).

1. H_2 (g) + Br_2 (g) → 2HBr (g)

Create Lewis structures for H_2, Br_2 and HBr.

Show/Hide Structures

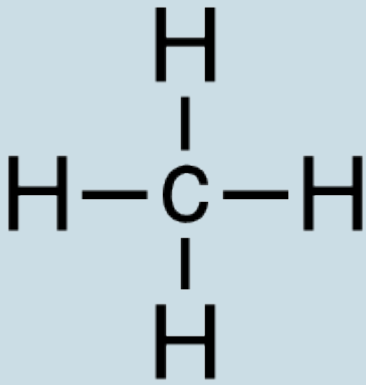


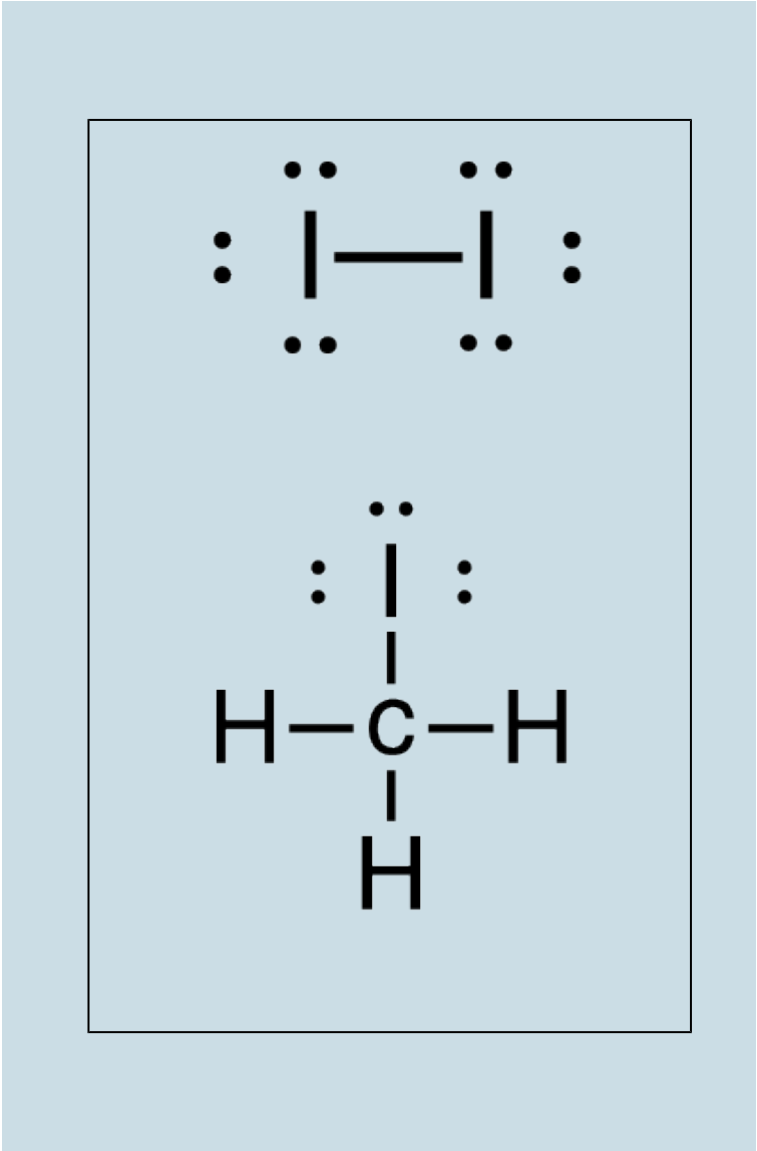


2. CH_4 (g) + I_2 (g) → CH_3I (g) + HI (g)

Create Lewis structures for CH_4, I_2, CH_2I and HI.

Show/Hide Structures

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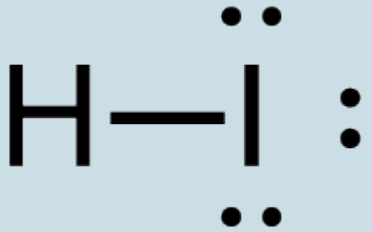
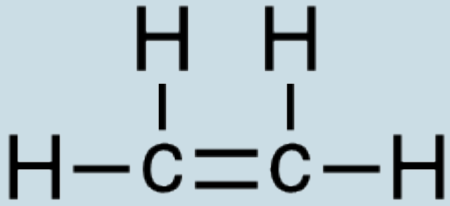
H

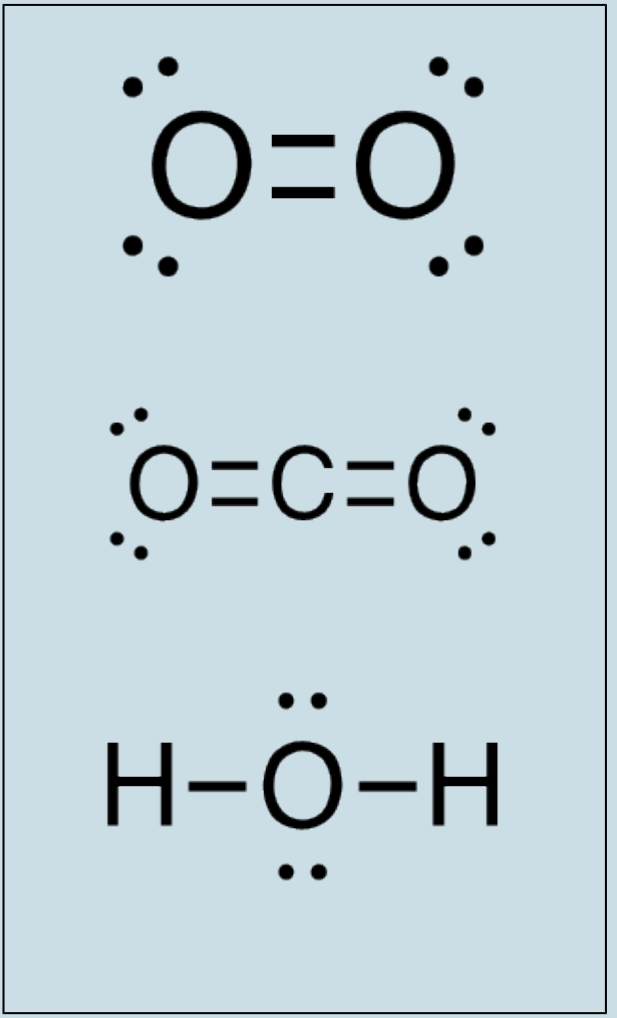


3. C_2H_4 (g) + $3O_2$ (g) → $2CO_2$ (g) + $2H_2O$ (g)

Create Lewis structures for C_2H_4, O_2, CO_2 and H_2O.

Show/Hide Structures




O=O
O=C=O
H–O–H

Recall that bonds require energy to break (start a reaction), and energy is released when bonds form (in the products of a reaction).

Show/Hide Don't Forget!

$$\Delta H = \left(\sum \text{ Bonds broken}\right) - \left(\sum \text{ Bonds formed}\right)$$

The energy of bonds formed is subtracted as they are formed in the reaction. Bond energy values, by definition, are the energy required to break the bond. By subtracting the sum of the product bonds formed, we are changing the sign of the energy to represent the opposite process (forming the bond).

When using the bond energies table, scan the table for your desired bond (i.e. (H-H)). The number beside it will be the one used in the calculation. Make sure you don't confuse single, double, and triple bonds!

Show/Hide Don't Forget!

The bond energy for H-H is 436 kJ.

Table 3: Complete Solution

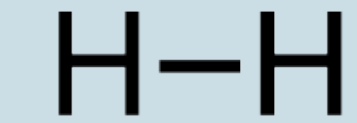
Complete Solution
The following equation will be used for each of the reactions: $\Delta H = \left(\sum \text{ Bonds broken }\right) - \left(\sum \text{ Bonds formed }\right)$ For a reaction to occur, bonds need to break, and new bonds need to form. When bonds break, energy is absorbed. When bonds form, energy is released. We use this to calculate the sum of the energy change over the reaction. How do we know which bonds are breaking and which are forming? **Show/Hide Don't Forget!** In a reaction, the bonds to the left of the arrow will break, and the bonds to the right will form. ___(break)___ → ___(form)___

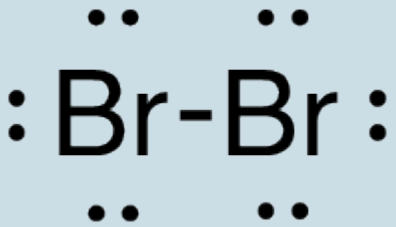
1. H_2 (g) + Br_2 (g) → 2HBr (g)

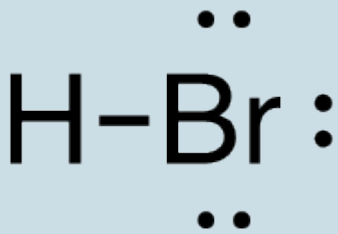
$$\Delta H = \left(\sum \text{Bonds broken}\right) - \left(\sum \text{Bonds formed}\right)$$

The bond between the two hydrogen and the two bromine atoms breaks. Two product molecules form, each with a hydrogen bonded to a bromine.

Show/Hide Structures







$$\Delta H = (1\,\text{mol}\,(H-H) + 1\,\text{mol}\,(Br-Br)) - (2\,\text{mol}\,(H-Br))$$

Using Table 4.6.1: Bond Energies (kJ/mol) from Section 4.6: Strengths of Ionic and Covalent Bonds (1), the values for each bond energy replaces their respective bonds in the equation.

$$\Delta H = (1\,\text{mol}(436\,\text{kJ/mol}) + 1\,\text{mol}(190.\,\text{kJ/mol})) - (2\,\text{mol}(370.\,\text{kJ/mol}))$$

When solving inside the brackets, keep stoichiometry in mind.

$$\Delta H = (626\text{kJ}) - (740.\,\text{kJ})$$

The energy released from the bonds formed is subtracted from the energy absorbed by the bonds broken.

$$\Delta H = -114\ \text{kJ}$$

The calculated value is negative, meaning the reaction was exothermic.

2. CH_4 (g) + I_2 (g) → CH_3I (g) + HI (g)

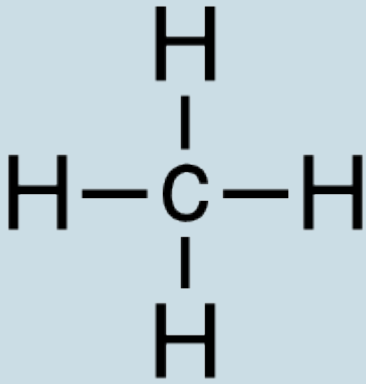
$$\Delta H = \left(\sum \text{Bonds broken}\right) - \left(\sum \text{Bonds formed}\right)$$

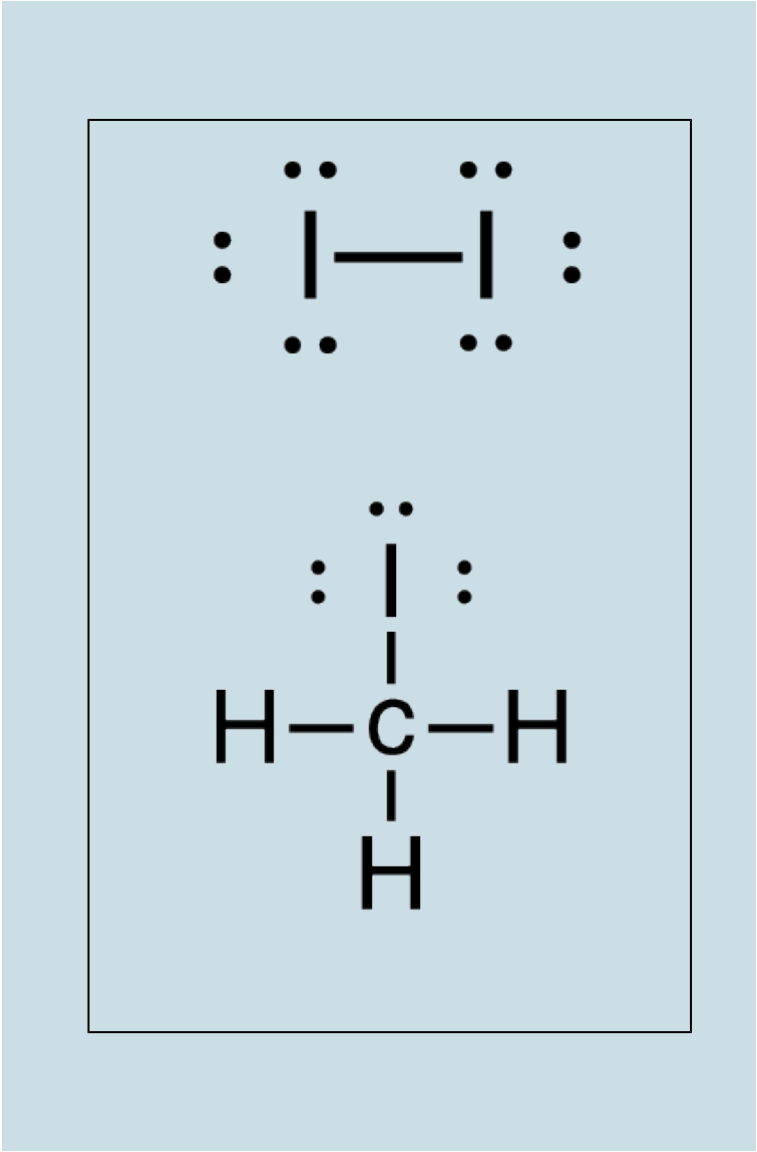
Four carbon-hydrogen and one iodine-iodine bonds break. Three carbon-hydrogen bonds, one carbon-iodine and one hydrogen-iodine, are formed.

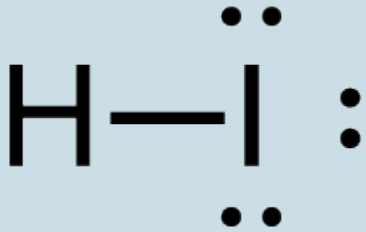
Show/Hide Think About This!

Make sure you have the correct bonds for CH_4 and CH_3I.

Show/Hide Structures







$$\Delta H = (4(C-H) + (I-I)) - (3(C-H) + (C-I) + (H-I))$$

Using Table 4.6.1: Bond Energies (kJ/mol) from Section 4.6: Strengths of Ionic and Covalent Bonds (1), the values for each bond energy replaces their respective bonds in the equation.

$$\Delta H = (4\text{mol}(415\text{kJ/mol}) + 1\text{mol}(150.\text{kJ/mol})) - (3\text{mol}(415\text{kJ/mol}) + 1\text{mol}(240.\text{kJ/mol}) + 1\text{mol}(295\text{kJ/mol}))$$

$$\Delta H = ((1660\text{kJ}) + (150.\text{kJ})) - ((1245\text{kJ}) + (240.\text{kJ}) + (295\text{kJ}))$$

When solving inside the brackets, keep stoichiometry in mind.

$$\Delta H = (1810\text{kJ}) - (1780\text{kJ})$$

The energy released from the bonds formed is subtracted from the energy absorbed by the bonds broken.

$$\Delta H = 30\ \text{kJ}$$

The calculated value is positive, meaning the reaction was endothermic

3. C_2H_4 (g) + $3O_2$ (g) → $2CO_2$ (g) + $2H_2O$ (g)

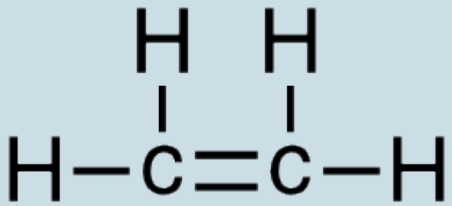
$$\Delta H = \left(\sum \text{Bonds broken}\right) - \left(\sum \text{Bonds formed}\right)$$

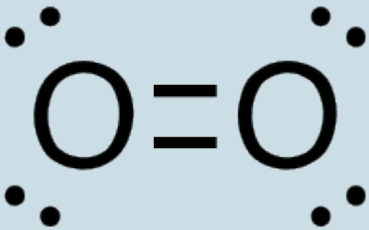
Two hydrogen-carbon, one carbon-carbon double, and three oxygen-oxygen double bonds break. Two molecules of CO_2 form that contain two carbon-oxygen double bonds and two molecules, each containing two hydrogen-oxygen bonds.

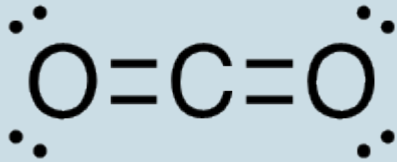
Show/Hide Think About This!

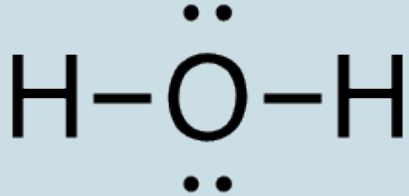
Make sure you have the correct bonds for C_2H_4, O_2 and CO_2.

Show/Hide Structures









$$\Delta H = (4(C-H) + (C=C) + 3(O=O)) - (2(2(C=O)) + 2(2(H-O)))$$

Using Table 4.6.1: Bond Energies (kJ/mol) from Section 4.6: Strengths of Ionic and Covalent Bonds (1), the values for each bond energy replaces their respective bonds in the equation.

$$\begin{aligned}\Delta H = (&4\text{mol}(415\text{kJ/mol}) + 1\text{mol}(611\text{kJ/mol}) \\ &+ 3\text{mol}(498\text{kJ/mol})) - (4\text{mol}(741\text{kJ/mol}) \\ &+ 4\text{mol}(464\text{kJ/mol}))\end{aligned}$$

When solving inside the brackets, keep stoichiometry in mind.

$$\Delta H = ((1660\text{kJ}) + (611\text{kJ}) + (1494\text{kJ})) - ((2964\text{kJ}) + (1856\text{kJ}))$$

$$\Delta H = (3765\text{kJ}) - (4820\text{kJ})$$

The energy released from the bonds formed is subtracted from the energy absorbed by the bonds broken.

$$\Delta H = -1055 \text{ kJ} = 1.05_5 \times 10^3 \text{ kJ}$$

The calculated value is negative, meaning the reaction was exothermic.

Check Your Work

When comparing the bond energy values, we see that the product bonds (2 H-Br) have a greater magnitude than the reactant bonds (H-H and Br-Br), so we would expect this reaction to have an exothermic ΔH.

Show/Hide Watch Out!

Make sure you add up all bonds and consider the reaction stoichiometry.

Does your answer make chemical sense?

Show/Hide Answer

When any reaction occurs, energy will be absorbed and released; however, the overall sum can be endothermic (requires more energy than it releases) or exothermic (releases more energy than it requires). We can numerically observe this using the enthalpy change from the bond energies equation.

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CHEMICAL BONDING – MOLECULAR GEOMETRY AND HYBRIDIZATION

Chemical Bonding — Molecular Geometry and Hybridization: Identify Central Atom Hybridization

Question

Identify the hybridization of the central atom in each of the following molecules and ions that contain multiple bonds:

1. CS_2
2. Cl_2CO (C is the central atom)
3. Cl_2SO (S is the central atom)
4. SO_2F_2 (S is the central atom)
5. XeO_2F_2 (Xe is the central atom)

Show/Hide Answer

1. sp
2. sp^2
3. sp^3
4. sp^3
5. sp^3d

Refer to Section 5.3: Hybrid Atomic Orbitals (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Create a Lewis structure of the molecule. **Show/Hide Hint** Refer to Section 4.4: Lewis Symblos and Structures (2).
2. Determine the electron-pair geometry of the molecule. **Show/Hide Hint** Recall using VSEPR to determine electron-pair geometry. Refer to Section 5.1: Molecular Structure Polarity (3).
3. Identify the hybridization of the centre atom based on the molecules' electron-pair geometry. **Show/Hide Hint** The hybridization of the centre atom will be determined by the electron-pair geometry, not the atom itself. For example, in a linear molecule, the centre atoms hybridization will always be sp.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

1. CS_2

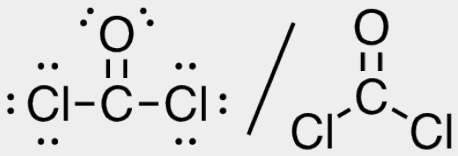
16 valence electrons, C central atom

This molecule has a linear electron-pair geometry: **sp hybridized**

(s + p)

2. Cl_2CO (C is the central atom)

24 valence electrons

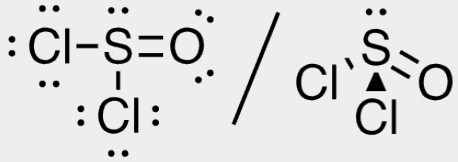


This molecule has a trigonal planar electron-pair geometry: **sp^2 hybridized**

(s + p + p)

3.Cl_2SO (S is the central atom)

26 valence electrons

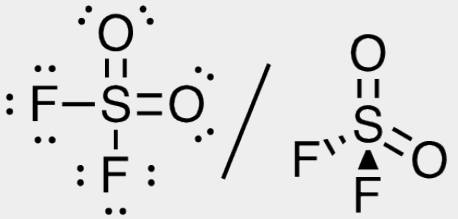


This molecule has a tetrahedral electron-pair geometry: **sp^3 hybridized**

(s + p + p + p)

4. SO_2F_2 (S is the central atom)

32 valence electrons

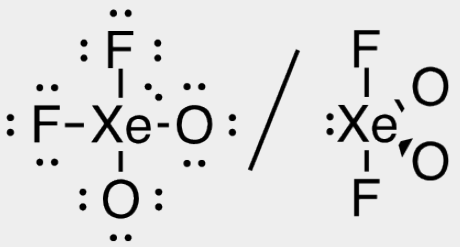


This molecule has a tetrahedral electron-pair geometry: **sp^3 hybridized**

(s + p + p + p)

5. XeO_2F_2 (Xe is the central atom)

34 valence electrons



This molecule has a trigonal bipyramidal electron-pair geometry: **sp^3d hybridized**

(s + p + p + p + d)

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a theory problem where you use your knowledge of molecular bonding and identify atomic orbital hybridization. **Show/Hide Resource** Refer to Section 5.3 Hybrid Atomic Orbitals (1).

What is the pattern associated with atomic orbital hybridization?

Show/Hide Think About This!

The hybridization of the centre atom will be determined by the electron-pair geometry, not the atom itself. For example, the centre atoms hybridization will always be sp in a linear molecule.

Number of electron domains (as determined by the number of bonding directions and lone pairs in the best Lewis structure) = Number of atomic orbitals required for hybridization.

Number of hybrid orbitals = Number of orbitals mixed.

Hybrid orbitals are named by type and number of orbitals mixed.

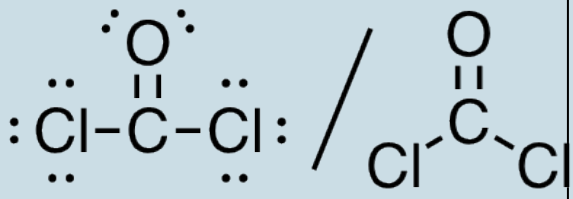
Show/Hide Don't Forget!

Recall the atomic orbitals: for n=2 there is 1 's' orbital (l=0) and 3 degenerate 'p' orbitals (l=1).

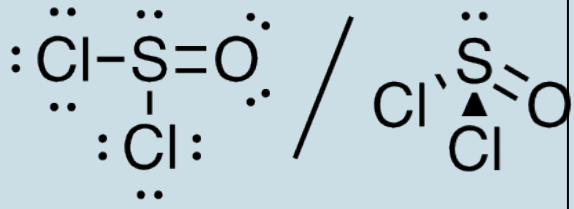
Note that 'd' orbitals (l=2) can only exist when n is greater than or equal to 3.

- 2 domains = 2 atomic orbitals must be hybridized = s + p = sp hybridization = linear electron domain geometry (EDG)
- 3 domains = 3 atomic orbitals must be hybridized = s + p + p = sp^2 hybridization = trigonal planar EDG
- 4 domains = 4 atomic orbitals must be hybridized = s + p + p + p = sp^3 hybridization = tetrahedral EDG
- 5 domains = 5 atomic orbitals must be hybridized = s + p + p + p + d = sp^3d hybridization = trigonal bipyramidal EDG
- 6 domains = 6 atomic orbitals must be hybridized = s + p + p + p + d + d = sp^3d^2 hybridization = octahedral EDG

Table 3: Complete Solution

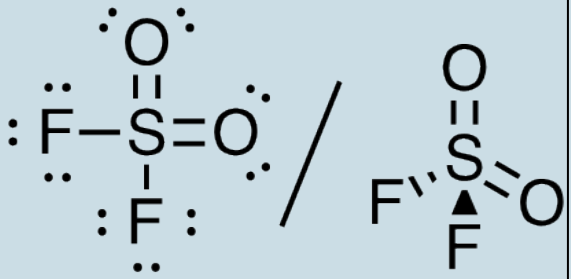
Complete Solution
CS_2 16 valence electrons, C central atom   This molecule has a linear electron-pair geometry: **sp hybridized**
2. Cl_2CO (C is the central atom) 24 valence electrons  This molecule has a trigonal planar electron-pair geometry : **sp^2 hybridized**

3. Cl_2SO (S is the central atom)
26 valence electrons



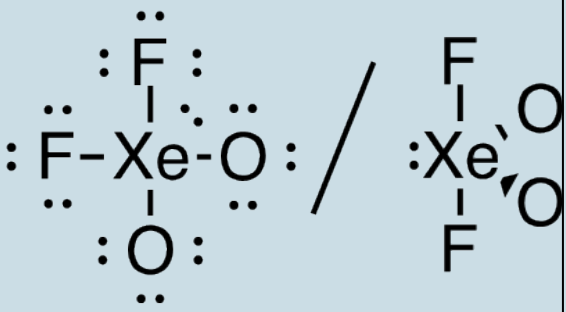
This molecule has a tetrahedral electron-pair geometry
: **sp^3 hybridized**

4. SO_2F_2 (S is the central atom)
32 valence electrons



This molecule has a tetrahedral electron-pair geometry
: **sp^3 hybridized**

5. XeO_2F_2 (Xe is the central atom)
34 valence electrons



This molecule has a trigonal bipyramidal electron-pair geometry: **sp^3d hybridized**

Check Your Work

Verify that:

- Your Lewis structure has all the valence electrons.
- You have counted the central atom's electron

domains correctly.

The name of our electron pair geometry and number of electron domains leads us to the correct hybridization.

Does your answer make chemical sense?

Show/Hide Answer

Hybrid orbitals form due to the covalent bonding within molecules. When 2 or more atoms create a covalent bond, their atomic orbitals will overlap to form these hybrid orbitals.

In this case, we are looking at the hybridization of the centre atom to see what kind of hybridization is happening to overlap with all the atoms. When molecules grow and involve more atoms, more bonds form, and thus, more orbitals become involved. This is why a linear molecule only uses two orbitals (s + p), while an octahedral molecule uses six (s + p + p + p + d + d).

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INTERMOLECULAR FORCES

Intermolecular Forces — Arrange Compounds in Order of Increasing Boiling Point

Question

Arrange each of the following sets of compounds in order of increasing boiling point temperature:

1. H_2O, HCl, SiH_4
2. Br_2, Cl_2, F_2
3. C_2H_6, CH_4, C_3H_8

Show/Hide Answer

1. $SiH_4 < HCl < H_2O$
2. $F_2 < Cl_2 < Br_2$
3. $CH_4 < C_2H_6 < C_3H_8$

Refer to Section 6.1: Intermolecular Forces (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify what intermolecular forces are acting on each of the molecules in question.
2. Rank the molecules based on their intermolecular forces (the stronger the forces, the higher the boiling point). **Show/Hide Hint** Intermolecular forces ranked from strongest to weakest: Hydrogen Bonding > Dipole-Dipole Forces > Dispersion Forces.
3. If two or more molecules have the same intermolecular forces, rank them based on the appropriate properties. **Show/Hide Hint** When comparing non-polar molecules, the larger and heavier a molecule is, the stronger the dispersion forces and the higher the boiling point temperature.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

1. HCl, H_2O, SiH_4

- SiH_4 — dispersion forces
- HCl — dispersion forces and dipole-dipole attractions
- H_2O — dispersion forces and hydrogen bonding

Hydrogen bonding is stronger than dipole-dipole attractions

Answer

$SiH_4 < HCl < H_2O$

2. F_2, Cl_2, Br_2

- F_2 — dispersion forces, 18 electrons
- Cl_2 — dispersion forces, 34 electrons
- Br_2 — dispersion forces, 70 electrons

All are non-polar, symmetrical diatomic molecules. The largest molecule, with the most electrons is the most polarizable and has the highest boiling point temperature.

Answer

$F_2 < Cl_2 < Br_2$

3. CH_4, C_2H_6, C_3H_8

- CH_4 — dispersion forces
- C_2H_6 — dispersion forces
- C_3H_8 — dispersion forces

All are non-polar molecules with dispersion forces.

The larger the molecule (longer carbon chains have a larger surface area), the stronger the temporary dipole interactions and the higher the boiling point temperature.

Answer

$CH_4 < C_2H_6 < C_3H_8$

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a theory problem where you rank the given compounds by their properties (boiling point). You can do this by evaluating the strength of their intermolecular forces. **Show/Hide Resource** Refer to Section 6.1: Intermolecular Forces (1).
How is boiling point impacted by intermolecular forces? **Show/Hide Don't Forget!** The stronger the intermolecular forces, the more energy is required to break the intermolecular forces and transition the compound between the liquid and gas phases. The stronger the intermolecular forces are, the more energy it would require to boil.
Recall the strength of the intermolecular forces. **Show/Hide Don't Forget!** Intermolecular forces = Hydrogen Bonding > Dipole-Dipole Forces > Dispersion Forces
If the molecules are impacted by the same intermolecular forces, which one will have the higher boiling point temperature? **Show/Hide Think About This!** If the molecules in question all have the same intermolecular forces, their boiling point temperatures will depend on the molecule's chemical properties. The size of the molecule will change its boiling point. The larger the molecule (molar mass/atomic radius/surface area), the higher the temperature.

Table 3: Complete Solution

Complete Solution
Identify all forces acting on each molecule. Hydrogen bonding is the strongest force, followed by dipole-dipole attractions, and the weakest force is the dispersion force. Dispersion forces are temporarily induced dipoles that act in all molecules. If dispersion forces are the only forces present, they determine the boiling point temperature. Dispersion forces are greater when the molecule has more electrons (i.e., more polarizable) or when the molecular structure has a greater surface area.
1. $SiH_4 < HCl < H_2O$ SiH_4 = Dispersion Forces HCl = Dipole-Dipole attractions + Dispersion forces H_2O = Hydrogen Bonding + Dispersion Forces
2. $F_2 < Cl_2 < Br_2$ F_2 = Dispersion Forces Cl_2 = Dispersion Forces Br_2 = Dispersion Forces All forces are the same type therefore it goes based on size. The largest atom has the highest boiling point temperature.
3. $CH_4 < C_2H_6 < C_3H_8$ All molecules have the same elements but differ in the size. The larger the molecule (larger size, molar mass and surface area), the higher the boiling point temperature.

Check Your Work

The question asked you to arrange in order of increasing boiling point temperature, so the lowest boiling point is first. The molecules will be arranged in order of weakest intermolecular attractions to the strongest (going from left to right).

Show/Hide Watch Out!

'<' means 'less than'

Make sure you are using this representation correctly.

Does your answer make chemical sense?

Show/Hide Answer

All molecules have intermolecular forces that determine the phase of a substance:

- Solids have the most intermolecular forces
- Liquids have less than solids
- Gases have the least

Transitioning between phases requires forming or breaking intermolecular forces. A boiling point is the transition between a liquid and gaseous state that requires breaking intermolecular forces.

Breaking intermolecular forces requires energy (heat). The intermolecular forces determine how much energy they require to break them: the stronger the force, the more energy it requires.

Hydrogen bonds are the strongest. This form occurs when hydrogen bonds to a molecule's most electronegative atoms (oxygen, nitrogen, or fluorine). It exists between adjacent molecules.

Dipole-dipole attractions are slightly weaker. Due to their molecular geometry, the molecules have permanent dipoles. The electron-rich

and electron-deficient regions of neighbouring molecules are attracted to each other.

Dispersion forces are the weakest and occur in all molecules due to the temporary displacement of electron clouds. When dispersion forces are the only intermolecular forces present, they can be ranked.

The instantaneous dipole is strongest when there are more electrons, the molecule is more polarizable, or the molecular shape has the greatest surface area.

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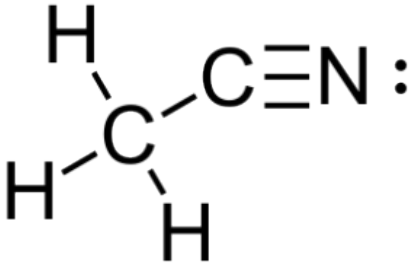
ORGANIC CHEMISTRY – BONDING AND STRUCTURE

Organic Chemistry — Bonding and Structure: Identify Hybridization and Sketch Orbital Overlap

Question

For the molecule acetonitrile:



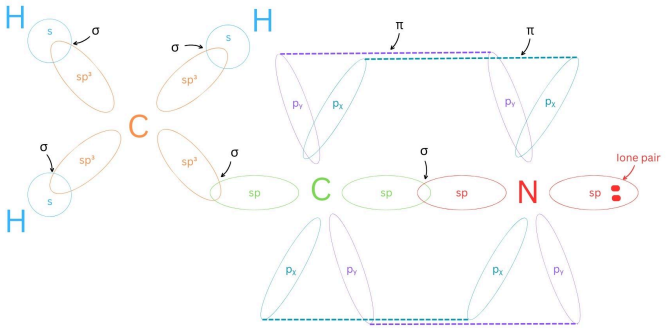
An acetonitrile molecule (Farmer et al. / LibreTexts) CC BY-SA 4.0 license

a. How many sigma and pi bonds does it have?
b. What orbitals overlap to form the C-H sigma bonds?
c. What orbitals overlap to form the C-C sigma bonds?
d. What orbitals overlap to form the C-N sigma bonds?
e. What orbitals overlap to form the C-N pi bonds?
f. What orbital contains the lone pair electrons on nitrogen?
g. Sketch the molecule showing the hybridized atomic orbital

'cloud' overlap.

Show/Hide Answer

a. 5 sigma and 2 pi.
b. A sp^3 hybrid orbital from carbon and an s orbital from hydrogen.
c. A sp^3 hybrid orbital from one carbon and a sp hybrid orbital from another carbon.
d. A sp hybrid orbital from carbon and a sp orbital from nitrogen.
e. A p_y and a p_z orbital from carbon and a p_y and p_z orbital from nitrogen.
f. A sp hybrid orbital.
g. Sketch below:



Refer to Section 7.1.7: sp Hybrid Orbitals and the Structure of Acetylene (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Count the number of single bonds (sigma) the molecule has. **Show/Hide Hint** There is a single bond between every single atom.
2. Count the number of double and triple bonds (pi) the molecule has. **Show/Hide Hint** Double and triple bonds are represented as second and third lines along a single bond.
3. Identify the hybridization of center atoms (the two carbon atoms). **Show/Hide Hint** The hybridization of the center atoms will depend on their electron domain geometry.
4. Identify the hybridization of the outer atoms, if any.
5. Identify which atoms are overlapping. The hybrid orbitals that overlap will depend on steps 3 and 4.
6. Sketch your diagram showing all overlaps and ensure you label everything.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

a. 5 sigma (single bonds) and 2 pi (one double and one triple bond).

b. A sp^3 hybrid orbital from carbon and an s orbital from hydrogen.

The hydrogen atoms are all unhybridized.

c. A sp^3 hybrid orbital from one carbon and a sp hybrid orbital from another carbon.

Both carbons are hybridized, but their electron domain geometries are not the same, meaning their hybridizations are different.

d. A sp hybrid orbital from carbon and a sp orbital from nitrogen.

Both carbon and nitrogen have a sp hybridization.

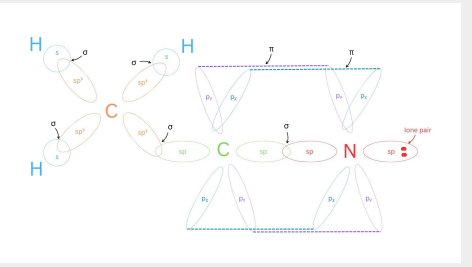
e. A p_y and a p_z orbital from carbon and a p_y and p_z orbital from nitrogen.

The ‘Y’ and ‘Z’ mean they have slightly different orientations.

f. A sp hybrid orbital.

Nitrogen has a linear electron domain geometry, meaning it has a sp hybridization in both directions.

g. Hand-drawn sketch below:



Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This is a theory type problem that tests your knowledge on atomic orbital hybridization. You must correctly identify the hybridization of multiple atoms in a molecule and sketch the orbital overlaps. **Show/Hide Resource** Refer to Section 7.1.7: sp Hybrid Orbitals and the Structure of Acetylene (1).
What are sigma and pi bonds? Recall that: • Sigma bonds are your single bonds. • Pi bonds are your double and triple bonds. **Show/Hide Don't Forget!** There is at least one sigma bond between each atom. Look at the bonds between your carbon and your nitrogen. How many lines do you see?
How do you identify atomic orbital hybridization? 1. Identify the electron domain geometry of your central atom. (in this case, the center atoms are carbons). 2. Your electron domain geometry will tell you the number of bonding directions attached to your atom. 3. Each bonding direction represents an orbital needed. **Show/Hide Think About This!** For instance, a tetrahedral must make four bonds, so it has an s+p+p+p (sp^3) hybridization. 4. Identify if your outer atoms require hybridization (if they do, they will also have multiple bonding directions, including lone pairs).

How do you know which orbitals are overlapping?
Show/Hide Think About This!
Each bond that is between the atoms will be an overlap. The hybridization of the orbitals will depend on the two atoms the bond is between.

How do you sketch the orbital overlaps?

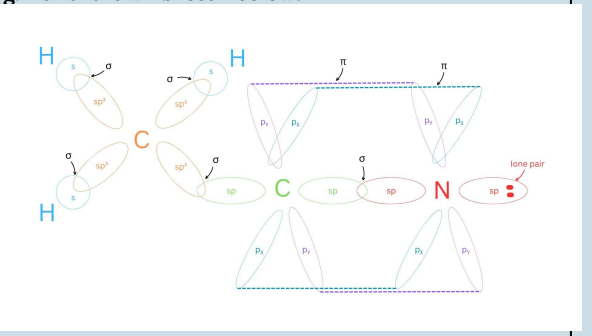
1. Begin by drawing your center atom with its orbitals in the shape of its electron domain geometry. (it is okay if they look like "sausages" if you label them with their hybridization)
2. Overlap these orbitals with orbitals representing the outer atoms.
3. Label these as sigma bonds.
4. The orbitals that overlap to form pi bonds are longer and skinnier than the sigma bonds. They overlap sideways, and therefore, connect above and below the sigma bond.

Table 3: Complete Solution

Complete Solution
a. 5 sigma (single bonds) and 2 pi (one double bond and one triple bond). There will always be a single bond between each atom in the molecule. A second or third line next to the single bond represents a double or triple bond. Count these in your Lewis structure form to identify the sigma and pi bonds.
b. A sp^3 hybrid orbital from carbon and an s orbital from hydrogen. This carbon atom makes bonds in four directions, which gives it a sp^3 hybridization. Three of these directions are hydrogen atoms. All of these hydrogens are unhybridized and have s orbitals. When the orbitals from the hydrogens and carbon overlap, they form a sigma bond.
c. A sp^3 hybrid orbital from one carbon and a sp hybrid orbital from another carbon. Although both atoms are hybridized, they have a different number of bonding directions, and therefore, one is sp^3 and the other is sp.
d. A sp hybrid orbital from carbon and a sp orbital from nitrogen. Both atoms bond in two different directions giving them sp orbital hybridization.
e. A p_y and a p_z orbital from carbon and a p_y and p_z orbital from nitrogen. These are the pi bonds. They are labelled with 'Y' and 'Z' as they have slightly different orientations on the axis. Pi orbitals make bonds above and below the sigma bond as they overlap sideways.

f. A sp hybrid orbital.
Nitrogen has two electron domain directions. One is towards the carbon in a triple bond, and the other is towards its lone pair; therefore, it has two hybridized sp orbitals. The orbital that contains nitrogen's lone pair is an sp orbital.

g. Hand-drawn sketch below:



Check Your Work

Review your answers with the sketch and the structure to make sure you have tracked all the bonds and orbitals

correctly. There are sigma bonds between each of the connected atoms, and the two pi bonds are the second and third bond between the C and N. Make sure that your identified orbitals match the electron domain geometry.

Does your answer make chemical sense?

Show/Hide Answer

Hybridized orbitals are created so all single bonds are made by the same orbitals and are equal. This is why hybridization will depend on the number of bonding directions the atom makes. The hybridization will likely vary between the atoms in the bond but will remain consistent within an atom itself.

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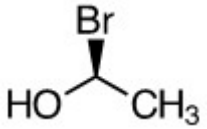
ORGANIC CHEMISTRY – STEREOCHEMISTRY

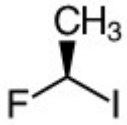
Organic Chemistry — Stereochemistry: Determine Stereocenter Configuration R or S

Question

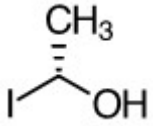
For the following compounds, assign R or S configurations for each stereocenter.

a. 

Compound A

b. 

Compound B

c. 

Compound C

Show/Hide Answer

a. S
b. R
c. R

Refer to Section 8.4: Absolute Configuration- R-S Sequence Rules (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify chiral carbon with four different groups attached
2. Assign priorities to substituents and label them one through four. **Show/Hide Resource** Refer to Section 8.4: Absolute Configuration- R-S Sequence Rules (1).
3. Rotate the molecule so that the lowest priority group (#4) is facing away from you (towards the back)
4. Count in the direction of 1 to 3 and identify if this is clockwise or counterclockwise. **Show/Hide Hint** Clockwise = R Counterclockwise = S

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

a. Compound A

- S
- Priority goes counterclockwise around the stereocenter.

b. Compound B

- R
- Priority goes clockwise around the stereocenter.

c. Compound C

- R
- The hydrogen (not shown in the line-dash-wedge structure) is

wedged towards the viewer; therefore, the chirality will be the opposite.

- Priority goes counterclockwise (S) around the stereocenter as drawn; therefore, the chiral center is R.

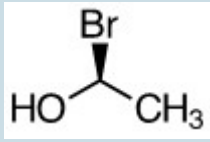
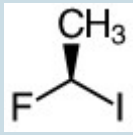
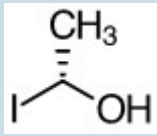
Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a theory problem where you assign the correct configuration to a carbon stereocenter (R or S). **Show/Hide Resource** Refer to Section 8.4: Absolute Configuration- R-S Sequence Rules (1).
For the following compounds, assign R or S configurations for each stereocenter. a.  *Compound A* b.  *Compound B* c.  *Compound C*

The rules to assign priority to substituents:

1. First, examine the atoms directly attached to the stereocenter of the compound. An atom with a higher atomic number takes precedence over an atom with a lower number. Hydrogen is the lowest possible priority atom because it has the lowest atomic number.

    a. Ensure that the lowest priority group is pointed away (dashed back)

2. If two or more substituents have the same element directly attached to chiral carbon, proceed along the substituent chains until you find a point of difference. Determine which chain has the first connection to an atom with the highest priority (the highest atomic number). That chain has the higher priority.
3. For assigning priority, treat multiple bonds as if each bond of the multiple bond is bonded to a unique atom. For example, an alkene substituent (CH_2=CH-) has a higher priority than an ethyl substituent (CH_3CH_2-).

Show/Hide Resource

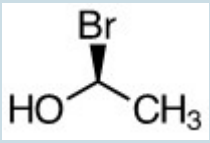
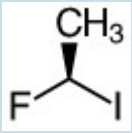
Refer to Section 8.4: Absolute Configuration- R-S Sequence Rules (1).

R vs S configuration

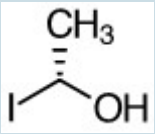
To identify the configuration of a stereocenter, you must identify if your order of priority goes in the clockwise or counterclockwise direction.

Clockwise = R
Counterclockwise = S

Table 3: Complete Solution

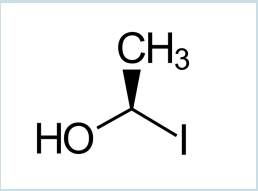
Complete Solution
a. Compound A  *Compound A* **Bromine** is the first priority (atomic number 35). **Oxygen** is the second priority (atomic number 8). **Carbon** is the third priority (atomic number 6). It goes counterclockwise around the stereocenter. **Answer: S**
b. Compound B  *Compound B* **Iodine** is the first priority (atomic number 53). **Fluorine** is the second priority (atomic number 9). **Carbon** is the third priority (atomic number 6). It goes clockwise around the stereocenter. **Answer: R**

c. Compound C



Compound C

Hydrogen is wedged forward, so you must rotate the molecule or reverse the stereochemistry determined, as drawn below.



Rotated Compound C

Hydrogen, the lowest priority group, is now dashed back.
Iodine is the first priority (atomic number 53).
Oxygen is the second priority (atomic number 8).
Carbon is the third priority (atomic number 6).

It goes counterclockwise around the stereocenter in the original figure.
It goes clockwise in the rotated molecule.

Answer: R

Check Your Work

Check to make sure you are following the guidelines of labelling priority. Ensure you go atom by atom.

Does your answer make chemical sense?

Show/Hide Answer

We use the "right hand" and "left hand" nomenclature to name the enantiomers of a chiral compound. We label the stereocenters as (R) or (S).

These naming rules provide an unambiguous name that indicates the molecule's stereochemistry.

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ORGANIC CHEMISTRY – CONFORMATIONAL ANALYSIS

Organic Chemistry — Conformational Analysis: Cycloalkane Chair Drawing and Interpretation

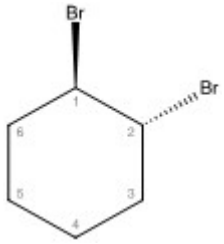
Question

Consider: Trans 1,2-dibromocyclohexane

a. Draw the simple line structure.
b. Draw the two chair confirmations numbering the carbons and labelling the positions as axial/equatorial.
c. Identify which is the more stable structure.

Show/Hide Answer

a.

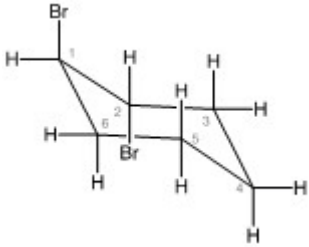


Simple line-dash-wedge structure

b. Chair conformations below:

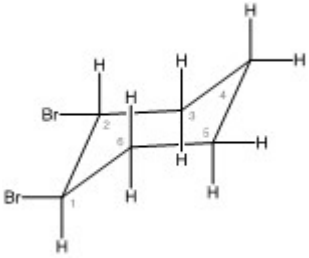
    i. Conformation 1, bromine substituants in axial

positions



Chair conformation 1 with bromine substituants in axial positions

ii. Conformation 2, bromine substituants in equatorial positions



Chair conformation 2 with bromine substituants in equatorial positions

c. The conformation with the bulkiest groups in equatorial positions is most stable; 1,3-diaxial interactions are minimized.

Refer to Section 9.4: Cyclohexane- A Strain-Free Cycloalkane (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Use the provided molecule name to draw its simple line structure.
2. Draw the templates of the two possible conformations. **Show/Hide Resource** Refer to Section 9.4: Cyclohexane- A Strain-Free Cycloalkane (1).
3. Number the carbons one through six.
4. Label the axial and equatorial positions.
5. Convert your simple line structure into your two templates.
6. Compare the two conformations and identify which one would be the most stable. **Show/Hide Hint** The most stable conformation is the one that has the least number of interactions between substituent atoms. The larger, more electronegative atoms are favoured in the **equatorial** positions as they will be impacted by less interactions with surrounding atoms. Refer to Section 9.5: Substituted Cyclohexanes (2).

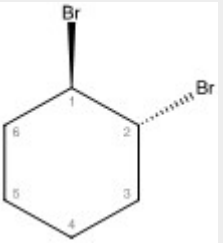
Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

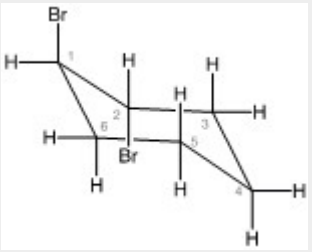
a. Simple Line Structure



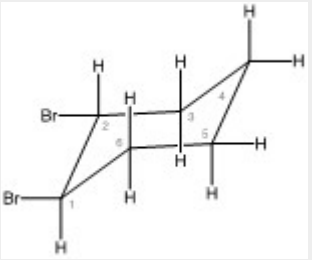
This molecule is trans, meaning one bromine is dashed back, and one is wedged forward. These bromines are on a six-carbon ring and attached to carbons one and two.

b. Chair conformations

i. Conformation 1 — Both bromines are in axial positions.



ii. Conformation 2 — Both bromines are in equatorial positions.



c. Conformation 2 is the most stable.

It has the least 1,3-diaxial interactions between the bromine groups and surrounding atoms.

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution Ideas

Guided Solution
This question is a theory problem where you test your understanding of cycloalkane naming and chair conformations. **Show/Hide Resource** Refer to Section 9.4: Cyclohexane- A Strain-Free Cycloalkane (1).

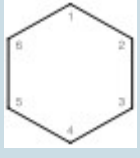
Recall how to sketch a line structure:

1. Identify if the structure is Cis or Trans.

Show/Hide Think About This!
Trans 1,2-dibromocyclohexane
This means one substituent is dashed back, and one is wedged forward.

2. Determine if the parent chain is in the form of a chain or ring. (This will be at the end of the name).

Show/Hide Don't Forget!

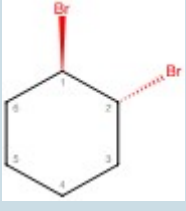


Cyclohexane

Trans 1,2-dibromo**cyclohexane**

3. Identify substituent atoms and which carbons they are connected to.

Show/Hide Don't Forget!



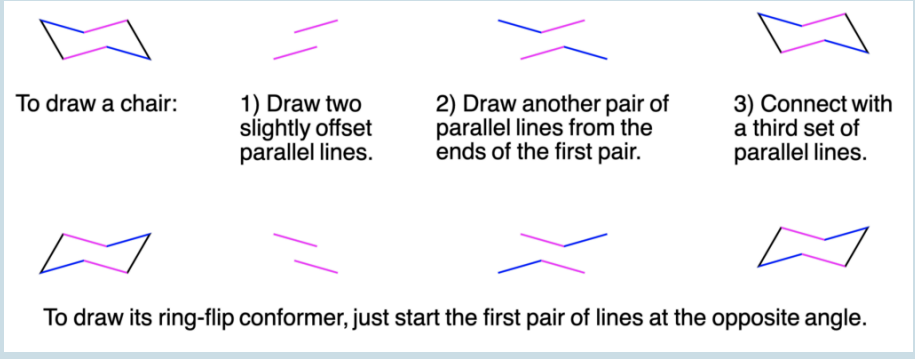
Trans
1,2-dibromocyclohexane

Trans **1,2-dibromo**cyclohexane.

How to draw the chair conformation:

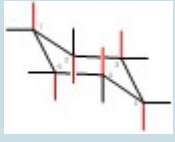
1. Draw two slightly offset parallel lines.
2. Draw another pair of parallel lines from the ends of the first pair.
3. Connect with the third set of parallel lines.
4. Start the first pair of lines at the opposite angle to draw its ring-flip conformer.

Show/Hide Don't Forget!

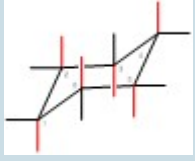


How to draw a chair conformation (Farmer et al. / LibreTexts) CC BY-SA license

Identify the axial and equatorial positions. Identify if the structure is Cis or Trans.
Show/Hide Don't Forget!
Axial positions in red:

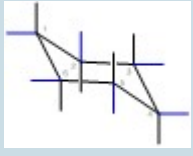


Conformation 1 axial positions

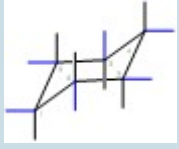


Conformation 2 axial positions

Equatorial Positions in blue:



Conformation 1
equitorial positions



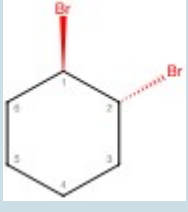
Conformation 2
equitorial positions

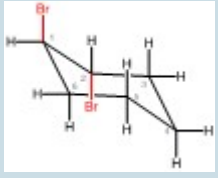
Convert your simple line structure to your chair conformation:

1. Match the numbered carbons from your line structure to your template.

2. Recall that substituents wedged forward will be on the higher ('up') position and the substituent dashed backwards will be on the lower ('down') position.

Show/Hide Watch Out!





Simple line structure converted to a chair conformation

Identify the more stable conformation.

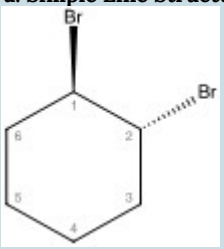
Show/Hide Don't Forget!

The most stable conformation is the one that has the least number of interactions between substituent atoms. The larger, more electronegative atoms are favoured in the equatorial positions as they will be impacted by fewer interactions with surrounding atoms.

Show/Hide Resource

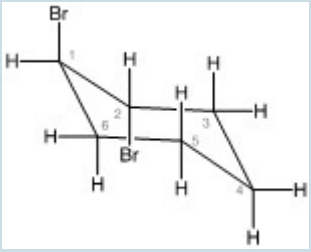
Refer to Section 9.5: Substituted Cyclohexanes (2).

Table 3: Complete Solution

Complete Solution
a. Simple Line Structure    This molecule is trans, meaning one bromine is dashed back and one is wedged forward. These bromines are on a six-carbon ring and attached to carbons one and two.

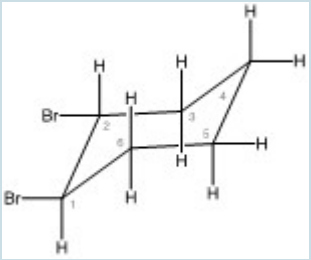
b. Chair Conformations

i. Conformation 1



Both bromines are in axial positions. The bromine on carbon one is in the highest position, and the bromine on carbon two is in the lowest position.

ii. Conformation 2



Both bromines are in equatorial positions. All axial and equatorial positions switch. The bromine on carbon one is in the highest position, and the bromine on carbon two is in the lowest position.

c. The equatorial conformation is the most stable.

It has the fewest interactions between the bromine groups and surrounding atoms because they are both in equatorial positions.

Check Your Work

To analyze if your answer is correct, evaluate which conformation has more equatorial positions and given the most space for any larger groups.

Why does this answer make chemical sense?

Show/Hide Answer

In the equatorial positions, the larger bromine atoms are the farthest away from all other substituent atoms. The more 1,3-diaxial interactions there are, the more energy the conformation requires, and the less stable the conformation would be.

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2. LibreTexts. 9.5: Substituted Cyclohexanes. In *CHEM 1500: Chemical Bonding and Organic Chemistry*. LibreTexts, 2022. https://chem.libretexts.org/Courses/Thompson_Rivers_University/CHEM1500%3A_Chemical_Bonding_and_Organic_Chemistry/09%3A_Organic_Chemistry_III_-_Conformational_Analysis/9.05%3A_Substituted_Cyclohexanes.
3. Blackstock, L; Brewer, S.; Jensen, A. 9.2: Question 9.E.2 PASS – Cycloalkane Chair, Axial vs. Equatorial, Most Stable. In *PASS Chemistry Book CHEM 1500*. LibreTexts, 2023. https://chem.libretexts.org/Courses/Thompson_Rivers_University/PASS_Chemistry_Book_CHEM_1500/09%3A_Organic_Chemistry_III_-_Conformational_Analysis/

9.03%3A_Question_9.E.2new_PASS_-_cycloalkane_chair_axial_vs._equatorial_most_stable.

4. Farmer, S.; Kennepohl, D.; Morsch, L.; Cunningham, K.; Reusch W., Bruner, R. 4.5: Conformations of Cyclohexane. In *Organic Chemistry (Morsch et al.)*. LibreTexts, 2022. https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Organic_Chemistry_(Morsch_et_al.)/04%3A_Organic_Compounds-_Cycloalkanes_and_their_Stereochemistry/4.05%3A_Conformations_of_Cyclohexane.

IDEAL GASES

Ideal Gases: General Gas Law, Changing Temperatures

Question

A spray can, which has a pressure of 1344 torr at 23°C, is used until it is empty, except for the propellent gas.

If the can is thrown into a fire at 475°C, what will be the pressure in the hot can in atmospheres?

Show/Hide Answer

Final pressure = 4.47 atm

Refer to Section 2.3 Relating Pressure, Volume, Amount, and Temperature – The Ideal Gas Law (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify the information given in the question and what conditions are changing.
2. Identify what the question is asking you to calculate and what variable it would be represented by.
3. Choose an equation that compares the correct relationships. **Show/Hide Hint** You will need to manipulate the equation to compare the initial and final conditions.
4. Do any necessary conversions to ensure you are using the appropriate units. **Show/Hide Hint** Calculations for ideal gases using temperature must have the temperature in Kelvin. Since we want our final pressure in atmospheres, we can convert the initial pressure to atmospheres in our calculation.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

$$\frac{P_i V_i}{n_i T_i} = \frac{P_f V_f}{n_f T_f}$$

$$\frac{P_i T_f}{T_i} = P_f$$

$$\frac{1344 \text{ torr}}{1} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 1.768 \text{ atm}$$

$$23^\circ \text{C} + 273.15 = 296 \text{K}$$

$$475^\circ \text{C} + 273.15 = 748 \text{K}$$

$$\frac{P_i T_f}{T_i} = P_f$$

$$\frac{(1.77 \text{ atm})(748 \text{k})}{296 \text{k}} = P_f$$

$$P_f = 4.47 \text{ atm}$$

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a calculation problem where we use the ideal gas laws to calculate how the pressure would change due to a change in conditions. **Show/Hide Resource** Refer to Section 2.3 Relating Pressure, Volume, Amount, and Temperature – The Ideal Gas Law (1).
A spray can, which has a pressure of 1344 torr at 23°C, is used until it is empty except for the propellent gas. If the can is thrown into a fire at **475°C, what will be the pressure** in the hot can in atmospheres? The question asks you to find the pressure after the can is heated. **Show/Hide Think About This!** The question tells us that the initial pressure is 1344 torr and the initial temperature is 23°C. It also gives us the final temperature, which is 475°C. We also know that the amount of gas inside the can stays constant before and after we evaluate its pressure.
If the can is heated, you can expect the final pressure to be higher than the initial pressure. **Show/Hide Watch Out!** Your calculated final pressure should be higher than the initial pressure. If it is not, then you must have made an error somewhere.

Recall the ideal gas equation.

Show/Hide Don't Forget!

$$PV=nRT$$

How can we manipulate it to find the information we want?

Show/Hide Think About This!

We know that the ideal gas equation is PV = nRT, where 'R' is a constant. Because this value is constant, we can isolate it and create a derived equation where the initial values equal the final values.

$$\begin{gathered}
\frac{P_i}{V_i n_i T_i}=R=\frac{P_f}{V_f n_f T_f} \\
\frac{P_i}{V_i n_i T_i}=\frac{P_f}{V_f n_f T_f}
\end{gathered}$$

Now, we can get rid of values that stay constant during this problem. In this case, the volume and number of moles remain constant; this means we can remove them. We can divide them out since they are the same on both sides.

$$\frac{P_i T_f}{T_i}=P_f$$

Once we isolate for our desired variable, we get our new equation, which we can plug in and use to solve for the final pressure.

Before plugging into your equation, ensure you use values with the correct units. If necessary, use conversion factors.

Show/Hide Don't Forget!

Since we want our final pressure in atmospheres, we will convert the initial pressure to atmospheres.

The pressure of an ideal gas is proportional to the temperature in Kelvin. Because of this, we must convert our temperatures to Kelvin to use our derived relationship.

Table 3: Complete Solution

Complete Solution
Conversions: Torr to atmospheres: \begin{equation} \frac{1344 \text { torr }}{1} \times \frac{1 \text { atm }}{760 \text { torr }}=1 . \mathrm{7 6}_8 \text { atm } \end{equation} Degree Celsius to Kelvin: \begin{equation} \begin{gathered} 23^{\circ} \mathrm{C}+273.15=\mathrm{2 9 6 K} \\ 475^{\circ} \mathrm{C}+273.15=\mathrm{7 4 8 K} \end{gathered} \end{equation}
Manipulating the ideal gas equation: \begin{equation} \mathrm{P V=n R T} \end{equation}
R is a constant, which means we can rearrange and isolate 'R.' Since it is a constant, the initial and final conditions will equal the 'R.' \begin{equation} \frac{\mathrm{P_i V_i}}{\mathrm{n_i T_i}}=\mathrm{R}=\frac{\mathrm{P_f V_f}}{\mathrm{n_f T_f}} \end{equation}
Since they both equal 'R,' they also equal each other. \begin{equation} \frac{\mathrm{P_i V_i}}{\mathrm{n_i T_i}}=\frac{\mathrm{P_f V_f}}{\mathrm{n_f T_f}} \end{equation}

Now, we can cancel out the variables with values that do not change for this problem. In this case, the volume and number of moles do not change. We can remove them from our equation.

$$\frac{\mathrm{P_i}}{\mathrm{T_i}}=\frac{\mathrm{P_f}}{\mathrm{T_f}}$$

Now, all we have to do is to isolate the desired variable, Pf.

$$\frac{\mathrm{P_i}\ \mathrm{T_f}}{\mathrm{T_i}}=\mathrm{P_f}$$

Plugging into the derived equation:

$$\begin{gathered}\frac{(1.77\ \mathrm{atm})(748\ \mathrm{K})}{\mathrm{296\ K}}=\mathrm{P_f}\\ \mathrm{P_f}=4.47\ \mathrm{atm}\end{gathered}$$

Check Your Work

If our calculation shows the final pressure as unchanged

or less than the initial pressure, an error likely occurred in the calculation process.

Does your answer make chemical sense?

Show/Hide Answer

We expected the final pressure to be higher than the initial pressure, and it is:

Pi = 1.77 atm, Pf = 4.47 atm

Amonton's Law says temperature and pressure are proportional, meaning that as temperature increases, pressure also increases. Using this knowledge, we know that our calculation must show that the final pressure is higher than the initial pressure.

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THERMOCHEMISTRY

Thermochemistry: Interpreting Thermochemical Equations and Sketching Enthalpy Diagrams

Question

Given the following thermochemical equation,

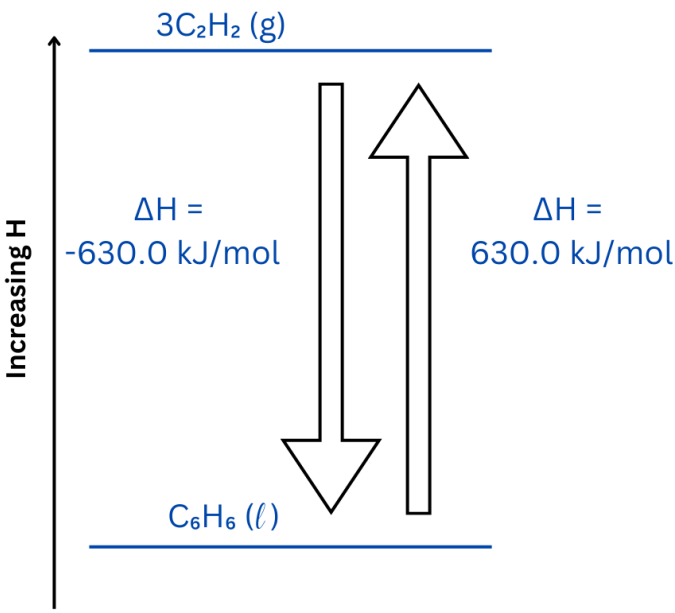
C_6H_6 (l) → $3C_2H_2$ (g) $\Delta H = 630.0$ kJ/mol.

Write the complete thermochemical equation for the reverse reaction. Sketch an enthalpy diagram showing the relative positions of all species and include arrows indicating both of the above reactions with appropriate values for ΔH reaction.

Show/Hide Answer

$3C_2H_2$ (g) → C_6H_6 (l)

$\Delta H = -630.0$ kJ/mol



Refer to Section 3.4: Enthalpy of Reaction (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify the reactants and products for the forward reaction.
2. Swap them to give the reverse reaction. **Show/Hide Hint** Recall that reversing a reaction changes the sign of ΔH. Refer to Section 3.4: Enthalpy of Reaction (1).
3. Manipulate the enthalpy value from the forward reaction to give the value for the reverse reaction. **Show/Hide Hint** The amount of energy will be the same regardless of the reaction's direction. However, energy is absorbed in one direction and released in the other.
4. Create the enthalpy diagram showing the reaction in both directions.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

$$3C_2H_2\,(g) \rightarrow C_6H_6\,(l)$$

The reactant and product from the forward reaction switch places.

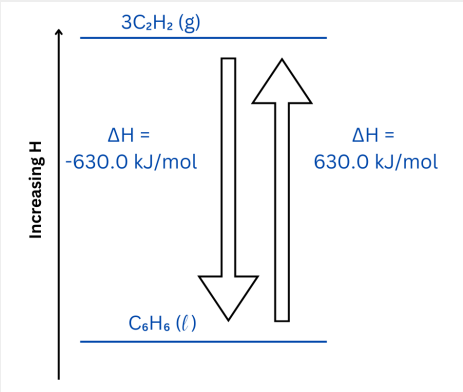
$$\Delta H = -630.0\ kJ/mol$$

The sign of the enthalpy value for the forward reaction flips.

The thermochemical equation for the reverse reaction is:

$$3C_2H_2\,(g) \rightarrow C_6H_6\,(l)\,\Delta H = -630.0\ kJ/mol$$

The enthalpy diagram shows the relative positions of all species and includes arrows indicating both of the above reactions with appropriate values for ΔH reaction.



The up arrow represents the forward reaction, and the down arrow represents the reverse reaction.

Refer to Section 3.4: Enthalpy of Reaction (1).

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a theory problem that tests your knowledge of enthalpy. You must find the reverse reaction given its forward reaction, find its enthalpy and sketch the diagram representing the reaction in both directions. **Show/Hide Resource** Refer to Section 3.4: Enthalpy of Reaction (1).
You have information about the forward reaction; how can it be manipulated to give the reverse reaction? **Show/Hide Think About This!** Recall that if a reaction is reversed, the reactants and products switch sides, and the opposite reaction occurs.
What about the enthalpy? **Show/Hide Don't Forget!** The magnitude of energy will be the same regardless of the reaction's direction. However, energy is absorbed in one direction and released in the other.
If the enthalpy change for the forward reaction is positive, what do you expect the enthalpy change for the reverse reaction to be? **Show/Hide Watch Out!** If the enthalpy for the forward reaction is positive, you can expect the enthalpy for the reverse reaction to be negative.

Recall how to sketch an enthalpy diagram:

- On the left-hand side, draw an arrow and label its direction with the corresponding enthalpy change (either increasing or decreasing).
- Draw your reactants and an arrow leading to the products.

Show/Hide Watch Out!

If the reaction is endothermic (meaning it has a positive enthalpy), the products will be higher than the reactants, and the reaction arrow will point upwards. The opposite is true for an exothermic reaction.

Show/Hide Don't Forget!

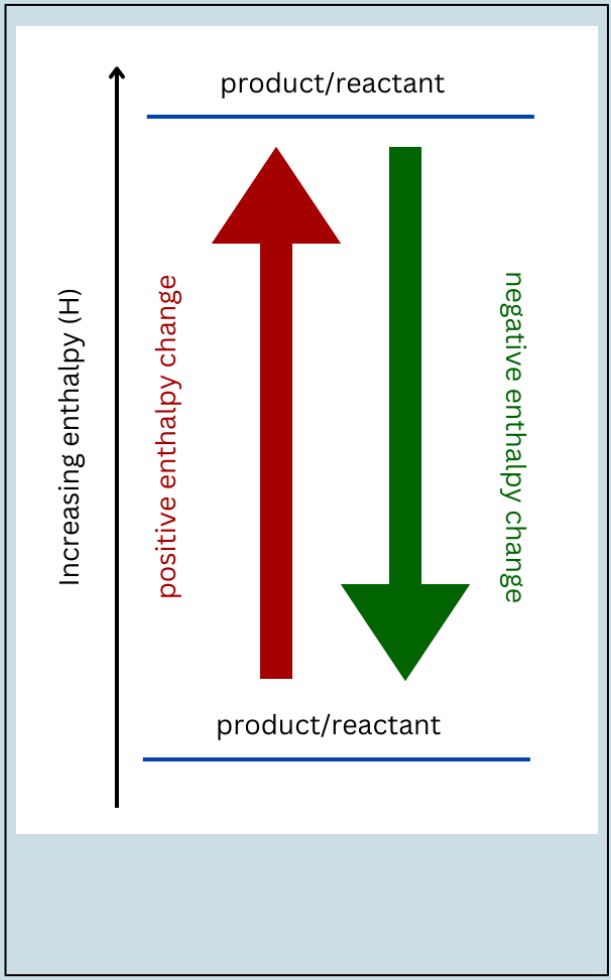
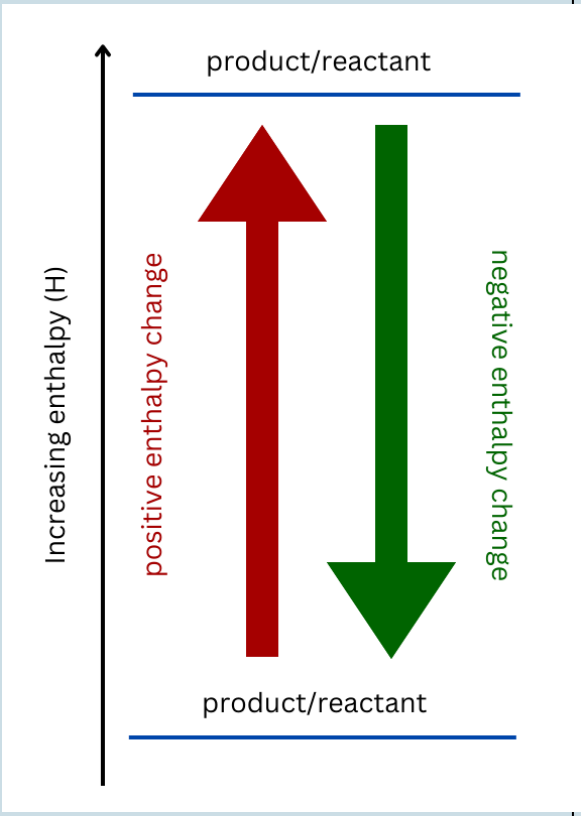

product/reactant
Increasing enthalpy (H)
positive enthalpy change
negative enthalpy change
product/reactant

Table 3: Complete Solution

Complete Solution
Given: C_6H_6 (l) → $3C_2H_2$ (g) ΔH = 630.0 kJ/mol **Reverse the reaction** $3C_2H_2$ (g) → C_6H_6 (l) The reactant and product from the forward reaction switch places. In the forward reaction three C_2H_2 molecules break to form one C_6H_6 molecule. In the reverse reaction one C_6H_6 molecule is broken to form three C_2H_2 molecules.
Change the sign of ΔH ΔH = 630.0 kJ/molThe sign of the enthalpy value for the forward reaction is flipped to give the enthalpy value of the reverse reaction. This will always be the case since one way is endothermic while the other is exothermic.

Now, use the enthalpy diagram template to position the reactant and product, paying attention to the sign of ΔH in each case to determine relative positions.

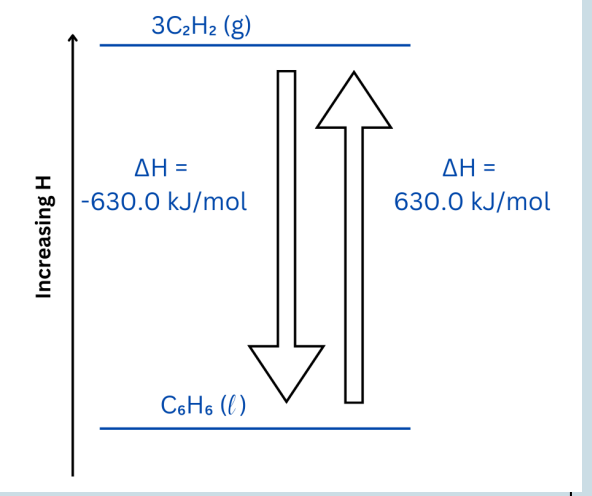


The forward and reverse reactions are placed on the enthalpy diagram. The upward arrow represents the forward reaction, and the downward arrow represents the reverse reaction. The forward reaction is endothermic meaning it requires an input of energy. The

reverse reaction is an exothermic reaction meaning energy is released from the reaction.

Answer: The complete thermochemical equation for the reverse reaction is therefore:
$3C_2H_2$ (g) → C_6H_6 (l) ΔH = -630.0 kJ/mol

Both reactions are represented on the enthalpy diagram:



Check Your Work

A complete thermochemical equation has a reactant, product and value of ΔH.

This question involves an endothermic reaction, represented by the up arrow on the enthalpy diagram. The reverse reaction is exothermic and represented as the up arrow.

Watch Out!

Make sure your 'down' arrow represents the exothermic reaction and your 'up' arrow represents the endothermic reaction.

Does your answer make chemical sense?

Show/Hide Answer

For a chemical reaction, the enthalpy of the reaction (ΔHrxn) is the difference

in enthalpy between products and reactants. Reversing a chemical reaction reverses the sign of the enthalpy. This reversal makes sense because a reaction occurring in one direction will be either exothermic or endothermic when the bonds break and form.

Therefore, if the same reaction happens but the opposite bonds break and form, the enthalpy will be in the opposite direction. Because of this, if the forward reaction is endothermic, the reverse reaction will be exothermic and vice versa.

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KINETICS

Kinetics: Writing Rate Expressions

Question

Ozone decomposes to oxygen according to the equation $2O_3(g) \rightarrow 3O_2(g)$.

Write the equation that relates the rate expressions for this reaction in terms of the disappearance of O_3 and the formation of oxygen.

Show/Hide Answer

$$\text{Rate Expression} = -\frac{1}{2}\left(\frac{\Delta[O_3]}{\Delta t}\right) = \frac{1}{3}\left(\frac{\Delta[O_2]}{\Delta t}\right)$$

Refer to Section 4.2: Chemical Reaction Rates (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify stoichiometry. **Show/Hide Hint** Make sure the reaction is balanced.
2. Identify what are reactants and what are products. **Show/Hide Hint** For general reaction: aA + bB → cC + dD $\text{rate} = -\frac{1}{a}\frac{\Delta[A]}{\Delta t} = -\frac{1}{b}\frac{\Delta[B]}{\Delta t} = \frac{1}{c}\frac{\Delta[C]}{\Delta t} = \frac{1}{d}\frac{\Delta[D]}{\Delta t}$

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

$$\text{Rate} = -\frac{1}{2}\left(\frac{\Delta\,[\text{O}_3]}{\Delta \text{t}}\right) = \frac{1}{3}\left(\frac{\Delta\,[\text{O}_2]}{\Delta \text{t}}\right)$$

Ozone is a reactant, so it requires a negative. The stoichiometric coefficient from the balanced reaction is 2, so the rate is multiplied by one-half.

Oxygen is a product, so it is positive. The stoichiometric coefficient is 3, so the rate is multiplied by one-third.

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a theory problem that requires you to set up the reaction rates for the given reaction. **Show/Hide Resource** Refer to Section 4.2: Chemical Reaction Rates (1).
What is a chemical reaction rate? Rate of formation/ decomposition = $\frac{(\text{change in concentration})}{(\text{time interval})}$ **Show/Hide Think About This!** Change in concentration = $\Delta[\text{reactant or product}] = [\ ]_f - [\ ]_i$ $\text{time interval} = \Delta t = t_f - t_i$
The reaction is written as $2O_3(g) \rightarrow 3O_2(g)$, meaning for the breakdown of every two ozone molecules, three oxygen molecules are produced. How is this used in your expression? **Show/Hide Think About This!** The stoichiometry in the reaction is used as coefficients in your rates. However, they are used in their reciprocal form.

Recall that the amount of reactants present decrease over time, and the amount of products increase. How is this information represented in your expression?

Show/Hide Don't Forget!

Reaction rates are positive. In the reaction rate expression, reacting compounds/molecules will have a negative sign in front of their fraction to indicate that they are decreasing in concentration over reaction time, while product terms will be positive to indicate they are increasing in concentration over reaction time.

$$\text{For a reaction A} \rightarrow \text{B}$$

$$\text{rate} = -\frac{\Delta[\text{A}]}{\Delta \text{t}}$$

$$\text{rate} = \frac{\Delta[\text{B}]}{\Delta \text{t}}$$

Check Your Work: Reactants decrease in concentration as the reaction proceeds while products increase. The reactant term has a negative sign, and the product term has a positive sign.

Show/Hide Watch Out!

Make sure the reactant has a negative sign in front of the concentration, and you use the 'Δ' symbol to represent change in both the numerator and denominator. Square brackets in the numerator represent concentration in M (moles/litre).

Show/Hide Think About This!

The number of products formed will always equal the number of reactants used. This is because reactants break to turn into products.

In a reaction rate, the reactants will need a negative sign. This is because the number of reactants will always decrease (negative) over time.

When a negative is multiplied by a negative, it becomes a positive, making the two rates equal.

Table 3: Complete Solution

Complete Solution
$$\text{Rate Expression } = -\frac{1}{2}\left(\frac{\Delta\left[O_3\right]}{\Delta t}\right) = \frac{1}{3}\left(\frac{\Delta\left[O_2\right]}{\Delta t}\right)$$ Ozone is a reactant, so it requires a negative. Two are used, so the expression is multiplied by one-half.Oxygen is a product, so it is positive. Three are used, so the rate is multiplied by one-third.Square brackets representing concentration in molarity are used for the numerator because we are looking at the change in the concentrations through time. The products will increase over time, and the reactants will decrease.

Check Your Work

Make sure the reactant term has a negative sign in front of the concentration, and you use the 'Δ' symbol to represent change in both the numerator and denominator. Square brackets in the numerator represent concentration in M (moles/litre). Stoichiometric coefficients show up as appropriate fractions to relate the change in reactants and products.

Does your answer make chemical sense?

Show/Hide Answer

The rate expression formula reflects the balanced stoichiometry for the reaction equation incorporated as a fraction coefficient term. The reactant term is negative because the concentration is decreasing overtime as the reactant molecules are transformed into product molecules. The product terms are positive because the concentration of product molecules is increasing over time as the reaction proceeds.

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EQUILIBRIUM

Chemical Equilibrium: Applying Le Chatelier's Principle to Determine Impact of Changing Pressure

Question

Consider the following equilibria:

$2NH_3\,(g) \rightleftharpoons N_2\,(g) + 3H_2\,(g)$; $\Delta H = 92kJ$

a. How will an increase in temperature affect the following equilibria?
b. How will a decrease in the volume of the reaction vessel affect the equilibria?

Show/Hide Answer

a. ΔT increases = System shifts right
b. ΔV decreases = System shifts left

Refer to Section 5.5: Shifting Equilibria – Le Chatelier's Principle (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify if the reaction is endothermic or exothermic. **Show/Hide Hint** Look at the sign of the provided enthalpy ΔH value: • A positive value indicates an endothermic reaction (heat is absorbed). • A negative value is exothermic (heat is released).
2. Identify which direction the reaction would shift to minimize this disturbance. **Show/Hide Hint** Is heat a reactant or a product for the reaction? If the amount of reactant or product increases, the equilibria will shift in the direction that reduces the reactant or product.
3. Identify which side of the reaction (the products or reactants) has higher moles. **Show/Hide Hint** Gases expand to fill the entire volume of their container. The concentration of a gas (mol/L) is defined by the container volume.
4. Identify which direction the reaction would shift to minimize this disturbance. **Show/Hide Hint** Equilibrium can be defined through concentration (K_c) or pressure (K_p). How does the disturbance to volume relate to pressure? Shifting to the side that has fewer total moles of gas will decrease the pressure in the container; meanwhile, shifting to the side with a higher total of gas moles will increase the pressure.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

a. ΔT increases = System shifts right

This is an endothermic reaction with a positive ΔH value. The reaction minimizes the disturbance of the increased temperature by favouring the forward reaction to absorb heat from the surroundings to form more products.

b. ΔV decreases = System shifts left

Pressure increases as volume

decreases. The reaction minimizes the disturbance of the shrinking container by favouring the reverse reaction, forming more reactants, which have less total moles of gas.

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a theory problem where you will use your knowledge of Le Chatelier's Principle to predict how a system will shift to counteract different disturbances to re-achieve equilibrium. **Show/Hide Resource** Refer to Section 5.5: Shifting Equilibria – Le Chatelier's Principle (1).
1. When the temperature is increased. Recall how to identify if a reaction is endothermic or exothermic. In this question you are given the enthalpy for the reaction. In this case the enthalpy is a positive value. **Show/Hide Don't Forget!** A positive enthalpy value means heat energy must be absorbed by the system from the surroundings for this reaction to occur. This reaction is endothermic. Knowing the reaction type will help because we now know which side of the reaction the energy (in the form of heat) is. **Show/Hide Think About This!** Consider 'heat' to be a reactant for an endothermic reaction. Since the temperature is increasing (adding more heat), we can predict how the system will shift to counteract the disturbance. **Show/Hide Watch Out!** The disturbance is increasing the amount of a reactant (i.e., heat). Therefore, the reaction will shift right to favour the forward reaction, absorbing (i.e., decreasing) heat and forming more products.

2. When the contained volume is decreased.

We can predict the shift of the reaction due to a change in volume by analyzing which side of the reaction has the greatest number of moles of gas.

Show/Hide Don't Forget!

To identify which side has a higher number of moles, look at the physical states of each species as well as the stoichiometric coefficients of all gas species on both the reactant and product sides.

Show/Hide Watch Out!

In this case the stoichiometry is two on the reactant side and four on the product side.

Consider how a change in volume impacts concentration and pressure of gases.

Show/Hide Think About This!

As volume decreases, concentration (mol/L) increases. As volume increases, concentration decreases.

Because the K expression uses the stoichiometric coefficients as exponents, if the total number of gas moles on the reactant and product sides of the reaction is different, the concentrations will be disproportionately impacted by a change in volume.

Show/Hide Don't Forget!

Recall that if the volume increases, the reaction will shift to the side with the higher moles. If the volume decreases, the reaction will shift to the side with lower moles.

Table 3: Complete Solution

Complete Solution
a. ΔT increases = Shifts right $Heat_{energy} + 2NH_3\,(g) \rightleftharpoons N_2\,(g) + 3H_2\,(g)$ The reaction is endothermic, meaning heat is a reactant. Equilibrium is achieved when the concentration of reactants and products no longer changes over time. An increase in temperature is an increase in the amount of a reactant. The reaction minimizes the disturbance of the increased temperature (added heat) by proceeding in the forward direction, absorbing heat from the surroundings.
b. ΔV decreases = Shifts left $2NH_3\,(g) \rightleftharpoons N_2\,(g) + 3H_2\,(g)$ Total moles of gas on the reactant side vs. product side (2 vs. 4); the reactants have fewer total moles of gas species. The reaction minimizes the disturbance of the shrinking container (which increases the pressure) by proceeding in the reverse direction. Shifting towards the side of the reaction with the least amount of moles of gas (reactants) will reduce the pressure inside the container, counteracting the disturbance to return to equilibrium.

Check Your Work

Think about the K expression. How does the disturbance impact the distribution of products and reactants.

Show/Hide Think About This!

1. Consider heat as a reactant for endothermic reactions and a product for exothermic reactions.
2. Consider how the change in volume of a container impacts the total pressure.

Show/Hide Answer

Systems at equilibrium can be disturbed by changes to temperature, concentration, and, in some cases, volume and pressure. If the number of moles of gas is different on the reactant and product sides of the reaction equation, volume and pressure changes

will disproportionately impact the distribution of products and reactants, disturbing the equilibrium.

Le Chatelier's Principle describes the system's response to these disturbances:

- The system will respond in a way that counteracts the disturbance.

Increasing the temperature will always shift an endothermic reaction right towards the formation of products and an exothermic reaction left towards the formation of reactants.

Decreasing the volume of a container increases the concentration of gas species and the internal pressure. The reaction will always shift to the side of the reaction equation with the fewest total moles of gases (reducing the internal pressure). Increasing the volume of a container decreases the concentration of gas species and the internal pressure. The reaction will always shift to the side of the reaction

equation with the greatest total moles of gases (increasing the internal pressure).

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ACID-BASE EQUILIBRIUM

Acid-Base Equilibrium: Predict Whether an Aqueous Salt Solution Will be Acidic, Basic or Neutral

Question

Predict whether an aqueous solution of Li_3N is acidic, basic, or neutral.

Show/Hide Answer

An aqueous solution of Li_3N will be basic.

Refer to Section 6.5: Hydrolysis of Salt Solutions (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Break the salt into its two ions (the positively charged metal and the negatively charged non-metal).
2. Identify the charges on both parts.
3. Write out the possible reactions that could occur between each ion and water. **Show/Hide Hint** Remember that it is possible for no reaction to occur.
4. Identify what products (if any) are produced and how they would impact the solution's acidity.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

$$\mathrm{Li_3\,N(aq)} \rightarrow 3\mathrm{Li^+(aq)} + \mathrm{N^{3-}(aq)}$$
$$\mathrm{Li^+(aq)} + \mathrm{H_2O(\ell)} \rightleftharpoons \text{No Reaction}$$
$$\mathrm{N^{3-}(aq)} + \mathrm{H_2O(\ell)} \rightleftharpoons \mathrm{NH^{2-}(aq)} + \mathrm{OH^-(aq)}$$

$\mathrm{N^{3-}}$ is a base because the lone pair on the nitrogen can accept a proton.

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a theory problem where you identify if an aqueous solution will be acidic, basic, or neutral based on your knowledge of how its ions will react in water. **Show/Hide Resource** Refer to Section 6.5: Hydrolysis of Salt Solutions (1).
When a salt dissolves in water, it breaks apart into ions, and the resulting solution is either acidic, basic or neutral. **Show/Hide Think About This!** To break apart a salt into its ions, you must identify which part acts as the metal (this will have a positive charge) and which part is the nonmetal (this will have a negative charge).
To predict if the solution is acidic, basic or neutral, you must first break apart the salt into its ions. **Show/Hide Think About This!** If you break it apart correctly, the charges of the two parts will add up to the overall charge of the original compound.

The next step is to analyze how the two parts react with the surrounding water molecules. You can do this by writing out their possible reactions to water, keeping in mind that it is possible for no reaction to occur at all. Recall how to write out ionization reactions.

Show/Hide Think About This!

React both parts with a water molecule. There are four possible outcomes:

1. The ion will be positively charged with no hydrogen to donate.
    - No reaction will occur.
2. The ion will be positively charged with a hydrogen to donate.
    - Hydronium ion will be produced.
3. The ion will be negatively charged with a hydrogen to donate.
    - Hydronium or hydroxide could be produced depending on the pKa of the amphiprotic species and pH of the solution.
4. The ion will be negatively charged and accept a hydrogen atom from the reacting water molecule.
    - Hydroxide will be produced.

Recall that you can predict whether an aqueous solution of a salt is acidic, basic or neutral by looking at the products each ion would produce when reacting with water.

Show/Hide Think About This!

- If hydronium is produced, the reaction is acidic.
- If hydroxide is produced, the reaction is basic.
- If no reaction occurs, it is neutral.
- If hydronium and hydroxide can be produced, compare the K_a vs. the K_b for each species.
    - if $K_a > K_b$: acidic
    - if $K_b > K_a$: basic
    - if $K_a = K_b$: neutral

Note: Do not forget about some important rules. If either of the ions produces a strong acid or base after reaction with water, they will ionize 100% back to reactants, forming a neutral solution!

Show/Hide Think About This!

Although these rules do not apply to this problem, it is important to watch out for them.

Table 3: Complete Solution

Complete Solution
Break apart the salt to identify its two 'parts' (i.e., the metal and the non-metal). Lithium has a positive charge of one, and the polyatomic nitrogen anion (azide) has a negative charge of three. \begin{gathered} \begin{equation} \mathrm{Li}_3\mathrm{~N}(\mathrm{aq}) \rightarrow 3 \mathrm{Li}^{+}(\mathrm{aq})+\mathrm{N}^{3-}(\mathrm{aq}) \end{equation} \end{gathered}
When the lithium cation is in water, no reaction occurs; this means this ion does not impact pH and is a neutral ion. The Li+(aq) ion is simply hydrated. \begin{gathered} \begin{equation} \mathrm{Li}^{+}(\mathrm{aq})+\mathrm{H}_2 \mathrm{O}(\ell) \rightleftharpoons \mathrm{No} \text { Reaction } \end{equation} \end{gathered}
The N^{3-} (azide) ion will accept a proton from the water, and the reaction produces hydroxide. This means N3- (aq) acts like a base. \begin{gathered} \begin{equation} \mathrm{N}^{3-}(a q)+\mathrm{H}_2 \mathrm{O}(\ell) \rightleftharpoons \mathrm{NH}^{2-}(\mathrm{aq})+\mathrm{OH}^{- }(\mathrm{aq}) \end{equation} \end{gathered}
If the above reaction does happen, N^{3-} (aq) is a weak base. Producing hydroxide makes the solution basic, and Li_3N is a basic salt.

Check Your Work

Look back to make sure you have correctly split the salt into its cation and ion. Then, verify that your reactions with water produce appropriate products. Water can act as an acid or a base, donating or accepting a proton.

Our N^{3-} (aq) anion acts like a weak base and is able to accept a proton from water, producing hydroxide. We know our pH would be basic, and this salt would form a basic solution.

Does your answer make chemical sense?

Show/Hide Answer

When salts dissolve into water, the salts break apart into hydrated ions (surrounded by water molecules). The pH of the solution is determined by both the salt and if it reacts with water. If the salt is basic, the resulting solution will also be basic.

For this reason, we can predict the pH of a solution by analyzing the salt and the reactions its ions can have with water.

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SOLUBILITY PRODUCT

Solubility Product: Predict Solubility in Presence of a Common Ion

Question

Predict the solubility of the species below in water:
Lead(I) oxalate, PbC_2O_4, $K_{sp} = 8.5 \times 10^{-9}$

Show/Hide Answer

The solubility of PbC_2O_4 will be 9.2×10^{-5} M.

Refer to Section 7.5: Solubility Equilibria (1).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. This species is a slightly soluble salt. We recognize that by the small value for the K_{sp}, the solubility product equilibrium constant.
2. Write the K_{sp} reaction showing the solubility product equilibrium. **Show/Hide Hint** Break the salt into its cation and anion, making sure the reaction is balanced. Use equilibrium arrows ⇌ to indicate that the reaction does not go fully to products.
3. Write the K_{sp}expression. **Show/Hide Hint** Recall when writing expressions for K that solids are not included.
4. Using your K_{sp}expression, relate the concentrations of ions in terms of a variable 'x.' **Show/Hide Hint** For every mole of a salt that dissolves, look at how many moles of each ion are formed.
5. Plug in your given K_{sp}value and solve for 'x' algebraically.
6. Then, relate ion concentration back to salt solubility.

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

$$PbC_2O_4(s) \rightleftharpoons Pb^{2+}(aq) + C_2O_4^{2-}(aq)$$
$$K_{sp} = [Pb^{2+}][C_2O_4^{2-}]$$

$$K_{sp} = 8.5 \times 10^{-9} = [Pb^{2+}][C_2O_4^{2-}]$$
$$8.5 \times 10^{-9} = (x)(x)$$
$$8.5 \times 10^{-9} = x^2$$
$$\sqrt{8.5 \times 10^{-9}} = \sqrt{x^2}$$

$$9.2 \times 10^{-5} = x$$
$$x = 9.2 \times 10^{-5}M = [Pb^{2+}] = [C_2O_4^{2-}]$$

The solubility of PbC_2O_4 is 9.2 x 10^{-5}M.

Formula does not parse

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This is a calculation problem where you must set up the K_{sp}expression for the given slightly soluble salt and solve for the molar concentration of each species. **Show/Hide Resource** Refer to Section 7.5: Solubility Equilibria (1).
When a salt dissolves in water, it breaks into its ions. This is a slightly soluble salt, so the concentrations of each ion will be small, but they will still be present in the solution. Break the salt into its cation and anion. **Show/Hide Think About This!** Look at the name of the compound. It will help you know the two 'parts' of the compound to break apart.
Looking at your reaction, write the K_{sp} expression. **Show/Hide Think About This!** A K_{sp} expression is the equilibrium constant expression for a slightly soluble salt. Since the reactant is a solid, it does not appear in the K_{sp} expression. $\mathrm{AB(s) \rightleftharpoons A^+(aq) + B^-(aq)}$ $\mathrm{K_{sp} = [A^+][B^-]}$
To use a K_{sp}expression to solve for the concentrations of its species, relate the concentrations of the ions to each other and replace each species in the expression with a variable 'x.' **Show/Hide Don't Forget!** Remember that the stoichiometry of each species will become the exponent for each x. (This is simple when the stoichiometric coefficient is one).
Then, look at the mole ratio and state the solubility of the salt to answer the question.

Table 3: Complete Solution

Complete Solution
The solubility product reaction: $\mathrm{PbC_2O_4(\,s) \rightleftharpoons Pb^{2+}(aq) + C_2O_4^{2-}(aq)}$
The K_{sp} expression. $\mathrm{K_{sp} = [Pb^{2+}][C_2O_4^{2-}]}$
Plug in your value for the solubility product constant K_{sp}: $\mathrm{8.5 \times 10^{-9} = [Pb^{2+}][C_2O_4^{2-}]}$
Replace your solute species with x's. Since $\mathrm{[Pb^{2+}] = [C_2O_4^{2-}]}$ $\mathrm{8.5 \times 10^{-9} = (x)(x) = x^2}$
Solve for x algebraically $\mathrm{8.5 \times 10^{-9} = x^2}$ $\mathrm{\sqrt{8.5 \times 10^{-9}} = \sqrt{x^2}}$ $\mathrm{9.\,2 \times 10^{-5} = x = [Pb^{2+}] = [C_2O_4^{2-}]}$ Since the concentration of each ion is 9.2 x 10^{-5} M, the solubility of PbC_2O_4 (aq) is 9.2 x 10^{-5} M.

Check Your Work

Since this is a slightly soluble salt, we expect the solubility to be a small numerical value.

The equilibrium constant for a dissolution reaction, known as the solubility product (K_{sp}), is defined in terms of the molar concentrations of the component ions raised to the appropriate stoichiometry. The K_{sp}expression also takes into account the mole ratio of the ions. When given the K_{sp}value, you can calculate the molar concentrations for each species involved.

Does your answer make chemical sense?

Show/Hide Answer

For this example, the mole ratio between the cation and anion was 1:1. For each mole of salt that dissolves, we get one mole of each ion. So once we determine the concentration of each ion, that is also equal to the solubility of the salt.

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ELECTROCHEMISTRY

Electrochemistry: Identify Anode and Cathode and Calculate Cell Potential

Question

Identify where each half reaction will occur (on the cathode or anode), write the overall balanced reaction, and calculate the E° cell.

$$\mathrm{Fe^{2+}(aq) + Cl_2(\,g) \rightarrow Fe^{3+}(aq) + 2Cl^{-}(aq)}$$

Show/Hide Answer

$\mathrm{Cl_2(\,g) + 2e^{-} \rightarrow 2Cl^{-}(aq)}$ occurs at the cathode.
$\mathrm{Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^{-}}$ occurs at the anode.
$\mathrm{E^{\circ}\ cell\ = 2.167\ V}$

Refer to Section 9.3: Standard Reduction Potentials (1).

Data is from Table 9.3.1: Selected Standard Reduction Potentials at 25 °C (1) and P1: Standard Reduction Potentials by Element (Table) (2).

Strategy Map

Do you need a little help to get started?

Check out the strategy map.

Show/Hide Strategy Map

Table 1: Strategy Map

Strategy Map Steps
1. Identify what is being oxidized and what is being reduced. **Show/Hide Hint** Look at the change in charge for each species.
2. Write out the half reactions and balance them. **Show/Hide Hint** Balance mass and balance charge.
3. Identify where each reaction occurs (at the anode/cathode). **Show/Hide Hint** The oxidization reaction will occur at the anode, and the reduction reaction will occur at the cathode.
4. Use the table in P1: Standard Reduction Potentials by Element (2) or Table 9.3.1: Selected Standard Reduction Potentials at 25 °C (1) to look up the E° for each reaction.
5. Use the E°cell equation to calculate the E°cell for the total reaction. **Show/Hide Hint** E°cell = E°cathode – E°anode

Solution

Do you want to see the steps to reach the answer?

Check out this solution.

Show/Hide Solution

$Fe^{2+}(aq) + Cl_2(g) \rightarrow Fe^{3+}(aq) + 2Cl^-(aq)$

Reduction Reaction (at cathode):

$$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$$
$$E^\circ = 1.269\ V$$

Oxidation Reaction (at anode):

$$\left(Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-\right) \times 2$$
$$E^\circ = -0.771\ V$$

Overall Reaction

$$2Fe^{2+}(aq) + Cl_2(g) \rightarrow 2Fe^{3+}(aq) + 2Cl^-(aq)$$

$$E^\circ \text{ cell} = E^\circ \text{ cathode} - E^\circ \text{ anode}$$
$$E^\circ \text{ cell} = (1.396\ V) - (-0.771\ V) = 2.167\ V$$

Guided Solution

Do you want more help?

The guided solution below will give you the reasoning for each step to get your answer, with reminders and hints.

Show/Hide Guided Solution

Table 2: Guided Solution

Guided Solution Ideas
This question is a calculation problem in which you must identify the cathode and anode reactions to calculate the E°cell potential for the overall reaction. **Show/Hide Resource** Refer to Section 9.3: Standard Reduction Potentials (1).
You need to identify which reactant was oxidized and which reactant was reduced. **Show/Hide Think About This!** • The oxidized reactant loses electrons, and its product will gain a positive charge. • The reduced reactant gains electrons, and its product will gain a negative charge. You can remember this by thinking of the phrase "LEO says GER" (Lose-electrons-oxidized) and (Gains-electrons-reduced).

You need to write out and balance the half reactions to find their E° values.

Show/Hide Think About This!

1. Write out the half-reactions by splitting up the oxidation and reduction reactions.
2. Once they are on their own, add the electrons in.
    - In the reduction reaction, the electron(s) will be a reactant; in the oxidation reaction, the electron(s) will be a product.
    - The number of electrons will be the same as the charge difference between the two species, accounting for the mole ratio.
3. The number of electrons must be the same in both reactions. If they do not cancel each other out, you must balance them by multiplying the entire half-reaction by a whole number. This ensures you lose and gain the same number of electrons, which balances electrons in the redox reaction.

Which reaction occurs at the anode? Which reaction occurs at the cathode?

Show/Hide Think About This!

The oxidization reaction will occur at the anode, and the reduction reaction will occur at the cathode. Think "An-Ox" (Anode-Oxidized) and "Red-Cat" (Reduction-Cathode).

Recall the E°cell equation.

You will look up the E° values for the half-reaction in the table in P1: Standard Reduction Potentials by Element (2) or Table 9.3.1: Selected Standard Reduction Potentials at 25 °C (1) and plug those values into the equation.

What about the stoichiometry of the reactions?

Show/Hide Watch Out!
E°cell = E°cathode – E°anode

Notice that some reactions in the table are written as the reduction reaction and some as the oxidization reaction. If you find the value for the opposite reaction than the one you need, flip the sign of the value.

The stoichiometry does not impact the calculation of E°.

Table 3: Complete Solution

Complete Solution
$Fe^{2+}(aq) + Cl_2(g) \rightarrow Fe^{3+}(aq) + 2Cl^-(aq)$ Iron is oxidized and chlorine is reduced. **Reduction Reaction (occurs at cathode):** $Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$ $E^\circ = 1.269\ V$ **Oxidation Reaction (occurs at anode):** $(Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-) \times 2$ Multiplied by two to make the electrons gained an lost equal so when the half-reactions are added together the electrons cancel each other out. $2Fe^{2+}(aq) \rightarrow 2Fe^{3+}(aq) + 2e^-$ $E^\circ = -0.771\ V$ **Overall Reaction** $2Fe^{2+}(aq) + Cl_2(g) \rightarrow 2Fe^{3+}(aq) + 2Cl^-(aq)$
Recall the E°cell equation: $E^\circ\ cell = E^\circ\ cathode - E^\circ\ anode$ Plug in the values from the table: $E^\circ cell = (1.396\ V) - (-0.771\ V) = \mathbf{2.167V}$

Check Your Work

You should balance the overall reaction in mass and the number of electrons lost and gained. The overall cell potential is a positive value, which means it is a spontaneous reaction.

Refer to Section 9.3: Standard Reduction Potentials (1).

Does your answer make chemical sense?

Show/Hide Answer

The cell potential (E°cell) is the potential difference between the two half-cells in an electrochemical cell. We can use this to calculate the likelihood of a reaction to occur spontaneously.

We use standard reduction potentials to calculate the cell potential, so the anode is subtracted to indicate its half reaction is reversed (occurs as the oxidation).

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Glossary

Acid ionization | reaction involving the transfer of a proton from an acid to water, yielding hydronium ions and the conjugate base of the acid

Acid ionization constant (K_a) | equilibrium constant for the ionization of a weak acid

Acid-base indicator | organic acid or base whose color changes depending on the pH of the solution it is in

Acidic | describes a solution in which $[H3O^+]>[OH^-]$

Alcohol | organic compound with a hydroxyl group (–OH) bonded to a carbon atom

Alkane | molecule consisting of only carbon and hydrogen atoms connected by single (σ) bonds

Alkene | molecule consisting of carbon and hydrogen containing at least one carbon-carbon double bond

Alkyl group | substituent, consisting of an alkane missing one hydrogen atom, attached to a larger structure

Alkyne | molecule consisting of carbon and hydrogen containing at least one carbon-carbon triple bond

Amonton's Law | when the volume of a gas is held constant, increasing the temperature of the gas increases its pressure

Anion | negatively charged atom or molecule (contains more electrons than protons)

Anode | electrode in an electrochemical cell at which oxidation occurs; information about the anode is recorded on the left side of the salt bridge in cell notation

Aqueous solution | solution for which water is the solvent, noted as physical state (aq)

Atmosphere (atm) | unit of pressure; 1 atm = 101,325 Pa

Atomic number (Z) | number of protons in the nucleus of an atom

Atomic orbital | mathematical function that describes the behavior of an electron in an atom (also called the wavefunction),

it can be used to find the probability of locating an electron in a specific region around the nucleus, as well as other dynamical variables

Atomic radius | the total distance from an atom's nucleus to the outermost orbital of electron

Axial position | location in a trigonal bipyramidal geometry in which there is another atom at a 180° angle and the equatorial positions are at a 90° angle

Azide ion | N^{3-}

Balanced equation | chemical equation with equal numbers of atoms for each element in the reactant and product

Base ionization | reaction involving the transfer of a proton from water to a base, yielding hydroxide ions and the conjugate acid of the base

Base ionization constant (K_b) | equilibrium constant for the ionization of a weak base

Basic | describes a solution in which $[H3O^+] < [OH^-]$

Bohr's model of the hydrogen atom | structural model in which an electron moves around the nucleus only in circular orbits, each with a specific allowed radius; the orbiting electron does not normally emit electromagnetic radiation, but does so when changing from one orbit to another.

Boiling point | temperature at which the vapor pressure of a liquid equals the pressure of the gas above it

Bond angle | angle between any two covalent bonds that share a common atom

Bond dipole moment | separation of charge in a bond that depends on the difference in electronegativity and the bond distance represented by partial charges or a vector

Bond distance | (also, bond length) distance between the nuclei of two bonded atoms

Bond energy | (also, bond dissociation energy) energy required to break a covalent bond in a gaseous substance

Bond length | distance between the nuclei of two bonded atoms at which the lowest potential energy is achieved

Brønsted-Lowry acid | proton donor

Brønsted-Lowry base | proton acceptor

Cathode | electrode in an electrochemical cell at which reduction occurs; information about the cathode is recorded on the right side of the salt bridge in cell notation

Cation | positively charged atom or molecule (contains fewer electrons than protons)

Central atom | atom to which one or more atoms or groups is attached through covalent bonds

Chair confirmation | A three-dimensional conformation of cyclohexane that resembles the rough shape of a chair. The chair form of cyclohexane is the lowest-energy conformation of the molecule

Chiral | Chiral molecules are those that do not have a plane of symmetry and are therefore not superimposable on their mirror image. Mirror image non-superimposable molecules.

***cis* configuration** | configuration of a geometrical isomer in which two similar groups are on the same side of an imaginary reference line on the molecule

Concentration | quantitative measure of the relative amounts of solute and solvent present in a solution

Conjugate acid | substance formed when a base gains a proton

Conjugate base | substance formed when an acid loses a proton

Covalent bond | bond formed when electrons are shared between atoms

Covalent compound | (also, molecular compound) composed of molecules formed by atoms of two or more different elements

Covalent radius | one-half the distance between the nuclei of two identical atoms when they are joined by a covalent bond

Cycloalkane | An alkane that contains a ring of carbons

***d* orbital** | region of space with high electron density that is either four lobed or contains a dumbbell and torus shape; describes orbitals with $l = 2$. An electron in this orbital is called a *d* electron

Diaxial | A pair of atoms or groups that are both in an axial position on a cyclohexane ring

Dimensional analysis | (also, factor-label method) versatile mathematical approach that can be applied to computations ranging from simple unit conversions to more complex, multi-step calculations involving several different quantities

Dipole moment | property of a molecule that describes the separation of charge determined by the sum of the individual bond moments based on the molecular structure

Dipole-dipole attraction | intermolecular attraction between two permanent dipoles

Dispersion force | (also, London dispersion force) attraction between two rapidly fluctuating, temporary dipoles; significant only when particles are very close together

Dissolved | describes the process by which solute components are dispersed in a solvent

Double bond | covalent bond in which two pairs of electrons are shared between two atoms

Effective nuclear charge (Z_{eff}) | charge that leads to the Coulomb force exerted by the nucleus on an electron, calculated as the nuclear charge minus shielding

Electrical potential | energy per charge; in electrochemical systems, it depends on the way the charges are distributed within the system; the SI unit of electrical potential is the volt (1V=1JC)

Electron | negatively charged, subatomic particle of relatively low mass located outside the nucleus

Electron domain | the region in which electrons are most likely to be found

Electron-pair geometry or Electron domain geometry | arrangement around a central atom of all regions of electron density (bonds, lone pairs, or unpaired electrons)

Electronegativity | tendency of an atom to attract electrons in a bond to itself

Element | substance that is composed of a single type of atom; a substance that cannot be decomposed by a chemical change

Endothermic process | chemical reaction or physical change that absorbs heat

Energy | capacity to supply heat or do work

Enthalpy (*H*) | sum of a system's internal energy and the mathematical product of its pressure and volume

Enthalpy change (Δ*H*) | heat released or absorbed by a system under constant pressure during a chemical or physical process

Equatorial position | one of the three positions in a trigonal bipyramidal geometry with 120° angles between them; the axial positions are located at a 90° angle

Equilibrium | in chemical reactions, the state in which the conversion of reactants into products and the conversion of products back into reactants occur simultaneously at the same rate; state of balance

Equilibrium constant (*K*) | value of the reaction quotient for a system at equilibrium

Excited state | state having an energy greater than the ground-state energy

Exothermic process | chemical reaction or physical change that releases heat

Group | vertical column of the periodic table

Heat (*q*) | transfer of thermal energy between two bodies

Hund's rule | every orbital in a subshell is singly occupied with one electron before any one orbital is doubly occupied, and all electrons in singly occupied orbitals have the same spin

Hybridization | model that describes the changes in the atomic orbitals of an atom when it forms a covalent compound

Hybrid orbital | orbital created by combining atomic orbitals on a central atom

Hydrogen bonding | occurs when exceptionally strong dipoles attract; bonding that exists when hydrogen is bonded to one of the three most electronegative elements: F, O, or N

Hydroxide | compound of a metal with the hydroxide ion OH^- or the group –OH

Ideal gas | a gas whose molecules do not interact and do not take up space

Intermolecular force | noncovalent attractive force between atoms, molecules, and/or ions

Ion | electrically charged atom or molecule (contains unequal numbers of protons and electrons)

Ion-dipole attraction | electrostatic attraction between an ion and a polar molecule

Ion-product constant for water (K_w) | equilibrium constant for the autoionization of water

Ionic bond | electrostatic forces of attraction between the oppositely charged ions of an ionic compound

Ionic compound | compound composed of cations and anions combined in ratios, yielding an electrically neutral substance

Isomers | compounds with the same chemical formula but different structures

Joule (J) | SI unit of energy; 1 joule is the kinetic energy of an object with a mass of 2 kilograms moving with a velocity of 1 meter per second, 1 J = 1 kg m2/s and

4.184 J = 1 cal

K_c | equilibrium constant for reactions based on concentrations of reactants and products

Kelvin (K) | SI unit of temperature; 273.15 K = 0 °C

Kinetic energy | energy of a moving body, in joules, equal to $\frac{1}{2}mv^2$ (where m = mass and v = velocity)

K_P | equilibrium constant for gas-phase reactions based on partial pressures of reactants and products

K_{sp} (Solubility product) | equilibrium constant for the dissolution of a slightly soluble electrolyte

Le Chatelier's principle | when a chemical system at equilibrium is disturbed, it returns to equilibrium by counteracting the disturbance

Lewis structure | diagram showing lone pairs and bonding pairs of electrons in a molecule or an ion

Lewis symbol | symbol for an element or monatomic ion that uses a dot to represent each valence electron in the element or ion

Line structure | an abbreviated drawing of a chemical structure which does not show all atoms, but uses lines to represent bonds and C atoms are implied at the corners of two lines

Linear | shape in which two outside groups are placed on opposite sides of a central atom

Liquid | state of matter that has a definite volume but indefinite shape

Liter (L) | (also, cubic decimeter) unit of volume; 1 L = 1,000 cm^3

Lone pair | two (a pair of) valence electrons that are not used to form a covalent bond

Magnetic quantum number (m_l) | quantum number signifying the orientation of an atomic orbital around the nucleus; orbitals having different values of m_l but the same subshell value of l have the same energy (are degenerate), but this degeneracy can be removed by application of an external magnetic field

Melting point | temperature at which the solid and liquid phases of a substance are in equilibrium; see also *freezing point*

Metal | element that is shiny, malleable, good conductor of heat and electricity

Metal (representative) | atoms of the metallic elements of groups 1, 2, 12, 13, 14, 15, and 16, which form ionic compounds by losing electrons from their outer *s* or *p* orbitals to become positively charged

Molar mass | mass in grams of 1 mole of a substance

Molar solubility | solubility of a compound expressed in units of moles per liter (mol/L)

Molarity (M) | unit of concentration, defined as the number of moles of solute dissolved in 1 liter of solution

Mole | amount of substance containing the same number of atoms, molecules, ions, or other entities as the number of atoms in exactly 12 grams of ^{12}C

Molecular compound | (also, covalent compound) composed of molecules formed by atoms of two or more different elements

Molecular equation | chemical equation in which all reactants and products are represented as neutral substances

Molecular formula | formula indicating the composition of a molecule of a compound and giving the actual number of atoms of each element in a molecule of the compound.

Molecular structure | arrangement of atoms in a molecule or ion

Molecule | bonded collection of two or more atoms of the same or different elements

Neutral | describes a solution in which $[H3O^+] = [OH^-]$

Nonmetal | element that appears dull, poor conductor of heat and electricity, in an ionic compound the nonmetal has accepted electrons to become a negatively charged anion

Nonpolar | a molecule that does not have an overall partial charge

Octahedral | shape in which six outside groups are placed around a central atom such that a three-dimensional shape is generated with four groups forming a square and the other two forming the apex of two pyramids, one above and one below the square plane

Octet rule | guideline that states main group atoms will form structures in which eight valence electrons interact with each nucleus, counting bonding electrons as interacting with both atoms connected by the bond

Optical isomer | (also, enantiomer) molecule that is a nonsuperimposable mirror image with identical chemical and physical properties, except when it reacts with other optical isomers

Orbital diagram | pictorial representation of the electron configuration showing each orbital as a box and each electron as an arrow

Organic compound | natural or synthetic compound that contains carbon

Overlap | coexistence of orbitals from two different atoms sharing the same region of space, leading to the formation of a covalent bond

Oxidized | the species that loses electrons in an oxidation reduction reaction is oxidized

***p* orbital** | dumbbell-shaped region of space with high electron

density, describes orbitals with $l = 1$. An electron in this orbital is called a p electron

Pauli exclusion principle | specifies that no two electrons in an atom can have the same value for all four quantum numbers

Period | (also, series) horizontal row of the periodic table

Periodic table | table of the elements that places elements with similar chemical properties close together

pH | logarithmic measure of the concentration of hydronium ions in a solution

Photon | smallest possible packet of electromagnetic radiation, a particle of light

Physical change | change in the state or properties of matter that does not involve a change in its chemical composition

Physical property | characteristic of matter that is not associated with any change in its chemical composition

Pi bond (π bond) | covalent bond formed by side-by-side overlap of atomic orbitals; the electron density is found on opposite sides of the internuclear axis

Polar covalent bond | covalent bond between atoms of different electronegativities; a covalent bond with a positive end and a negative end

Polar molecule | (also, dipole) molecule with an overall dipole moment

Polyatomic ion | ion composed of more than one atom

Pressure | force exerted per unit area

Principal quantum number (n) | quantum number specifying the shell an electron occupies in an atom

Quantum number | integer number having only specific allowed values and used to characterize the arrangement of electrons in an atom

R | A generalized abbreviation for an organic partial structure.

R configuration | The configuration at a chirality center as specified using the Cahn–Ingold–Prelog sequence rules.

Rate expression | mathematical representation relating reaction

rate to changes in amount, concentration, or pressure of reactant or product species per unit time

Rate of reaction or reaction rate | measure of the speed at which a chemical reaction takes place

Reactant | substance undergoing a chemical or physical change; shown on the left side of the arrow in a chemical equation

Reaction quotient (Q) | ratio of the product of molar concentrations (or pressures) of the products to that of the reactants, each concentration (or pressure) being raised to the power equal to the coefficient in the equation

Reduced | the species which gains electrons in a oxidation reduction reaction is reduced

Reduction half-reaction | the "half" of an oxidation-reduction reaction involving reduction; the half-reaction in which electrons appear as reactants; balanced when each atom type, as well as the charge, is balanced

Rydberg's Constant (R_H) | 2.18×10^{-18} J

s orbital | spherical region of space with high electron density, describes orbitals with $l = 0$. An electron in this orbital is called an *s* electron

S configuration | the configuration at a chirality center as specified using the Cahn–Ingold–Prelog sequence rules.

Salt | an ionic compound consisting of a positively charged cation and a negatively charged anion

Shell | set of orbitals with the same principal quantum number, n

SI units (International System of Units) | standards fixed by international agreement in the International System of Units (*Le Système International d'Unités*)

Sigma bond (σ bond) | covalent bond formed by overlap of atomic orbitals along the internuclear axis

Significant figures | (also, significant digits) all of the measured digits in a determination, including the uncertain last digit

Single bond | bond in which a single pair of electrons is shared between two atoms

Solid | state of matter that is rigid, has a definite shape, and has a fairly constant volume

Solubility | extent to which a solute may be dissolved in water, or any solvent

Solubility product (K_{sp}) | equilibrium constant for the dissolution of a slightly soluble electrolyte

Soluble | a substance is able to be dissolved in a solvent

Solute | solution component present in a concentration less than that of the solvent

Solvation | exothermic process in which intermolecular attractive forces between the solute and solvent in a solution are established

Solvent | solution component present in a concentration that is higher relative to other components

sp hybrid orbital | one of a set of two orbitals with a linear arrangement that results from combining one s and one p orbital

sp^2 hybrid orbital | one of a set of three orbitals with a trigonal planar arrangement that results from combining one s and two p orbitals

sp^3 hybrid orbital | one of a set of four orbitals with a tetrahedral arrangement that results from combining one s and three *p* orbitals

sp^3d hybrid orbital | one of a set of five orbitals with a trigonal bipyramidal arrangement that results from combining one s, three *p*, and one *d* orbital

sp^3d^2 hybrid orbital | one of a set of six orbitals with an octahedral arrangement that results from combining one s, three *p*, and two *d* orbitals

Spin quantum number (m_s) | number specifying the electron spin direction, either +1/2 or −1/2

Standard cell potential (E^o_{cell}) | the cell potential when all reactants and products are in their standard states (1 bar or 1 atm or gases; 1 M for solutes), usually at 298.15 K; can be calculated by subtracting the standard reduction potential for the half-reaction at the anode from the standard reduction potential for the half-reaction occurring at the cathode

Standard reduction potential ($E°$) | the value of the reduction

under standard conditions (1 bar or 1 atm for gases; 1 M for solutes) usually at 298.15 K; tabulated values used to calculate standard cell potentials

Standard state | set of physical conditions as accepted as common reference conditions for reporting thermodynamic properties; 1 bar of pressure, and solutions at 1 molar concentrations, usually at a temperature of 298.15 K

State function | property depending only on the state of a system, and not the path taken to reach that state

Stereocenter | An alternative name for a chirality center

Stereochemistry | The branch of chemistry concerned with the three-dimensional arrangement of atoms in molecules

Stereoisomers | Isomers that have their atoms connected in the same order but have different three-dimensional arrangements. The term stereoisomer includes both enantiomers and diastereomers

Stoichiometry | relationships between the amounts of reactants and products of a chemical reaction

Stoichiometric coefficients | the numbers written in front of atoms, ions and molecules in a chemical reaction to balance the number of each element on both the reactant and product sides of the equation

Structural formula | shows the atoms in a molecule and how they are connected

Temperature | intensive property of matter that is a quantitative measure of "hotness" and "coldness"

Tetrahedral | shape in which four outside groups are placed around a central atom such that a three-dimensional shape is generated with four corners and 109.5° angles between each pair and the central atom

Thermochemical equation | a balanced stoichiometric equation that has reactants, products and the value of enthalpy change, DH

Thermochemistry | study of measuring the amount of heat absorbed or released during

Torr | unit of pressure; 1 torr=760 atm

***trans* configuration** | configuration of a geometrical isomer in which two similar groups are on opposite sides of an imaginary reference line on the molecule

Trigonal bipyramidal | shape in which five outside groups are placed around a central atom such that three form a flat triangle with 120° angles between each pair and the central atom, and the other two form the apex of two pyramids, one above and one below the triangular plane

Trigonal planar | shape in which three outside groups are placed in a flat triangle around a central atom with 120° angles between each pair and the central atom

Triple bond | bond in which three pairs of electrons are shared between two atoms

Unit | standard of comparison for measurements

Unit conversion factor | ratio of equivalent quantities expressed with different units; used to convert from one unit to a different unit

Valence bond theory | description of bonding that involves atomic orbitals overlapping to form σ or π bonds, within which pairs of electrons are shared

Valence electrons | electrons in the outermost or valence shell (highest value of n) of a ground-state atom; determine how an element reacts

Valence shell | outermost shell of electrons in a ground-state atom; for main group elements, the orbitals with the highest n level (s and p subshells) are in the valence shell, while for transition

Valence shell electron-pair repulsion theory (VSEPR) | theory used to predict the bond angles in a molecule based on positioning regions of high electron density as far apart as possible to minimize electrostatic repulsion

Van der Waals force | attractive or repulsive force between molecules, including dipole-dipole, dipole-induced dipole, and London dispersion forces; does not include forces due to covalent or ionic bonding, or the attraction between ions and molecules

Volume | amount of space occupied by an object

Version History

This page provides a record of changes made to this learning resource, PASSchem. Each update increases the version number by 0.1. The most recent version is reflected in the exported files for this resource.

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