Michigan Science Olympiad Coaches Workshop Virtual Presentation Saturday, November 2, 2024 Chemistry Lab C

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For coaches, students, and event supervisors:

1. **Read the rules.**
2. **Know the rules.**
3. **Follow the rules.**

General Rules

GENERAL RULES, CODE OF ETHICS, AND SPIRIT OF THE PROBLEM

The goal of competition is to give one's best effort while displaying honesty, integrity, and good sportsmanship. Everyone is expected to display courtesy and respect as outlined in the Science Olympiad Pledges. Teams are expected to make an honest effort to follow the rules and the spirit of the problem (not interpret the rules so they have an unfair advantage). Failure by a participant, coach, or guest to abide by these codes, accepted safety procedures, or rules below, may result in an assessment of penalty points or, in rare cases, disqualification by the Tournament Director from the event, the tournament, or future tournaments.

1. Actions and items (e.g., tools, notes, resources, supplies, electronics, etc.) are permitted, unless they are explicitly excluded in the rules, are unsafe, or violate the spirit of the problem.
2. While competing in an event, participants may not leave without the event supervisor's approval and must not receive any external assistance. All electronic devices capable of external communication as well as calculator applications on multipurpose devices (e.g., laptop, phone, tablet) are not permitted unless expressly permitted in the event rule or by an event supervisor. Cell phones, if not permitted, must be turned off. At the discretion of the event supervisor, participants may be required to place their cell phones in a designated location.
3. Participants, coaches and other adults are responsible for ensuring that any applicable school or Science Olympiad policy, law, or regulation is not broken. All Science Olympiad content such as policies, requirements, rule corrections and rule clarifications on www.soinc.org must be treated as if it were included in the printed rules.

General Rules

4. All pre-built devices presented for judging must be constructed, impounded, and operated by one or more of the 15 current team members unless stated otherwise in the rules. If a device has been removed from the event area, appeals related to that device will not be considered.
5. **During the tournament, participants are only permitted to practice with any built or designed device at a Tournament event venue prior to competing if the Tournament Director makes the facilities open to all teams to practice.**
6. Officials are encouraged to apply the least restrictive penalty for rules infractions - see examples in the Scoring Guidelines. Event supervisors must provide prompt notification of any penalty, disqualification or tier ranking.
7. State and Regional Tournament Directors must notify teams of any site-dependent rule or other rule modification with as much notice as possible, ideally at least 30 days prior to the tournament.

Eye Protection Guide

This resource was created to help teams comply with the Science Olympiad Policy on Eye Protection adopted on July 29, 2015 and posted on the Science Olympiad Website (soinc.org).

Participant/Coach Responsibilities: Participants are responsible for providing their own protective eyewear. Science Olympiad is unable to determine the degree of hazard presented by equipment, materials and devices brought by the teams. Coaches must ensure the eye protection participants bring is adequate for the hazard. All protective eyewear must bear the manufacturer's mark Z87. At a tournament, teams without adequate eye protection will be given a chance to obtain eye protection if their assigned time permits. If required by the event, participants will not be allowed to compete without adequate eye protection. This is **non-negotiable**.

Corresponding Standards: Protective eyewear used in Science Olympiad must be manufactured to meet the American National Standards Institute (ANSI) standard applicable at its time of manufacture. The current standard is ANSI/ISEA Z87.1-2015. Competitors, coaches and event supervisors are not required to acquire a copy of the standard. The information in this document is sufficient to comply with current standards. Water is not a hazardous liquid and its use does not require protective eyewear unless it is under pressure or substances that create a hazard are added.

Eye Protection Guide

Compliant Eyewear Categories: If an event requires eye protection, the rules will identify one of these three categories. Compliance is simple as ABC:

CATEGORY A

- Description: Non-impact protection. They provide basic particle protection only
- Corresponding ANSI designation/required marking: Z87
- Examples: Safety glasses; Safety spectacles with side shields; and Particle protection goggles (these seal tightly to the face completely around the eyes and have direct vents around the sides, consisting of several small holes or a screen that can be seen through in a straight line)

CATEGORY B

- Description: Impact protection. They provide protection from a high inertia particle hazard (high mass or velocity)
- Corresponding ANSI designation/required marking: Z87+
- Example: High impact safety goggles

CATEGORY C

- Description: Indirect vent chemical/splash protection goggles. These seal tightly to the face completely around the eyes and have indirect vents constructed so that liquids do not have a direct path into the eye (or no vents at all). If you are able to see through the vent holes from one side to the other, they are NOT indirect vents
- Corresponding ANSI designation/required marking: Z87 (followed by D3 is the most modern designation but, it is not a requirement)
- Example: Indirect vent chemical/splash protection goggles

Eye Protection Guide

Examples of Non-Compliant Eyewear:

- Face shields/visors are secondary protective devices and are not approved in lieu of the primary eye protection devices below regardless of the type of vents they have.
- Prescription Glasses containing safety glass should not be confused with safety spectacles. "Safety glass" indicates the glass is made to minimize shattering when it breaks. Unless these glasses bear the Z87 mark they are not approved for use.

Notes:

1. A goggle that bears the Z87+ mark and is an indirect vent chemical/splash protection goggle will qualify for all three Categories A, B & C
2. VisorGogs do not seal completely to the face, but are acceptable as indirect vent chemical/splash protection goggles

Proper Eye Protection (Category C) is required for all participants in all SO chemistry events.

Chemistry Lab (Division C)

Forensics (Division C)

Materials Science (Division C)

Crime Busters (Division B)

Potions and Poisons (Division B)

Coaches and participants are responsible for providing/having/bringing Category C eye protection to events. Event supervisors are not responsible for providing eye protection to participants.

Participants without proper eye protection will not be allowed to compete in these events.

SAFETY FIRST!

GOGGLES ARE FOR EYE PROTECTION, NOT FOREHEAD OR NECK PROTECTION

VISORGOGS ARE ACCEPTABLE

LAB COATS OR LAB APRONS ARE REQUIRED FOR ALL PARTICIPANTS TO WEAR IN ALL CHEMISTRY EVENTS.

Coaches and participants are responsible for providing/having/bringing lab coats or aprons to events. Event supervisors are not responsible for providing lab coats or aprons to participants.

Participants must be covered from the neck to the wrists and toes.

Participants without proper protection will not be allowed to compete in these events.

PANTS

NO

NO

YES

Pants must be loose fitting. No short pants. Ankles, feet and toes must be covered (no open toed shoes or sandals).

Science Olympiad is not a fashion contest.

Chemistry events require appropriate clothing to minimize skin contact with any spilled chemicals.

CHEMISTRY LAB EQUIPMENT LIST

All Division C Chemistry events require participants to bring lab equipment to their events. Participants may bring any or all of the equipment on the list, and in any quantities.

Find the Division C Chemistry Lab Equipment list at:

https://www.soinc.org/chem-lab-c

The Division C Chemistry Lab Equipment list may also be found in the rules manual, page C71.

Each team may bring any or all of the items listed below for use in Division C Chemistry Events. Teams not bringing these items will be at a disadvantage as Event Supervisors will not provide the listed lab equipment. A penalty of up to 10% may be given if a team brings prohibited lab equipment to the event.

Item & Expected Use	Likely to be used in:			
	Chemistry Lab	Forensics	Environmental Chemistry	Materials Science
Box - Containing all of the kit materials	X	X	X	X
Graduated Cylinders (10 - 100 mL) - Measuring volumes	X		X	
Beakers (50 - 500 mL) - Doing reactions, developing chromatograms	X	X	X	X
Erlenmeyer Flasks (10 - 250 mL) - Doing reactions	X		X	
Test Tubes - Mix Chemicals, heat chemicals	X	X	X	X
Test Tube Brush - Clean Test Tubes	X	X	X	X
Test Tube Holder - Holds test tubes for heating	X	X	X	
Test Tube Rack - Hold Test Tubes	X	X	X	X
Spot Plates - For semi-micro scale reactions, testing solubility, pH	X	X	X	
Petri Dishes - Doing reactions, developing chromatograms	X	X	X	X
Slides - To put hairs, crystals, or fibers on for use with a microscope		X		
Cover Slips - To cover & prevent items from coming off slides		X		
Droppers - Add small amounts of liquids to reactions	X	X	X	X
Spatulas or spoons - Getting small amounts of solids out of containers	X	X	X	X
Metal Tongs, Forceps, or Tweezers – Holding & retrieving objects	X	X	X	X
Stirring Rods - Stirring mixtures	X	X	X	X
Thermometer - Determining the temperature of a solution	X	X	X	
pH paper/meter - Test acidity or alkalinity of solution	X	X	X	
Hand Lens - Magnification of small items for identification		X		
Flame Loop – For identification of ions in a compound		X		
Filter Paper - Filter solids from liquids	X		X	
Funnel - Hold Filter Paper	X		X	
9V battery - Electrolysis	X		X	X
Alligator Clip Wires - Connecting meters to metals	X		X	X
Nail - Electrolysis	X		X	X
Piece of Cu metal - Electrolysis	X		X	X
Piece of Zn metal - Electrolysis	X		X	X
Multimeter - Measuring current, voltage, and resistivity	X		X	X
9V or less Battery Conductivity Tester - Determining ionic strength of solution	X	X	X	X
Calipers-mechanical, not digital - Measuring lengths very precisely	X			X
Paper Towels - Cleaning	X	X	X	X
Pencil - Writing, Marking Chromatogram		X		
Ruler - Measuring lengths		X		
Magnets – For extraction and identification of iron filings	X	X	X	X
Cobalt Blue Glass – To filter out any sodium that might contaminate flame test from hands		X		

New from NSO for 2025 (soinc.org): CHEMISTRY EXPECTATIONS DIVISION C

Chemistry Event Supervisors have the following expectations of Science Olympiad team members participating in the Chemistry events:

1. Students will have researched proper PPE for the chemistry lab and know what goggles belong to which group and to show up properly attired.

2. Students will know how to light a match, candle, and Bunsen burner.

3. Students will know how to do both strip and sheet paper chromatography and how to do R_f values.

4. Students are expected to know how to use standard chemistry measuring instruments, including but not limited to graduated cylinders, thermometers, pH paper, conductivity meters, multi-meters, calipers, and rulers.

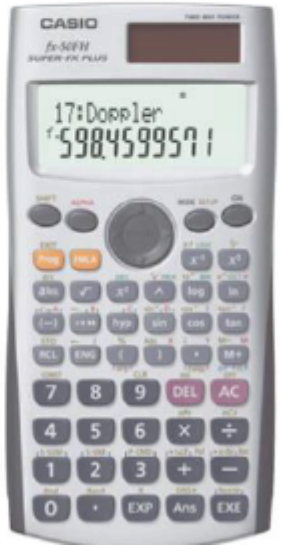
5. Students are expected to know how to use laboratory glassware stated in the rules and standard techniques associated, such as quantitative transfer, meniscus reading, titration, filtration, mixing, cleaning glassware, weighing by difference, etc.

CALCULATORS FOR CHEMISTRY LAB

The following document was prepared to offer some guidance to teams as they select calculators for use in different Science Olympiad events. **The calulator class listed in the event rules is the most complex calculator level allowed for the event. It is acceptable to use a lower calculator class in the event (e.g., Class III calculator is allowed for the event students are therefor allowed to use a class I, class II or class III calculator).** By no means are the calculators listed here inclusive of all possible calculators; instead they are offered as common examples. The decisions of the event supervisors will be final.

Class III- Stand-alone, programmable, graphing calculators and **stand-alone non-graphing, programmable calculators,** often look like the calculator shown on the right. Some examples are: Casio 975 0/9850/9860, HP 40/50/PRIME, and TI 83/84/89/NSPIRE/VOYAGE.

To identify a stand-alone non-graphing, programmable calculators Are look for the presence of the 'EXE' button, the 'Prog' button, or a 'file' button. Examples include but are not limited to: Casio Super FXs, numerous older Casio models, and HP 35S. A calculator of this type with the buttons labeled is shown to the right.



PROG Button

EXE Button

Chemistry Lab
2025 Rules
Equilibrium
and
Chemical Reactions and Stoichiometry

CHEMISTRY LAB 2025

1. **DESCRIPTION:** Teams will complete one or more tasks and answer a series of questions involving the scientific processes of chemistry focused in the areas of equilibrium and **chemical reactions/stoichiometry**.

   A TEAM OF UP TO: 2 **EYE PROTECTION:** C

   CALCULATOR: Class III **APPROXIMATE TIME:** 50 minutes

2. **EVENT PARAMETERS:**
   a. Each participant must bring safety equipment (e.g., goggles, lab coat, apron), a writing implement, and may bring a stand-alone calculator (Class III).
   b. Each participant may bring one unique 8.5" x 11" sheet of paper, which may be in a sheet protector sealed by tape or laminated, with information on both sides in any form and from any source.
   c. Teams should bring any or all of the items listed on the Division C Chemistry Events Lab Equipment List, posted on soinc.org. Teams not bringing these items will be at a disadvantage, as they are not provided.
   d. Participants must wear goggles, an apron or a lab coat and have skin covered from the neck down to the wrist and toes. Gloves are optional, but if the host requires a specific type, they will notify teams. Pants should be loose fitting; if the host has more specific guidelines, they will notify teams in advance of the tournament. Shoulder-length or longer hair must be tied back. Participants removing safety clothing/ goggles or unsafely handling materials, or equipment will be penalized or disqualified.
   e. Supervisors will provide any required reagents, additional glassware, and/or references that are needed for the tasks (e.g., Periodic Table, table of standard reduction potentials, any constants needed).

CHEMISTRY LAB 2025

3. **THE COMPETITION:**
   a. The competition will consist of a series of tasks focused in the areas of equilibrium and **chemical reactions/ stoichiometry**. These tasks could include hands-on activities, questions on listed topics, interpretation of data (e.g., graphs, diagrams, tables), or observation of an established and running experiment.
   b. Teams may be asked to collect data using a probeware set-up demonstrated by the Supervisor(s). Following a demonstration of the sensors/probes, participants may be given data sets to interpret.
   c. Nomenclature, formula writing, & stoichiometry (mole conversions & percentage yield) are essential tools of chemistry & may be included in the event. Participants are expected to know the symbols & charges for: nitrate, carbonate, phosphate, acetate, sulfate, ammonium, bicarbonate, & hydroxide. Participants should know how to use the "ite" form of anion (one less oxygen than the "ate" form). With a periodic table, participants should be able to obtain charges for monatomic ions (e.g., Na^{+}, S^{2-}).

CHEMISTRY LAB 2025

d. Equilibrium: Students must be able to write equilibrium reactions, predict the direction of a reaction using Le Châtelier's Principle, calculate an equilibrium constant, & use equilibrium constant to determine concentrations. Tasks will be chosen from the following:
   i. Use a titration or data of a weak acid/base with a strong acid/base to calculate an equilibrium constant.
   ii. Investigate an equilibrium reaction and determine what happens when it is stressed.
   iii. Stoichiometry of equilibrium reactions.
   iv. Construct/use a standard absorption curve to determine an equilibrium constant.
   v. Use a colorimeter to predict a curve.
   vi. State & Nationals: knowledge/application of equilibrium to separate chemicals may be included.
e. Participants should understand the following about **Chemical Reactions/Stoichiometry**:
   i. Classification of reaction type.
   ii. Balancing reactions.
   iii. Reaction prediction (including predicting products of metathesis reactions, solubility, oxidation-reduction, total ionic and net ionic equations).

CHEMISTRY LAB 2025

4. **SCORING**:
   a. High score wins. Points will be divided evenly between equilibrium and **chemical reactions/stoichiometry**.
   b. Time may be limited at each task but will not be used as a tiebreaker or for scoring.
   c. Ties will be broken by pre-selected questions.
   d. A penalty of up to 10% may be given if the area is not cleaned up as instructed.
   e. A penalty of up to 10% may be given if a team brings prohibited lab equipment to the event.

Internet Video Resources

Bozeman Science AP Chemistry AP Chemistry — bozemanscience

Crash Course Chemistry Crash Course - Chemistry (thecrashcourse.com)

Khan Academy AP Chemistry AP® Chemistry | College Chemistry | Khan Academy

University of Colorado Boulder PhET simulations PhET: Free online physics, chemistry, biology, earth science and math simulations (colorado.edu)

Internet Resources

Free, online textbooks:

Science – OpenStax

AP Chemistry Textbook.pdf - Google Drive

Free Download Chemistry (11th Ed.) By Steven Zumdahl, Susan Zumdahl and Donald DeCoste | Chemistry.Com.Pk

Home - Chemistry LibreTexts

Silberberg - Chemistry LibreTexts

Spencer, Bodner, Rickard: Chemistry: Structure and Dynamics, 4th Edition - Instructor Companion Site

Internet Resources

84 Activitiy Central - Sciences - Chemistry by Texas Instruments

Science Nspired - Chemistry by Texas Instruments

12: Equilibrium and Le Chatelier's Principle (Experiment) - Chemistry LibreTexts

Chem Lab | Science Olympiad

Science Olympiad Student Center - Scioly.org

Submit a Question and Rule Clarifications | Science Olympiad

Rules Corrections | Science Olympiad

Which students should do Chemistry Lab?

Use the most experienced chemistry students if possible:

- **AP Chemistry or IB Chemistry**
- **Honors Chemistry**
- **General Chemistry**

- **Students should have good working knowledge of math as it applies to chemistry.**

KEYS FOR COACHING

PRACTICE, PRACTICE, PRACTICE!

DO AS MANY LABS DEALING WITH EQUILIBRIUM AND CHEMICAL REACTIONS AND STOICHIOMETRY AS POSSIBLE.

Questions?

See your friendly, neighborhood chemistry teacher.

Get a good AP Chemistry (or other college level) textbook.

Look up labs to do and information on the internet.

CHEMICAL EQUILIBRIUM

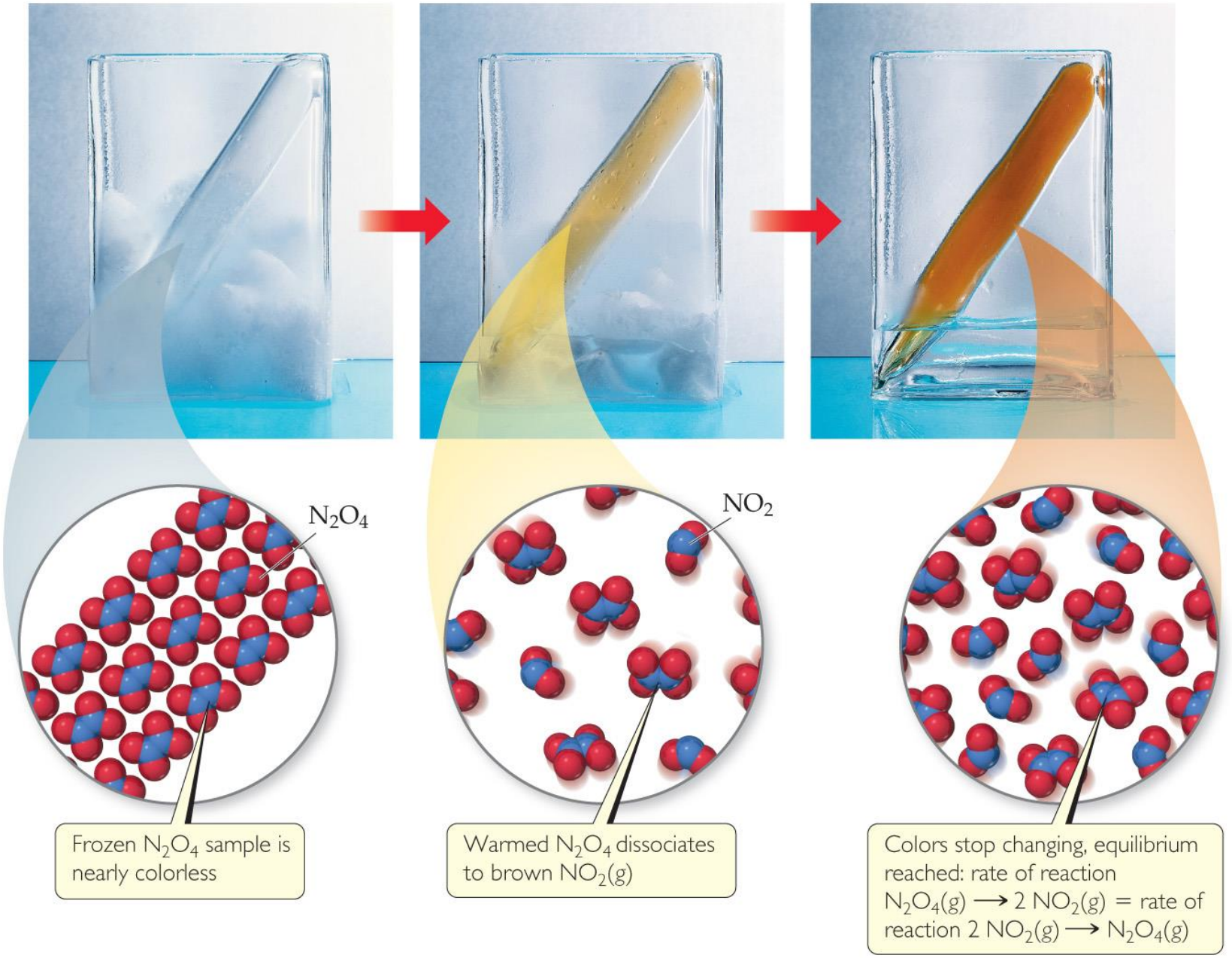
Equilibrium

Chemical equilibrium occurs when opposing reactions proceed at equal rates (dynamic equilibrium). An equilibrium reaction is a reversible reaction.

At equilibrium, the concentrations of reactants and products do not change. The reaction appears to be stopped, but the reactant and product molecules are constantly changing back and forth at equal rates.

$$\text{heat} + N_2O_{4\,(g)} \Leftrightarrow 2\,NO_{2\,(g)}$$

colorless brown



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The rate law for the forward reaction is:

$$\text{rate} = k_f [N_2O_4]$$

The rate law for the reverse reaction is:

$$\text{rate} = k_r [NO_2]^2$$

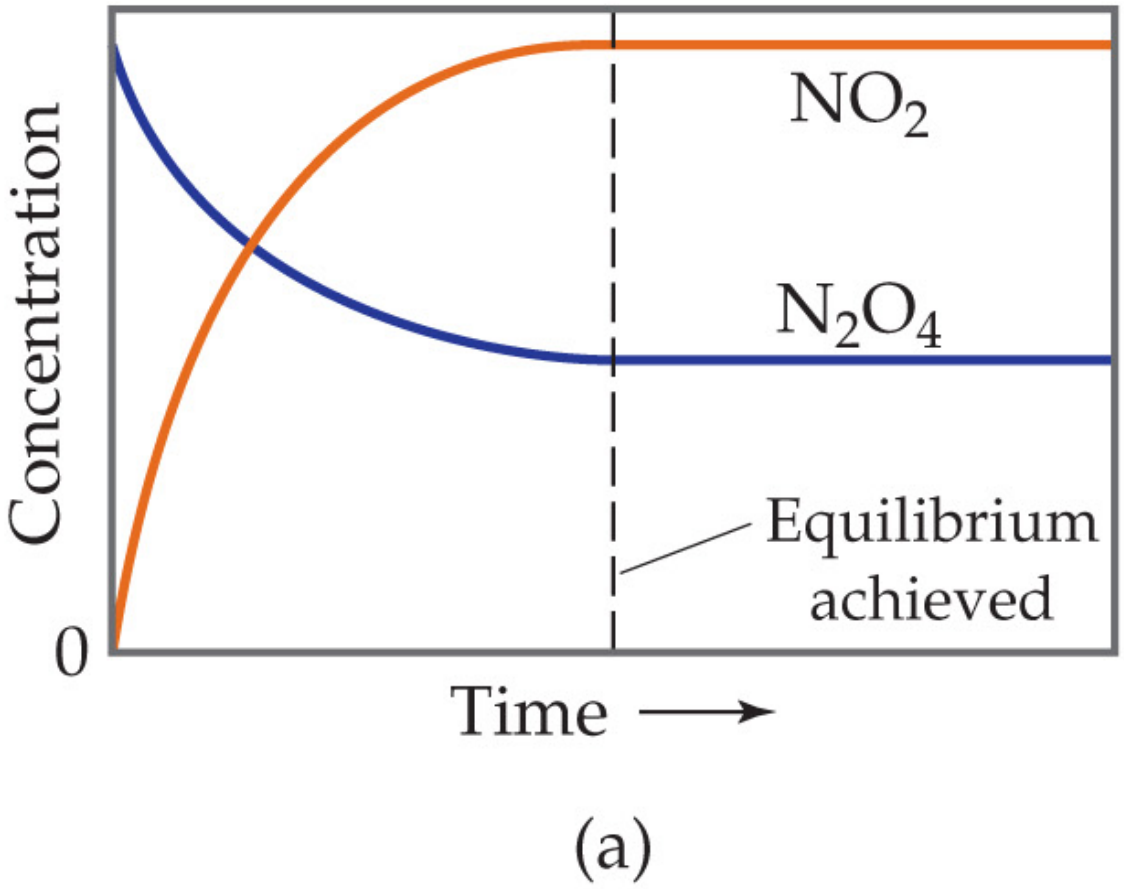
At equilibrium the two rates are equal:

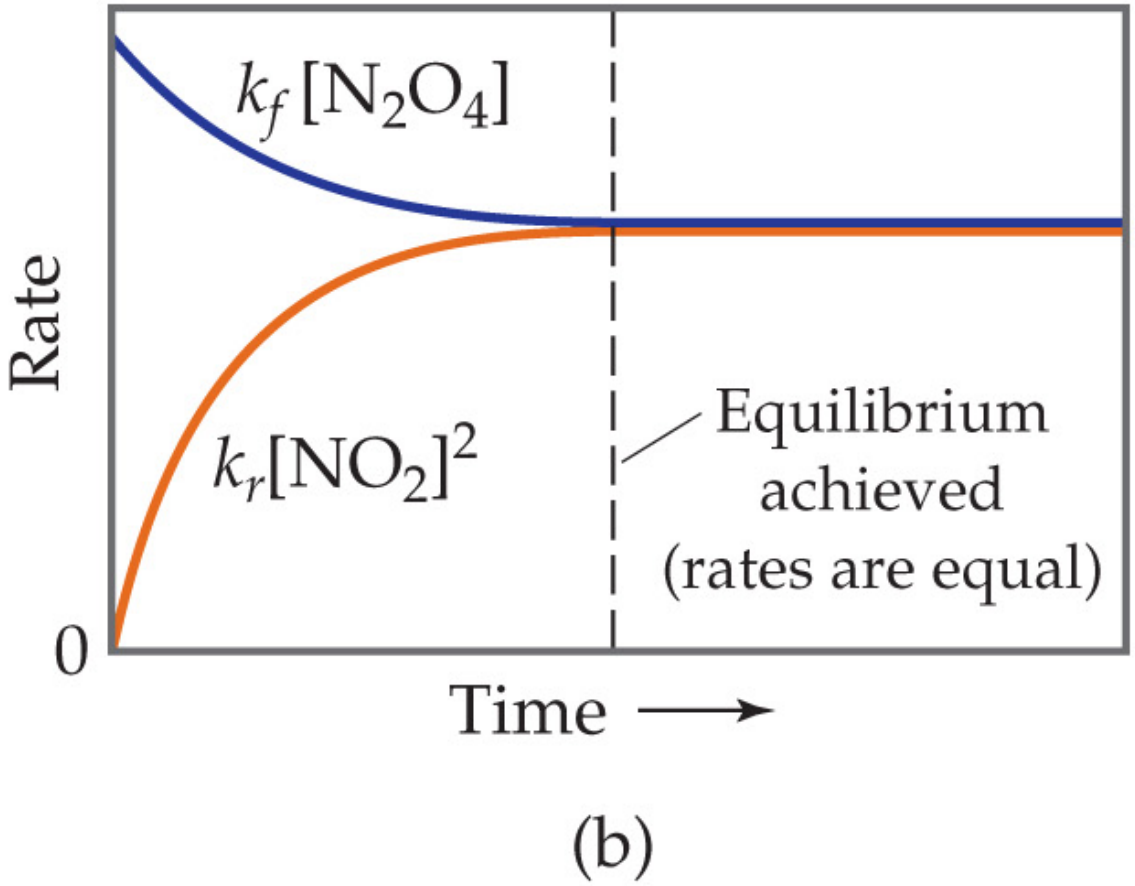
$$k_f [N_2O_4] = k_r [NO_2]^2 \text{ ,or,}$$

$$[NO_2]^2 / [N_2O_4] = k_f / k_r$$

= a constant called the equilibrium constant.

At equilibrium, the concentrations remain constant, but the rates are equal.





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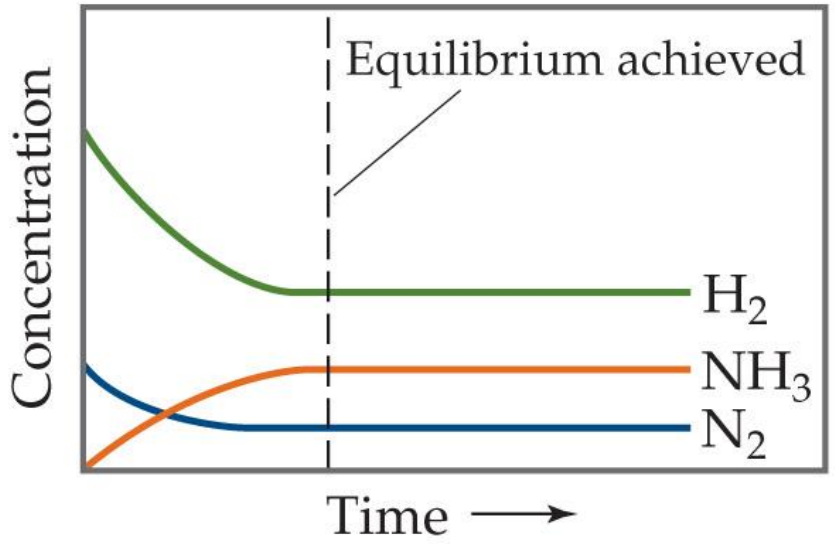
The Equilibrium Constant

A reaction at equilibrium must exist in a closed, insulated container, so no matter or energy can enter or leave the system.

The equilibrium point can be reached from either direction, starting with all reactants and no products, all products and no reactants, or some reactants and some products.



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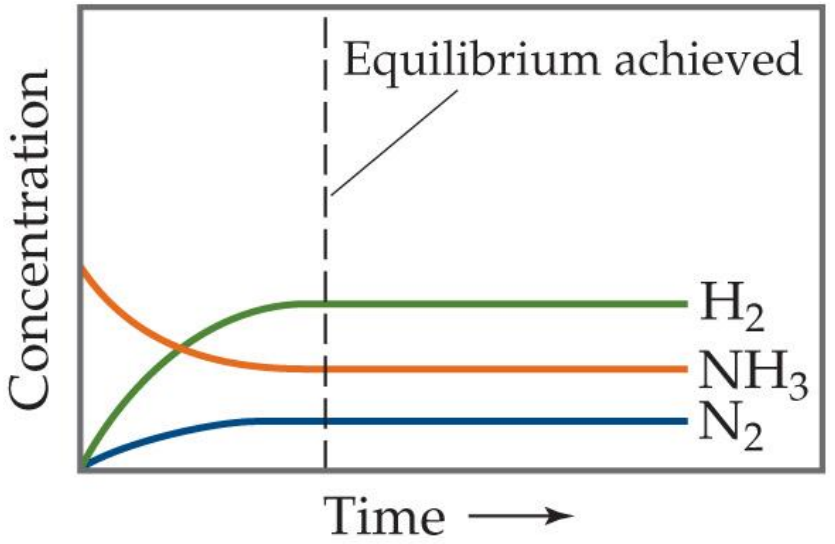

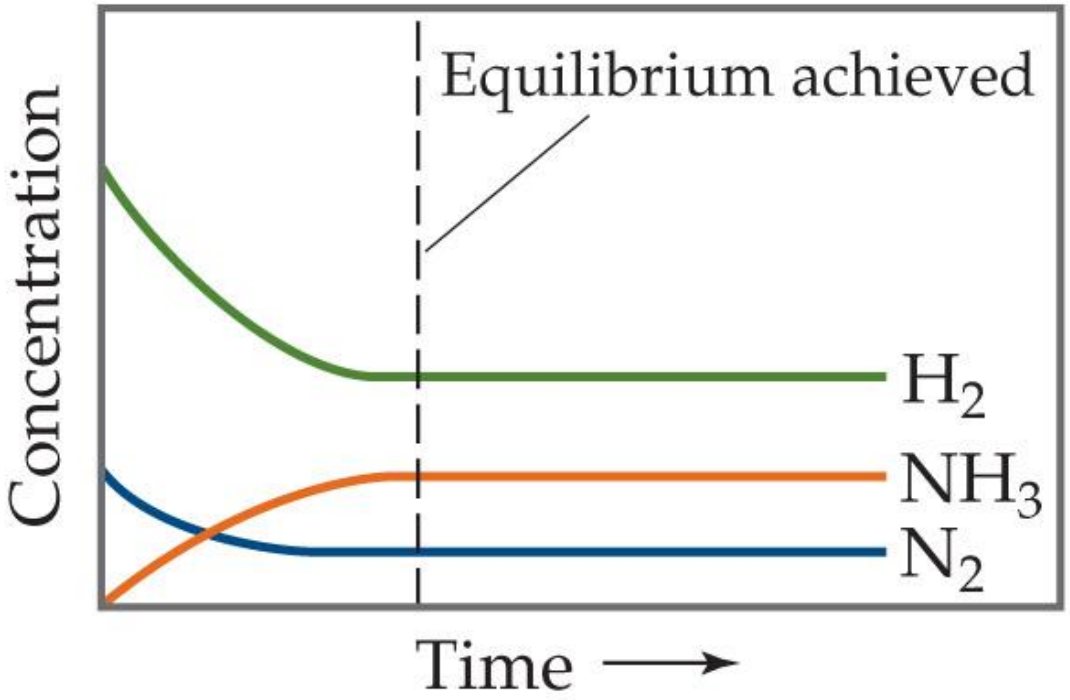

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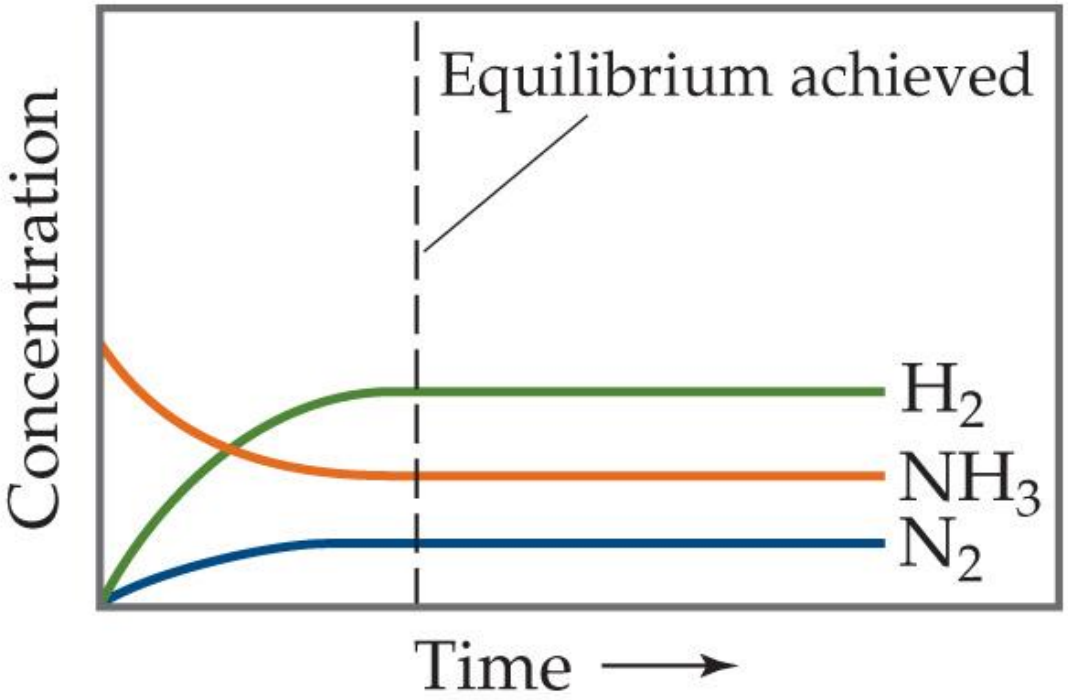
Starting with all reactants, no product.



Starting with product and no reactants.

$$N_2 + 3\,H_2 \Leftrightarrow 2\,NH_3$$

The Law of Mass Action

The law of mass action expresses the relationship between the concentrations of the reactants and products present at equilibrium.

The equilibrium relationship for the general equation $aA + bB \leftrightarrow cC + dD$, is expressed as:

$$K_c = ([C]^c [D]^d) / ([A]^a [B]^b)$$

Or,

$$K_c = [products]^m / [reactants]^n$$

This relationship is called the equilibrium-constant expression, or the equilibrium expression. The constant K_c, is the equilibrium concentration constant.

The equilibrium-constant expression depends only on the stoichiometry of the reaction, not on its mechanism.

Evaluating K_c

TABLE 15.1 • Initial and Equilibrium Concentrations of $N_2O_4(g)$ and $NO_2(g)$ at 100 °C

Experiment	Initial $[N_2O_4]$ (M)	Initial $[NO_2]$ (M)	Equilibrium $[N_2O_4]$ (M)	Equilibrium $[NO_2]$ (M)	K_c
1	0.0	0.0200	0.00140	0.0172	0.211
2	0.0	0.0300	0.00280	0.0243	0.211
3	0.0	0.0400	0.00452	0.0310	0.213
4	0.0200	0.0	0.00452	0.0310	0.213

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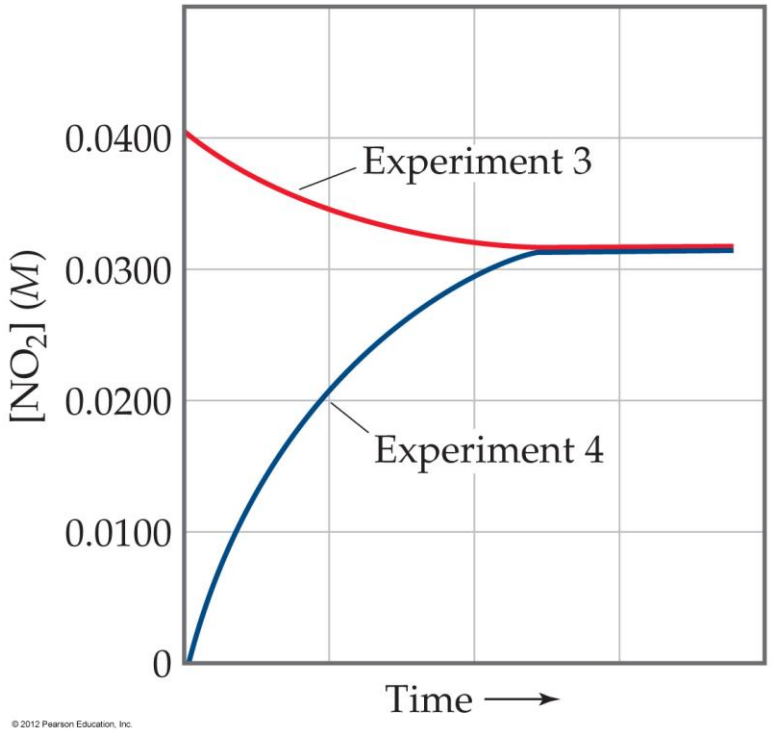

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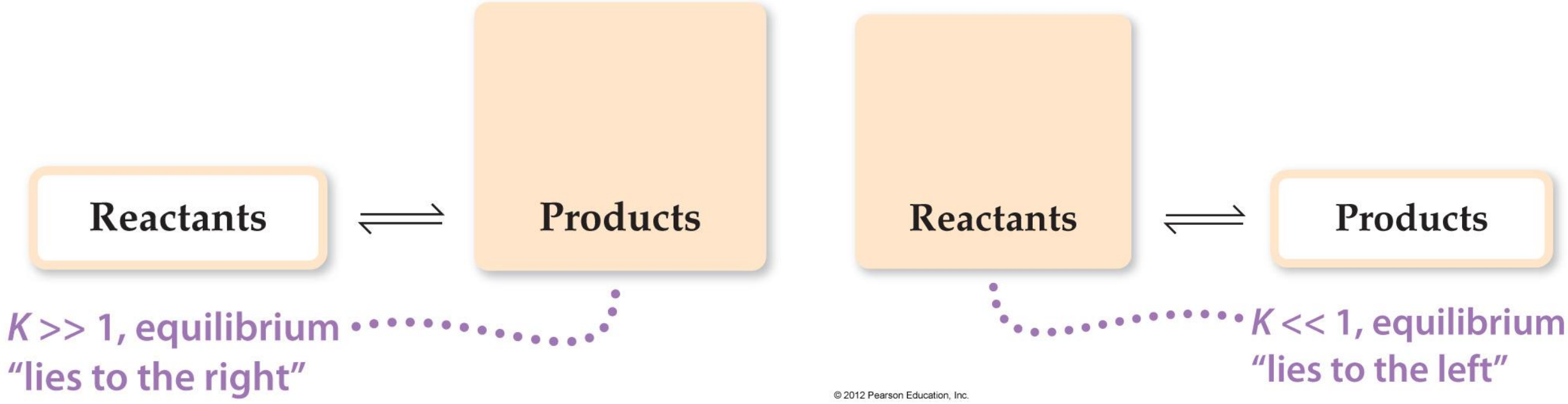
At equilibrium, $K_c = [NO_2]^2 / [N_2O_4]$

The Magnitude of Equilibrium Constants

When K_c is very large, the position of equilibrium lies to the right, meaning the concentration of the products is much greater than the concentration of the reactants.

When K_c is very small, the position of equilibrium lies to the left, meaning the concentration of the reactants is much greater than the concentration of the products.



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The Direction of the Chemical Equation and K

For the reaction $N_2O_{4\,(g)} \Leftrightarrow 2\ NO_{2\,(g)}$ at 100°C, K = 0.212.

For the reaction $2\ NO_{2\,(g)} \Leftrightarrow N_2O_{4\,(g)}$ at 100°C, K = 4.72.

The value of the equilibrium constant for a reaction written one way is the reciprocal of the equilibrium constant for the same reaction written in the reverse direction.

Relating Chemical Equation Stoichiometry and Equilibrium Constants

The value of K_c depends on the coefficients of the chemical equation, therefore, the chemical equation needs to be stated with the value of K_c.

If two or more equilibrium reaction equations are added together to get an overall equation, the values of the individual equilibrium constants are multiplied together to get the equilibrium constant for the overall reaction.

Heterogeneous Equilibria

Homogeneous equilibrium is a chemical equilibrium with all of the reactants and products in the same phase.

Heterogeneous equilibrium is a chemical equilibrium with different phases for species in the reaction.

When an equilibrium substance is in the solid or liquid state, its concentration remains constant, and therefore, is included as part of the equilibrium constant.

In other words, do not include values for the concentrations of solids or liquids in the equilibrium constant expression. Only include the concentrations of ions in solution or other aqueous substances or gases.

Calculating Equilibrium Constants

When the equilibrium concentrations and the chemical equilibrium equation are known, the value of the equilibrium constant is easily calculated.

Example: $N_{2(g)} + 3\,H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

$2.46\,atm \quad 7.38\,atm \quad 0.166\,atm$

$$K_p = \frac{(NH_3)^2}{(N_2)(H_2)^3} = \frac{(0.166)^2}{(2.46)(7.38)^3} = 2.79 \times 10^{-5}$$

Calculating Equilibrium Constants

When the eq. concentrations of one or more species are unknown, they can be determined if the value of K_c for the reaction and the eq. equation is known.

The creation of an ICE table is useful in determining these concentrations.

I - initial concentrations

C - change in concentrations

E - equilibrium concentrations

Example: $H_2 + I_2 \rightleftarrows 2\ HI$

	H_2	I_2	HI
Initial	1.000×10^{-3} M	2.000×10^{-3} M	0 M
Change	$-x$ -0.935×10^{-3} M	$-x$ -0.935×10^{-3} M	$+1.87 \times 10^{-3}$ M $2x$
* Equilibrium	$.065 \times 10^{-3}$ M	1.065×10^{-3} M	1.87×10^{-3} M

$$K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{(1.87 \times 10^{-3})^2}{(0.065 \times 10^{-3})(1.065 \times 10^{-3})} = 51$$

Predicting the Direction of a Reaction

Whether or not a reaction is at equilibrium can be determined by calculating a reaction quotient Q_c, and comparing the value of Q_c with the value of K_c.

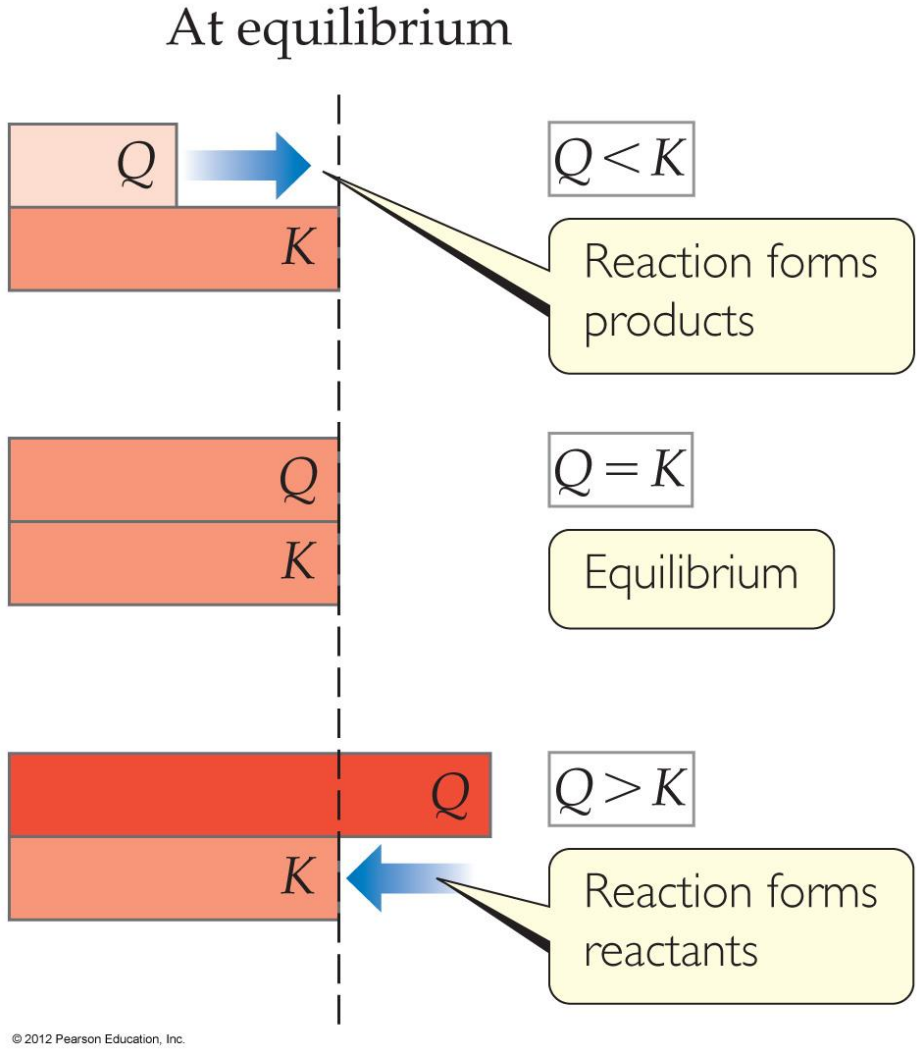
Q_c is calculated in the exact same way as K_c, but the concentrations of the reactants and products at any point in the reaction may be used.

If Q = K, the reaction is at equilibrium.

If Q < K, the reaction needs to make more products (proceed to the right).

If Q > K, the reaction needs to make more reactants (proceed to the left).

Predicting the Direction of a Reaction



Le Châtelier's Principle

Le Châtelier's Principle states: If a system at equilibrium is disturbed by a change in temperature, pressure, or a component concentration, the system will shift its equilibrium position so as to counteract the effect of the disturbance.

Three things can change a system at equilibrium:

1. Changes in reactant or product concentrations,

2. Changes in volume or pressure,

3. Changes in temperature.

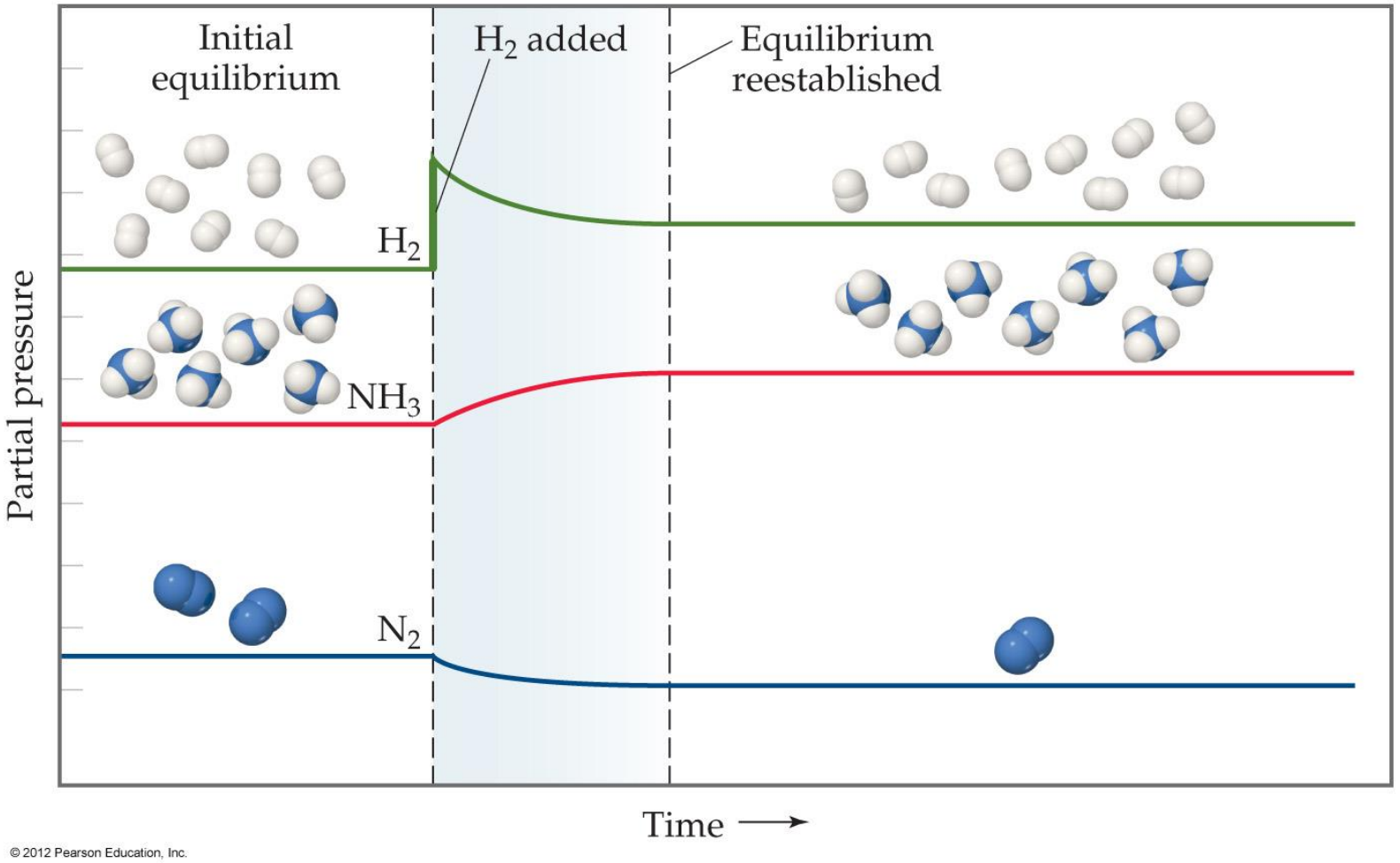
Concentration Changes

When the concentration of a reactant or product is increased, the system will react to reduce the amount of that reactant or product and establish a new equilibrium point.

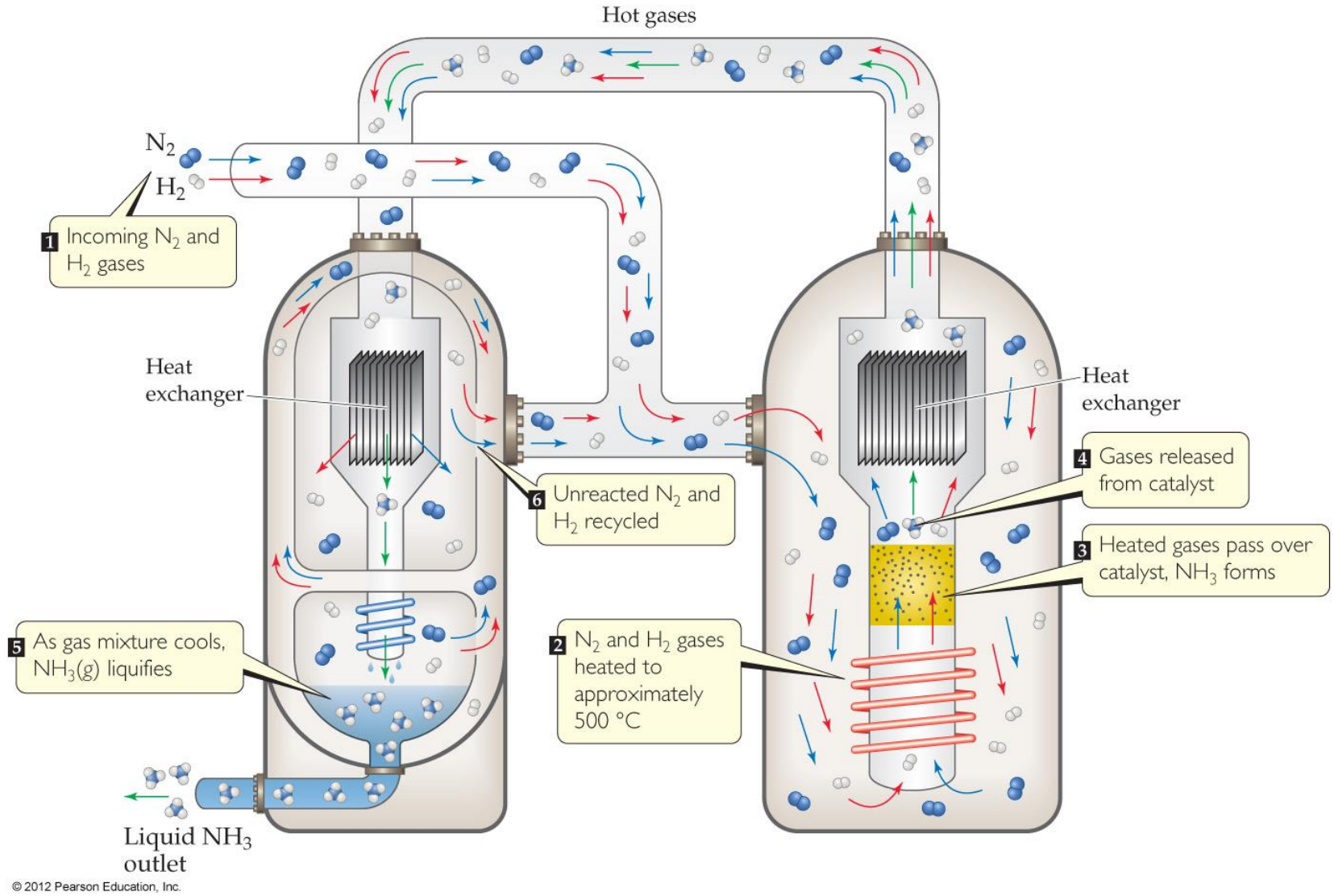
When the concentration of a reactant or product is decreased, the system will react to increase the amount of that reactant or product and establish a new equilibrium point.

Reactant Concentration Increase

$$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g)$$



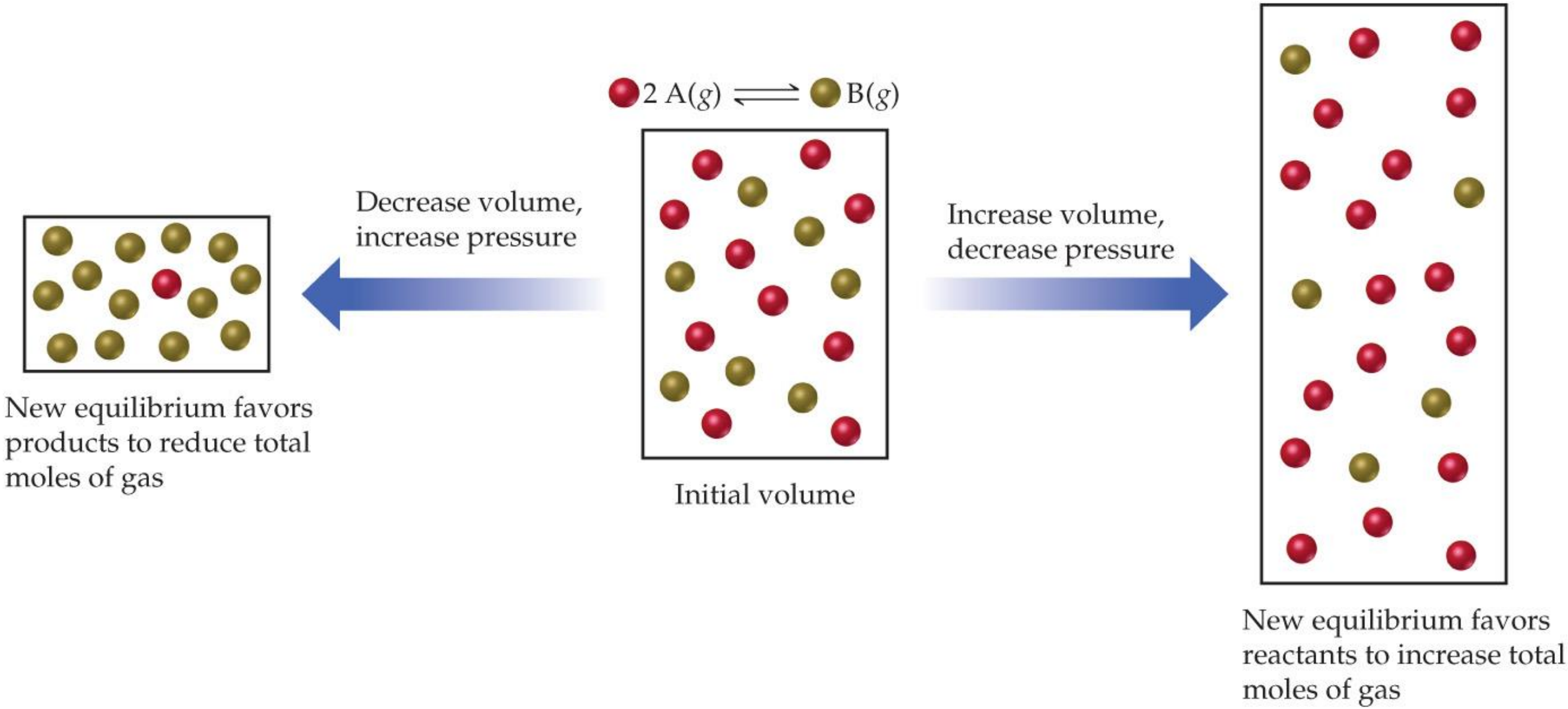
Product Concentration Decrease – The Haber Process



Pressure Changes

When the pressure on a system containing one or more gases is increased, the system will react to produce fewer gas molecules and establish a new equilibrium point. (Look at the coefficients in the balanced equation of the equilibrium reaction.)

When the pressure on a system containing one or more gases is decreased, the system will react to produce more gas molecules and establish a new equilibrium point. (Look at the coefficients in the balanced equation of the equilibrium reaction.)



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Temperature Changes

To determine the effect of a temperature change, the chemical equation for the equilibrium system must be written and indicate which direction is endothermic and which direction is exothermic.

When temperature is increased, the reaction proceeds more in the endothermic direction to absorb the increase in heat.

When temperature is decreased, the reaction proceeds more in the exothermic direction to replace the loss of heat.

Reactants + heat ⇔ products

Forward is endothermic. Reverse is exothermic.

Reactants ⇔ products + heat

Forward is exothermic. Reverse is endothermic.

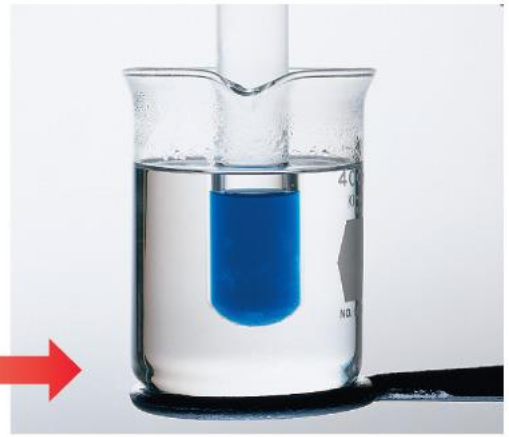
$\Delta H > 0$, endothermic reaction

$$\text{Heat} + Co(H_2O)_6^{2+}(aq) + 4\,Cl^-(aq) \rightleftharpoons CoCl_4^{2-}(aq) + 6\,H_2O(l)$$

Pink — Blue

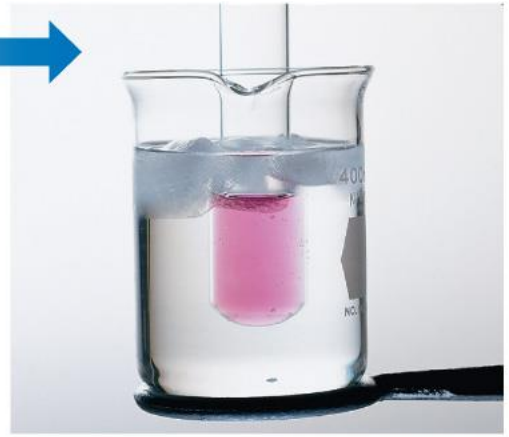
At equilibrium, significant amounts of both pink $Co(H_2O)_6^{2+}$ and blue $CoCl_4^{2-}$ are present; solution appears violet

Heat



Add heat: reaction shifts right to increase blue $CoCl_4^{2-}$ concentration and decrease pink $Co(H_2O)_6^{2+}$ concentration

Cool



Remove heat: reaction shifts left to decrease blue $CoCl_4^{2-}$ concentration and increase pink $Co(H_2O)_6^{2+}$ concentration

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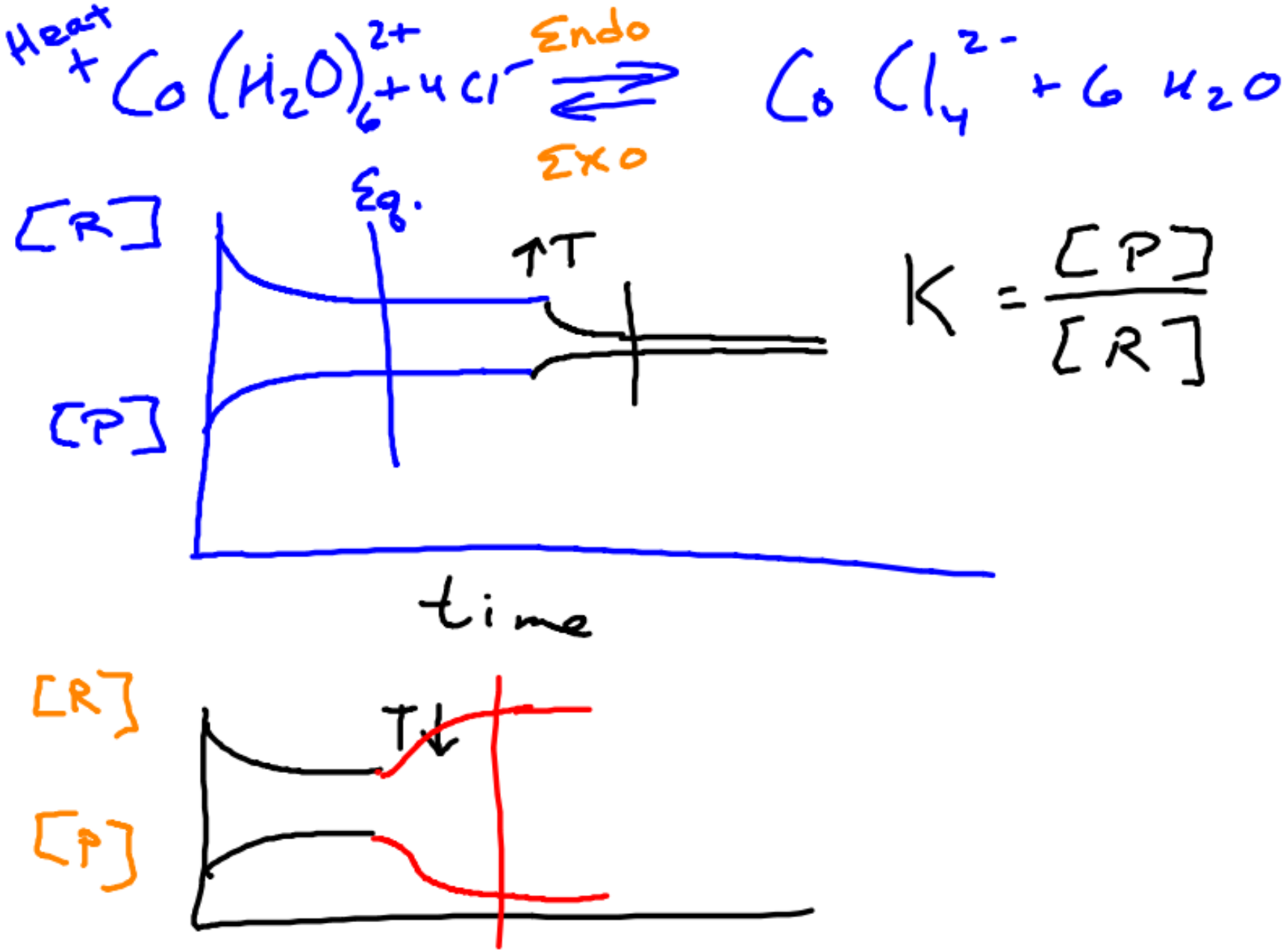
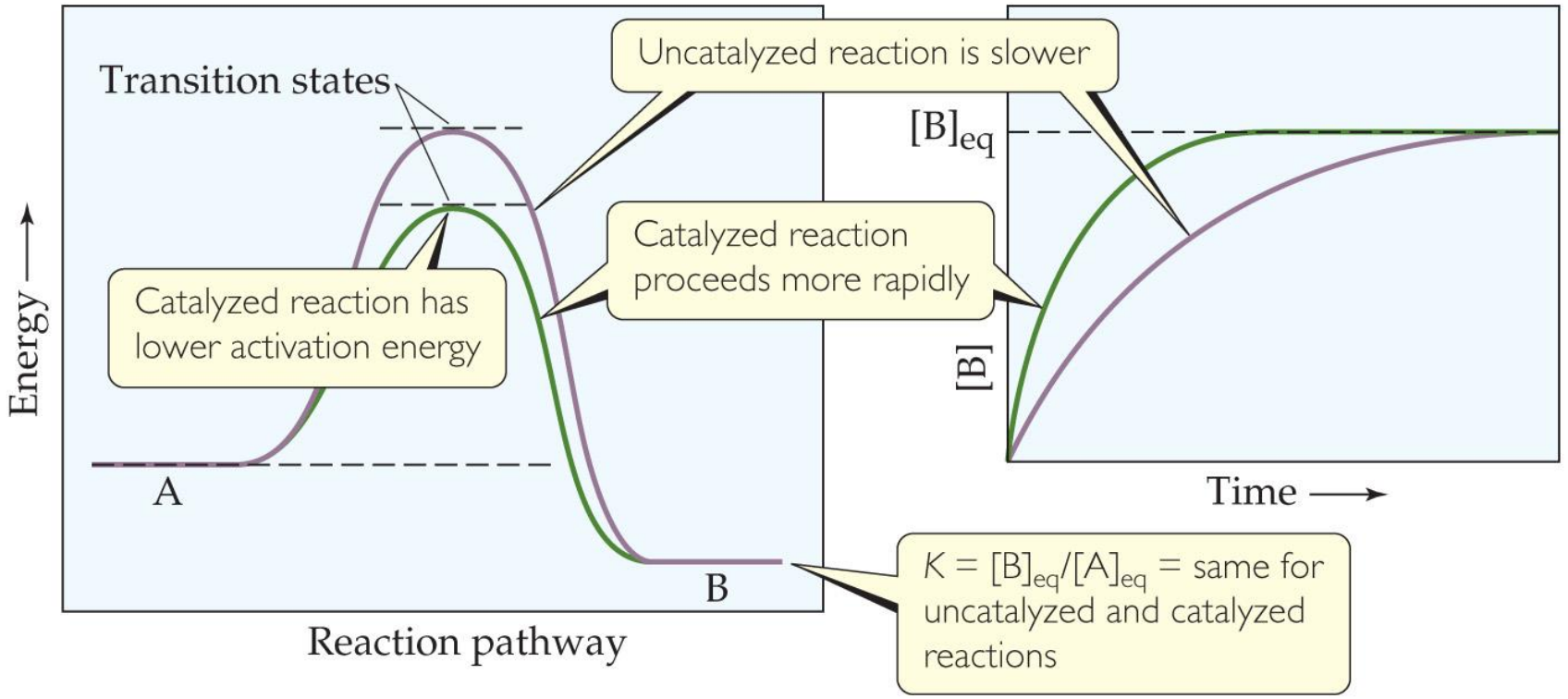

Heat
+
$Co(H_2O)_6^{2+} + 4Cl^-$
Endo
Exo
$CoCl_4^{2-} + 6H_2O$
[R]
[P]
Eq.
↑T
time
$K = \frac{[P]}{[R]}$
[R]
[P]
T↓

Catalysts

A catalyst will increase the rates of both the forward and reverse reactions, but will not change the point of equilibrium, the equilibrium concentrations, or the value of the equilibrium constant.



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CHEMICAL REACTIONS

Chemical Reactions

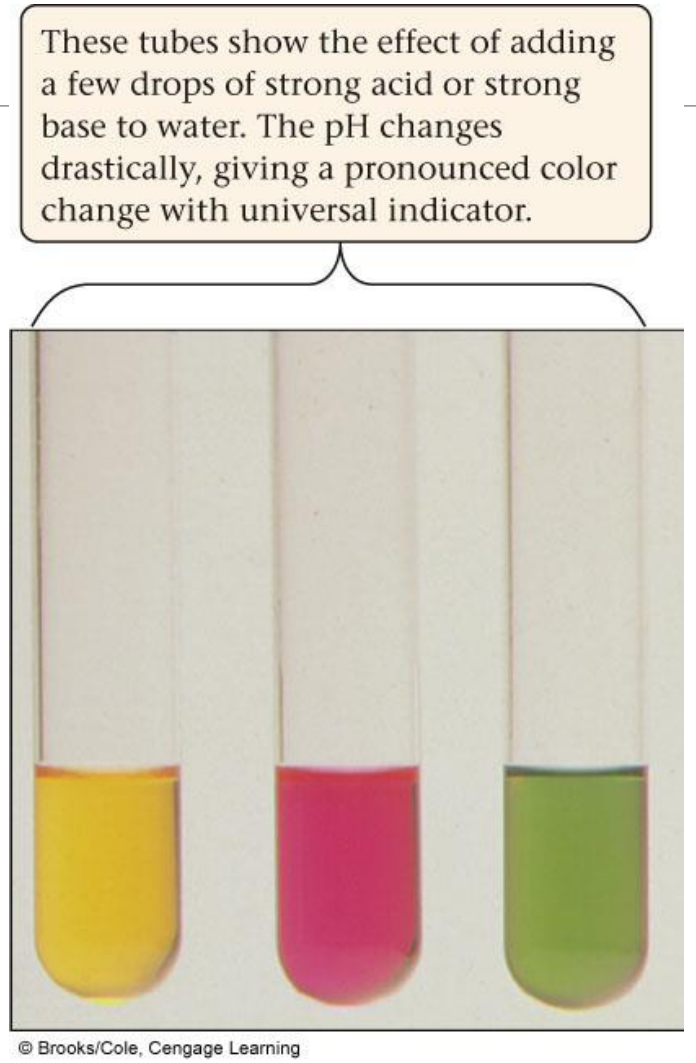
Chemical reactions produce ***chemical changes*** in the chemical composition of matter by rearranging the combination of atoms or ions comprising the matter. Chemical reactions occur in nature or in a laboratory. Examples of natural chemical reactions include rusting of iron, photosynthesis, burning of combustible/flammable materials, fermentation to produce alcohol, respiration and cellular metabolism to name a few.

Chemical reactions begin with one or more substances undergoing a chemical change. The substances undergoing a change are ***reactants***.

Chemical reactions end with one or more new substances formed. The substances formed are ***products***.

Signs of Chemical Reactions

1. Color Changes.

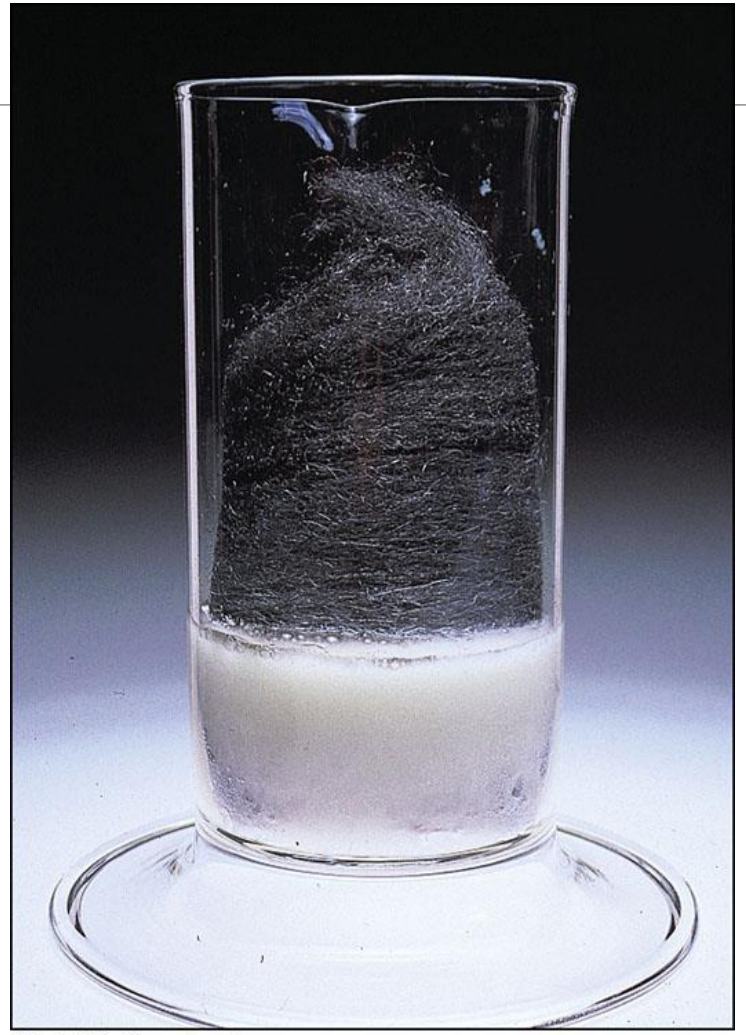


Signs of Chemical Reactions

2. Solid precipitate forms.

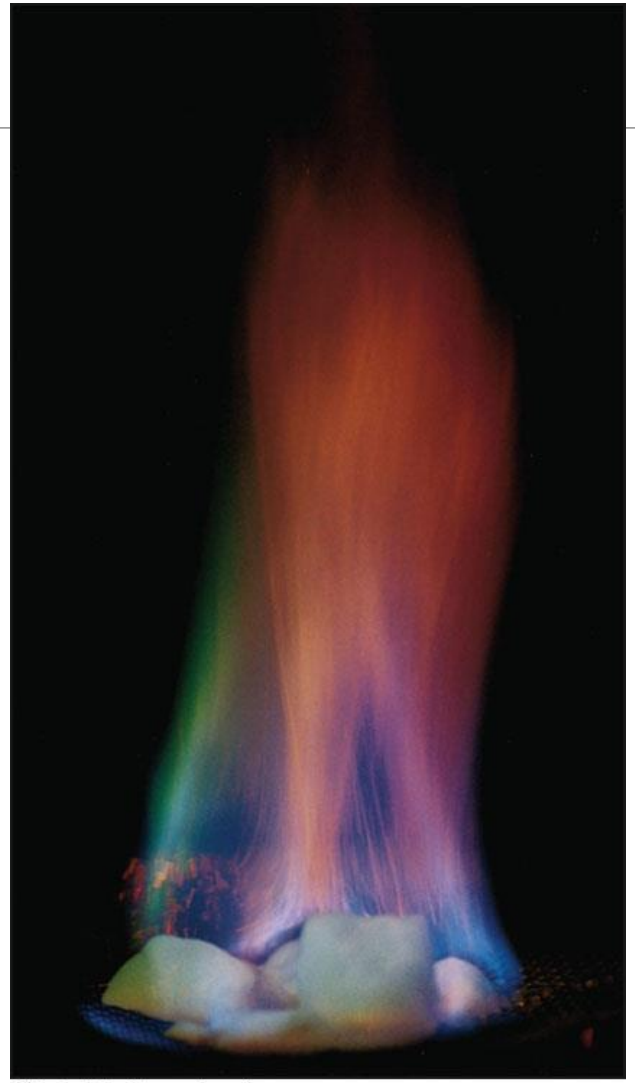
Signs of Chemical Reactions

3. Bubbles (gas) form.



Signs of Chemical Reactions

4. Heat and/or a flame is produced, or heat is absorbed.



Types of Chemical Reactions

There are two general categories of chemical reactions. ***Metathesis reactions*** are those in which there are no change in the oxidation numbers of the atoms in the reaction, and ***oxidation – reduction reactions*** (redox reactions), those involving changes in the oxidation numbers of the atoms in the reaction.

Examples of Metathesis Reactions: Double Replacement or Double Displacement Reactions

General Form: $AB + CD \rightarrow AD + CB$

The reactants and products are ionic compounds, and the reactions occurs in water.

Example: $AgNO_{3\,(aq)} + NaCl_{\,(aq)} \rightarrow NaNO_{3\,(aq)} + AgCl_{\,(s)}$

Knowledge of solubility rules allows for the prediction of the formula(s) of the product(s) of the reaction, or no reaction.

Solubility Rules

Common Soluble Ionic Compounds

1. Compounds containing F^-, NO_3^-, $C_2H_3O_2^-$, NH_4^+, Li^+, Na^+, K^+, Rb^+, Cs^+, or Fr^+, no exceptions
2. Compounds containing Cl^-, Br^- or I^-, except when combined with Ag^+, Hg_2^{2+} or Pb^{2+}
3. Compounds containing SO_4^{2-}, except when combined with Sr^{2+}, Ba^{2+}, Hg_2^{2+} or Pb^{2+}

Common Insoluble Ionic Compounds

4. Compounds containing S^{2-}, except when combined with NH_4^+, Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+, Ca^{2+}, Sr^{2+}, or Ba^{2+}
5. Compounds containing CO_3^{2-}, except when combined with NH_4^+, Li^+, Na^+, K^+, Rb^+, Cs^+ or Fr^+
6. Compounds containing PO_4^{3-}, except when combined with NH_4^+, Li^+, Na^+, K^+, Rb^+, Cs^+ or Fr^+
7. Compounds containing OH^-, except when combined with NH_4^+, Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+, Ca^{2+}, Sr^{2+}, or Ba^{2+}

Examples of Metathesis Reactions: Acid-Base Reactions

There are three general types of acid-base reactions, and all of them are metathesis reactions. The first is the Arrhenius neutralization reaction, represented by the general statement: Acid + Base → Water + Salt (ionic compound). The Arrhenius definition of an acid is any species increasing the concentration of H^+ ions (protons) (or hydronium ions, H_3O^+), in an aqueous solution. Acids have H written first in the chemical formulas. Older systems of writing formulas of carboxylic acids may not follow this rule. Examples include HCl, HI, HBr, $HC_2H_3O_2$ (or CH_3CO_2H or CH_3COOH). The Arrhenius definition of a base is any species increasing the concentration of hydroxide ions, OH^-, in an aqueous solution. Bases have OH written last in the chemical formulas. Examples include NaOH, KOH, $Ca(OH)_2$, $Ba(OH)_2$.

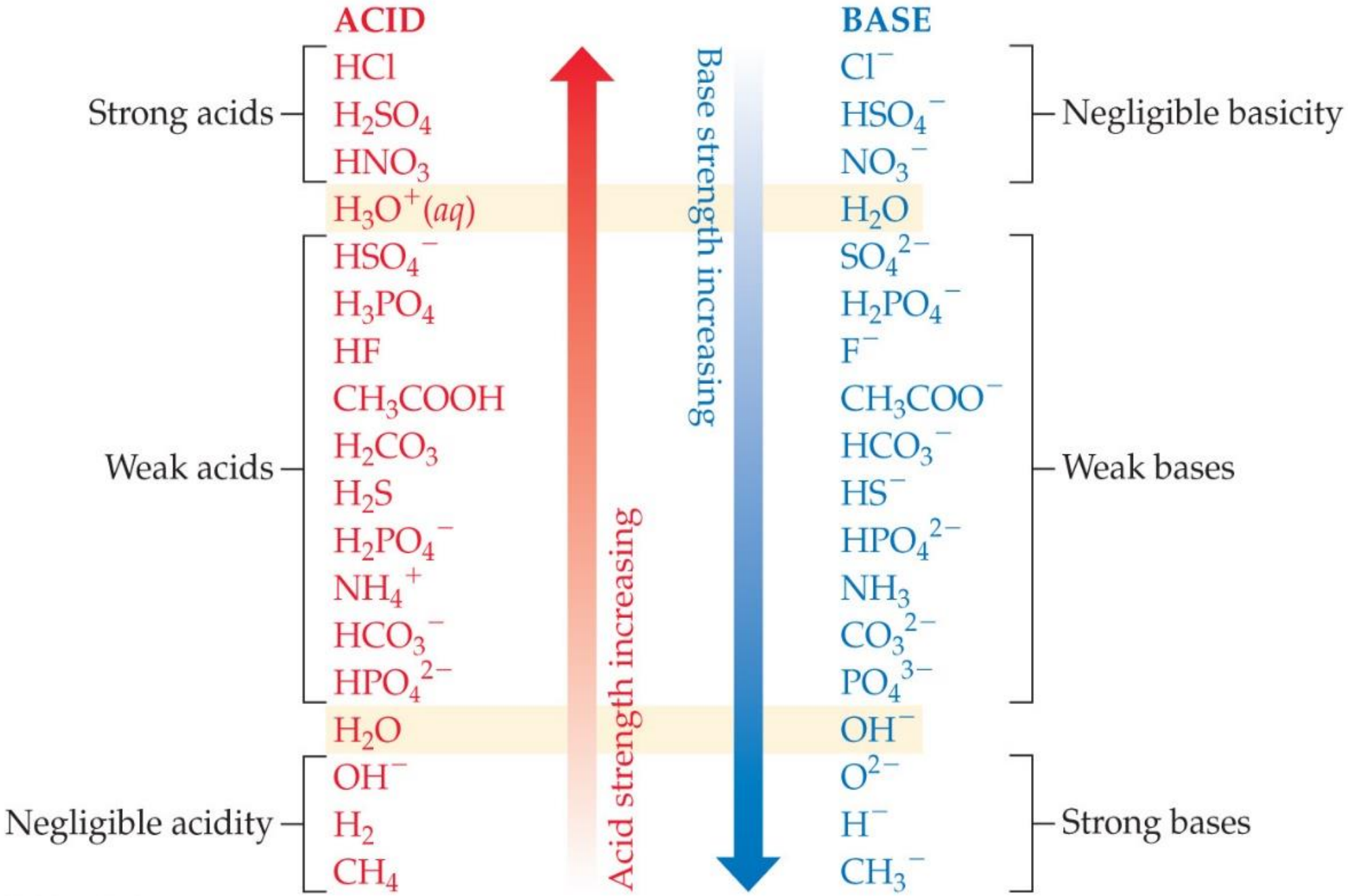
Acid-Base Reactions

An example of the neutralization reaction type is $HCl + NaOH \rightarrow H_2O + NaCl$.

There are seven strong acids: HCl, HI, HBr, H_2SO_4, HNO_3, $HClO_3$, and $HClO_4$. These acids ionize 100% when added to water. Weak acids ionize considerably less in water (about 10% or less). There are eight strong bases: LiOH, NaOH, KOH, RbOH, CsOH, $Ca(OH)_2$, $Sr(OH)_2$, and $Ba(OH)_2$. These bases are ionic compounds with high solubility (dissociation) in water. Weak hydroxide bases (ionic compounds) have low solubility (dissociation) in water.

Acid-Base Reactions

The second general type of acid-base reaction is the Brønsted-Lowry reaction, whereby an H^+ ion transfers from a stronger acid to a stronger base to form a weaker acid and a weaker base. The general statement for the reaction is Stronger Acid + Stronger Base → Weaker Acid + Weaker Base. The substance donating the proton is the stronger acid, and the substance accepting the proton is the stronger base. The products of the reaction are conjugates of the reactants. The conjugate of the stronger acid is the weaker base and the conjugate of the stronger base is the weaker acid. Conjugate acid-base pairs differ by a single proton. A table of some Brønsted-Lowry conjugate acid-base pairs follows.

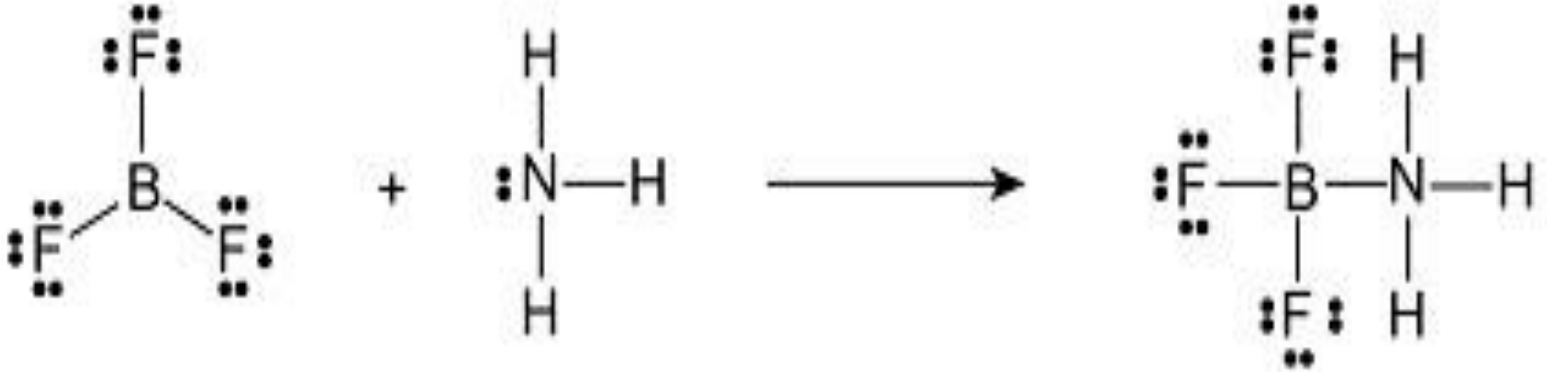

ACID
BASE
Strong acids
HCl
H_2SO_4
HNO_3
$H_3O^+(aq)$
Weak acids
HSO_4^-
H_3PO_4
HF
CH_3COOH
H_2CO_3
H_2S
$H_2PO_4^-$
NH_4^+
HCO_3^-
HPO_4^{2-}
H_2O
Negligible acidity
OH^-
H_2
CH_4
Acid strength increasing
Base strength increasing
Cl^-
HSO_4^-
NO_3^-
H_2O
SO_4^{2-}
$H_2PO_4^-$
F^-
CH_3COO^-
HCO_3^-
HS^-
HPO_4^{2-}
NH_3
CO_3^{2-}
PO_4^{3-}
OH^-
O^{2-}
H^-
CH_3^-
Negligible basicity
Weak bases
Strong bases

Acid-Base Reactions

An example of this type of reaction is $HC_2H_3O_2 + NH_3 \rightleftharpoons NH_4^+ + C_2H_3O_2^-$. The reaction is naturally reversible and reaches a state of chemical equilibrium, indicated by the two opposing arrows. The longer arrow represents the direction in which the point of equilibrium lies. In this example, the products are favored over the reactants.

Acid-Base Reactions

The third general type of acid-base reaction is the Lewis acid-base reaction. Lewis acids typically have valence electron arrangements allowing them to accept a pair of electrons to form a covalent bond. Lewis bases typically have valence electron arrangement with at least one unshared pair of electrons to share with the Lewis acid to form the covalent bond. An example is $NH_3 + BF_3 \rightarrow H_3NBF_3$.



Oxidation-Reduction (Redox) Reactions

Oxidation Numbers

Oxidation numbers are the charge an atom in a compound would have if the bonded electrons in the compound belonged to atoms completely based on electronegativity values. Electronegativity is the ability of atoms to attract bonded electrons. Electronegativity values range from 0.7 (Fr) to 4.0 (F). Elements with higher electronegativity values attract bonded electrons more than elements with lower electronegativity values.

H 2.1																	He ---
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne ---
Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.2	S 2.5	Cl 3.0	Ar ---
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 3.0
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6
Cs 0.7	Ba 0.9	La-Lu 1.1-1.2	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	Rn ---
Fr 0.7	Ra 0.9	Ac-No 1.1-1.7															

The rules for assigning oxidation numbers to atoms are:

1. Uncombined elements have an oxidation number of zero.

2. Monatomic ions have an oxidation number equal to the charge of the ion.

3. The oxidation number of hydrogen is +1 when combined with a nonmetal.

4. The oxidation number of hydrogen is -1 when combined with a metal.

5. Group 1 metals have an oxidation number of +1 in compounds.

6. Group 2 metals have an oxidation number of +2 in compounds.

7. Fluorine always has an oxidation number of -1 in compounds.

8. Oxygen usually has an oxidation number of -2. Exceptions: when oxygen has a single covalent bond to another oxygen atom in a molecule, or when it exists as the peroxide (O_2^{2-}) ion.

9. The sum of the oxidation numbers of the atoms or ions in the formula of a neutral substance must equal zero.

10. The sum of the oxidation numbers of the atoms in a polyatomic ion must equal the charge on the polyatomic ion.

11. The position of the elements on the periodic table can help to determine the oxidation numbers of the atoms in a formula. Elements toward the lower left tend to be more positive while elements toward the upper right tend to be more negative. This is the electronegativity trend on the periodic table.

The rules for assigning oxidation numbers to atoms are:

1. Uncombined elements have an oxidation number of zero.
2. Monatomic ions have an oxidation number equal to the charge of the ion.
3. The oxidation number of hydrogen is +1 when combined with a nonmetal.
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6. Group 2 metals have an oxidation number of +2 in compounds.
7. Fluorine always has an oxidation number of -1 in compounds.
8. Oxygen usually has an oxidation number of -2. Exceptions: when oxygen has a single covalent bond to another oxygen atom in a molecule, or when it exists as the peroxide (O_2^{2-}) ion.
9. The sum of the oxidation numbers of the atoms or ions in the formula of a neutral substance must equal zero.
10. The sum of the oxidation numbers of the atoms in a polyatomic ion must equal the charge on the polyatomic ion.
11. The position of the elements on the periodic table can help to determine the oxidation numbers of the atoms in a formula. Elements toward the lower left tend to be more positive while elements toward the upper right tend to be more negative. This is the electronegativity trend on the periodic table.

Redox Reactions: Synthesis or Direct Combination Reactions

General Form: A + B → AB, where A and B may be elements or compounds and AB is a compound.

Example: 2 Na + Cl_2 → 2 NaCl

The oxidation numbers of the reactants are zero. The oxidation number of Na in the product is +1 and the oxidation number of Cl in the product is -1. Since the oxidation number of Na went from 0 to +1 (an increase in oxidation number), Na is the substance undergoing oxidation. Since the oxidation number of Cl went from 0 to -1 (a decrease in oxidation number), Cl is the substance undergoing reduction.

Decomposition Reactions (may or may not be redox reactions)

General Form: AB → A + B, where AB is a compound and the products A and B may be elements or compounds. An analysis reaction separates a compound into its elements.

Example (electrolysis of water): $2\ H_2O \rightarrow 2\ H_2 + O_2$.

The oxidation number of H in the reactant is +1 and the oxidation number of H in the product is 0 (reduction). The oxidation number of O in the reactant is -2 and the oxidation number of O in the product is 0 (oxidation).

The following is an example of another decomposition reaction, but none of the oxidation numbers change:

$H_2CO_3 \rightarrow H_2O + CO_2$.

Redox Reactions: Single Replacement or Single Displacement Reactions

General Form: A + BC → B + AC, where A is a more active metal, B is a less active metal, and C is an anion.

Example: $Cu + 2\ AgNO_3 \rightarrow 2\ Ag + Cu(NO_3)_2$

Knowledge of the Activity Series helps to predict whether a particular combination of substances will react. The Activity Series (below) lists the most active metal at the top of the list (Li) and the least active metal (Au) at the bottom of the list. The metal atoms of the more active metals will replace the ions of the less active metals in solutions.

These reactions involve the transfer of electrons from the metal atoms to the metal ions in the solution creating changes in oxidation numbers of these species.

TABLE 4.5 • Activity Series of Metals in Aqueous Solution

Metal	Oxidation Reaction
Lithium	$Li(s) \longrightarrow Li^+(aq) + e^-$
Potassium	$K(s) \longrightarrow K^+(aq) + e^-$
Barium	$Ba(s) \longrightarrow Ba^{2+}(aq) + 2e^-$
Calcium	$Ca(s) \longrightarrow Ca^{2+}(aq) + 2e^-$
Sodium	$Na(s) \longrightarrow Na^+(aq) + e^-$
Magnesium	$Mg(s) \longrightarrow Mg^{2+}(aq) + 2e^-$
Aluminum	$Al(s) \longrightarrow Al^{3+}(aq) + 3e^-$
Manganese	$Mn(s) \longrightarrow Mn^{2+}(aq) + 2e^-$
Zinc	$Zn(s) \longrightarrow Zn^{2+}(aq) + 2e^-$
Chromium	$Cr(s) \longrightarrow Cr^{3+}(aq) + 3e^-$
Iron	$Fe(s) \longrightarrow Fe^{2+}(aq) + 2e^-$
Cobalt	$Co(s) \longrightarrow Co^{2+}(aq) + 2e^-$
Nickel	$Ni(s) \longrightarrow Ni^{2+}(aq) + 2e^-$
Tin	$Sn(s) \longrightarrow Sn^{2+}(aq) + 2e^-$
Lead	$Pb(s) \longrightarrow Pb^{2+}(aq) + 2e^-$
Hydrogen	$H_2(g) \longrightarrow 2\,H^+(aq) + 2e^-$
Copper	$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^-$
Silver	$Ag(s) \longrightarrow Ag^+(aq) + e^-$
Mercury	$Hg(l) \longrightarrow Hg^{2+}(aq) + 2e^-$
Platinum	$Pt(s) \longrightarrow Pt^{2+}(aq) + 2e^-$
Gold	$Au(s) \longrightarrow Au^{3+}(aq) + 3e^-$

Redox Reactions: Combustion Reactions

Combustion reactions generally have two reactants, a fuel and oxygen. If the fuel contains C and H (it may contain O), the products will be CO_2 and H_2O if the reaction is complete. Combustion reactions produce energy in the form of heat and light (flame). Some combustion reactions do not require C and H, but they still produce heat and light.

General Form: Fuel + $O_2 \rightarrow H_2O + CO_2$

Example: $CH_4 + 2\ O_2 \rightarrow 2\ H_2O + CO_2$

The oxidation number of C in the reactant is -4 (C is more electronegative than H) and it is +4 in the product (C is less electronegative than O), so C undergoes oxidation. The oxidation number of O in the reactant is 0 (element) and it is -2 in the product, so O undergoes reduction.

Synthesis reactions may be combustion reactions if the reactant combines with oxygen to produce one product, giving off heat and light.

Example: $2\ Mg + O_2 \rightarrow 2\ MgO$

Redox Reactions: Disproportionation Reactions

A disproportionation reaction is one in which different atoms of an element in a reactant undergo reduction or oxidation.

Example: $2\ H_2O_2 \rightarrow 2\ H_2O + O_2$

Each O atom in the reactant has an oxidation number of -1. The O in the product H_2O has an oxidation number of -2 (reduction), and the oxidation number of the O in the product O_2 is 0 (oxidation).

Redox Reactions: Electrochemical Reactions

Separating the reactants of a single replacement reaction into two half-cells will make an electrochemical reaction to produce electricity to do useful work. The Activity Series is the basis of the reaction. To predict the voltage produced by the reaction under standard conditions, use the Table of Standard Reduction Potentials (below).

Example: Oxidation Half-Reaction: $Zn \rightarrow Zn^{2+} + 2\ e^-$ $E°_{oxidation} = +0.76\ V$

Reduction Half-Reaction: $Cu^{2+} + 2\ e^- \rightarrow Cu$ $E°_{reduction} = +0.34\ V$

Net Chemical Equation: $Zn + Cu^{2+} \rightarrow Cu + Zn^{2+}$ $E°_{cell} = +1.10\ V$

TABLE 20.1 • Standard Reduction Potentials in Water at 25 °C

E°_{red} (V)	Reduction Half-Reaction
+2.87	$F_2(g) + 2\,e^- \longrightarrow 2\,F^-(aq)$
+1.51	$MnO_4^-(aq) + 8\,H^+(aq) + 5\,e^- \longrightarrow Mn^{2+}(aq) + 4\,H_2O(l)$
+1.36	$Cl_2(g) + 2\,e^- \longrightarrow 2\,Cl^-(aq)$
+1.33	$Cr_2O_7^{2-}(aq) + 14\,H^+(aq) + 6\,e^- \longrightarrow 2\,Cr^{3+}(aq) + 7\,H_2O(l)$
+1.23	$O_2(g) + 4\,H^+(aq) + 4\,e^- \longrightarrow 2\,H_2O(l)$
+1.06	$Br_2(l) + 2\,e^- \longrightarrow 2\,Br^-(aq)$
+0.96	$NO_3^-(aq) + 4\,H^+(aq) + 3\,e^- \longrightarrow NO(g) + 2\,H_2O(l)$
+0.80	$Ag^+(aq) + e^- \longrightarrow Ag(s)$
+0.77	$Fe^{3+}(aq) + e^- \longrightarrow Fe^{2+}(aq)$
+0.68	$O_2(g) + 2\,H^+(aq) + 2\,e^- \longrightarrow H_2O_2(aq)$
+0.59	$MnO_4^-(aq) + 2\,H_2O(l) + 3\,e^- \longrightarrow MnO_2(s) + 4\,OH^-(aq)$
+0.54	$I_2(s) + 2\,e^- \longrightarrow 2\,I^-(aq)$
+0.40	$O_2(g) + 2\,H_2O(l) + 4\,e^- \longrightarrow 4\,OH^-(aq)$
+0.34	$Cu^{2+}(aq) + 2\,e^- \longrightarrow Cu(s)$
0 [defined]	$2\,H^+(aq) + 2\,e^- \longrightarrow H_2(g)$
−0.28	$Ni^{2+}(aq) + 2\,e^- \longrightarrow Ni(s)$
−0.44	$Fe^{2+}(aq) + 2\,e^- \longrightarrow Fe(s)$
−0.76	$Zn^{2+}(aq) + 2\,e^- \longrightarrow Zn(s)$
−0.83	$2\,H_2O(l) + 2\,e^- \longrightarrow H_2(g) + 2\,OH^-(aq)$
−1.66	$Al^{3+}(aq) + 3\,e^- \longrightarrow Al(s)$
−2.71	$Na^+(aq) + e^- \longrightarrow Na(s)$
−3.05	$Li^+(aq) + e^- \longrightarrow Li(s)$

STOICHIOMETRY

THE MATHEMATICS OF CHEMICALS AND CHEMICAL REACTIONS

The Mole
Avogadro's Number

Many of the calculations in chemistry involve a quantity called a mole. A mole of anything is equal to the number of atoms in exactly 12 grams of Carbon-12. The number of things in a mole is 6.022×10^{23}. This is Avogadro's number, or Avogadro's constant, N_A, and is one of the seven basic units (quantity) in the SI System.

*Lorenzo Romano Amedeo Carlo Avogadro, conte di Quaregna e Cerreto (*August 9, 1776 - July 9, 1856)

Equivalence Relationships

Calculations in chemistry also involve equivalence relationships. An equivalence relationship shows how two different quantities are related to each other.

Example equivalence relationships are:

1 mole C-12 = 12 g C-12

1 mole C-12 = 6.022×10^{23} atoms C-12

12 g C-12 = 6.022×10^{23} atoms C-12

1 mole H_2O = 18 g H_2O

1 mole H_2O = 6.022×10^{23} molecules H_2O

18 g H_2O = 6.022×10^{23} molecules H_2O

Conversion Factors

A conversion factor uses an equivalence relationship to convert a given quantity into another equivalent quantity.

Example:

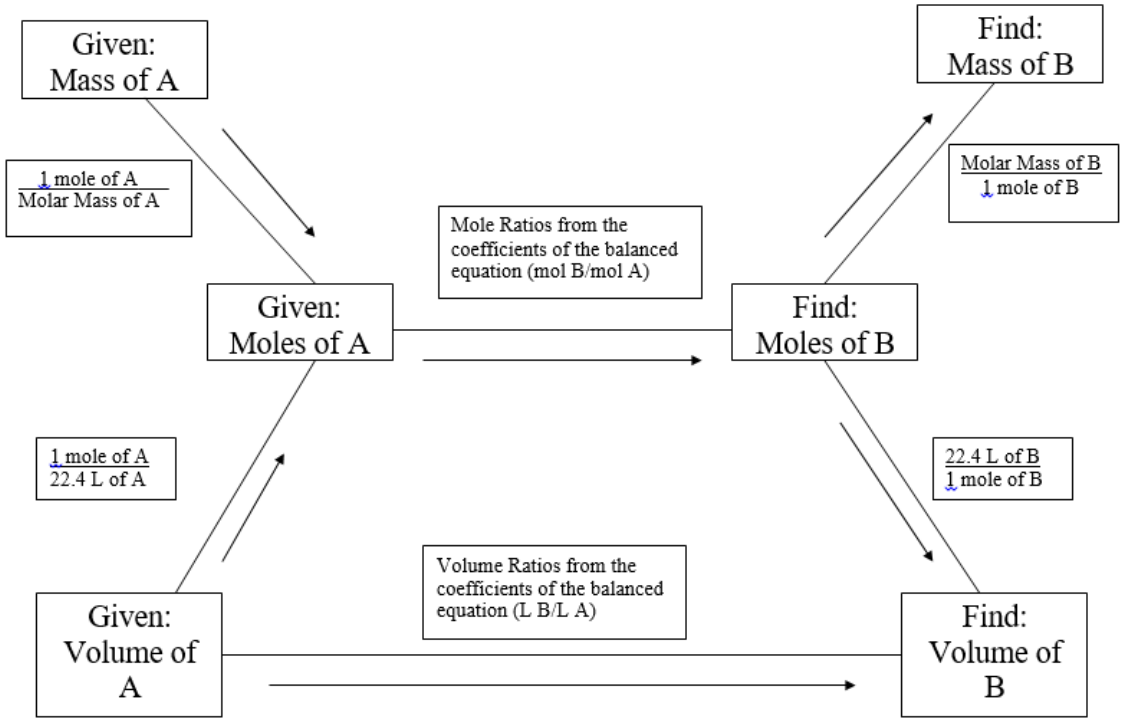
Convert 65.8 grams C-12 into moles C-12.

(65.8 ~~g C-12~~)(1 mol C-12/12 ~~g C-12~~) = 5.48 mol C-12

Note: the numbers in conversion factors are not considered for significant figure purposes as they are defined quantities or exact quantities, not measured quantities.

Conversions in Chemical Reactions

Equivalence relationships exist between substances in a chemical reaction and are determined by using the coefficients of the substances in a balanced chemical equation for the reaction. When an equation is balanced, use the coefficient ratios to convert a quantity of one substance into a quantity of another substance.



Conversions in Chemical Reactions

Example:

Given the following balanced chemical equation, convert the given mass (43.2 g) of the reactant sodium, Na, into the expected mass in grams of sodium chloride, NaCl, assuming there is enough chlorine for the reaction to go to completion.

$$2\ Na + Cl_2 \rightarrow 2\ NaCl$$

(43.2 ~~g Na~~)(1 ~~mol Na~~/23.0 ~~g Na~~)(2 ~~mol NaCl~~/2 ~~mol Na~~)(58.4 g NaCl/1 ~~mol NaCl~~) = 110 g NaCl

Other Stoichiometry Situations

Stoichiometry is also used in other chemistry calculations including (but not limited to):

Chemical Analysis

Empirical Formulae

Percent Composition

Solutions (Concentrations, Moles, Volumes)

Students should become familiar with all of the different types of calculations used in chemistry. Practice as many problems as possible.