

## Index

### A

**absolute temperature**

[1.3: Temperature](#)

**absolute zero**

[5.7: The Third Law of Thermodynamics](#)

**absorbance**

[11.2: Measuring Reaction Rates](#)

**acetic acid**

[9.8: Acid-Base Equilibria](#)

**acid/base equilibrium**

[9.9: Buffers](#)

**acid/base reaction**

[9.9: Buffers](#)

**activated complex**

[11.11: Transition State Theory](#)

[12.1: Reaction Mechanisms](#)

**activation energy**

[11.9: Temperature Dependence](#)

[11.10: Collision Theory](#)

**activities**

[9.3: Activities and Fugacities](#)

**activity**

[7.8: Non-ideality in Solutions - Activity](#)

**activity coefficient**

[7.8: Non-ideality in Solutions - Activity](#)

**adiabatic**

[5.2: Heat Engines and the Carnot Cycle](#)

**adiabatic bomb calorimetry**

[3.4: Calorimetry](#)

**Adiabatic Changes**

[3.3: Reversible and Irreversible Pathways](#)

[5.4: Calculating Entropy Changes](#)

**adiabatic compressibility**

[5.8: Adiabatic Compressibility](#)

**adiabatic expansion**

[6.8: The Difference between  \$C\_p\$  and  \$C\_v\$](#)

**adiabatic process**

[3.3: Reversible and Irreversible Pathways](#)

[5.8: Adiabatic Compressibility](#)

**air pressure**

[1.2: Pressure and Molar Volume](#)

**Alessandro Volta**

[10.1: Electricity](#)

**alpha**

[4.5: The Joule-Thomson Effect](#)

**ambient air pressure**

[1.2: Pressure and Molar Volume](#)

**Amedeo Avogadro**

[2.1: The Empirical Gas Laws](#)

**Ancient Egyptians**

[10.1: Electricity](#)

**Anders Celsius**

[1.3: Temperature](#)

**anode**

[10.3: Half Cells and Standard Reduction Potentials](#)

**Arrhenius equation**

[11.9: Temperature Dependence](#)

[11.10: Collision Theory](#)

[11.11: Transition State Theory](#)

**arrhenius prefactor**

[11.10: Collision Theory](#)

**arrow of time**

[5.1: Introduction to the Second Law](#)

**atmospheric chemistry**

[12.10: Catalysis](#)

**attractive forces**

[2.6: Collisions with Other Molecules](#)

**autocatalysis**

[12.11: Oscillating Reactions](#)

**autoionization**

[9.8: Acid-Base Equilibria](#)

**average speed in gas**

[2.3: The Kinetic Molecular Theory of Gases](#)

**Avogadro's number**

[1.1: The System and the Surroundings](#)

[2.4: Kinetic Energy](#)

**Avogadro's law**

[2.1: The Empirical Gas Laws](#)

**azeotrope**

[8.8: Non-ideality - Henry's Law and Azeotropes](#)

**azeotropes**

[8.8: Non-ideality - Henry's Law and Azeotropes](#)

### B

**barometer**

[1.2: Pressure and Molar Volume](#)

**basic pH**

[9.8: Acid-Base Equilibria](#)

**battery chemistry**

[10.2: The connection to  \$\Delta G\$](#)

**Benjamin Franklin**

[10.1: Electricity](#)

**benzoic acid**

[3.4: Calorimetry](#)

**bimolecular**

[12.1: Reaction Mechanisms](#)

**bimolecular reaction**

[12.1: Reaction Mechanisms](#)

**bimolecular reactions**

[11.10: Collision Theory](#)

**binary mixture**

[8.8: Non-ideality - Henry's Law and Azeotropes](#)

**binary mixtures**

[8.6: Phase Diagrams for Binary Mixtures](#)

**binary system**

[7.4: The Gibbs-Duhem Equation](#)

**biochemistry**

[5.2: Heat Engines and the Carnot Cycle](#)

**BIPM**

[1.4: The Zeroth Law of Thermodynamics](#)

**boiling point elevation**

[7.6: Colligative Properties](#)

**boiling point of water**

[1.3: Temperature](#)

**boiling points**

[8.7: Liquid-Vapor Systems - Raoult's Law](#)

**Boltzmann**

[5.6: Entropy and Disorder](#)

[5.7: The Third Law of Thermodynamics](#)

**Boltzmann equation for entropy**

[5.6: Entropy and Disorder](#)

**Boltzmann's equation**

[5.6: Entropy and Disorder](#)

**bomb calorimeter**

[3.4: Calorimetry](#)

**bomb calorimetry**

[3.4: Calorimetry](#)

**bond dissociation**

[3.7: Lattice Energy and the Born-Haber Cycle](#)

**bond energy**

[3.6: Reaction Enthalpies](#)

**Boyle temperature**

[2.7: Real Gases](#)

**Boyle's Law**

[2.1: The Empirical Gas Laws](#)

[4.3: Compressibility and Expansivity](#)

**buffer**

[9.9: Buffers](#)

**buffer solution**

[9.9: Buffers](#)

### C

**calculation**

[5.7: The Third Law of Thermodynamics](#)

**Calculus**

[7.5: Non-ideality in Gases - Fugacity](#)

**calories**

[1.5: Work and Energy](#)

**calorimetry**

[3.2: Work and Heat](#)

[3.4: Calorimetry](#)

**car batteries**

[10.4: Entropy of Electrochemical Cells](#)

**carbon dioxide**

[8.8: Non-ideality - Henry's Law and Azeotropes](#)

**carbon monoxide crystal**

[5.6: Entropy and Disorder](#)

**Carnot cycle**

[5.1: Introduction to the Second Law](#)

[5.2: Heat Engines and the Carnot Cycle](#)

**Carnot engine**

[5.3: Entropy](#)

**catalyst**

[12.2: Concentration Profiles for Some Simple Mechanisms](#)

[12.8: The Michaelis-Menten Mechanism](#)

[12.10: Catalysis](#)

**catalytic decomposition of ozone**

[12.10: Catalysis](#)

**cathode**

[10.3: Half Cells and Standard Reduction Potentials](#)

**cell potential**

[10.2: The connection to  \$\Delta G\$](#)

[10.3: Half Cells and Standard Reduction Potentials](#)

[10.4: Entropy of Electrochemical Cells](#)

**Celsius scale**

[1.3: Temperature](#)

**chain reaction**

[12.9: Chain Reactions](#)

**chain rule**

[4.6: Useful Definitions and Relationships](#)

[6.4: Volume Dependence of Helmholtz Energy](#)

**changes in energy**

[4.2: Total and Exact Differentials](#)

**changing volume**

[6.4: Volume Dependence of Helmholtz Energy](#)

## chaos

5.6: Entropy and Disorder

## Charles' Law

4.3: Compressibility and Expansivity

## Charles' Law

2.1: The Empirical Gas Laws

## Charles's Law

2.1: The Empirical Gas Laws

## chemical compounds

8.9: Solid-Liquid Systems - Eutectic Points

## chemical equations

11.7: The Method of Initial Rates

## chemical equilibria

9: Chemical Equilibria

## chemical equilibrium

12.6: The Equilibrium Approximation

## chemical kinetics

11.4: 0th order Rate Law

11.7: The Method of Initial Rates

11.8: The Method of Half-Lives

11.10: Collision Theory

12.2: Concentration Profiles for Some Simple Mechanisms

12.3: The Connection between Reaction

Mechanisms and Reaction Rate Laws

12.4: The Rate Determining Step Approximation

12.5: The Steady-State Approximation

12.6: The Equilibrium Approximation

## chemical pathway

12.1: Reaction Mechanisms

## chemical physics

2.5: Graham's Law of Effusion

## chemical potential

7.3: Chemical Potential

7.4: The Gibbs-Duhem Equation

7.5: Non-ideality in Gases - Fugacity

7.6: Colligative Properties

7.7: Solubility

8.2: Single Component Phase Diagrams

8.3: Criterion for Phase Equilibrium

8.4: The Clapeyron Equation

9.2: Chemical Potential

## chemical potential equation

7.3: Chemical Potential

## chemical reaction

9.1: Prelude to Chemical Equilibria

9.2: Chemical Potential

11.1: Reaction Rate

11.3: Rate Laws

## chemical reaction rates

11.11: Transition State Theory

## chemical reactions

2.6: Collisions with Other Molecules

3.1: Prelude to Thermodynamics

3.4: Calorimetry

6.1: Free Energy Functions

7.1: Thermodynamics of Mixing

10.4: Entropy of Electrochemical Cells

11.2: Measuring Reaction Rates

11.6: 2nd order Rate Laws

11.7: The Method of Initial Rates

11.8: The Method of Half-Lives

11.9: Temperature Dependence

12.5: The Steady-State Approximation

## chemical systems

9.1: Prelude to Chemical Equilibria

## chemical thermodynamics

6.6: Temperature Dependence of A and G

7.5: Non-ideality in Gases - Fugacity

## chemistry

3.1: Prelude to Thermodynamics

5.2: Heat Engines and the Carnot Cycle

5.3: Entropy

5.8: Adiabatic Compressibility

6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work

6.5: Pressure Dependence of Gibbs Energy

6.7: When Two Variables Change at Once

7.4: The Gibbs-Duhem Equation

## chlorofluorocarbons

12.10: Catalysis

## Clapeyron equation

8.4: The Clapeyron Equation

8.5: The Clausius-Clapeyron Equation

## Clausius inequality

5.5: Comparing the System and the Surroundings

## Clausius models

2.7: Real Gases

## closed system

1.1: The System and the Surroundings

## colligative properties

7.6: Colligative Properties

7.7: Solubility

## colligative property

7.6: Colligative Properties

## collision cylinder

2.6: Collisions with Other Molecules

## collision frequency

2.4: Kinetic Energy

2.6: Collisions with Other Molecules

## collision theory

11.9: Temperature Dependence

11.10: Collision Theory

## collision volume

2.4: Kinetic Energy

## collisional cross section

2.6: Collisions with Other Molecules

11.10: Collision Theory

## Collisions with wall

2.4: Kinetic Energy

## column height

1.2: Pressure and Molar Volume

## combined gas law

2.1: The Empirical Gas Laws

## combustion

3.1: Prelude to Thermodynamics

## combustion reactions

3.4: Calorimetry

## common ion effect

9.10: Solubility of Ionic Compounds

## competitive pathways

12.2: Concentration Profiles for Some Simple Mechanisms

## composition

1.1: The System and the Surroundings

8.6: Phase Diagrams for Binary Mixtures

8.8: Non-ideality - Henry's Law and Azeotropes

## compositional constraint

7.4: The Gibbs-Duhem Equation

## compositional variables

8.3: Criterion for Phase Equilibrium

## compressibility

7.3: Chemical Potential

## compressibility factor

2.7: Real Gases

4.3: Compressibility and Expansivity

7.5: Non-ideality in Gases - Fugacity

## compression factor

2.7: Real Gases

7.5: Non-ideality in Gases - Fugacity

## concentration

12.5: The Steady-State Approximation

## concentration cell

10.5: Concentration Cells

## concentration change

11.1: Reaction Rate

## concentration data

11.2: Measuring Reaction Rates

11.8: The Method of Half-Lives

## concentration dependence

11.8: The Method of Half-Lives

## concentration measurement

11.2: Measuring Reaction Rates

## concentration profile

12.2: Concentration Profiles for Some Simple Mechanisms

## Concentration Profiles

12.2: Concentration Profiles for Some Simple Mechanisms

## concentration vs time

11.3: Rate Laws

## conjugate base

9.8: Acid-Base Equilibria

9.9: Buffers

## conservation of energy

1.5: Work and Energy

## constant pressure

5.4: Calculating Entropy Changes

6.8: The Difference between  $C_p$  and  $C_v$

7.4: The Gibbs-Duhem Equation

## constant pressure heat capacity

3.3: Reversible and Irreversible Pathways

6.8: The Difference between  $C_p$  and  $C_v$

## constant temperature

6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work

6.4: Volume Dependence of Helmholtz Energy

7.4: The Gibbs-Duhem Equation

## constant volume

6.8: The Difference between  $C_p$  and  $C_v$

## constant volume heat capacity

3.3: Reversible and Irreversible Pathways

6.8: The Difference between  $C_p$  and  $C_v$

## cooling curve

8.2: Single Component Phase Diagrams

8.10: Cooling Curves

## cooling effect

4.5: The Joule-Thomson Effect

## $C_p$

4.1: Prelude to Putting the First Law to Work

4.5: The Joule-Thomson Effect

6.8: The Difference between  $C_p$  and  $C_v$

## critical behavior

2.7: Real Gases

## critical point

2.7: Real Gases

## critical temperature

8.6: Phase Diagrams for Binary Mixtures

## cryoscopic constant

7.6: Colligative Properties

## crystal

5.7: The Third Law of Thermodynamics

## $C_v$

4.1: Prelude to Putting the First Law to Work

6.8: The Difference between  $C_p$  and  $C_v$

## cyclic permutation rule

- 4.3: Compressibility and Expansivity
- 4.6: Useful Definitions and Relationships

## cyclical process

- 5.2: Heat Engines and the Carnot Cycle

## D

### Dalton's Law

- 9.2: Chemical Potential

### Daniel cell

- 10.4: Entropy of Electrochemical Cells

### Debye extrapolation

- 5.7: The Third Law of Thermodynamics

### decay process

- 11.8: The Method of Half-Lives

### degree of dissociation

- 9.5: Degree of Dissociation

### degrees of freedom

- 8.3: Criterion for Phase Equilibrium

### density

- 1.1: The System and the Surroundings
- 5.8: Adiabatic Compressibility

### derivative

- 7.4: The Gibbs-Duhem Equation

### derivative form

- 11.3: Rate Laws

### deviation from ideality

- 2.6: Collisions with Other Molecules

### deviation from kinetic theory

- 2.6: Collisions with Other Molecules

### deviations

- 2.2: The Ideal Gas Law

### deviations from ideality

- 7.5: Non-ideality in Gases - Fugacity

### Dieterici

- 2.7: Real Gases

### differential equations

- 6.6: Temperature Dependence of A and G
- 6.8: The Difference between Cp and Cv

### diffusion

- 2.5: Graham's Law of Effusion

### direction of change

- 9.1: Prelude to Chemical Equilibria

### disorder

- 5.6: Entropy and Disorder

### displacement

- 1.5: Work and Energy

### dissociation

- 9.10: Solubility of Ionic Compounds

### distillation

- 8.7: Liquid-Vapor Systems - Raoult's Law
- 8.8: Non-ideality - Henry's Law and Azeotropes

### Dumas Bulb

- 9.7: The Dumas Bulb Method for Measuring Decomposition Equilibrium

### dynamic equilibrium

- 12.2: Concentration Profiles for Some Simple Mechanisms

## E

### ebullioscopic constant

- 7.6: Colligative Properties

### effective rate constant

- 12.7: The Lindemann Mechanism

### efficiency

- 5.2: Heat Engines and the Carnot Cycle
- 5.3: Entropy

### effusion

- 2.5: Graham's Law of Effusion

### Einstein

- 3.1: Prelude to Thermodynamics

### electric circuit

- 10.1: Electricity

### electric fish

- 10.1: Electricity

### electric motor

- 10.1: Electricity

### electricity history

- 10.1: Electricity

### electrochemical cell

- 10.2: The connection to  $\Delta G$

### electrochemical cells

- 10.3: Half Cells and Standard Reduction Potentials

### electrochemistry

- 10.1: Electricity
- 10.2: The connection to  $\Delta G$
- 10.3: Half Cells and Standard Reduction Potentials
- 10.4: Entropy of Electrochemical Cells

### electrolyte

- 9.10: Solubility of Ionic Compounds

### electron affinity

- 3.7: Lattice Energy and the Born-Haber Cycle

### electron transfer

- 3.1: Prelude to Thermodynamics

### electrostatic attraction

- 10.1: Electricity

### elementary reaction

- 12.1: Reaction Mechanisms

### elementary reactions

- 12.1: Reaction Mechanisms

### empirical gas laws

- 2.1: The Empirical Gas Laws

### empirical laws

- 2.2: The Ideal Gas Law

### empirical methods

- 11.3: Rate Laws

### empirical model

- 3.5: Temperature Dependence of Enthalpy
- 11.9: Temperature Dependence

### endothermic process

- 3.2: Work and Heat

### endothermic reaction

- 3.4: Calorimetry
- 9.7: The Dumas Bulb Method for Measuring Decomposition Equilibrium

### endothermic reactions

- 5.1: Introduction to the Second Law

### energy

- 1.5: Work and Energy
- 3.3: Reversible and Irreversible Pathways
- 5.2: Heat Engines and the Carnot Cycle

### energy barrier

- 11.9: Temperature Dependence

### energy conservation

- 5.1: Introduction to the Second Law

### energy conversion

- 1.5: Work and Energy

### energy dispersal

- 5.6: Entropy and Disorder

### energy flow

- 1.4: The Zeroth Law of Thermodynamics
- 1.5: Work and Energy
- 3.1: Prelude to Thermodynamics

### energy optimization

- 6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work

### energy systems

- 3.1: Prelude to Thermodynamics

### energy units

- 1.5: Work and Energy

### enthalpy

- 3.3: Reversible and Irreversible Pathways
- 3.5: Temperature Dependence of Enthalpy
- 4.1: Prelude to Putting the First Law to Work
- 4.5: The Joule-Thomson Effect
- 4.6: Useful Definitions and Relationships
- 5.7: The Third Law of Thermodynamics
- 6.1: Free Energy Functions
- 6.2: Combining the First and Second Laws - Maxwell's Relations
- 6.6: Temperature Dependence of A and G
- 6.8: The Difference between Cp and Cv

### enthalpy change

- 3.4: Calorimetry
- 3.7: Lattice Energy and the Born-Haber Cycle
- 6.1: Free Energy Functions

### enthalpy formation

- 3.7: Lattice Energy and the Born-Haber Cycle

### enthalpy of combustion

- 3.4: Calorimetry

### enthalpy of formation

- 3.5: Temperature Dependence of Enthalpy

### enthalpy of fusion

- 5.4: Calculating Entropy Changes
- 7.7: Solubility

### enthalpy of mixing

- 7.1: Thermodynamics of Mixing

### enthalpy of vaporization

- 8.5: The Clausius-Clapeyron Equation

### entropy

- 5.1: Introduction to the Second Law
- 5.3: Entropy
- 5.6: Entropy and Disorder
- 5.7: The Third Law of Thermodynamics
- 6.1: Free Energy Functions
- 6.4: Volume Dependence of Helmholtz Energy
- 6.6: Temperature Dependence of A and G

### entropy calculation

- 5.4: Calculating Entropy Changes
- 5.6: Entropy and Disorder

### entropy change

- 6.1: Free Energy Functions
- 6.7: When Two Variables Change at Once

### entropy change of the surroundings

- 5.5: Comparing the System and the Surroundings

### entropy change of the system

- 5.5: Comparing the System and the Surroundings

### entropy changes

- 5.3: Entropy
- 5.4: Calculating Entropy Changes

### Entropy of galvanic cell

- 10.4: Entropy of Electrochemical Cells

### entropy of mixing

- 7.1: Thermodynamics of Mixing

### enzyme catalysis

- 12.8: The Michaelis-Menten Mechanism

### enzyme kinetics

- 12.8: The Michaelis-Menten Mechanism

## enzyme reactions

11.3: Rate Laws

## EOS

3.3: Reversible and Irreversible Pathways

## equation derivation

6.4: Volume Dependence of Helmholtz Energy

7.4: The Gibbs-Duhem Equation

## equation of state

1.1: The System and the Surroundings

## equations of state

3.3: Reversible and Irreversible Pathways

## equilibrium

1.5: Work and Energy

7.4: The Gibbs-Duhem Equation

9.1: Prelude to Chemical Equilibria

9.2: Chemical Potential

9.7: The Dumas Bulb Method for Measuring

Decomposition Equilibrium

9.9: Buffers

9.10: Solubility of Ionic Compounds

12.2: Concentration Profiles for Some Simple

Mechanisms

## equilibrium approximation

12.3: The Connection between Reaction

Mechanisms and Reaction Rate Laws

12.6: The Equilibrium Approximation

12.8: The Michaelis-Menten Mechanism

## equilibrium composition

9.4: Pressure Dependence of  $K_p$  - Le Châtelier's Principle

## equilibrium constant

9.2: Chemical Potential

9.4: Pressure Dependence of  $K_p$  - Le Châtelier's Principle

9.6: Temperature Dependence of Equilibrium

Constants - the van 't Hoff Equation

9.8: Acid-Base Equilibria

9.10: Solubility of Ionic Compounds

11.11: Transition State Theory

## equilibrium constants

9.3: Activities and Fugacities

## equilibrium shift

9.4: Pressure Dependence of  $K_p$  - Le Châtelier's Principle

## equilibrium state

9.1: Prelude to Chemical Equilibria

## equilibrium system

8.3: Criterion for Phase Equilibrium

## ethanol

4.6: Useful Definitions and Relationships

## Euler relation

4.2: Total and Exact Differentials

6.2: Combining the First and Second Laws - Maxwell's Relations

## eutectic halt

8.10: Cooling Curves

## eutectic point

8.9: Solid-Liquid Systems - Eutectic Points

## Evangelista Torricelli

1.2: Pressure and Molar Volume

## exact differential

4.2: Total and Exact Differentials

## Exact Differentials

4.2: Total and Exact Differentials

## example calculation

3.5: Temperature Dependence of Enthalpy

## exothermic

3.2: Work and Heat

## exothermic reaction

3.4: Calorimetry

## exothermic reactions

5.1: Introduction to the Second Law

6.6: Temperature Dependence of A and G

## expansion coefficient

4.3: Compressibility and Expansivity

## expansion work

3.2: Work and Heat

## experimental data analysis

11.7: The Method of Initial Rates

## experimental uncertainty

11.2: Measuring Reaction Rates

## exponential decay

11.5: 1st order rate law

## extensive property

1.1: The System and the Surroundings

## extensive variables

1.1: The System and the Surroundings

## F

## Fahrenheit scale

1.3: Temperature

## Faraday's constant

10.1: Electricity

## first law

6.2: Combining the First and Second Laws - Maxwell's Relations

## first law of thermodynamics

3.2: Work and Heat

## first order

11.8: The Method of Half-Lives

## first order rate law

11.5: 1st order rate law

## first order reaction

11.5: 1st order rate law

## force

1.2: Pressure and Molar Volume

1.5: Work and Energy

## free energy

6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work

6.6: Temperature Dependence of A and G

## free energy of mixing

7.1: Thermodynamics of Mixing

## freezer

5.2: Heat Engines and the Carnot Cycle

## freezing point

8.4: The Clapeyron Equation

## freezing point depression

7.6: Colligative Properties

## freezing point depression constant

7.6: Colligative Properties

## freezing point of water

1.3: Temperature

## frequency of collisions

2.6: Collisions with Other Molecules

## fugacities

9.3: Activities and Fugacities

## fugacity

7.5: Non-ideality in Gases - Fugacity

## fugacity coefficient

7.5: Non-ideality in Gases - Fugacity

## fundamental constants

2.2: The Ideal Gas Law

## G

## G. Daniel Fahrenheit

1.3: Temperature

## galvanic cell

10.3: Half Cells and Standard Reduction Potentials

## gas behavior

2.2: The Ideal Gas Law

## gas effusion

2.5: Graham's Law of Effusion

## gas expansion

3.3: Reversible and Irreversible Pathways

4.5: The Joule-Thomson Effect

## gas laws

2.1: The Empirical Gas Laws

2.5: Graham's Law of Effusion

3.2: Work and Heat

## gas mixtures

9.4: Pressure Dependence of  $K_p$  - Le Châtelier's Principle

## gas molecules

2.6: Collisions with Other Molecules

## gas phase

2.6: Collisions with Other Molecules

## gas pressure derivation

2.4: Kinetic Energy

## gases

3.1: Prelude to Thermodynamics

7.1: Thermodynamics of Mixing

## gases in liquids

8.8: Non-ideality - Henry's Law and Azeotropes

## Gibbs energy of mixing

7.1: Thermodynamics of Mixing

## Gibbs free energy

6.1: Free Energy Functions

6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work

6.5: Pressure Dependence of Gibbs Energy

6.6: Temperature Dependence of A and G

10.2: The connection to  $\Delta G$

## Gibbs function

6.1: Free Energy Functions

6.2: Combining the First and Second Laws - Maxwell's Relations

7.3: Chemical Potential

7.4: The Gibbs-Duhem Equation

7.7: Solubility

9.1: Prelude to Chemical Equilibria

9.2: Chemical Potential

## Gibbs Phase Rule

8.3: Criterion for Phase Equilibrium

8.6: Phase Diagrams for Binary Mixtures

## glass tube

1.2: Pressure and Molar Volume

## gold example

6.5: Pressure Dependence of Gibbs Energy

## Graham's law

2.5: Graham's Law of Effusion

## H

## harmonic oscillator

1.5: Work and Energy

## heat

1.5: Work and Energy

3.2: Work and Heat

5.2: Heat Engines and the Carnot Cycle

## heat capacity

- 3.2: Work and Heat
- 3.3: Reversible and Irreversible Pathways
- 3.5: Temperature Dependence of Enthalpy
- 4.2: Total and Exact Differentials
- 4.4: The Joule Experiment
- 4.6: Useful Definitions and Relationships
- 5.2: Heat Engines and the Carnot Cycle
- 5.4: Calculating Entropy Changes
- 5.7: The Third Law of Thermodynamics
- 6.8: The Difference between Cp and Cv

## heat engines

- 5.2: Heat Engines and the Carnot Cycle

## heat is not a state function

- 5.3: Entropy

## heat of sublimation

- 3.7: Lattice Energy and the Born-Haber Cycle

## heat of vaporization

- 3.7: Lattice Energy and the Born-Haber Cycle

## heat pump

- 5.2: Heat Engines and the Carnot Cycle

## heat transfer

- 3.2: Work and Heat
- 5.3: Entropy

## heating system

- 8.2: Single Component Phase Diagrams

## Helmholtz free energy

- 6.1: Free Energy Functions
- 6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work
- 6.6: Temperature Dependence of A and G

## Helmholtz function

- 6.1: Free Energy Functions
- 6.2: Combining the First and Second Laws - Maxwell's Relations
- 6.4: Volume Dependence of Helmholtz Energy

## Henry's law

- 8.8: Non-ideality - Henry's Law and Azeotropes

## hess's law

- 3.6: Reaction Enthalpies

## heterogeneous

- 1.1: The System and the Surroundings

## heterogeneous equilibria

- 9.3: Activities and Fugacities

## high and low temperatures

- 5.3: Entropy

## high concentrations

- 7.2: Partial Molar Volume

## historical development of temperature scales

- 1.3: Temperature

## homogeneous

- 1.1: The System and the Surroundings

## Hooke's Law

- 1.5: Work and Energy

## hydrolysis

- 9.8: Acid-Base Equilibria

## ICE table

- 9.4: Pressure Dependence of Kp - Le Châtelier's Principle
- 9.5: Degree of Dissociation
- 9.9: Buffers

## ideal behavior

- 7.1: Thermodynamics of Mixing
- 9.3: Activities and Fugacities

## ideal gas

- 3.2: Work and Heat
- 3.3: Reversible and Irreversible Pathways
- 4.4: The Joule Experiment
- 5.8: Adiabatic Compressibility
- 6.4: Volume Dependence of Helmholtz Energy
- 6.7: When Two Variables Change at Once
- 6.8: The Difference between Cp and Cv
- 7.3: Chemical Potential
- 7.5: Non-ideality in Gases - Fugacity
- 8.5: The Clausius-Clapeyron Equation

## ideal gas behavior

- 4.5: The Joule-Thomson Effect

## ideal gas expansion

- 5.4: Calculating Entropy Changes

## ideal gas law

- 1.5: Work and Energy
- 2.2: The Ideal Gas Law
- 2.4: Kinetic Energy
- 2.7: Real Gases
- 3.1: Prelude to Thermodynamics
- 4.2: Total and Exact Differentials

## ideal gases

- 3.4: Calorimetry
- 7.1: Thermodynamics of Mixing
- 9.2: Chemical Potential

## ideal mixture

- 8.7: Liquid-Vapor Systems - Raoult's Law

## immiscible liquids

- 8.6: Phase Diagrams for Binary Mixtures

## immiscible solids

- 8.9: Solid-Liquid Systems - Eutectic Points

## incompressible substances

- 6.5: Pressure Dependence of Gibbs Energy

## Incongruent Melting

- 8.9: Solid-Liquid Systems - Eutectic Points

## inexact differentials

- 4.2: Total and Exact Differentials

## infinitesimal time intervals

- 11.1: Reaction Rate

## initial rate

- 11.2: Measuring Reaction Rates

## initiation step

- 12.9: Chain Reactions

## instrumentation

- 11.2: Measuring Reaction Rates

## integral

- 3.5: Temperature Dependence of Enthalpy

## integrated rate law

- 11.5: 1st order rate law

## integrated rate laws

- 11.8: The Method of Half-Lives

## integration

- 7.2: Partial Molar Volume

## intensive properties

- 4.3: Compressibility and Expansivity

## intensive property

- 1.1: The System and the Surroundings

## intensive variables

- 1.1: The System and the Surroundings

## intermediate

- 12.5: The Steady-State Approximation

## intermediate formation

- 12.2: Concentration Profiles for Some Simple Mechanisms

## intermediate species

- 12.6: The Equilibrium Approximation

## intermediate state

- 11.11: Transition State Theory

## intermediates

- 12.3: The Connection between Reaction Mechanisms and Reaction Rate Laws

## intermolecular forces

- 7.1: Thermodynamics of Mixing

## intermolecular interactions

- 2.7: Real Gases

## intermolecular potential

- 2.7: Real Gases

## internal energy

- 3.2: Work and Heat
- 3.3: Reversible and Irreversible Pathways
- 3.4: Calorimetry
- 4.1: Prelude to Putting the First Law to Work
- 4.2: Total and Exact Differentials
- 4.4: The Joule Experiment
- 6.2: Combining the First and Second Laws - Maxwell's Relations
- 6.4: Volume Dependence of Helmholtz Energy
- 6.8: The Difference between Cp and Cv

## internal pressure

- 4.4: The Joule Experiment

## International Practical Temperature Scale of 1990

- 1.4: The Zeroth Law of Thermodynamics

## inversion temperature

- 4.5: The Joule-Thomson Effect

## ionic compounds

- 9.10: Solubility of Ionic Compounds

## ionic solid formation

- 3.7: Lattice Energy and the Born-Haber Cycle

## ionic strength

- 7.8: Non-ideality in Solutions - Activity

## ionization energy

- 3.6: Reaction Enthalpies
- 3.7: Lattice Energy and the Born-Haber Cycle

## irreversible process

- 3.3: Reversible and Irreversible Pathways

## isenthalpic process

- 4.5: The Joule-Thomson Effect

## isentropic process

- 5.8: Adiabatic Compressibility

## Isobaric Changes

- 5.4: Calculating Entropy Changes

## isobaric process

- 3.3: Reversible and Irreversible Pathways

## isobaric thermal expansivity

- 4.3: Compressibility and Expansivity

## isochoric

- 3.2: Work and Heat

## isochoric pathway

- 5.4: Calculating Entropy Changes

## isochoric process

- 3.3: Reversible and Irreversible Pathways
- 6.7: When Two Variables Change at Once

## isolated system

- 1.1: The System and the Surroundings

## isomerization

- 12.2: Concentration Profiles for Some Simple Mechanisms

## isothermal

- 3.2: Work and Heat
- 5.2: Heat Engines and the Carnot Cycle

## isothermal bomb calorimetry

3.4: Calorimetry

## isothermal changes

5.4: Calculating Entropy Changes

## Isothermal Changes in Entropy

5.4: Calculating Entropy Changes

## isothermal compressibility

4.3: Compressibility and Expansivity

4.6: Useful Definitions and Relationships

5.8: Adiabatic Compressibility

## isothermal compression

4.6: Useful Definitions and Relationships

## isothermal expansion

6.4: Volume Dependence of Helmholtz Energy

6.7: When Two Variables Change at Once

7.1: Thermodynamics of Mixing

## isothermal mixing

7.1: Thermodynamics of Mixing

## isothermal process

3.3: Reversible and Irreversible Pathways

## Italian physicist

1.2: Pressure and Molar Volume

## J

### James P. Joule

3.2: Work and Heat

### Joule Experiment

3.2: Work and Heat

4.4: The Joule Experiment

## joules

1.5: Work and Energy

## K

### Kelvin

1.3: Temperature

### Kelvin scale

1.3: Temperature

## kinetic analysis

12.7: The Lindemann Mechanism

## kinetic data

11.2: Measuring Reaction Rates

## kinetic energy

1.5: Work and Energy

2.4: Kinetic Energy

11.9: Temperature Dependence

## kinetic molecular theory

2.2: The Ideal Gas Law

2.4: Kinetic Energy

2.5: Graham's Law of Effusion

2.6: Collisions with Other Molecules

## Kinetic Molecular Theory of Gases

2.3: The Kinetic Molecular Theory of Gases

## kinetics

11.5: 1st order rate law

11.8: The Method of Half-Lives

12.1: Reaction Mechanisms

## Kirchhoff's law

3.5: Temperature Dependence of Enthalpy

## Knudsen cell

2.5: Graham's Law of Effusion

## L

### Lattice Energy

3.7: Lattice Energy and the Born-Haber Cycle

## Le Chatelier's principle

9.4: Pressure Dependence of  $K_p$  - Le Châtelier's Principle

## lever rule

8.6: Phase Diagrams for Binary Mixtures

8.7: Liquid-Vapor Systems - Raoult's Law

8.9: Solid-Liquid Systems - Eutectic Points

## lightning experiment

10.1: Electricity

## Lindemann mechanism

12.7: The Lindemann Mechanism

## liquid phase

8.9: Solid-Liquid Systems - Eutectic Points

## liquid to solid

8.2: Single Component Phase Diagrams

## lower critical temperature

8.6: Phase Diagrams for Binary Mixtures

## lower inversion temperature

4.5: The Joule-Thomson Effect

## Ludwig Boltzmann

5.6: Entropy and Disorder

## M

### mathematical rigor

6.7: When Two Variables Change at Once

### mathematics

6.4: Volume Dependence of Helmholtz Energy

## maximum boiling point

8.8: Non-ideality - Henry's Law and Azeotropes

## maximum boiling point azeotrope

8.8: Non-ideality - Henry's Law and Azeotropes

## maximum efficiency

5.2: Heat Engines and the Carnot Cycle

## maximum work

6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work

## Maxwell relation

6.4: Volume Dependence of Helmholtz Energy

6.5: Pressure Dependence of Gibbs Energy

## Maxwell relations

4.4: The Joule Experiment

4.5: The Joule-Thomson Effect

6.2: Combining the First and Second Laws -

Maxwell's Relations

6.7: When Two Variables Change at Once

6.8: The Difference between  $C_p$  and  $C_v$

## mean activity coefficient

7.8: Non-ideality in Solutions - Activity

## mean free path

2.6: Collisions with Other Molecules

## measurable quantities

4.6: Useful Definitions and Relationships

## measurement

1.4: The Zeroth Law of Thermodynamics

## melting ice

5.4: Calculating Entropy Changes

## melting point

7.7: Solubility

## mercury

1.2: Pressure and Molar Volume

## Method of Initial Rates

11.7: The Method of Initial Rates

## Michael Faraday

10.1: Electricity

## Michaelis constant

12.8: The Michaelis-Menten Mechanism

## minimum boiling point

8.8: Non-ideality - Henry's Law and Azeotropes

## minimum boiling point azeotrope

8.8: Non-ideality - Henry's Law and Azeotropes

## miscibility

8.8: Non-ideality - Henry's Law and Azeotropes

8.9: Solid-Liquid Systems - Eutectic Points

## mixture variables

8.6: Phase Diagrams for Binary Mixtures

## mixtures

7.1: Thermodynamics of Mixing

7.2: Partial Molar Volume

7.3: Chemical Potential

7.4: The Gibbs-Duhem Equation

## modern refrigerators

4.5: The Joule-Thomson Effect

## molar adjustments

7.4: The Gibbs-Duhem Equation

## molar enthalpy change

3.5: Temperature Dependence of Enthalpy

## molar entropy

5.4: Calculating Entropy Changes

5.7: The Third Law of Thermodynamics

7.3: Chemical Potential

8.4: The Clapeyron Equation

## molar heat capacities

4.1: Prelude to Putting the First Law to Work

## molar mass

2.5: Graham's Law of Effusion

5.8: Adiabatic Compressibility

## molar volume

1.1: The System and the Surroundings

3.1: Prelude to Thermodynamics

6.5: Pressure Dependence of Gibbs Energy

7.3: Chemical Potential

8.4: The Clapeyron Equation

8.5: The Clausius-Clapeyron Equation

## mole

2.1: The Empirical Gas Laws

## mole fraction

7.1: Thermodynamics of Mixing

7.7: Solubility

8.7: Liquid-Vapor Systems - Raoult's Law

## mole fractions

8.6: Phase Diagrams for Binary Mixtures

9.2: Chemical Potential

## molecular beam experiments

2.6: Collisions with Other Molecules

## molecular collision

11.11: Transition State Theory

## molecular collisions

2.4: Kinetic Energy

2.5: Graham's Law of Effusion

2.6: Collisions with Other Molecules

11.9: Temperature Dependence

11.10: Collision Theory

## molecular cross section

2.6: Collisions with Other Molecules

## molecular diameter

2.6: Collisions with Other Molecules

## molecular interactions

2.6: Collisions with Other Molecules

## molecular mass

2.4: Kinetic Energy

## molecular orientation

5.6: Entropy and Disorder

## molecular size

- 2.6: Collisions with Other Molecules
- 2.7: Real Gases

## molecular speed

- 2.5: Graham's Law of Effusion

## molecular speeds

- 2.4: Kinetic Energy

## molecularity

- 12.1: Reaction Mechanisms
- 12.4: The Rate Determining Step Approximation

## moles

- 1.1: The System and the Surroundings

## Montreal Protocol

- 12.10: Catalysis

## most probable speed in gas

- 2.3: The Kinetic Molecular Theory of Gases

## N

### NaCl lattice energy

- 3.7: Lattice Energy and the Born-Haber Cycle

### naphthalene

- 3.4: Calorimetry

### natural variable

- 6.2: Combining the First and Second Laws - Maxwell's Relations

### natural variables

- 6.5: Pressure Dependence of Gibbs Energy

### negative order

- 12.6: The Equilibrium Approximation

### Nernst equation

- 10.2: The connection to  $\Delta G$
- 10.3: Half Cells and Standard Reduction Potentials

### neutral water

- 9.8: Acid-Base Equilibria

### Newton

- 5.8: Adiabatic Compressibility

### Newtonian physics

- 1.5: Work and Energy

### nuclides

- 11.5: 1st order rate law

### number density

- 2.4: Kinetic Energy
- 2.6: Collisions with Other Molecules

## O

### open system

- 1.1: The System and the Surroundings

### order of reaction

- 11.7: The Method of Initial Rates
- 12.3: The Connection between Reaction Mechanisms and Reaction Rate Laws

### organic chemistry

- 8.6: Phase Diagrams for Binary Mixtures

### oscillating reactions

- 12.11: Oscillating Reactions

### osmosis

- 7.6: Colligative Properties

### osmotic pressure

- 7.6: Colligative Properties

### oxidation

- 10.1: Electricity
- 10.3: Half Cells and Standard Reduction Potentials

### Ozone

- 12.10: Catalysis

## ozone decomposition

- 12.10: Catalysis

## ozone hole

- 12.10: Catalysis

## ozone layer

- 12.10: Catalysis

## P

### partial derivative

- 6.4: Volume Dependence of Helmholtz Energy

### partial derivatives

- 3.2: Work and Heat
- 4.1: Prelude to Putting the First Law to Work
- 4.3: Compressibility and Expansivity
- 4.4: The Joule Experiment
- 4.6: Useful Definitions and Relationships
- 5.8: Adiabatic Compressibility
- 6.2: Combining the First and Second Laws - Maxwell's Relations

### Maxwell's Relations

- 6.7: When Two Variables Change at Once

### partial molar property

- 7.2: Partial Molar Volume

### partial molar quantities

- 7.4: The Gibbs-Duhem Equation

### partial molar volume

- 7.2: Partial Molar Volume
- 7.3: Chemical Potential

### partial pressures

- 7.1: Thermodynamics of Mixing

### Partially Miscible Liquids

- 8.6: Phase Diagrams for Binary Mixtures

### partition function

- 11.11: Transition State Theory

### partition functions

- 11.11: Transition State Theory

### Pascal (Pa)

- 1.2: Pressure and Molar Volume

### pH

- 9.8: Acid-Base Equilibria

### pH control

- 9.9: Buffers

### phase behavior

- 8.6: Phase Diagrams for Binary Mixtures

### phase boundaries

- 8.1: Prelude to Phase Equilibrium

### phase boundary

- 8.4: The Clapeyron Equation

### phase change

- 5.7: The Third Law of Thermodynamics
- 7.7: Solubility
- 8.2: Single Component Phase Diagrams
- 8.4: The Clapeyron Equation

### phase changes

- 5.4: Calculating Entropy Changes

### phase diagram

- 8.1: Prelude to Phase Equilibrium
- 8.2: Single Component Phase Diagrams
- 8.6: Phase Diagrams for Binary Mixtures
- 8.7: Liquid-Vapor Systems - Raoult's Law
- 8.9: Solid-Liquid Systems - Eutectic Points

### phase diagrams

- 8.8: Non-ideality - Henry's Law and Azeotropes

### phase equilibria

- 8.5: The Clausius-Clapeyron Equation

## phase equilibrium

- 8.3: Criterion for Phase Equilibrium
- 8.4: The Clapeyron Equation
- 8.9: Solid-Liquid Systems - Eutectic Points

### Phase Rule

- 8.3: Criterion for Phase Equilibrium

### phase separation

- 8.6: Phase Diagrams for Binary Mixtures

### phase stability

- 8.2: Single Component Phase Diagrams

### phase transitions

- 8.5: The Clausius-Clapeyron Equation

### phases

- 8.1: Prelude to Phase Equilibrium

### physical chemistry

- 6.8: The Difference between  $C_p$  and  $C_v$
- 7.2: Partial Molar Volume

### physical properties

- 1.4: The Zeroth Law of Thermodynamics

### physics

- 1.2: Pressure and Molar Volume
- 1.5: Work and Energy
- 3.1: Prelude to Thermodynamics
- 5.3: Entropy
- 5.8: Adiabatic Compressibility
- 6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work
- 6.4: Volume Dependence of Helmholtz Energy

### platinum resistance thermometer

- 1.4: The Zeroth Law of Thermodynamics

### potassium bromide

- 3.7: Lattice Energy and the Born-Haber Cycle

### potential energy

- 1.5: Work and Energy
- 10.1: Electricity

### pressure

- 1.1: The System and the Surroundings
- 1.2: Pressure and Molar Volume
- 1.5: Work and Energy
- 2.1: The Empirical Gas Laws
- 2.4: Kinetic Energy
- 2.6: Collisions with Other Molecules
- 3.1: Prelude to Thermodynamics
- 3.2: Work and Heat
- 4.1: Prelude to Putting the First Law to Work
- 4.5: The Joule-Thomson Effect
- 4.6: Useful Definitions and Relationships
- 6.1: Free Energy Functions
- 6.4: Volume Dependence of Helmholtz Energy
- 6.8: The Difference between  $C_p$  and  $C_v$
- 7.5: Non-ideality in Gases - Fugacity
- 8.4: The Clapeyron Equation
- 8.6: Phase Diagrams for Binary Mixtures

### pressure change

- 6.5: Pressure Dependence of Gibbs Energy

### pressure changes

- 9.4: Pressure Dependence of  $K_p$  - Le Châtelier's Principle

### pressure dependence

- 6.5: Pressure Dependence of Gibbs Energy
- 7.3: Chemical Potential

### Pressure Dependence of Equilibrium Constant

- 9.4: Pressure Dependence of  $K_p$  - Le Châtelier's Principle

### Pressure Dependence of Gibbs Energy

- 6.5: Pressure Dependence of Gibbs Energy

### pressure measurement

- 1.2: Pressure and Molar Volume
- 4.4: The Joule Experiment

## principle of corresponding states

2.7: Real Gases

## propagation step

12.9: Chain Reactions

## proton transfer

9.8: Acid-Base Equilibria

## purification

8.7: Liquid-Vapor Systems - Raoult's Law

## Q

## quadratic equation

9.9: Buffers

## R

## radioactive decay

11.5: 1st order rate law

## radiocarbon dating

11.8: The Method of Half-Lives

## randomness

5.6: Entropy and Disorder

## Raoult's law

7.6: Colligative Properties

8.7: Liquid-Vapor Systems - Raoult's Law

8.8: Non-ideality - Henry's Law and Azeotropes

## Rapid Equilibrium Approximation

12.2: Concentration Profiles for Some Simple Mechanisms

12.3: The Connection between Reaction Mechanisms and Reaction Rate Laws

12.6: The Equilibrium Approximation

## rate constant

11.1: Reaction Rate

11.5: 1st order rate law

11.6: 2nd order Rate Laws

11.7: The Method of Initial Rates

11.8: The Method of Half-Lives

12.2: Concentration Profiles for Some Simple Mechanisms

## rate constants

11.10: Collision Theory

## rate determining step

12.3: The Connection between Reaction Mechanisms and Reaction Rate Laws

12.4: The Rate Determining Step Approximation

## rate determining step approximation

12.4: The Rate Determining Step Approximation

## rate equations

11.8: The Method of Half-Lives

## rate law

11.3: Rate Laws

11.4: 0th order Rate Law

12.1: Reaction Mechanisms

12.3: The Connection between Reaction Mechanisms and Reaction Rate Laws

12.4: The Rate Determining Step Approximation

12.5: The Steady-State Approximation

12.6: The Equilibrium Approximation

## rate laws

11.3: Rate Laws

11.7: The Method of Initial Rates

## rate of change

11.1: Reaction Rate

12.5: The Steady-State Approximation

## reaction dynamics

12.6: The Equilibrium Approximation

## reaction enthalpy

3.5: Temperature Dependence of Enthalpy

3.6: Reaction Enthalpies

## reaction kinetics

11.1: Reaction Rate

11.4: 0th order Rate Law

11.6: 2nd order Rate Laws

## reaction mechanism

11.11: Transition State Theory

12.1: Reaction Mechanisms

12.4: The Rate Determining Step Approximation

12.5: The Steady-State Approximation

12.6: The Equilibrium Approximation

## reaction mechanisms

11.10: Collision Theory

12.2: Concentration Profiles for Some Simple Mechanisms

12.3: The Connection between Reaction Mechanisms and Reaction Rate Laws

## reaction mixture

9.1: Prelude to Chemical Equilibria

9.2: Chemical Potential

## reaction order

11.3: Rate Laws

11.8: The Method of Half-Lives

12.5: The Steady-State Approximation

## reaction orders

11.10: Collision Theory

## reaction pathways

12.3: The Connection between Reaction Mechanisms and Reaction Rate Laws

## reaction profile

11.9: Temperature Dependence

## reaction quotient

9.2: Chemical Potential

10.2: The connection to  $\Delta G$

## reaction rate

11.1: Reaction Rate

11.7: The Method of Initial Rates

11.10: Collision Theory

12.4: The Rate Determining Step Approximation

12.6: The Equilibrium Approximation

## reaction rates

11.2: Measuring Reaction Rates

11.9: Temperature Dependence

## reaction spontaneity

9.2: Chemical Potential

## reaction thermodynamics

6.6: Temperature Dependence of A and G

## real gases

7.5: Non-ideality in Gases - Fugacity

## reciprocal rule

4.3: Compressibility and Expansivity

## reduced variables

2.7: Real Gases

## reduction

10.1: Electricity

10.3: Half Cells and Standard Reduction Potentials

## reduction potential

10.3: Half Cells and Standard Reduction Potentials

## reference pressure

7.3: Chemical Potential

## refrigerator

5.2: Heat Engines and the Carnot Cycle

## relationships in gases

2.1: The Empirical Gas Laws

## relative speed

2.6: Collisions with Other Molecules

## repulsive forces

2.6: Collisions with Other Molecules

## reverse osmosis

7.6: Colligative Properties

## reversible expansion

1.5: Work and Energy

## reversible path

5.4: Calculating Entropy Changes

## reversible pathway

5.3: Entropy

## reversible process

3.3: Reversible and Irreversible Pathways

## reversible processes

6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work

## reversible reaction

12.6: The Equilibrium Approximation

## reversible reactions

12.2: Concentration Profiles for Some Simple Mechanisms

## Richard Smalley

1.5: Work and Energy

## RMS speed in gas

2.3: The Kinetic Molecular Theory of Gases

## Robert Boyle

2.1: The Empirical Gas Laws

## Rudolf Clausius

5.1: Introduction to the Second Law

## S

## Sadi Carnot

5.2: Heat Engines and the Carnot Cycle

## salt solution

9.8: Acid-Base Equilibria

## saturation

7.7: Solubility

## scanning calorimetry

8.2: Single Component Phase Diagrams

## scientific method

12.5: The Steady-State Approximation

## Sean M. Carroll

5.1: Introduction to the Second Law

## second law

6.2: Combining the First and Second Laws - Maxwell's Relations

## Second Law of Thermodynamics

5.1: Introduction to the Second Law

5.2: Heat Engines and the Carnot Cycle

## second order

11.8: The Method of Half-Lives

## second order rate law

11.6: 2nd order Rate Laws

## second order reaction

11.6: 2nd order Rate Laws

## Second Virial Coefficient

2.7: Real Gases

## side products

12.1: Reaction Mechanisms

## single component system

8.3: Criterion for Phase Equilibrium

## single component systems

8.6: Phase Diagrams for Binary Mixtures

## SiO<sub>2</sub>

5.7: The Third Law of Thermodynamics

## slowest step

12.4: The Rate Determining Step Approximation

## solubility

- 7.7: Solubility
- 8.6: Phase Diagrams for Binary Mixtures
- 8.8: Non-ideality - Henry's Law and Azeotropes
- 9.10: Solubility of Ionic Compounds

## solubility dependency

- 8.6: Phase Diagrams for Binary Mixtures

## solubility product

- 9.10: Solubility of Ionic Compounds

## solubility reduction

- 9.10: Solubility of Ionic Compounds

## solute

- 7.6: Colligative Properties
- 7.7: Solubility

## solutions

- 7.6: Colligative Properties

## solvation sphere

- 7.2: Partial Molar Volume

## solvent

- 7.6: Colligative Properties

## sound waves

- 5.8: Adiabatic Compressibility

## specific heat

- 1.5: Work and Energy
- 3.2: Work and Heat

## specific heat capacity

- 3.5: Temperature Dependence of Enthalpy

## spectrophotometry

- 11.2: Measuring Reaction Rates

## speed of sound

- 5.8: Adiabatic Compressibility

## spontaneity

- 6.1: Free Energy Functions
- 7.1: Thermodynamics of Mixing
- 9.1: Prelude to Chemical Equilibria
- 10.3: Half Cells and Standard Reduction Potentials

## spontaneity criterion

- 10.2: The connection to  $\Delta G$

## spontaneity direction

- 9.1: Prelude to Chemical Equilibria

## spontaneous change

- 3.3: Reversible and Irreversible Pathways
- 5.1: Introduction to the Second Law

## spontaneous process

- 7.1: Thermodynamics of Mixing
- 9.2: Chemical Potential

## spontaneous processes

- 5.1: Introduction to the Second Law
- 6.1: Free Energy Functions

## stable compound

- 8.9: Solid-Liquid Systems - Eutectic Points

## standard atmosphere

- 1.2: Pressure and Molar Volume

## standard cell potential

- 10.2: The connection to  $\Delta G$
- 10.4: Entropy of Electrochemical Cells

## standard conditions

- 10.3: Half Cells and Standard Reduction Potentials

## standard enthalpy of formation

- 3.6: Reaction Enthalpies

## standard hydrogen electrode

- 10.3: Half Cells and Standard Reduction Potentials

## standard pressure

- 7.3: Chemical Potential

## standard reduction potential

- 10.3: Half Cells and Standard Reduction Potentials

## standard state

- 3.6: Reaction Enthalpies

## standard states

- 3.7: Lattice Energy and the Born-Haber Cycle
- 9.2: Chemical Potential

## state function

- 1.1: The System and the Surroundings
- 5.3: Entropy

## state variable

- 3.2: Work and Heat

## state variables

- 1.1: The System and the Surroundings
- 3.1: Prelude to Thermodynamics
- 4.1: Prelude to Putting the First Law to Work
- 4.2: Total and Exact Differentials
- 4.3: Compressibility and Expansivity
- 6.2: Combining the First and Second Laws - Maxwell's Relations
- 6.7: When Two Variables Change at Once

## statistical mechanics

- 5.6: Entropy and Disorder

## steady state approximation

- 12.2: Concentration Profiles for Some Simple Mechanisms
- 12.3: The Connection between Reaction Mechanisms and Reaction Rate Laws
- 12.5: The Steady-State Approximation
- 12.6: The Equilibrium Approximation

## steam engines

- 5.2: Heat Engines and the Carnot Cycle

## stoichiometric coefficients

- 9.2: Chemical Potential

## stoichiometric concerns

- 11.1: Reaction Rate

## stopped flow

- 11.2: Measuring Reaction Rates

## strong electrolyte

- 7.2: Partial Molar Volume

## sublimation

- 8.5: The Clausius-Clapeyron Equation

## surroundings

- 1.1: The System and the Surroundings

## system

- 1.1: The System and the Surroundings

## system equilibrium

- 7.4: The Gibbs-Duhem Equation

## T

## Taylor Series Expansion

- 2.7: Real Gases

## temperature

- 1.1: The System and the Surroundings
- 1.3: Temperature
- 1.4: The Zeroth Law of Thermodynamics
- 1.5: Work and Energy
- 2.1: The Empirical Gas Laws
- 2.6: Collisions with Other Molecules
- 3.1: Prelude to Thermodynamics
- 4.1: Prelude to Putting the First Law to Work
- 4.5: The Joule-Thomson Effect
- 4.6: Useful Definitions and Relationships
- 6.1: Free Energy Functions
- 6.8: The Difference between  $C_p$  and  $C_v$
- 7.7: Solubility
- 8.4: The Clapeyron Equation
- 8.6: Phase Diagrams for Binary Mixtures

## temperature change

- 3.2: Work and Heat
- 3.4: Calorimetry

## temperature conversion

- 1.3: Temperature
- 3.5: Temperature Dependence of Enthalpy

## temperature definition

- 8.3: Criterion for Phase Equilibrium

## temperature dependence

- 2.4: Kinetic Energy
- 3.5: Temperature Dependence of Enthalpy
- 5.7: The Third Law of Thermodynamics
- 6.5: Pressure Dependence of Gibbs Energy
- 6.6: Temperature Dependence of A and G
- 8.5: The Clausius-Clapeyron Equation
- 11.9: Temperature Dependence

## Temperature Dependence of Equilibrium

### Constant

- 9.6: Temperature Dependence of Equilibrium Constants - the van 't Hoff Equation

## Temperature Dependence of Gibbs

### Energy

- 6.6: Temperature Dependence of A and G

## Temperature Dependence of Helmholtz

### Energy

- 6.6: Temperature Dependence of A and G

## Temperature Dependence to Rates

- 11.9: Temperature Dependence

## temperature effects

- 10.4: Entropy of Electrochemical Cells

## temperature scale

- 5.7: The Third Law of Thermodynamics

## temperature scales

- 1.3: Temperature
- 1.4: The Zeroth Law of Thermodynamics

## temperature vs. composition

- 8.7: Liquid-Vapor Systems - Raoult's Law

## termination step

- 12.9: Chain Reactions

## termolecular

- 12.1: Reaction Mechanisms

## termolecular reaction

- 12.1: Reaction Mechanisms

## theory of gases

- 2.2: The Ideal Gas Law

## thermal decomposition

- 11.10: Collision Theory

## thermal equilibrium

- 1.4: The Zeroth Law of Thermodynamics

## thermal expansion

- 4.6: Useful Definitions and Relationships

## thermal physics

- 6.4: Volume Dependence of Helmholtz Energy

## thermalized gas

- 2.4: Kinetic Energy

## thermochemistry

- 4.1: Prelude to Putting the First Law to Work

## thermodynamic cycle

- 3.7: Lattice Energy and the Born-Haber Cycle

## thermodynamic functions

- 3.5: Temperature Dependence of Enthalpy
- 4.3: Compressibility and Expansivity
- 7.3: Chemical Potential

## thermodynamic variables

- 6.2: Combining the First and Second Laws - Maxwell's Relations

## thermodynamics

- 1.5: Work and Energy
  - 2.1: The Empirical Gas Laws
  - 3.1: Prelude to Thermodynamics
  - 3.2: Work and Heat
  - 3.3: Reversible and Irreversible Pathways
  - 3.4: Calorimetry
  - 3.7: Lattice Energy and the Born-Haber Cycle
  - 4.1: Prelude to Putting the First Law to Work
  - 4.2: Total and Exact Differentials
  - 4.3: Compressibility and Expansivity
  - 4.4: The Joule Experiment
  - 4.5: The Joule-Thomson Effect
  - 4.6: Useful Definitions and Relationships
  - 5.1: Introduction to the Second Law
  - 5.2: Heat Engines and the Carnot Cycle
  - 5.3: Entropy
  - 5.4: Calculating Entropy Changes
  - 5.6: Entropy and Disorder
  - 5.7: The Third Law of Thermodynamics
  - 5.8: Adiabatic Compressibility
  - 6.1: Free Energy Functions
  - 6.2: Combining the First and Second Laws - Maxwell's Relations
  - 6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work
  - 6.4: Volume Dependence of Helmholtz Energy
  - 6.5: Pressure Dependence of Gibbs Energy
  - 6.6: Temperature Dependence of  $A$  and  $G$
  - 6.7: When Two Variables Change at Once
  - 6.8: The Difference between  $C_p$  and  $C_v$
  - 7.3: Chemical Potential
  - 7.4: The Gibbs-Duhem Equation
  - 8.3: Criterion for Phase Equilibrium
  - 8.4: The Clapeyron Equation
  - 9.2: Chemical Potential
  - 9.6: Temperature Dependence of Equilibrium Constants - the van 't Hoff Equation
- ## thermometer
- 1.4: The Zeroth Law of Thermodynamics
- ## third law entropy
- 5.7: The Third Law of Thermodynamics
- ## Third Law of Thermodynamics
- 5.7: The Third Law of Thermodynamics
- ## time rate change
- 11.4: 0th order Rate Law
- ## time traveling observers
- 5.1: Introduction to the Second Law
- ## Torricelli barometer
- 1.2: Pressure and Molar Volume
- ## Torricellian vacuum
- 1.2: Pressure and Molar Volume
- ## total differential
- 4.2: Total and Exact Differentials
  - 6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work
  - 6.4: Volume Dependence of Helmholtz Energy
  - 6.5: Pressure Dependence of Gibbs Energy
  - 6.7: When Two Variables Change at Once
  - 7.2: Partial Molar Volume
- ## Total Differentials
- 4.2: Total and Exact Differentials
- ## total pressure effects
- 9.4: Pressure Dependence of  $K_p$  - Le Châtelier's Principle
- ## transition state
- 11.11: Transition State Theory
- ## transition state theory
- 11.9: Temperature Dependence
  - 11.11: Transition State Theory
- ## triple point
- 8.3: Criterion for Phase Equilibrium

## triple point of water

- 1.4: The Zeroth Law of Thermodynamics

## Two Variables Change at Once

- 6.7: When Two Variables Change at Once

## types of systems

- 1.1: The System and the Surroundings

## U

### unimolecular

- 12.1: Reaction Mechanisms

### unimolecular reaction

- 12.1: Reaction Mechanisms

### unimolecular reactions

- 11.10: Collision Theory

### unitless constants

- 9.3: Activities and Fugacities

### units

- 2.2: The Ideal Gas Law

### units of pressure

- 1.2: Pressure and Molar Volume

### universal content

- 3.1: Prelude to Thermodynamics

### universal gas constant

- 2.2: The Ideal Gas Law

### universe

- 1.1: The System and the Surroundings

### upper critical temperature

- 8.6: Phase Diagrams for Binary Mixtures

### upper inversion temperature

- 4.5: The Joule-Thomson Effect

## V

### valid mechanism

- 12.1: Reaction Mechanisms

### van 't Hoff equation

- 9.6: Temperature Dependence of Equilibrium Constants - the van 't Hoff Equation

### van der Waals constants

- 2.7: Real Gases

### van der Waals equation

- 2.7: Real Gases
- 6.4: Volume Dependence of Helmholtz Energy

### van der waals gas

- 4.4: The Joule Experiment

### van der Waals law

- 3.1: Prelude to Thermodynamics

### van't Hoff plot

- 9.7: The Dumas Bulb Method for Measuring Decomposition Equilibrium

### vapor pressure

- 2.5: Graham's Law of Effusion
- 7.6: Colligative Properties
- 8.5: The Clausius-Clapeyron Equation
- 8.7: Liquid-Vapor Systems - Raoult's Law

### vapor pressure lowering

- 7.6: Colligative Properties

### vaporization

- 8.5: The Clausius-Clapeyron Equation

### velocity distribution

- 2.4: Kinetic Energy

### vibrational frequency

- 11.11: Transition State Theory

## viral EOS

- 2.7: Real Gases

## Virial Equation

- 2.7: Real Gases

## volatile compounds

- 8.8: Non-ideality - Henry's Law and Azeotropes

## volatile liquids

- 8.7: Liquid-Vapor Systems - Raoult's Law

## voltage measurement

- 10.3: Half Cells and Standard Reduction Potentials

## voltaic pile

- 10.1: Electricity

## volume

- 1.1: The System and the Surroundings
- 1.5: Work and Energy
- 2.1: The Empirical Gas Laws
- 4.1: Prelude to Putting the First Law to Work
- 4.6: Useful Definitions and Relationships
- 6.1: Free Energy Functions
- 6.8: The Difference between  $C_p$  and  $C_v$
- 7.1: Thermodynamics of Mixing

## volume decrease

- 7.2: Partial Molar Volume

## Volume Dependence of Helmholtz Energy

- 6.4: Volume Dependence of Helmholtz Energy

## volume expansion

- 5.4: Calculating Entropy Changes

## W

### water phase diagram

- 8.4: The Clapeyron Equation

### weak acid

- 9.8: Acid-Base Equilibria
- 9.9: Buffers

### weak base

- 9.8: Acid-Base Equilibria

### weak bases

- 9.8: Acid-Base Equilibria

### William Gilbert

- 10.1: Electricity

### William Lord Kelvin

- 1.3: Temperature

### work

- 1.5: Work and Energy
- 3.2: Work and Heat
- 5.2: Heat Engines and the Carnot Cycle

### work extraction

- 6.3:  $\Delta A$ ,  $\Delta G$ , and Maximum Work

## Z

### Zero Law of Thermodynamics

- 1.4: The Zeroth Law of Thermodynamics

### zero order

- 11.8: The Method of Half-Lives

### zeroth law of thermodynamics

- 1.1: The System and the Surroundings
- 1.4: The Zeroth Law of Thermodynamics

### zeroth order reaction

- 11.4: 0th order Rate Law