**TRIGONOMETRIC IDENTITIES**

Right Triangle Identities

A triangle with words on it

Description automatically generated

Pythagorean Identities

Double Angle Identities

Half Angle Identities

Sum and Difference Formulas

Product to Sum Formulas

Sum to Product Formulas

Laws

**PROPERTIES OF LOGARITHMS**

Product Rule

Quotient Rule

Power Rule

Change of Base

**GREEK ALPHABET**

|  |  |  |
| --- | --- | --- |
| Letter | Name | Mathematical Use |
| Α α | Alpha | Area underneath a normal curve |
| Β β | Beta | Beta Function |
| Γ γ | Gamma | Gamma Function |
| Δ δ | Delta | Upper: A finite difference  Lower: Used as change in x in the delta-epsilon proof of a limit |
| Ε ε | Epsilon | Lower: a surreal number that is bigger than zero, but smaller than all the non-negative numbers, also used as y in delta-epsilon proof of a limit |
| Ζ ζ | Zeta | Riemann Zeta Function |
| Η η | Eta | Viscosity of a fluid |
| Θ θ | Theta | Lower: Variable that represents an angle |
| Ι ι | Iota | No major mathematical use |
| Κ κ | Kappa | No major mathematical use |
| Λ λ | Lambda | Lagrange Operations Lambda calculus |
| Μ μ | Mu | N/A |
| Ν ν | Nu | N/A |
| Ξ ξ | Xi | Riemann Xi function |
| Ο ο | Omicron | Ordering |
| Π π | Pi | Upper: the product operator (same use as summation)  Lower: Archimedes' constant, pi |
| Ρ ρ | Rho | No major mathematical use |
| Σ σ/ς | Sigma | Upper: The summation operator |
| Τ τ | Tau | N/A |
| Υ υ | Upsilon | No major mathematical use |
| Φ φ | Phi | Upper:  The golden ratio conjugate −0.618…  A common symbol for the parametrization of a surface in vector calculus.  Lower:  The golden ratio 1.618…  Euler's Totient Function |
| Χ χ | Chi | No major mathematical use |
| Ψ ψ | Psi | Lower:  The wave function in the Schrödinger equation of quantum mechanics  Reciprocal Fibonacci constant  Polygamma Function |
| Ω ω | Omega | Uppercase: Ohms Lower: Angular Frequency |

**METHODS OF DIFFERENTIATION**

**APPLICATIONS OF DIFFERENTIATION**

L'Hopital’s Rule

Critical/Turnaround Points

Mean Value Theorem

If is continuous on and differentiable on then there is a such that

Newton’s Method

Tangent and Secant Lines

Tangent of f(x)

Secant of f(x)

**BASIC METHODS OF INTEGRATION**

**BASIC RULES OF INTEGRATION**

**THE FUNDAMENTAL THEOREM OF CALCULUS**

**FINITE SUMS**

**APPLICATIONS OF DEFINITE INTEGRATION**

Average Value of a Function on [a, b]

Volume by Disks (x-axis rotation)

Volume by Washers (x-axis rotation)

Volume by Shells (y-axis rotation)

Arc Length

Surface Area of Revolution

Work

Moments and Center of Mass

Center of Mass:

**HYPERBOLIC TRIGONOMETRIC FUNCTION IDENTITIES**

**PARTIAL FRACTION DECOMPOSITION**

**NUMERICAL INTEGRATION**

The Trapezoidal Rule

\*all terms besides the first and last term have a coefficient of 2

Simpson’s Rule

**FIRST ORDER DIFFERENCIATION**

A first order differential equation is an equation where

First Order Linear Equations

To solve the linear equation , multiply both sides by the integrating factor and integrate both sides.

**IMPROPER INTEGRALS**

Integrals with infinite limits of integration are improper integrals of type I.

Integrals of functions that become infinite at a point within the interval of integration are improper integrals of type II.

**TESTS OF CONVERGANCE AND DIVERGANCE FOR IMPROPER INTEGRALS**

Direct Comparison Test

Limit Comparison Test

If

Then

**SERIES AND SEQUENCES**

Geometric Series

Power Series

Power series about x = 0

Power series about x = a (center a)

Convergence Theorem for Power Series

If the power series

Power Series Multiplication

Taylor Series

The Taylor Series generated by f at x = a is

Euler’s Identity

Maclaurin Series

Binomial Series

where

and

**TESTS FOR SERIES CONVERGANCE AND DIVERGANCE**

n-th Term Test

The Integral Test

If f(x) is a positive, continuous, decreasing function on the interval

Absolute Value Test

The Ratio Test

The Root Test

Alternating Series Test

The series

Alternating Series Estimation Theorem

**PARAMETRIC AND POLAR EQUATIONS**

Basics

Derivatives

Arc Length

Surfaces of Revolution

Polar Equations

Arc Length of a Polar Curve

Lines

Ellipse with Semimajor Axis a

Regular Conic

**CONIC SECTIONS**

Ellipses

Foci on the y-axis

Hyperbolas

Center-to-focus distance:   
Foci:   
Vertices:

Asymptotes: or

Center-to-focus distance:   
Foci:   
Vertices:   
Asymptotes: or

**VECTORS**

Basics

Magnitude

Direction

Operations

Unit Vectors

Dot Product

To find a vector orthogonal of two vectors, take the cross product

Vector Projections and Scalar Components

Determinants

Cross Product

where n is the unit vector

Parametric Vectors  
Equation of a Line  
A vector equation of the line passing through the point in the direction of the vector is , or  
Distance Between a Point and a Line

**PLANES**The plane passing through the point with a nonzero normal vector is described by the equation   
  
**QUADRIC SURFACES**TraceA trace of a surface is the set of points at which the surface intersects a plane that is parallel to one of the coordinate planes. The traces in the coordinate planes are called the xy-trace, the yz-trace, and the xz-trace.

Quadric Surfaces  
Quadric surfaces are described by the general quadratic (second-degree) equation in   
  
**VECTOR-VALUED FUNCTIONS**Differentiation  
Unit Tangent Vector  
Integration  
Indefinite  
Motion in Space  
Speed  
Two-Dimensional Motion in a Gravitational Field  
Consider an object moving in a plane with a horizontal -axis and a vertical -axis, subject only to the force of gravity. Given the initial velocity and the initial position , the velocity of the object, for , is  
and the position is  
Assume an object traveling over horizontal ground, acted on only by the gravitational force, has an initial position and initial velocity . The trajectory, which is a segment of a parabola, has the following properties.  
Arc Length  
Curvature  
Let describe a smooth parameterized curve. If denotes arc length and is the unit tangent vector, the curvature is

Principal Unit Normal Vector  
Let describe a smooth curve parameterized by arc length. The principal unit normal vector at a point on the curve at which is  
For other parameters, we use the equivalent formula  
.  
  
Tangential and Normal Components of the Acceleration  
The acceleration vector of an object moving in space along a smooth curve has the following representation in terms of its tangential component (in the direction of and its normal component (in the direction of ):  
Unit Binormal Vector and Torsion  
Let be a smooth parameterized curve with unit tangent and principal unit normal vectors and , respectively. Then at each point of the curve at which the curvature is nonzero, the unit binormal vector is  
and the torsion is

**INTRODUCTION TO HIGH-DIMENSIONAL CALCULUS**Limits  
The function has the limit as approaches , written  
Let and be real numbers and suppose and . Assume is a constant, and is an integer.

Sum:

Difference:

Constant multiple:

Product:

Quotient: , provided

Power:

Root: , where we assume if is even.  
  
**PARTIAL DERIVATIVES**  
A group of math equations

Description automatically generated

Directional Derivatives  
Let be differentiable at and let be a unit vector in the -plane. The directional derivative of at in the direction of is  
  
Tangent Plane at P(a, b, c)

Linear Approximation  
Lagrange Equations

**MULTIPLE INTEGRATION**Double Integrals

Average Value  
  
Double Integrals in Polar Regions

Triple Integrals  
Average Value

Cylindrical Coordinates  
Transformations same as polar coordinates  
   
Spherical Coordinates  
Regtangular 🡪 Spherical  
Spherical 🡪 Regtangular

A diagram of a point

Description automatically generated

1D Center of Mass

2D Center of Mass  
D Center of Mass  
Jacobians  
Transformation of Two Variables  
Transformation of Three Variables

Change of Variables for Triple Integrals  
**VECTOR FIELDS**Vector Fields in Let and be defined on a region of . A vector field in is a function that assigns to each point in a vector . The vector field is written as

A vector field is continuous or differentiable on a region of if and are continuous or differentiable on , respectively.

Radial Fields in   
Let . A vector field of the form , where is a scalarvalued function, is a radial vector field. Of specific interest are the radial vector fields

where is a real number. At every point (except the origin), the vectors of this field are directed outward from the origin with a magnitude of .

Potential Functions  
Let be differentiable on a region of or . The vector field is a gradient field and the function is a potential function for .

Find Potential Functions in Suppose is a conservative vector field. To find such that , use the following steps:   
1. Integrate with respect to to obtain , which includes an arbitrary function .  
2.   
3. Integrate with respect to to obtain , including an arbitrary function .  
4.

**LINE INTEGRALS**

PROCEDURE   
Evaluating the Line Integral

1. Find a parametric description of in the form , for .
2. Compute .
3. Make substitutions for and in the integrand and evaluate an ordinary integral:

Line Integral of a Vector Field

Work Done in a Force Field

Circulation  
Let be a continuous vector field on a region of , and let be a closed smooth oriented curve in . The circulation of on is , where is the unit vector tangent to consistent with the orientation.

Flux

Simple vs. Closed Curves  
Suppose a curve (in or ) is described parametrically by , where . Then is a simple curve if for all and , with ; that is, never intersects itself between its endpoints. The curve is closed if ; that is, the initial and terminal points of are the same.

Conservative Fields  
Conservative if there exists a scalar function such that .

Fundamental Theorem for Line Integrals

Independent of Path Line Integral: C1 and C2 have the same terminal and initial points  
  
Closed Curve Line Integrals  
Notation:

**UNITS**

|  |  |  |  |
| --- | --- | --- | --- |
| Quantity | Common Symbol | SI Unit | Base Units |
| Acceleration |  |  |  |
| Angle |  | Radian (rad) or degree (˚ ) |  |
| Substance Amount |  | mole | mol |
| Angular Acceleration |  |  |  |
| Angular Frequency |  |  |  |
| Angular Momentum |  |  |  |
| Angular Velocity |  |  |  |
| Area |  |  |  |
| Charge |  |  |  |
| Capitance |  | farad (F) |  |
| Density |  |  |  |
| Drag Coefficient |  | *N/A* | *N/A* |
| Current |  |  |  |
| Electric Dipole Moment |  |  |  |
| Electric Field |  |  |  |
| Electric Flux |  |  |  |
| Energy |  |  |  |
| Kinetic Energy |  |  |  |
| Potential Energy |  |  |  |
| Entropy |  | J/K |  |
| Force |  |  |  |
| Frequency |  |  |  |
| Heat |  |  |  |
| Length |  | meter | m |
| Distance |  | meter | m |
| Magnetic Dipole Moment |  |  |  |
| Magnetic Field |  |  |  |
| Magnetic Flux |  |  |  |
| Mass |  |  | kg |
| Moment of Inertia |  |  |  |
| Momentum |  |  |  |
| Period |  | s | s |
| Potential |  |  |  |
| Power |  |  |  |
| Pressure |  | pastcal |  |
| Resistance |  |  |  |
| Speed |  |  |  |
| Temperature |  |  | K |
| Time |  | second | s |
| Torque |  |  |  |
| Velocity |  |  |  |
| Volume |  |  |  |
| Wavelength |  |  |  |
| Work |  |  |  |
| Position | x | m | m |

**VECTORS—PHYSICAL MATHEMATICS**

Basics

Magnitude

Direction

Operations

Unit Vectors

Dot Product

Vector Projections and Scalar Components

Determinants

Cross Product

where n is the unit vector

**KINEMATICS—MECHANICS**   
    
(subscript x refers to the dimension, every value must be in the same dimension)  
  
**NEWTON’S LAWS—MECHANICS**First Law  
The Law of Inertia  
“A body at rest remains at rest or, if in motion, remains in motion at constant velocity unless acted on by a net external force.”  
  
Second Law  
   
Third Law  
Forces are equal and opposite  
“Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that it exerts.”

**APPLICATIONS OF NEWTON’S LAWS—MECHANICS**Common Forces

Hooke’s Law:

Friction  
Friction is a force that opposes relative motion between systems in contact.

Drag Force and Terminal Speed

**MECHANICAL ENERGETICS AND MOMENTUM—MECHANICS**Law of Conversion of Energy: Energy cannot be created or destroyed in a closed system  
Law of Conversion of Momentum: Momentum is always conserved  
Basics

Impulse Momentum:

Potential Energy  
 Angular Energy and Momentum on

Collisions  
Elastic - no net loss in kinetic energy in the system as a result of the collision; both energy and momentum are conserved

Perfectly Inelastic Collision – Objects come together, there is a net loss of kenetic energy  
Explosion/Inelastic Collision – Net gain or loss in kenetic energy  
  
Object Equilibrium – All forces are balanced

Power

**ANGULAR MECHANICS—MECHANICS**Kinematics

Linear-Angular Conversions

Frequency and Periods

Torque and Angular Forces

Energy and Rotational Momentum   
  
Moments of Inertia

Disk/Cylinder:

Ring:

Rod or Plank (about center):

Rod or Plank (about end):

Sphere:

Sphere Hallow:

Satellite:

**CENTER OF MASS—PHYSICAL MATHEMATICS**1D Center of Mass

2D Center of Mass

**FLUID MECHANICS—MECHANICS**Pressure and Density (Constant Density)

Absolute Pressure accounts for atmospheric pressure, gauge pressure does not

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Unit | mmHg/torr | Pa | atm | kPa |
| mmHg/torr | 1 | 133.322 |  |  |
| Pa |  | 1 |  |  |
| atm | 760 | 101325 | 1 | 101.325 |
| kPa | 7.50062 | 1000 |  | 1 |

Pascal’s Principle: change in pressure applied to an enclosed fluid is transmitted undiminished to all portions of the fluid

Buoyancy

Buoyant Force: the upward force on any object in any fluid

Archimedes’ Principle: buoyant force on an object equals the weight of the fluid it displaces

Fluid Dynamics, Viscosity, and Turbulance

Ideal Fluid: fluid with negligible viscosity

Flow Rate: Volume of fluid that flows through a pipe during a time

Viscosity: a measure of the internal friction in a fluid; flow resistance

Turbulent Flow: type of fluid flow in which layers mix together via eddies and swirls

Poiseuille’s Law for Resistance

Laminar Flow: type of fluid flow in which layers do not mix

Bernoulli  
Applying conservation of energy to an incompressible frictionless fluid yields the equation:

**MECHANICAL WAVES—MECHANICS**

Basics

Transverse Wave: wave in which the disturbance is perpendicular to the direction of propagation; up to down to up

Longitudinal Wave: wave in which the disturbance is parallel to the direction of propagation; side to side

Node: A place where the string is stationary

Crest: Highest point

Trough: Lowest point

Pulse: A single disturbance

Wave Equations

Waves on Stretched String

Waves in Fluid

Energy, Power, and Intensity of Waves

Interference

Superposition: phenomenon that occurs when two or more waves arrive at the same point, if there is phase shift the following equation is used

Constructive Interference: when two waves arrive at the same point exactly in phase; that is, the crests of the two waves are precisely aligned, as are the troughs

Destructive Interference: when two identical waves arrive at the same point exactly out of phase; that is, precisely aligned crest to trough

Resonance and Standing Waves

Standing Wave: waves that bounce back and forth through a particular region, effectively becoming stationary

**SOUND—MECHANICS**Basics

Sound: a disturbance of matter that is transmitted from its source outward

Speed Equations

Sound Intensity

Doppler Effect

|  |  |  |  |
| --- | --- | --- | --- |
| Dopper Effect | Stationary observer | Observer moving toward source | Observer moving away from source |
| Stationary source |  |  |  |
| Source moving towards observer |  |  |  |
| Source moving away from observer |  |  |  |

Shock Waves

Mach number:

Sine of angle formed by shock wave:

**GRAVITATION—MECHANICS**Basics

Escape and Orbit

Kepler’s Laws

1. every planet moves along an ellipse, with the Sun located at a focus of the ellipse
2. a planet sweeps out equal areas in equal times, meaning it has a constant areal velocity
3. the square of the period is proportional to the cube of the semi-major axis of the orbit

Black Holes

Black Hole: mass that becomes so dense, that it collapses in on itself, creating a singularity at the center

Event Horizon: location near a black hole from within which no object, even light, can escape

Schwarzschild Radius: the distance to the event horizon

**HEAT AND TEMPERATURE—THERMODYNAMICS**

Tempurature

Tempurature: the mechanical energy of particles in the system

Thermal Equilibrium: condition in which heat no longer flows between two objects that are in contact; the two objects have the same temperature

Conduction: heat transfer through stationary matter by physical contact

Zeroth Law of Thermodynamics: law that states that if two objects are in thermal equilibrium, and a third object is in thermal equilibrium with one of those objects, it is also in thermal equilibrium with the other object

Thermal Expansion: change in size or volume of a given system as its temperature changes

Thermal Stress: stress resulting from temperature changes

Heat

Heat: a type of energy transfer that is caused by a temperature difference (sometime kcal or cal used as unit, instead of joule)

Internal Energy: the sum of the microscopic energies of the system

Heat Transfer:

Phase Changes

Phases

Triple Point: pressure and temperature at which a substance exists in equilibrium as a solid, liquid, and gas

Critical Point: the combination of temperature and pressure above which the liquid and gas phases are indistinguishable

* Critical Pressure: pressure at the critical point
* Critical Temperature: temperature at the critical point

Phase Diagram: graph of pressure vs. temperature of a particular substance, showing at which pressures and temperatures the phases of the substance occur

A diagram of a graph

Description automatically generated

Sublimation: phase change from solid to gas

Heat of Fusion:

Heat of Vaporization:

Vapor: gas at a temperature below the critical temperature

Vapor Pressure: pressure at which a gas coexists with its solid or liquid phase

Heat Transfer

Conduction: heat transfer through stationary matter by physical contact

Convection: heat transfer by the macroscopic movement of a fluid

Transfer by Radiation: when microwaves, infrared radiation, visible light, or another form of electromagnetic radiation is emitted or absorbed

Rate of Conductive Heat Transfer

System Conversions

|  |  |
| --- | --- |
| Conversion | Equation |
| Celsius to Fahrenheit |  |
| Fahrenheit to Celsius |  |
| Celsius to Kelvin |  |
| Kelvin to Celsius |  |
| Fahrenheit to Kelvin |  |
| Kelvin to Fahrenheit |  |

Absolute Zero: No energy in system; 0 kelvin

**KINETIC THEORY OF GASES—THERMODYNAMICS**

Ideal Gas Laws

Boyle’s Law:

Charles’ Law:

Avogadro’s Law:

Gay-Lussac’s Law:   
  
Combined Gas Law:

Ideal Gas Law

Van der Waals Equation

A table of numbers and symbols

Description automatically generated

Kinetic Theory of Gases

Average KE per Molecule

Internal Energy

Root Mean Speed of a Molecule

Heat Capacity

Heat Capacity of an Ideal Monatomic Gas at Constant Volume

Equipartition

Degree of Freedom (d): independent possible motion of a molecule; amount of dimensions the molecule can move

Equipartition Theorem

Molecular Speeds

Maxwell-Boltzmann Distribution of Speeds: the distribution function for speeds of particles in an ideal gas

Average Speeds

Peak Speed

**THE FIRST LAW—THERMODYNAMICS**

First Law

Change in internal energy between two equilibrium states is

In other words, energy in neither created nor destroyed.

Applications

Internal Energy of a System

Internal Energy of a Monatomic Ideal Gas

**CARNOT CYCLE OF THE SECOND LAW—THERMODYNAMICS**

Basics

Adiabatic: No change in heat

Reservoir: A collection of heat at a single temperature

Carnot Cycle: cycle that consists of two isotherms at the temperatures of two reservoirs and two adiabatic processes connecting the isotherms; hypothetical working cycle with the highest possible efficiency between the same two reservoirs

* The Carnot cycle is the most efficient engine for a reversible cycle designed between two reservoirs.

Carnot Engine: Engine that operates on a Carnot cycle

Carnot’s Principle: No engine working between two reservoirs at constant temperatures can have a greater efficiency than a reversible engine.

**THE SECOND LAW—THERMODYNAMICS**

Clausius Statement of the Second Law

Clausius Statement: heat never flows spontaneously from a colder object to a hotter object

Kelvin Statement of the Second Law

Kelvin Statement: it is impossible to convert the heat from a single source into work without any other effect.

This statement falsifies the concept of a “perfect engine,” an engine that can convert heat into work with 100% efficiency.

It is impossible to turn all heat flowing from a hot reservoir to work.

It is impossible to transfer all heat from a cold reservoir to a hot reservoir without work.

Entropy

Entropy: state function of the system that changes when heat is transferred between the system and the environment

Entropy Statement of the Second Law

Entropy Statement: the entropy of a closed system and the entire universe never decreases.

Applications

Heat Engines: a device used to extract heat from a source and then convert it into mechanical work that is used for all sorts of applications

Reversiable Process: a process in which the system and environment can be restored to exactly the same initial states that they were in before the process occurred

Irreversible Process: Entropy increases; the system and its environment cannot be restored to their original states at the same time

Refrigerator: an engine made to remove heat from a specific area

A refrigerator (or heat pump) absorbs heat from the cold reservoir at Kelvin temperature and discards heat to the hot reservoir at Kelvin temperature , while work W is done on the engine’s working substance, as shown by the arrow pointing toward the system in the figure.

**THE THIRD LAW—THERMODYNAMICS**

The Third Law: The absolute zero temperature cannot be reached through any finite number of cooling steps.

\*not much information in given in the thermodynamics section, the third law requires quantum physics to understand and prove

**CHARGES AND FIELDS—ELECTRICITY AND MAGNETISM**Fundamental Properties

Basics

Static Electricity: buildup of electric charge on the surface of an object

Conductors: Materials in which the outer electrons in the atoms are free to move in the material

Insulators: Materials in which electrons are tightly bound to the nucleus and are not free to move about

Charging by Induction: process by which an electrically charged object brought near a neutral object creates a charge separation in that object

Properties of Electric Charge

* Charge is quantized: electric charge comes in discrete amounts, and there is a smallest possible amount of charge that an object can have,
* The magnitude of the charge is independent of the type: the smallest possible positive charge (to four significant figures) is +e, and the smallest possible charge is -e.
* Charge is conserved: Charge can neither be created nor destroyed; it can only be transferred from place to place, from one object to another.

Charging by Friction

When you rub two *insulators* together, objects are given a net charge

Charges and Force

Electric Fields and Charge Distributions

= point charge

linear charge density

= surface charge density

= volume charge density

Drawing Electric Fields

1. Electric field lines either originate on positive charges or come in from infinity, and either terminate on negative charges or extend out to infinity.
2. The number of field lines originating or terminating at a charge is proportional to the magnitude of that charge. A charge of 2q will have twice as many lines as a charge of q.
3. At every point in space, the field vector at that point is tangent to the field line at that same point.
4. The field line density at any point in space is proportional to (and therefore is representative of) the magnitude of the field at that point in space.
5. Field lines can never cross. Since a field line represents the direction of the field at a given point, if two field lines crossed at some point, that would imply that the electric field was pointing in two different directions at a single point. This in turn would suggest that the (net) force on a test charge placed at that point would point in two different directions. Since this is obviously impossible, it follows that field lines must never cross.

Electric Dipoles

Dipole: two equal and opposite charges that are fixed close to each other

Dipole Moment: it characterizes the combination of distance between the opposite charges, and the magnitude of the charges

Rotation of a Dipole:

**ELECTRIC FLUX AND GAUSS’S LAW—ELECTRICITY AND MAGNETISM**Basics of Flux

Flux (general): describes how much of something goes through a given area

Area Vector (): flat surface of area A has the following magnitude and direction

* Magnitude is equal to area (A)
* Direction is along the normal to the surface

Electrix Flux

Flat Surface

Open Surface

Closed Surface

Gauss’s Law

The flux of the electric field through any closed surface (a Gaussian surface) is equal to the net charge enclosed divided by the permittivity of free space :  
Simplified Version

**ELECTRIC POTENTIAL—ELECTRICITY AND MAGNETISM**

Electric Potential Energy

Work Done by Charge

Electric Potential Energy

Electric Potential

Electric Potential: potential energy per unit charge

Electric Field

**CAPACITANCE—ELECTRICITY AND MAGNETISM**

Basics

Capacitor: a device used to store electrical charge and electrical energy

Electrodes: another name for electrical conductors

Vacuum Capacitor: Capacitor in a vacuum

Dielectric: insulating material between the space of a capacitor

Capacitance: the ratio of the maximum charge Q that can be stored in a capacitor to the applied voltage V across its plates

Parallel Combination

A diagram of a circuit

Description automatically generated

Series Combination

A diagram of a battery

Description automatically generated

Energy Stored of a Capacitor

Capacitor with a Dielectric

**CURRENT AND RESISTANCE—ELECTRICITY AND MAGNETISM**

Electrical Current

Electrical Current: rate at which charge flows

Circuit: complete path that an electrical current travels along

Conventional Current: current that flows through a circuit from the positive terminal of a battery through the circuit to the negative terminal of the battery

Drift Velocity

Drift Velocity (): average velocity of the free charges; velocity of a charge as it moves nearly randomly through a conductor, experiencing multiple collisions, averaged over a length of a conductor, whose magnitude is the length of conductor traveled divided by the time it takes for the charges to travel the length

Current Density

Current Density (): the flow of charge through an infinitesimal area, divided by the area

Resistivity

Conductivity: analogous to thermal conductivity and is a measure of a material’s ability to conduct or transmit electricity

Resistivity: the resistivity of a material is a measure of how strongly a material opposes the flow of electrical current

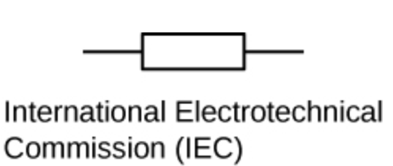
Resistance

Resistance: the ratio of the voltage to the current

Resistors

Visual Representation Methods:

A logo with text on it

Description automatically generated

A diagram of a resistor

Description automatically generated

Ohm’s Law

Electrical Power

Power Gained or Lost:

Power Dissipated by a Resistor:

**DIRECT-CURRENT CIRCUITS—ELECTRICITY AND MAGNETISM**

Resistors in Series and Parallel

A diagram of a wire with text

Description automatically generated

A diagram of a circuit

Description automatically generated

Kirchhoff’s Rules

First Rule

Kirchhoff’s First Rule (the junction rule): The sum of all currents entering a junction must equal the sum of all currents leaving the junction

A diagram of a mathematical equation

Description automatically generated

Second Law

Kirchhoff’s Second Rule (the loop rule): The algebraic sum of changes in potential around any closed circuit path (loop) must be zero

RC Circuits

**MAGNETIC FORCES AND FIELDS—ELECTRICITY AND MAGNETISM**

Magnetic Forces and Magnetism

Magnetic Force (charge q moving at ):

Field Lines

1. The direction of the magnetic field is tangent to the field line at any point in space. A small compass will point in the direction of the field line.
2. The strength of the field is proportional to the closeness of the lines. It is exactly proportional to the number of lines per unit area perpendicular to the lines (called the areal density).
3. Magnetic field lines can never cross, meaning that the field is unique at any point in space.
4. Magnetic field lines are continuous, forming closed loops without a beginning or end. They are directed from the north pole to the south pole.

A diagram of a magnet

Description automatically generatedA diagram of a magnetic field

Description automatically generatedA diagram of a magnetic field

Description automatically generated

Magnetic Force (on wire of arbitrary length and shape)

Straight Wire:

Charged Particle in a Magnetic Field

Force and Torque

Motors: the most common application of magnetic force on current-carrying wires. Motors contain loops of wire in a magnetic field. When current is passed through the loops, the magnetic field exerts torque on the loops, which rotates a shaft.

A diagram of a physics equation

Description automatically generated with medium confidence

**INTODUCTION TO CHEMISTRY**Basic Terms  
Chemistry: The study of matter and the changes that

matter undergoes  
Atoms: submicroscopic particles that make up matter

Law: A brief statement that summarizes past

observations and allows you to predict future

ones based on the results of many experiments.  
Theory: Tentative explanation for the characteristics and behavior of nature.  
  
States of Matter  
Solid: fixed shape and volume  
Liquid: fixed volume but no fixed shape  
Gas: no fixed volume or shape  
  
Changes to Matter  
Physical: atoms or molecules do not change their identity  
Chemical: change that alters the composition of matter

Physical Properties: Can be observed without changing a substance into another substance

Ex. Boiling Point  
Chemical Properties: Can only be observed when a substance is changed into another substance  
Ex. Flammability  
  
Temperature Conversions  
   
Significant Figure Rules   
1. All nonzero numbers are significant.

2. Captive zeroes are significant.

3. Leading zeroes are never significant.

4. Trailing zeroes are significant if the number contains a decimal point.  
  
Multiplication/division: the answer has the same

number of sig figs as the measurement with the

fewest number of sig figs  
Addition/subtraction: the answer has the same

number of decimal places as the measurement with

the fewest number of decimal places.

Density  
Intensive Property: independent of quantity  
Extensive Property: depends on quantity

**ATOMS, MOLECULES, AND IONS**Fundamental Laws  
Law of Conservation of Mass (Antoine Lavoisier): during a chemical reaction matter is not created or destroyed.  
Law of Definite Proportions (Joseph Proust): a given compound always contains exactly the same proportion of elements by mass.  
  
Dalton’s Atomic Theory

* Each element is composed of atoms
* All atoms of a given element are identical\*\*; the atoms of different elements are different.
* Compounds are formed when atoms of different elements combine in whole number ratios.
* Atoms of an element are not changed into atoms of a different element by chemical reactions—they are just reorganized.

Experiments

|  |  |  |
| --- | --- | --- |
| Scientist | Tool Used | Discovery Made |
| JJ Thomson | Cathode Rays | charge/mass ratio of the electron Cathode rays (electrons) always attracted to positive plates |
| Thomson | N/A | Created plum pudding model |
| Robert Millikan | Oil Drop | Determined charge and mass of an electron |
| Ernest Rutherford | Gold Foil | Nucleus of an atom Created Nuclear Theory |

The Nuclear Theory  
1. There is a very small, dense nucleus with most of the atom’s mass and all of its positive charge.

2. Most of the volume of atom is empty space, throughout which electrons are dispersed.

3. # protons is equal to # electrons so charge is neutral.  
  
Proton Mass: 1amu  
Neutron Mass: 1.009amu  
Electron Mass: 0.00054858amu  
  
The Modern Atom  
Nucleus: neutrons and protons  
Electrons: orbit nucleus  
  
Symbol Format  
SYMBOL-MASS  
  
Isotope: Same number of protons, different number of neutrons  
Ion: An atom with a net electric charge

Polyatomic Ions  
Polyatomic Ion: an ion that contains more than one atom  
  
Common Polyatomic Ions

|  |  |
| --- | --- |
| Name | Formula |
| Ammonium |  |
| Nitrite |  |
| Nitrate |  |
| Chlorate |  |
| Perchlorate |  |
| Cyanide |  |
| Acetate |  |
| Bicarbonate |  |
| Hydroxide |  |
| Permanganate |  |
| Carbonate |  |
| Sulfite |  |
| Sulfate |  |
| Chromate |  |
| Phosphate |  |

Types of Elements  
Metals

Solids at room temperature  
Reflective Surfaces  
Conduct heat and electricity  
Lose electrons in bonds  
  
Nonmetals  
Found in all states  
Gain electrons  
  
Metalloids  
Have properties of both nonmetals and metals  
**NOMENCLATURE**  
(++ means space)

Ionic Compounds  
Type I (only one type of ion formed):   
Name of cation (metal) ++ base name of anion (nonmetal) + ide  
  
Type II (more than one type of ion can be formed):  
Name of cation + (charge of metal in roman numerals in parentheses) ++ base name of anion + ide  
  
Molecular Compounds  
prefix of subscript (if mono ignore) + name of 1st element ++ prefix of subscript + base name of 2nd element + ide  
  
Acids (first element is hydrogen)  
Binary (two-element)  
hydro + base name of non-metal + ic ++ acid  
  
Oxyacid (hydrogen + polyatomic ion)

* Polyatomic ion ends in -ate  
  base name of polyatomic ion + ic ++ acid
* Polyatomic ion ends in -ite  
  base name of polyatomic ion + ous ++ acid

Bases (contain OH)  
Cation name + hydroxide  
  
Hydrate ( where A is a compound and B is the coefficient of water)  
compound name ++ prefix of B + hydrate

**STOICHIOMETRY**Avogadro’s Number: or the number equal to the number of carbon atoms in exactly 12 grams of pure C-12.

1 mol of compound = molar mass () grams of compound

Basic Stoichiometric Operations  
Converting Quantity of Compound to Moles  
Mass: divide by molar mass  
Volume: divide by 22.4 or multiply by molarity  
  
Switching Compounds  
Multiply by molar ratio:   
  
Converting Moles to Quantity of Compound  
To Mass: multiply by molar mass  
To Volume: multiply by 22.4 or divide my molarity  
  
Formula Types  
Empirical: Lowest whole number ratio of elements  
Molecular: a multiple of the empirical formula  
  
Finding an empirical formula from percent of element one ( element (  
For each   
   
  
For each , divide by smallest amount of moles   
For each,   
If all coeffs. are not whole number, find a number which when multiplied by each of the ratios would make them all whole numbers (call this number M)  
  
The subscript of each element is going to be the coeff. of times M (M is one if all coeffs. were already whole)  
  
Combustion Analysis (a process of burning a compound in oxygen and determining values from the result)

Composition  
Percent Composition:   
  
**SOLUTION REACTIONS**  
Solvent: Dissolving substance  
Solute: Substance being dissolved  
Solution: the mixture of the solvent and solute  
Concentration: amount of solute dissolved in a given amount of solvent; measured by molarity

Dissociation  
Dissociation: the breaking up of a compound into simpler substances

When ionic compounds dissolve in water, they dissociate  
(not all ionic compounds are soluble in water)  
Electrolytes  
Electrolytes: substances whose water solution is a conductor of electricity  
  
Strong Electrolytes: dissociate completely (soluble ionic compounds, strong acids and strong bases)  
Weak Electrolytes: partially dissociated (weak acids and weak bases)  
Nonelectrolytes: not dissociated at all (molecular compounds like sugar)  
  
Acids and Bases  
Acid: A substance that produces when dissolved in water  
Base: A substance that produces when dissolved in water  
  
Strong Acid/Base: dissociate completely  
Weak Acid/Base: partially dissociated   
  
Monoprotic: Hydrogen only donates one proton, usually only one hydrogen atom  
Polyprotic: Hydrogen donates more than one proton, usually more than one hydrogen atom

|  |  |  |  |
| --- | --- | --- | --- |
| Strong Acids | Strong Bases | Weak Acids | Weak Bases |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
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|  |  |  |  |
|  |  |  |  |

Solubility  
A compound is soluble in a liquid if it dissolves in

that liquid.  
A compound is insoluble if it does not dissolve.

Solubility Rules  
1. All common salts of the Group 1A elements and ammonium are soluble.

2. All common acetates, nitrates, bicarbonates and chlorates are soluble.

3. Compounds of Group VIIA elements (Cl, Br, I) are soluble except those of silver, mercury (I), and lead.

4. All sulfates are soluble except those of barium, strontium, lead, calcium, silver, and mercury (I).

5. Except for those with cations in Rule 1, carbonates, hydroxides, chromates, phosphates, sulfides, oxides are not soluble.  
  
Types of Chemical Equations  
Molecular equation: tells you basic overview of a chemical reaction  
Complete Ionic Equation: shows how species are actually present in solution  
Split up the aqueous solutions and move all subscripts for non-polyatomic ions to the front, add charges, keep states  
: An ionic equation that makes up only the substances that contribute to the reaction/make the solid or gas

Spectator Ions: Ions that are in the complete ionic but not in the net ionic, or do not participate in the chemical reaction  
 **TYPES OF REACTIONS**

Precipitation Reaction

|  |  |
| --- | --- |
| Input | Output |
| Min 2 aq | Min 1 s |

Example  
No Precipitate Formed: No reaction  
Example  
Predicting the Products

1. Exchange ions.
   1. (+) ion from one reactant with (-) ion from the other.
2. Balance charges of combined ions to get formula of each product.
3. Balance the equation.
4. Determine solubility of each product in water.
   1. Use the solubility rules.

If neither product will precipitate, no reaction.

Acid-Base (neutralization) Reaction

|  |  |
| --- | --- |
| Input | Output |
| Acid + Base | Salt + |

Example  
Gas Evolution Reaction

|  |  |
| --- | --- |
| Input | Output |
| N/A | Min 1 g |

Example  
**REDOX REACTIONS**

Redox Reaction: Reactions that involve a transfer of electrons  
Oxidation: the loss of electrons  
Reduction: gain of electrons  
  
Oxidation and Reduction must occur together  
A substance that causes the oxidation of another substance is called the oxidizing agent.

The oxidizing agent is always REDUCED.

Likewise, the reducing agent is always OXIDIZED.

Examples  
Iron rusting, bleaching of hair and production of electricity in batteries are all redox  
  
Rules of Oxidation

1. An atom in its elemental form has an O.N. of 0.
2. For any monatomic ion, the O.N. is the same as the charge on the ion. In ionic compounds, alkali metals have an ox. # of +1; alkaline earth metals have an ox. # of +2
3. O.N. of O in compounds is usually -2
4. O.N. of H is usually +1
5. O.N. of F in compounds is -1. Other halogens also take an oxidation number of -1 unless combined with oxygen or with each other.
6. The sum of the O.Ns of all of the atoms in a species equals the overall charge on that species .

Examples  
Types of Redox Reactions

|  |  |
| --- | --- |
| Type of Reaction | What Happens |
| Single Displacement | free element displaces a less active element in a compound  If free element is less active than element in compound no reaction will occur |
| Combustion | Reactions which is a reactant |
| Synthesis/Combination | Two (or more) reactants combine together to make one product |
| Decomposition | A large molecule is broken apart into smaller molecules or its elements  Have only one reactant, make 2 or more products |
| Double Displacement | Two replacements, acid-base rxns and precipitation rxns |

Activity Series

A chart with text and symbols

Description automatically generated with medium confidence  
  
Dilution  
   
  
Titrations  
In a titration, a solution of accurately known concentration, called a standard solution, is added gradually to another solution of unknown concentration, until the chemical reaction between the two solutions is complete.

**ENERGY AND WORK**Basics

Energy: the ability to do work or transfer heat  
Internal Energy: KE + PE  
Exothermic: Energy is released (-q)  
Endothermic: Energy is absorbed (+q)  
Work done my system: -w  
Work done on system: +w

Heat Capacity (c): Amount of heat required to raise the temperature of a substance by 1˚ C ()

Specific Heat: Amount of energy required to raise 1g of substance 1˚ C

Specific Heat of Water: 4.184

Laws of Thermodynamics

1. Law of Conservation of Energy: Energy is neither created nor destroyed; it can only change forms
2. Entropy of a closed system always increases; energy scatters
3. The entropy of a system approaches a constant as temperature approaches absolute zero (0 K)

Energy of Motion and Work

Potential Energy  
 Angular  
 on

Bomb Calorimeter

Bomb Calorimeter: measures the energy in a reaction; substance reacts and reacts heat into the water and the bomb

Total heat evolved

Conversions

Properties of Entropy

* Δ*H* depends on the quantities of reactants and products
* Δ*H* for a reaction in the forward direction is opposite in sign, to Δ*H* for the reverse reaction

Hess’s Law

Hess’s Law: if a reaction is carried out in a series of steps, Δ*H* for the overall reaction will be equal to the sum of the enthalpy changes for the individual steps  
  
Law of Summation of Heats of Formation

**GASES**

Basics

* Gases are composed of particles that are flying around very fast in their container(s)
* The particles travel in straight lines until they encounter either the container wall or another particle, then they bounce off
* If you were able to take a snapshot of the particles in a gas, you would find that it is mostly empty space

Pressure

Units of Pressure

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Unit | mmHg/torr | Pa | atm | kPa |
| mmHg/torr | 1 | 133.322 |  |  |
| Pa |  | 1 |  |  |
| atm | 760 | 101325 | 1 | 101.325 |
| kPa | 7.50062 | 1000 |  | 1 |

Gas Laws

Boyle’s Law:

Charles’ Law:

Avogadro’s Law:

Gay-Lussac’s Law:   
  
Combined Gas Law:

Ideal Gas Law:

STP

STP is a condition where

* Pressure: 1 atm
* Temperature: 0 ˚ C

At STP, one mole of any gas occupies 22.4 L

Partial Pressure

Kinetic Molecular Theory

Assumptions

* The size of a gas particle is negligibly small. (the particles themselves occupy no volume even though they have mass)
* The average KE of the gas depends only on T in K
* Collisions of the gas particles with each other or with walls is completely elastic. (there is no overall loss of energy during a collision)

Movement

According to KMT smaller gases must move faster than larger ones in order for them to have the same kinetic energy

Diffusion: process by which gas molecules spread out in response to a concentration gradient. (perfume)

Effusion: escape of gas molecules through a tiny hole into an evacuated space

Real Gases

Gases behave ideally when the following are true

1. the volume of the gas particles is negligible compared to the space between them.
2. the forces between the gas particles are not significant.   
     
   Van der Waals Equation

A table of numbers and symbols

Description automatically generated

**LIGHT AND WAVES**

Light is both a wave and a particle, it has properties of both.

Waves

A diagram of a waveform

Description automatically generated

Quantization of Energy

E is the energy of a quantum

Energy can only be lost or gained in whole number quantities allowed by the formula

Electromagentic Spectrum

A diagram of different types of microwave

Description automatically generated

The Photoelectric Effect

The Photoelectric Effect: The ejection of electrons from the surface of a metal when light shines on it

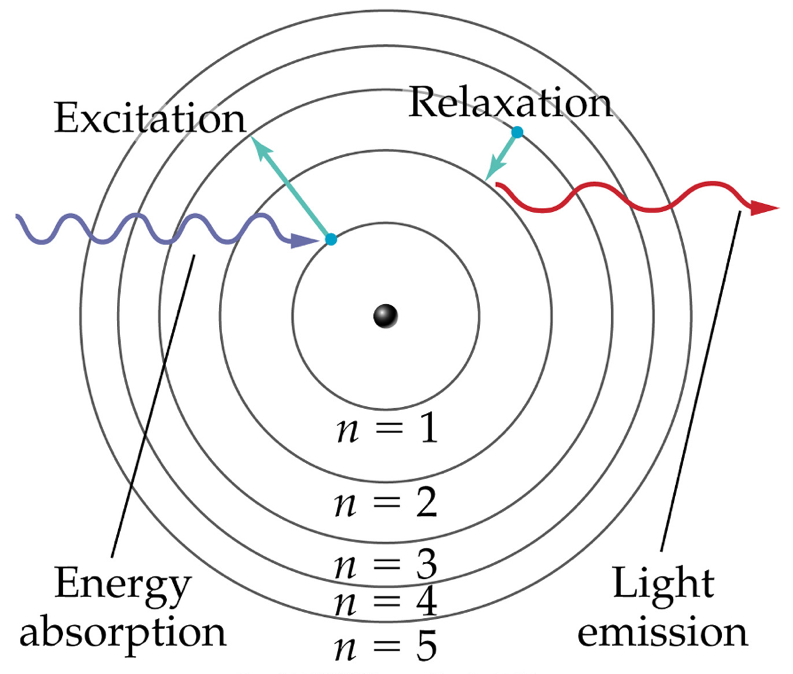
Electrons are ejected only if the light exceeds a certain “threshold” frequency

The number of electrons ejected was proportional to the intensity of the light, but the energies were not

The Bohr Theory

Continuous Spectra: all wavelengths of visible light are present

Line Spectra: only specific wavelengths are present



A diagram of a graph

Description automatically generated

De Broglie Relation

**QUANTUM MECHANICS**

Heisenberg’s uncertainty principle: For something as small as an electron, it is impossible to know exactly the position and the speed simultaneously

Quantum Numbers

Principle quantum number (n)

* Tells the size of the orbital.
* Larger n means it has a greater distance from the electron in the orbital to the nucleus, and therefore the larger the orbital.
* Can be any integer from 1 to infinity.
* Recall that the value of n determines the energy of the orbital. (not the case if there is more than 1 electron)

Angular momentum quantum number (*l*)

* describes the shape of the atomic orbital.
* Values are integers that depend on n
* For a given value of n, *l* can range from 0 to n-1.
* The value of *l* is designated by letters: s(0), p(1), d(2) and f (3).

Magnetic quantum number (

* describes the orientation of the orbital in space.
* The value of ml depends on *l*.
* ml can be any integer from –*l* to + *l*.
* The number of subshells in a shell is equal to n and the number of orbitals in a shell is equal to n2.

Spin quantum number (

* Experiments on the emission spectra of H and Na showed that each line could be split into 2 lines by the application of an external magnet.
* The only way to explain this was to assume that electrons behave like tiny magnets.
* If something spins then it can generate a magnetic field.
* Two possible spin orientations +1/2 or -1/2

A diagram of different colored circles

Description automatically generated

Two electrons with the same n are said to belong to the same shell.

Two electrons with the same n and l are said to belong to the same subshell.

Electron Configuration

Pauli exclusion principle: no two electrons can have the same four quantum numbers; an orbital can hold at most two electrons, and then only if the electrons have opposite spins

Hund’s Rule: When filling orbitals that have the same energy, place one electron in each before completing pairs

A table with numbers and symbols

Description automatically generated

* A number denoting the energy level (4)
* A letter denoting the type of orbital (p)
* A superscript denoting the number of electrons in those orbitals (5)

Aufbau principle: a scheme used to reproduce the ground state electron configurations of atoms by following the “building up” order

1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 5f

A table with numbers and arrows

Description automatically generated

Excited State: Any quantum state of the system that has a higher energy than the ground state (that is, more energy than the absolute minimum)

Orbital Diagram  
An orbital diagram shows how the orbitals of a sub shell are occupied by electrons

Exceptions to Aufbau

Cr & Cu

* This is because the 4s and 3d are so close in energy and the added stability of half-filled and completely filled subshells
* Actual electron configurations are always determined experimentally through spectroscopy.
* This anomaly happens in the f-block as well.

Valence Electrons: The outermost electrons are called valence electrons

Electron Configurations of Ions

* As metals lose electrons to form cations the electrons are lost from the valence shell first
* As nonmetals gain electrons to form anions, the electrons are added to the valence shell

Magnetic Properties

Paramagnetic: unpaired e

Diamagnetic: all paired e

**PERIODIC TRENDS AND CHARGES**

Effective Nuclear Charge (): It is the pull/force an electron “feels” from the nucleus

* explains the reason for the periodic properties and trends of the elements
* increases going across periods
* decreases going down groups

Atomic Radius: The bonding atomic radius is defined as one-half of the distance between covalently bonded nuclei.

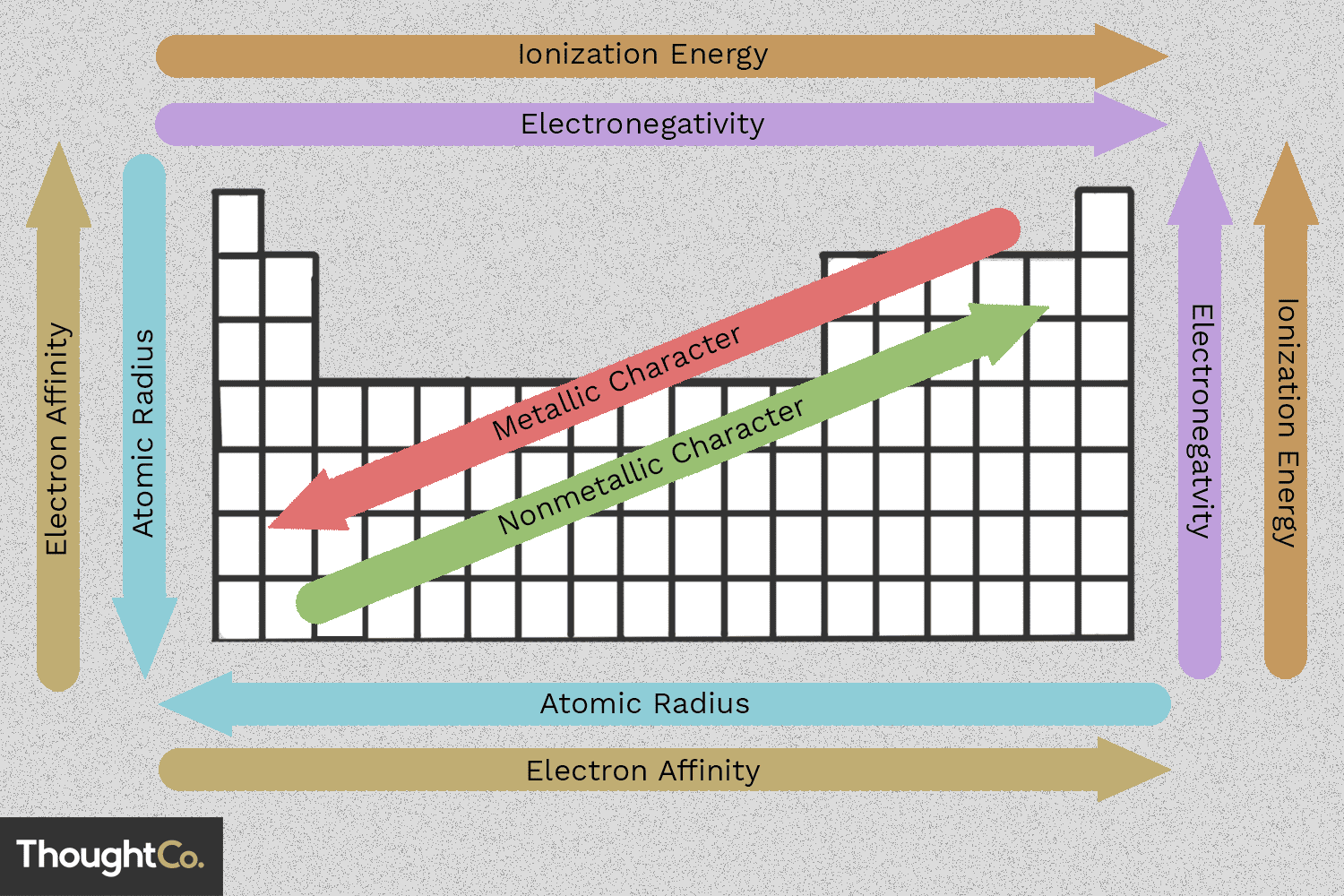
Sizes of Ions

Cations are smaller than their parent atoms: The outermost electron(s) are removed and repulsions between electrons are reduced.

Anions are larger than their parent atoms: Electrons are added and repulsions between electrons are increased

Isoelectronic Series: In an isoelectronic series, ions have the same number of electrons  
In an isoelectronic series, ionic size decreases with an increasing charge

Periodic Trends



Ionization Energy: The ionization energy is the amount of energy required to remove the highest energy electron from the ground state of a gaseous atom or ion

Electron Affinity: the willingness to accept electrons into the valence shell

Metallic Character: How closely an elements properties match the ideal properties of a metal  
  
Group Properties

Group IA, Alkali Metals

* Largest atomic radii
* React violently with water to form H2
* Readily ionized to 1+
* Metallic character, oxidized in air

Group IIA, Alkali Earth Metals

* Readily ionized to 2+
* React with water to form H2
* Closed s shell configuration
* Metallic

Transition Metals

* May have several oxidation states
* Metallic
* Reactive with acids

Group III A

* Metals (except for boron)
* Several oxidation states (commonly 3+)

Group IV A

* Form the most covalent compounds
* Oxidation numbers vary between 4+ and 4-

Group V A

* Form anions generally(1-, 2-, 3-), though positive oxidation states are possible
* Form metals, metalloids, and nonmetals

Group VI A

* Form 2- anions generally, though positive oxidation states are possible
* React vigorously with alkali and alkali earth metals
* Nonmetals

Halogens

* Diatomic gases
* Most reactive nonmetals (F is so reactive that it steals e from almost anything it comes into contact with, even water. It is very difficult and dangerous to work with).
* Melting and boiling points increase with increasing atomic #.
* High electronegativity (electron affinity)

Noble Gases

* Monatomic gases
* Minimal reactivity due to the fact that their electron configurations are so stable.
* Until early 1960’s they were called inert gases because they thought they could not form compounds.
* Now Xe (XeF2 , XeF4 & XeF6), Kr (KrF2) and Ar (HArF) are only ones that form compounds.

**CHEMICAL BONDING**

Basics

**Ionic Bonds**: electrons transferred

* Usually a metal and a nonmetal
* metals have low ionization energies and nonmetals have negative electron affinities
* metals gives up one or more electrons (to become cation) to nonmetal (which becomes anion) and then the opposite charges are attracted to each other, thus lowering their overall potential energies

**Covalent Bonds**: electrons sharred

Polar Covalent Bond: bonding electrons are unevenly shared; bonding electrons spend more time near one of the two atoms involved

Nonpolar Covalent Bond: bonding electrons are evenly shared

* two nonmetals
* nonmetals have high ionization energies (it is difficult to remove an e from them)
* when 2 nonmetals bond, they often share electrons in order to look like noble gas (8 valence electrons)
* Octet Rule
* the shared electrons interact with both nuclei and decrease the potential energy of both

Electronegativity: The ability of an atom to attract bonding electrons to itself

Polarity: the difference in electronegativity

Nonpolar Bond

Polar Bond

Ionic

Valence Electrons: Outermost electrons, valence electrons are held most loosely and chemical bonding involves the transfer or sharing of electrons between two or more atoms

Lewis Bonding Theory: Lewis Theory emphasizes valence electrons to explain bonding

Lewis Structures

In a Lewis structure, we represent the valence electrons of main-group elements as dots surrounding the symbol for the element

Ionic Bonds (Lewis Structure)

Cations have Lewis symbols without valence electrons

Anions have Lewis symbols with eight valence electrons

A diagram of a number and a line

Description automatically generated with medium confidence

Covalent Bonds (Lewis Structure)

Bonding pairs: pairs of electrons that are shared between two atoms

Lone pairs: pairs of electrons that are alone

A diagram of a number of dots and arrows

Description automatically generated

Single Bond: 1 pair of electrons (2 electrons)

Double Bond: 2 pairs of electrons (4 electrons)

Triple Bond: 3 pairs of electrons (6 electrons)

More electrons: stronger bond

Stronger bond: shorter bond

Writing the Lewis Structure  
Step 1: Total all valence electrons in the molecular formula

* For a polyatomic anion, add the number of negative charges to this total
* For a polyatomic cation, subtract the number of positive charges from this total

Step 2: Arrange the atoms symmetrically, with the least electronegative atom in the center. Place one pair of electrons between the central atom and each peripheral atom.

Step 3: Distribute the remaining electrons to the peripheral atoms to satisfy the octet rule.

Step 4: Distribute any remaining electrons to the central atom. If there are fewer than eight electrons on the central atom, a multiple bond may be necessary.

Exceptions to the Octet Rule

* Expanded Octet: Generally, if a nonmetal is in the third period or greater it can accommodate as many as twelve electrons, if it is the central atom. These elements have unfilled “d” orbitals that become involved in bonding.
* Electron Deficiency: Boron (B) and Beryllium (Be) are the only atoms that can be electron deficient
* Free Radicals: Odd number of electrons around the central atom: Results in an unpaired electron which is very reactive

Resonance

Resonance: Extensions of Lewis theory suggest that there is some degree of delocalization of the electrons

Resonance Structures: When there is more than one Lewis structure for a molecule that differ only in the position of the electrons

Real molecule is a hybrid (combination) of all possible Lewis structures

Lattice Energy

Lattice Energy: tells us how much stabilization results from arranging oppositely charged ions in an ionic solid

* Magnitude depends on charges of ions, sizes and arrangement
* Attraction increases as magnitude of charge increases and distance decreases

Coulomb’s Law:

Formal Charges

In certain instances, more than one feasible Lewis structure can be illustrated for a molecule

In order to determine the correct structure we can use formal charge.

The best Lewis structure is the one with the fewest charges

or

puts a negative charge on the most electronegative atom

Bond Energies/Enthalpies

Chemical reactions involve breaking bonds in reactant molecules and making new bonds to create the products

The can be estimated by comparing the cost of breaking old bonds to the income from making new bonds

Bond Energy: The amount of energy it takes to break one mole of a bond in a compound

We use average bond energies to estimate the

(works best when all items in gas state)

A table with numbers and symbols

Description automatically generated

**MOLECULAR GEOMETRY AND BOND THEORIES**

Taste

* The taste of a food depends on the interaction between the food molecules and taste cells on your tongue
* The main factors that affect this interaction are the shape of the molecule and charge distribution within the molecule
* The food molecule must fit snugly into the active site of specialized proteins on the surface of taste cells
* When this happens, changes in the protein structure cause a nerve signal to transmit

VSEPR Theory (Valence Shell Electron

Pair Repulsion Theory)

This theory is based off the assumptions that Electron groups around the central atom will be most stable when they are as far apart as possible

Electron Groups

One electron group is constituted from either

* A lone pair of electrons
* A bond, one bond is one electron group no matter the bond type

Electron Group Geometry

Electron Group Geometry: arrangement of electron domains around central atom

There are five basic arrangements of electron groups

around a central atom

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Central Electron Group Count | Angle | Example |
| Linear | 2 | 180˚ |  |
| Trigonal Planar | 3 | 120˚ |  |
| Tetrahedral | 4 | 109.5˚ |  |
| Trigonal bipyramidal | 5 | x: 120˚  y: 90˚ |  |
| Octahedral | 6 | 90˚ |  |

Molecular Geometry

A screenshot of a cell phone

Description automatically generated

Multiple Central Atoms

Some molecules have more than one central atom

Geometries are assigned for each central atom

Just because a molecule possesses polar bonds does not mean the molecule as a whole will be polar.

Polarity and Solubility

Like dissolves like, for example polar dissolves polar

Valence Bond Theory

* A bond forms when singly occupied atomic orbitals on two atoms overlap (more overlap generally means stronger bond)
* The two electrons shared in the region of overlap must be of opposite spin.
* Formation of a bond results in lower potential energy for the system

Diagram of a graph with blue dots and a red line

Description automatically generated

Electron Overlap

A diagram of a diagram of a complex

Description automatically generated with medium confidence

* Increased overlap brings the electrons and nuclei closer together while simultaneously decreasing electron-electron repulsion
* However, if atoms get too close, the internuclear repulsion greatly raises the energy.

Hybridization

A white sheet with black text

Description automatically generated

Types of Bonds

(sigma) bond is a “head-to-head” overlap of orbitals, all bonds

A (pi) bond is a “side-to-side” overlap of parallel “p” orbitals, creating an electron distribution above and below the bond axis, only double bonds

**INTERMOLECULAR FORCES**

Basics

Intermolecular Forces: Forces holding molecules together: liquids and solids have definite volumes, which means that there are attractive forces holding the particles together

* Much weaker than covalent of ionic bonds

Intramolecular Forces: Forces holding the molecule itself together, for example a covalent bond

Bond Polarity and Dipoles

Partial Charge: Charge of each part of a molecule based on electronegativity, denoted by the symbol

Types of Intermolecular Forces

* Ion–Dipole attractions: form between ions and polar molecules; can only occur in a mixture
* Hydrogen Bonding: a particularly strong type of dipole–dipole attraction.

Substances containing both hydrogen bonding donors (molecules with H bonded to N, O, or F) and hydrogen bonding acceptors (molecules with a lone pair on N, O, or F)

* Dipole–Dipole attractions: form between two polar molecules.
* Dispersion Forces: occur between all molecules, but are most notable between nonpolar molecules

Polarizability: The ability of an electron cloud to become asymmetric

* Smaller atoms do not polarize readily

Outer electrons are close to the nucleus

There are few core electrons for shielding from the nuclear charge

* Larger atoms polarize more readily

Outer electrons farther from nucleus

There are more core electrons for shielding

Electronegativity: The ability of an atom to attract bonding electrons to itself

Polarity: the difference in electronegativity

0≤ΔEN<.4 Nonpolar Bond

0.4<ΔEN<2.0 Polar Bond

ΔEN≥2.0 Ionic

Properties of Liquids

Viscosity: resistance to flow, determined by strength of the intermolecular attractions and temperature

Surface Tension: the tendency of a liquid to minimize its surface

Molecules in the center of a liquid form intermolecular forces with other molecules of the liquid in all directions, resulting in no net pull in any direction for any molecule

Molecules at the surface of the liquid, however, have no liquid molecules above them, so they experience a downward pull

Cohesion: Attraction between like particles

Adhesion: Attraction between unlike particles

Capillary Action: The ability of a liquid to flow against gravity up a narrow tube

Phase Changes

Melting: Solid 🡪 Liquid

Freezing: Liquid 🡪 Solid

Evaporation/Vaporization: Liquid 🡪 Gas

Condensation: Gas 🡪 Liquid

Sublimation: Solid 🡪 Gas

Deposition: Gas 🡪 Solid

A table with numbers and text

Description automatically generated

**SOLUTIONS**

Basics

Solution: homogenous mixture of two or more substances, solvent and solute

Solvent: Substance with the greatest number of moles

Solute: Any other substances, substances being dissolved

Substances dissolve if the solute and solvent can form intermolecular forces

A table with text on it

Description automatically generated

Energetics

Solvation: When solvent particles surround solute particles

Hydration: In aqueous solutions, water molecules surround solute particles

Solution Formation:

1. The intermolecular forces between solute particles are broken (endothermic)
2. The intermolecular forces between solvent particles also are broken (endothermic)
3. New intermolecular forces form between solute and solvent particles (exothermic)

Enthalpy of Solution (): overall energy change; sum of these steps

Solubility

Solubility: Most gaseous and solid solutes will dissolve only to a certain extent in a given liquid solvent at a given temperature

* The solubility of most solids in water increases with increasing temperature of the solution
* Unlike most solids, the solubility of gases decreases as temperature increases

Saturated Solution: A solution that contains the maximum amount of dissolved solute at a given temperature

Unsaturated Solution: If the solution contains less than the maximum amount of solute

Supersaturated Solution: If you lower the temperature of a saturated solution, the solution now holds more solute than is stable

* Excess solid will reform in a process called recrystallization

Henry’s Law: At any given temperature, the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas above the surface of the liquid.

Concentration: Percent by mass, mass of solute/total mass of solution

Molality: Different that molarity (mol/L), experiments with ranging tempuratures use this

Mole Fraction: number of moles of that component divided by the total number of moles of everything in the solution

A table with text on it

Description automatically generated

Colligative Properties

Colligative Properties: physical properties that depend only upon the concentration of solute particles

Vapor-Pressure Lowering: A molecule or atom on the surface of a liquid with sufficient energy to overcome the attractive forces can escape to the gas phase

v

Ideal Solutions: Solutions that follow Raoult’s law exactly

Deviations:

* Ideal Solutions: the attractions between the solute and solvent particles are equal in strength to the attractions between solvent particles
* Solute-Solvent Attraction is Stronger than the Solvent-Solvent: lower vapor pressures than those predicted by Raoult’s law
* Solute-Solvent Attraction is Weaker than the Solvent-Solvent: higher vapor pressures than those predicted by Raoult’s law

Raoult’s Law for volatile components (two liquids):

Vapor Composition: The mole fraction in the vapor will not be the same as the mole fraction in the solution, but can be determined from the partial pressures of each gas in the vapor

Freezing Point Depression: Addition of a solute to a solvent will cause the freezing point of the solution to be lowered compared to that of the pure solvent

* For a liquid to become a solid, the randomly ordered molecules in the liquid phase must form an orderly array in the solid phase
* The solute particles interfere with the process of making the orderly array of molecules and prevent freezing at the liquid’s normal freezing-point temperature.
* Because solute particles the lower vapor pressure of the solvent, the boiling point of a solution is higher than that of the pure solvent.

A diagram of different types of liquid

Description automatically generated

Freezing-Point Depression:

Boiling Point Elevation:

A table with numbers and letters

Description automatically generated

Osmosis

Semipermeable Membrane: allows some, but not all, molecules to pass through

Osmosis: the flow of solvent from a solution of lower concentration to a solution of higher concentration through a semipermeable membrane

Osmotic Pressure

Van’t Hoff Factor:

When the solute is a strong electrolyte, use these equations for freezing-point depression, boiling-point elevation, and osmotic pressure:

**CHEMICAL KINETICS**

Basics

Average Reaction Rate

Instantaneous Rate

It is important to note that the value of k does not depend on the concentration of bromine. The rate constant is constant at constant temperature

Stoichiometry and Reaction Rates

The Rate Law

The values of the exponents in the rate law indicate the order of the reaction with respect to each reactant.

Determination of the Rate Law

* Rate laws are commonly determined using a table of starting reactant concentrations and initial rates
* The initial rate is the instantaneous rate at the beginning of the reaction
* By varying the starting concentrations of reactants and observing the changes that result in the initial rate, we can determine how the rate depends on each reactant concentration. This is called the method of initial rates

Reaction Orders

Zeroth

Initial rate does not change based on concentration

Differential Rate Law:

Integrated Rate Law:

Half Life:

First

Linear relationship between initial rate and concentration

Differential Rate Law:

Integrated Rate Law:

Half Life:

Second

Quadratic relationship between initial rate and concentration

Differential Rate Law:

Integrated Rate Law:

Half Life:

A screenshot of a math equation

Description automatically generated

1. The exponents in a rate law must be determined from a table of experimental data—in general, they are not related to the stoichiometric coefficients in the balanced chemical equation
2. Comparing changes in individual reactant concentrations with changes in rate shows how the rate depends on each reactant concentration
3. Reaction order is generally defined in terms of reactant concentrations rather than product concentrations.

Collision Theory

* Chemical reactions generally occur as a result of collisions between reacting molecules
* A greater frequency of collisions usually leads to a higher reaction rate
* According to the collision theory of chemical kinetics, the reaction rate is directly proportional to the number of molecular collisions per second:

Not every collision between molecules results in a reaction

Effective Collision: A collision that does result in a reaction

If kinetic energies of the molecules are small, the molecules will merely bounce off each other

Activation Energy : minimum amount of energy required to initiate a chemical reaction

Molecules must also be oriented in a way that favors reaction

Activated Complex (also called transition state): [in an effective collision] a temporary species formed by the reactant molecules as a result of the collision

Arrhenius Equation

Reaction Mechanisms

Elementary Reactions

Overall Reaction:

Elementary Reactions:

A math equations with numbers and symbols

Description automatically generated

Intermediates: species that appear in the mechanism of the reaction but not in the overall balanced equation

* Each step in a reaction mechanism represents an elementary reaction, one that occurs in a single collision of the reactant molecules
* The molecularity of an elementary reaction is essentially the number of reactant molecules involved in the collision
* Elementary reactions may be unimolecular (one reactant molecule), bimolecular (two reactant molecules), or termolecular (three reactant molecules). These molecules may be of the same or different types
* In general, we cannot tell just by looking at the balanced equation whether the reaction occurs as shown or in a series of steps
* This determination must be made using data obtained experimentally

Rate Determining Step: the slowest step in the sequence

Plausible Mechanisms

1. The individual steps (elementary processes) must sum to the correct overall reaction
2. The rate-determining step (the slow step) must give the same rate law as the experimentally determined rate law

Catalysts

Catalyst: a substance that increases the rate of a chemical reaction without itself being consumed

Heterogeneous Catalysis: the reactants and the catalyst are in different phases

Homogeneous Catalysis: the reactants and the catalyst are

dispersed in a single phase, usually liquid

Enzymes: biological catalysts

* The amazing fact about enzymes is that not only can they increase the rate ofc biochemical reactions by factors ranging from 10^6 to 10^18, but they are also highly specific
* An enzyme acts only on certain reactant molecules, called substrates, while leaving the rest of the system unaffected
* Enzyme catalysis is usually homogeneous because the substrate and enzyme are both present in an aqueous solution

**CHEMICAL EQUILIBRIUM**

Basics

Equilibrium: a system in which both forward and reverse processes are occurring at the same rate

Product Favored Reaction: reactions that produce mostly products, leaving only a small quantity of reactants

Reactant Favored Reaction: reactions that proceed only slightly to products before appearing to stop--leaving a large quantity of reactants

Equilibrium Constant

Law of Mass Action: a mathematical model empirically derived in 1864 from the experiments of two Norwegian chemists

1. At equilibrium, the amounts of reactants and products are constant
2. Once a system reaches chemical equilibrium, two opposing chemical transformations (the forward and reverse reactions) occur at the same rate

the products are favored

the reactants are favored

neither are favored

Constant with Pressure (containing only gasses)

Reactant Quotient

Reaction Quotient: a fraction with product concentrations in the numerator and reactant concentrations in the denominator—with each concentration raised to a power equal to the corresponding stoichiometric coefficient in the balanced chemical equation

Same formulas as, At Equilibrium:

Homogeneous Equilibrium: when the products and reactants of an equilibrium reaction form a single phase, whether gas or liquid

Heterogeneous Equilibrium: a system whose reactants, products, or both are in more than one phase (reaction of gas with solid or liquid)

Exclusions: the molar concentrations of pure liquids and solids normally do not vary greatly with temperature, their concentrations are treated as constants

reaction towards right (products)

reaction is at equilibrium

reaction towards left (reactants)

Le Châtelier’s Principle

Le Châtelier’s Principle: states that when a stress is applied to a system at equilibrium, the system will respond by shifting in the direction that minimizes the effect of the stress

Stress: refers to addition or removal of a product or reactant and a change in volume (resulting in a change in concentration or partial pressure) or a change in temperature

Shift: a net forward reaction of reactants to form products or a net reverse reaction of products to form reactants

A blue and white table with black text

Description automatically generated

A table with text on it

Description automatically generated

A graph showing the temperature change

Description automatically generated with medium confidence

Presence of catalyist does nothing to Q or K.

**ACID-BASE THEORY**

Arrhenius Acids and Bases

Arrhenius acids: Compounds that dissociate in solution to give hydrogen ions

Arrhenius bases: compounds that dissociate in solution to give hydroxide ions

Brønsted-Lowry Acid-Base Theory

According to theory, an acid donates a proton while a base accepts a proton

Conjugate Base: product acid that has an extra electron

Conjugate Acid: product acid that has a missing electron

A diagram of a formula

Description automatically generated

Acid Dissociation

Acid Dissociation Constant (): a special equilibrium constant that quantifies acid strength, with larger values indicating stronger acids

Because is the negative logarithm of , the smaller the , the stronger the acid.

Base Dissociation

Base Dissociation Constant (): a special equilibrium constant that quantifies base strength, with larger values indicating stronger bases

Water

Amphoteric: when a substance can act as both an acid and a base

Autoionization Constant of Water (): The equilibrium constant for a reaction with water

The magnitude of indicates that water autoionizes only to a tiny extent, nonetheless, pure water does contain small concentrations of the hydronium and hydroxide ions. You can use an ICE table to determine [H 3 O+ ] and [OH – ] in pure water

Example

A table with a formula

Description automatically generated with medium confidence

pH

pH: The potential of hydrogen, equal to the negative logarithm of the hydronium ion concentration

\* The number of significant figures in a logarithm is represented by the number of digits to the right of the decimal point.

A diagram of a chemical reaction

Description automatically generated with medium confidence

pOH

pOH: A measure of the concentration of hydroxide ion in a solution

Mixtures of Acids

Types

1. Mixture of strong acids
2. Mixture of both strong and weak acids
3. Mixture of weak acids

Strong Acids

In a mixture of strong acids, the potential sources of include:

* The complete dissociation of each of the strong acids
* The autoionization of water

Usually, the contribution of water can be ignored because it is irrelient compared to the contribution of the acids

Salts

Salt: An ionic compound where the constituent ions dissociate from each other when it dissolves; a compound formed when an acid reacts with a base, which can form solutions that are either pH neutral, acidic, or basic

Salt Hydrolysis: Chemical reactions that occur when chemical bonds are broken using water, often resulting in a change in pH

**ACID-BASE EQUALIBRIA**

Buffer Solutions

Buffer solution: A solution that resists a drastic change in pH upon the addition of a strong acid or strong base

* Buffer solutions resist changes in pH because buffers contain a significant amount of a weak acid and its conjugate base or a weak base and its conjugate acid

Buffer capacity: The quantity of strong acid or strong base a buffer can neutralize before its pH changes by 1 pH unit

* Influenced not only by the actual concentration of buffer components but also by their relative concentrations
* Maximum buffer capacity: When the buffer components have equal concentrations

Henderson-Hasselbalch Equation (pH after addition of strong acid or base):

Acid-Base Titrations

Acid-Base Titration: a useful analytical technique in which an acidic (or basic) solution of known concentration is used to determine the concentration of a different basic (or acidic) solution

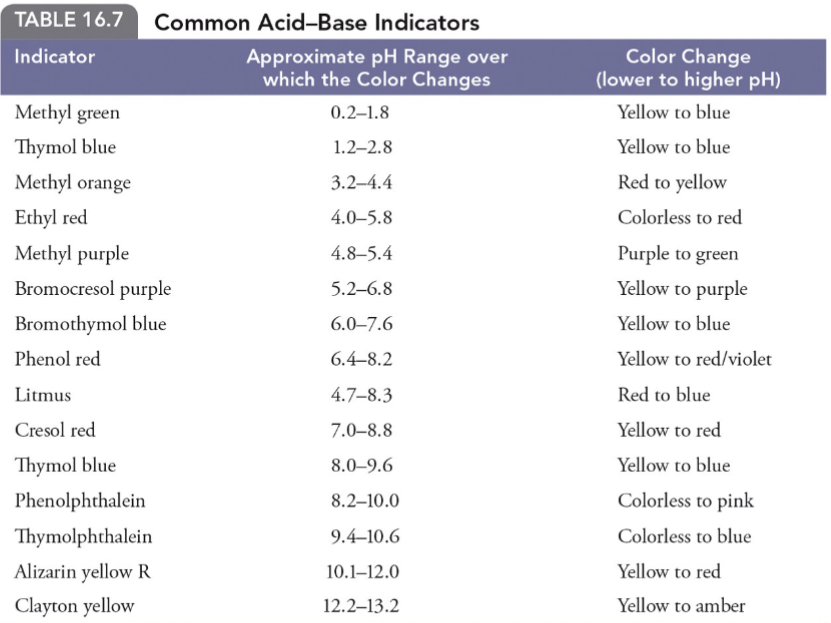
Titrant: A solution with a known concentration that is reacted with an unknown sample until the equivalence point is reached

Titrant Curve: A plot of pH versus volume of titrant added over the course of the titration

Acid-Base Indicators

Titrations are typically monitored with a pH indicator, which is a substance that exhibits a sharp change in color at or near the endpoint

Indicator: Weak organic acids that have an equilibrium between themselves and their conjugate base represented by an equilibrium equation



Polyprotic acids: Acids that have more than one acidic proton and multiple equivalence points

Solubility-product constant (): The K value for equilibrium systems that involve a solid substance dissolving in solution

the larger the magnitude of , the more the equilibrium favors products

Ion Product ()

1. If Qsp < Ksp, the solution is unsaturated and no precipitate forms
2. If Qsp = Ksp, the solution is saturated; the system is at equilibrium
3. If Qsp > Ksp, the solution is supersaturated and a precipitate will form under most conditions

pH Effects on Solubility

1. If a substance contains the conjugate base of a weak acid, addition of a strong acid (a source of H3O+) causes the solubility to increase
2. If a substance contains the hydroxide ion, addition of another substance that increases [OH –] causes the solubility to decrease

**ENTROPY, FREE ENERGY, AND EQUILIBRIUM**

Basics and Entropy

First law of thermodynamics: The total amount of energy in the universe is constant and answers several fundamental questions about energy changes.

Entropy (S): The quantitative measure of how much energy has spread out, or how widely it spreads out, at a specified temperature.

W represents the number of arrangements the components of a system possesses. Each different arrangements is called a microstate

Second law of thermodynamics: The entropy of the universe increases in any spontaneous process.

The change in entropy for the ice is the amount of energy dispersed at a certain temperature:

Conditions of Changes in Enthalpy ()

* The standard state for a gas is the pure gas at a pressure of exactly 1 atm
* The standard state for a solution is a concentration of 1 M
* The standard state for a pure solid or liquid is the most stable form of the pure solid or liquid at a pressure of 1 atm

The same conditions can be used to define standard change in entropy ():

standard molar entropy

Standard molar entropies are derived from the third law of thermodynamics, which states that the entropy of a perfect crystal at absolute zero is equal to zero.

Gibbs Free Energy

Gibbs Free Energy: the maximum amount of useable energy available from a closed system under conditions of constant temperature and pressure. In other words, Gibbs free energy is the amount of energy free to do work

Standard Gibbs Free Energy: all the reactants and products are in their standard states

Standard Gibbs Free Energy of Formation (  
): the free energy change that results when 1 mol of a substance is formed directly from its constituent elements in their standard states

Gibbs Free Energy in Nonstandard Conditions:

Chemical reactions seek out conditions with the lowest Gibbs free energy

**ELECTROCHEMISTRY**

Redox Reactions

Redox Reaction: A reaction in which electrons are transferred from one substance (which is oxidized) to another substance (which is reduced)

A redox reaction may be split into half-reactions: one half-reaction for oxidation, another for reduction

A diagram of a chemical formula

Description automatically generated

Redox reactions can be used to produce an electric current

A diagram of a chemistry experiment

Description automatically generated

Electrochemical Cells

Electrochemical Cells: Devices that are divided into two half-cells, each hosting one half-reaction

Voltaic Cell: a device that produces an electrical current from a spontaneous redox reaction

Electromotive Force: The driving force that results in the motion of electrons from one electrode to the other

Cell potential (): The potential difference between an anode and cathode in an electrochemical cell, measured in volts; cell potential is an intensive (independent of quantity) property

Standard Cell Potential (): cell potential under standard conditions (1 M and 1 atm)

Electrochemical Notation

* In electrochemical cell notation, the anode is written on the left and the cathode is written on the right
* Electrodes are included at the extreme left and right ends for the anode and cathode, respectively
* Vertical lines represent phase boundaries. A double vertical line represents a salt bridge

A diagram of an anode cathode and cathode

Description automatically generated

In some instances, the components of one or both half cells may be in the same phase. In these cases, the components are separated by commas

Cell Potential

Standard Reducion Potential

scientists assign the standard hydrogen electrode a potential of zero volts

Spontaneous redox reactions have positive values

1. Substances that have more positive standard reduction potentials are more likely to undergo reduction (function as cathodes)
2. Substances that have more negative standard reduction potentials are more likely to undergo oxidation (function as anodes)

Gibbs Free Energy

Equilibrium Constant

R=

Cell Potential Under Non-Standard Conditions

Electrolysis: A process in an electrolytic cell where an electric current is supplied to drive a nonspontaneous redox reaction.

Faraday's law of electrolysis: the masses of reactants and products consumed or produced during electrolysis are directly proportional to both the magnitude of electric current passing through the electrode and the time that the current flows.

**READING**

Basics

* Total of 54 questions for two sections: 27 questions per module; **25-33 reading, 19-31 writing questions total**
* **32 minutes per module** (64 minutes total): 1 minute and 10 seconds per question
* Both modules are formatted the same way; the reading and writing questions are not in separate sections
* Second section is scaled based on the first; if you do bad on the first section the second will be quite easy, and vise-versa

Plural Possession: s’

Singular Possession: ‘s

Strategies

Match (Which choice completes the text with the most logical and precise word or phrase?): Choose a word that works best in the thing; it may not feel completely right

Meaning (As used in the text, what does the word “word” most nearly mean?): Process of elimination

**MATH**

Quadratic

Standard Form:

Vertex Form:

Vertex (h, k): h = -b/2a

No Solutions:

One Solution:

Two Solutions:

Linear

No solution: slopes must be same (parallel)

Absolute Value: Simplify the equation and think about what numbers yield both the negative and positive versions of other side of the equation